The Safety of Ontario's Nuclear Power Reactors

A SCIENTIFIC AND TECHNICAL REVIEW

Vol. 1 Report to the Minister, Technical Report and Annexes

F. Kenneth Hare
Commissioner

Ontario Nuclear Safety Review
Toronto, Ontario
29 February, 1988

THE SAFETY OF ONTARIO'S NUCLEAR POWER REACTORS

A Scientific and Technical Review

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F. Kenneth Hare
Commissioner

March 21, 1988

The Honourable Robert C. Wong
Minister of Energy
Government of Ontario
Queen's Park
Toronto, Ontario

Dear Mr. Wong:

I have the honour to present my report as Commissioner of the Ontario Nuclear Safety Review, as requested in December 1986 by your predecessor, the Honourable Vincent G. Kerrio.

The report is in several volumes. In addition to my own short report to yourself as Minister (containing conclusions, recommendations and a summary) there is a technical report, a volume of appendices written by my colleagues, and a set of selected consultants' reports. Ontario Hydro's and Atomic Energy of Canada Limited's submissions are also presented as support documents. A large group of submissions from various public interest groups, individuals, professional bodies and the union movement has also been deposited with your staff. Obviously this is a record of work completed by many persons in a little over a year. I hope it will prove a valuable contribution to Ontario's picture of its own achievements.

It has been a great privilege for me to have been allowed to undertake this Review. I am most grateful to your staff for help and above all to Ontario Hydro for its patience.

Yours sincerely,

F. Kenneth Hare
Commissioner

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NOTE TO READER

A list of acronyms and abbreviations (including scientific units) begins on p. 261. The following are very frequently used and will be needed by the reader throughout the text:

AECB	Atomic Energy Control Board, the federal regulating agency
AECL	Atomic Energy of Canada Limited, a federal Crown corporation
CANDU	Canada Deuterium Uranium, the family of reactors used in Canada
GWh	Unit of energy, equivalent to a power of 1 billion watts working for 1 h
IAEA	International Atomic Energy Agency, a Vienna-based United Nations specialised agency
ICRP	International Commission on Radiological Protection, an independent advisory agency
LOCA	Loss of coolant accident
MWe and MWt	Megawatts (millions of watts) of power, "e" being electric output, "t" thermal (steam)
Sv and mSv	Sievert and millisievert, units of absorbed radiological dose (normal natural dose in Canada is about 2 mSv/yr)

Minister

You should incorporate in your review an examination of the steps taken to date by the Atomic Energy Control Board, Atomic Energy of Canada Limited, Ontario Hydro and the Ministry of the Solicitor General arising from the information they have received on the accident at the Chernobyl nuclear station in the Soviet Union. The Ministry of Energy has already discussed with the International Atomic Energy Agency (IAEA) and Ontario Hydro the establishment of an Operational Safety Review Team (OSART) to perform an in-depth review of operating practices in Ontario Hydro's nuclear stations. I will ask the federal government to request this of the IAEA. The results of an OSART assessment will be provided to you and you will have access to the OSART team members.

You may commission specific technical reports from consultants. In particular, you should obtain the views of experts who are not associated with the nuclear industry.

I understand that it is your intention to consult widely to obtain a cross-section of technical and scientific views and information and that you will invite submissions from interested groups on the scientific and engineering dimensions of nuclear safety.

I welcome this approach and I have agreed that the budget for the nuclear safety review will include funds to assist such interested groups in the preparation of technical submissions. I have also agreed to your request for close collaboration with the Royal Society of Canada, in carrying out this important assignment.

A provisional budget of $1.5 million has been established for the Nuclear Safety Review (including expenses for the OSART review). This will be subject to review in late January 1987, when you will have a detailed budget available for my approval. You can use the administrative facilities of the Ministry of Energy in drawing on these funds, arranging office accommodation and staff support, through the Deputy Minister.

I wish to receive your report before or no later than December 31, 1987. This report will be provided to the Members of the Legislature and released to the public. Furthermore, it is my intention that all studies commissioned by you and all materials submitted by interested groups to you will be made available to the public.

My best wishes and appreciation to you in undertaking this major assignment.

Yours sincerely,

Vincent G. Kerrio
Minister

Ontario

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October 20, 1987

Professor F. Kenneth Hare
Commissioner
Ontario Nuclear Safety Review
180 Bloor Street West
Suite 303
Toronto, Ontario
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Dear Professor Hare:

On your appointment as Commissioner of the Ontario Nuclear Safety Review in December 1986, my predecessor, the Honourable Vincent G. Kerrio, requested that you report to him by December 31, 1987. You indicated in March this year that there had been a number of delays in arranging for accommodation and equipment and in establishing the advisory panel with the Royal Society of Canada. As a consequence you advised the Ministry that it would be difficult to complete your report by December 31, and it was agreed that a review of the reporting date would be made in September in the light of progress made at that time.

I understand that you are confident that you will be able to report to me on February 29, 1988 and my intent in writing to you today is to formally acknowledge this new reporting date.

Ministry of Energy staff will make the administrative adjustments to service contracts and to accommodation and equipment leases that will be necessary for your organization to continue through to March 31, 1988.

May I take this opportunity to assure you of my continuing support in the task you have undertaken on behalf of the Government and the people of the Province.

Yours sincerely,

Robert C. Wong
Minister

THE ROYAL SOCIETY OF CANADA

LA SOCIÉTÉ ROYALE DU CANADA

March 12, 1988

Dr. F. Kenneth Hare, C.C., F.R.S.C.
Commissioner
The Ontario Nuclear Safety Review
Suite 303
180 Bloor Street West
Toronto, Ontario
M5S 2V6

Dear Dr. Hare:

You will remember that as part of the collaboration between the Royal Society of Canada and the Ontario Nuclear Safety Review, I appointed a panel of three distinguished external reviewers to examine your report. The terms of reference established by the Royal Society for this review panel were the following:

1. The Society Reviewers will study the Commission report, in particular seeking to assure themselves that, within the mandate:

   i) The investigation has been performed competently and thoroughly.

   ii) Recommendations made and opinions expressed by the Commissioner are soundly based and are adequately supported.

2. Reviewers' criticisms will, as far as possible, be resolved in discussion with the Commissioner and, as appropriate, with the Advisory Panel.

   i) If criticisms are satisfactorily resolved the Reviewers will report accordingly.

   ii) If some significant matters remain unresolved the Reviewers will record their dissenting opinion.

Having attended with you both meetings of the review panel, each of three days, and having received and examined the formal report of the panel, I am fully satisfied that it has exercised most thoroughly its responsibilities as established by the Society. I have, therefore, accepted the report.

Dr. F. Kenneth Hare, C.C., F.R.S.C.
p. 2
March 12, 1988

The review panel's report is transmitted to you to be added to your report, as Commissioner, to the Ontario Minister of Energy, with the understanding that both reports will be published. The Royal Society is happy to have been of service to you and to the Government of Ontario.

Yours sincerely,

Digby J. McLaren,
President

344 Wellington St.,
Ottawa, Ontario
K1A 0N4

Residence of H.E. Duckworth
76 Wilton Street
Winnipeg, Manitoba R3M 3C1

March 12, 1988

Dr. D.J. McLaren O.C., F.R.S.C.
President
The Royal Society of Canada
344 Wellington Avenue
Ottawa, Ontario
K1A 0N4

Dear Mr. President:

On the 4th August 1987 you invited us to conduct a critical review of a Report being prepared by the Ontario Nuclear Safety Review Commission. We subsequently accepted your invitation.

The terms of reference you gave the Panel were:

"1. The Society Reviewers will study the Commission report, in particular seeking to assure themselves that, within the mandate:

i) The investigation has been performed competently and thoroughly.

ii) Recommendations made and opinions expressed by the Commissioner are soundly based and are adequately supported.

2. Reviewers' criticisms will, as far as possible, be resolved in discussion with the Commissioner and, as appropriate, with the Advisory Panel.

i) If criticisms are satisfactorily resolved the Reviewers will report accordingly.

ii) If some significant matters remain unresolved the Reviewers will record their dissenting opinion."

Dr. F.K. Hare, the Commissioner appointed by the Hon. Vincent G. Kerrio, Minister of Energy, Province of Ontario, sent us the draft Report in December 1987. After reading the draft we attended a Review Meeting on 3rd-5th January 1988 in Toronto. On that visit we met the Advisory Panel. We held extensive discussions with the Commissioner. In February the Commissioner sent us a revised draft Report. Following an examination of that draft we held further meetings in Toronto on 10th-12th March 1988. During that period we completed our discussions with the Commissioner. We were given every assistance in examining, understanding and reviewing the Report during our visits. We are grateful to the Royal Society, the Commissioner and his staff and the members of the Advisory Panel who together have greatly encouraged and helped us to carry out the work you invited us to undertake. All of them, especially the Commissioner, have been receptive and constructive in hearing our views and criticisms.

The Commissioners' terms of reference were set out in a letter to him from the Minister on 18th December 1986. The relevant parts asked Dr. Hare to:

> "review. . . the safety of the design, operating procedures and emergency plans associated with Ontario Hydro's CANDU nuclear generating plants,"

and indicated that the review

> ". . . would not include such matters as uranium mining, refining and fuel fabrication, disposal of spent nuclear fuel, decommissioning of a reactor at the end of its useful life, and the potential sale of tritium extracted from heavy water."

In carrying out those terms of reference the principal steps taken by the Commission were of significance to us if we were to understand the general basis of the Report and Appendices, which, together with the relevant supporting documents, were put before us. The important stages in the work were:

- appointment of an experienced Commissioner and his staff
- appointment of an Advisory Panel of 8 individuals
- the engagement of 37 Consultants to advise on specific technical subjects (some of whom acted as senior advisors to the Commissioner)
- the solicitation of briefs from all interested in the subject
- the provision of funding to enable certain intervenor groups to prepare briefs
- a Workshop to which the authors of all briefs were invited
- extensive consultation by the Commissioner and his staff with nuclear industry and nuclear regulatory representatives in Canada, the United Kingdom, the United States, France, Sweden and elsewhere
- the appointment by the RSC of an independent Review Panel to review the final Report
- meeting of the Review Panel with the Commissioner and the Advisory Panel to discuss the draft Report (4th January 1988)
- meeting of the Review panel with the Commissioner to discuss the final Report (10th-12th March 1988)

We also note that the Government of Canada arranged for an Operational Safety Review Team (OSART) of the IAEA to review the operation of the Pickering Nuclear Generating Station. Use was made of this report by the Commissioner.

We are now able to reply to your invitation and first, we respond to the formal terms you gave us.

1. (i) The investigation has been performed with competence and thoroughness.

   (ii) The recommendations made and opinions expressed by the Commissioner are soundly based and are adequately supported.

2. Our criticisms of the draft Report have been thoroughly discussed with the Commissioner and have been satisfactorily resolved in every respect.

We wish to add to our formal answers some further conclusions. In our opinion, high scholarly standards have been achieved. By this we mean that all the relevant information has been assembled and reviewed, with critical disinterest. The Report will, we consider, serve as an authoritative document for those interested in nuclear power operation in Ontario.

The Report is an outstanding piece of work done under pressure of time and polarized opinion. We have formed the opinion that it more than adequately meets the requirements set out by the Minister.

Finally, we have between us had the opportunity to draft, read or criticise a substantial number of Reports, both public and private. Against that experience we regard the Ontario Nuclear Safety Review Report as exemplary.

Yours sincerely,

Henry E Duckworth

H.E. Duckworth, Ph.D. (Physics), O.C., F.R.S.C.
Chairman, RSC Review Panel

I.J.O. Korchinski, Ph.D. (Ch. Eng.)

Frank Layfield

Frank Layfield, Q.C.

Biographical Sketches of Commissioner, Advisory Panel, and Royal Society of Canada Reviewers

(a) Commissioner

DR. F. KENNETH HARE is University Professor Emeritus in Geography at the University of Toronto, Chancellor of Trent University, and Commissioner of the Ontario Nuclear Safety Review. He was educated at the University of London (King's College and the London School of Economics) and the Université de Montréal, and his academic career included appointments as Dean of Arts and Science of McGill University, Master of Birkbeck College, University of London, President of the University of British Columbia, Director of the Institute for Environmental Studies, University of Toronto, and Provost of Trinity College in the University of Toronto. Dr. Hare has served with a number of official bodies, foundations, institutions, and inquiries in Canada and abroad, notably as Chairman of the Climate Program Planning Board of Environment Canada, Chairman of the Royal Society of Canada Commission on Lead in the Environment, Chairman of the Royal Society of Canada Study of the Nuclear Winter Phenomenon, Chairman of the Canadian peer review panel on documents related to a proposed Canada/United States Treaty on Transboundary Air Pollution, and Chairman of the Federal Study Group on Nuclear Waste Management. He is a Companion of the Order of Canada and a Fellow of the Royal Society of Canada.

(b) Advisory Panel

DR. IAN BURTON is a Professor of Geography at the University of Toronto and Director of the International Federation of Institutes for Advanced Study. He was educated at the University of Birmingham and the University of Chicago and has served as Director of the Institute for Environmental Studies, University of Toronto, as Senior Advisor to the International Development Research Centre, and as Visiting Professor to the University of East Anglia and to Clark University. His many other professional activities in Canada and abroad have included appointments as Co-Chairman of the Energy, Mines and Resources

Symposium on Perceptions and Attitudes in Resource Management, as a member of the US Scientific Advisory Board Conference on the Long-term Biological Consequences of Nuclear War, as a consultant to the US Assessment of Research on Natural Hazards Project, as a member of the World Health Organization Expert Advisory Panel on Environmental Pollution and Hazards, as a consultant to the Railway Transport Committee of the Canadian Transport Commission to advise on the rail transport of hazardous commodities, and as a consultant to the Royal Commission on the Ocean Ranger Marine Disaster to advise on risk assessment and perception with respect to offshore oil and gas exploration. He is a Fellow of the Royal Society of Canada.

DR. JAMES M. HAM is Professor of Science, Technology and Public Policy at the University of Toronto and Chairman of the Industrial Disease Standards Panel of the Province of Ontario. He is a graduate of the University of Toronto and the Massachusetts Institute of Technology in Electrical Engineering and is actively engaged in research in automatic control. In the course of his career at the University of Toronto, Dr. Ham has served as Head of the Department of Electrical Engineering, Dean of Applied Science and Engineering, Chairman of the Research Board, Dean of the School of Graduate Studies, and President. He conducted the Royal Commission inquiry into the Health and Safety of Workers in Mines and served as Chairman of the Advisory Committee on Safety to the Royal Commission on the Ocean Ranger Marine Disaster. He is an Officer of the Order of Canada.

DR. ROBERT H. HAYNES is Distinguished Research Professor, Biology Department, York University, Toronto. He was educated at the University of Western Ontario. Dr. Haynes has been a member of the faculty of York University since 1968 and has held academic appointments at the University of California, Berkeley, and the University of Chicago. Among the many professional societies to which he belongs are the Genetics Society of America, the Society for Risk Analysis, the Environmental Mutagen Society, and the Radiation Research Society. He has served as a member of the National Research Council of Canada and the Committee on Radiobiology of the US National Academy of Sciences. He currently is a member of the Research

Council of the Canadian Institute for Advanced Research and is Chairman of the Advisory Committee on the Life Sciences of the Natural Sciences and Engineering Research Council of Canada. He was Chairman of the Committee that wrote "Guidelines on the Use of Mutagenicity Tests in the Toxicological Evaluation of Chemicals," the 1986 report of the Environment Contaminants Advisory Committee on Mutagenesis prepared for the Department of National Health and Welfare and Environment Canada. Dr. Haynes is the President of the XVI International Congress of Genetics, Toronto, 1988. He is a fellow of the Royal Society of Canada, from which he will receive the Flavelle Medal in 1988.

DR. JOHN D. McGEACHY is Professor of Mechanical Engineering and Associate Dean of the Faculty of Applied Science at Queen's University. Dr. McGeachy studied Mechanical Engineering at Queen's University and the University of Illinois and was employed in generating station construction in Britain and Canada and in fuel management and station maintenance in nuclear generating stations operated by the Commonwealth Edison Company in the United States. Since his appointment to the faculty of Queen's University in 1975, he has maintained involvement with the power industry through research and consulting, particularly in the areas of maintenance and life extension of generating station equipment.

DR. WLADIMIR PASKIEVICI is Dean of Research and Graduate Studies at the École polytechnique de Montréal. He studied in Argentina and France and obtained a PhD in physics from the Université de Strasbourg. Dr. Paskievici came to Canada in 1958 and began an academic career at the École polytechnique where he subsequently created and later headed the Nuclear Engineering Institute. His areas of expertise in the nuclear field are reactor physics, control, and safety, and he has done extensive work on risk comparison between different energy sources. He has been Chairman of the Atomic Energy Control Board (AECB) Reactor Safety Advisory Committee for the Province of Quebec and a member of the AECB Advisory Committee on Nuclear Safety and has served as a consultant to the AECB to review safety regulation.

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MR. RALPH D. TORRIE is an independent consultant and author who specialises in energy, environmental, and international development. He holds an honours Bachelor of Science degree from the University of Waterloo. Mr. Torrie was the Assistant Director of the Energy Research Group of the United Nations University and the International Development Research Centre. He has worked on a wide range of projects involving energy end-use analysis, research management, technology and market assessment of energy technologies, energy policy analysis, nuclear safety assessment, and environmental policy. His interest and involvement in nuclear issues began in the early 1970s when he worked in the Concepts Section of the Safety Systems Branch of Atomic Energy of Canada Limited. He was later a major participant in the Ontario Royal Commission on Electric Power Planning, where he was a researcher and representative of the Ontario Coalition for Nuclear Responsibility. He has performed extensive critical analyses of various aspects of the CANDU fuel cycle and has appeared on several occasions as an expert witness before the Ontario Legislative Select Committee on Ontario Hydro Affairs and various other public inquiries.

(c) Royal Society of Canada Reviewers

DR. HENRY E. DUCKWORTH, Chairman of the Royal Society of Canada Review Panel, is a physicist and senior university administrator. He is currently President Emeritus of the University of Winnipeg, Professor Emeritus of the University of Manitoba, Chancellor of the University of Manitoba, and Chairman of the Advisory Committee on Nuclear Safety of the Atomic Energy Control Board. Dr. Duckworth was educated at the University of Manitoba and the University of Chicago. He is an Officer of the Order of Canada and a former President of the Royal Society of Canada.

DR. I.J.O. KORCHINSKI recently retired as Vice-President, Manufacturing, of Shell Canada. He spent over 30 yr with the Shell organisation, involved in refining, exploration, production, and research. In addition, he taught Chemical Engineering at the University of California, Berkeley. Dr. Korchinski was educated at the University of Saskatchewan and the University of Toronto.

SIR FRANK LAYFIELD, Q.C., is a British barrister-at-law, called to the bar in 1954. He has been involved in several public inquiries in the United Kingdom, most notably as Inspector of the Sizewell B Inquiry.

I Conclusions and Recommendations*

A. Scope

C.R.O.1 I present my conclusions and recommendations in the form of one major conclusion, two major recommendations (with supporting discussions), and a group of less general conclusions and recommendations, each important in its own right. I have indicated (left-hand side of page) where in the Technical Report or appendices detailed arguments may be found.

C.R.O.2 The assessment is made with respect to two groups of persons--the work-force employed in the nuclear stations, and the Ontario public and with respect to two situations--normal operations, and accidents.

C.R.O.3 There are additional recommendations in the appendices. These are as put forward by the authors. I have incorporated some of them in my recommendations. Others, of a more specialised character, are presented for consideration by the appropriate bodies.

B. Major Conclusions and Recommendations

1. Overall safety

Major Conclusion 1 - Overall Safety

C.R.1.1 **The Ontario Hydro reactors are being operated safely and at high standards of technical performance. No significant adverse impact has been detected in either the work-force or the public.**

* The Ontario Nuclear Safety Review is written simply as "the Review."

Source

whole text — **The risk of accidents serious enough to affect the public adversely can never be zero, but is very remote.**

C.R.1.2 Evidence in support of or modifying this conclusion includes the following:

(i) Cancer mortality is low and general health good among exposed work-force members (mostly male) of both Ontario Hydro and Atomic Energy of Canada Limited (AECL) after two to three decades of record. Average radiation doses of these groups are at least several hundred times greater than those of members of the general public. [paras. 244-249]

(ii) There is still time, however, for latent cancers to show themselves in both groups, so continued observation is necessary. [para. 245]

(iii) There has been no known radiation-related fatality due to an accident at reactors operated by either Ontario Hydro or AECL.

(iv) Although there have been several accidents at Ontario Hydro stations, none has resulted in significant releases of radioactive materials to the environment; the emergency coolant injection systems (ECISs) and the final containment barriers--the vacuum buildings--have never been needed. [paras. 164-183]

(v) Calculation suggests that even in the case of an accident involving loss of coolant plus failure to shut down at the weakest reactors--those of Pickering A--containment would remain almost intact, and escape of radioactive substances would be very low. [Table 14, p. 152]

(vi) The technical and radiological training of reactor staff is excellent. [para. 147]

C.R.1.3 But future safe performance requires changes in four main areas. The reactors have not behaved perfectly, and there have been several serious malfunctions. Their components are ageing. Some

Source

aspects of the operational system are open to criticism. The provincial emergency measures system requires action. There are problems in the regulatory area. All these are discussed below.

C.R.1.4 A general conclusion is that **human performance of individuals and institutions is the key to future safety.** There must be a sound safety culture throughout Ontario Hydro, and it must be directed from the top down.

para. 37(i)

C.R.1.5 Ontario Hydro has an outstanding reputation among international technical and professional groups, which regard it as one of the world's leading utilities. It deserves this reputation in the technical subjects covered in this report. Especially strong are its design, construction, and safety analysis groups.

2. Ontario Hydro corporate affairs

C.R.2.1 The above notwithstanding, there are several matters in which action by the province and Ontario Hydro would improve future safety prospects and probably economic performance (the two being inextricably mixed).

Major Recommendation 1 - The Human Element

That Ontario Hydro:

(i) ensure that, at an early date, its operational organisation be thoroughly re-examined, in close cooperation with independent consultants who have international management experience;

(ii) commission a study of factors affecting human performance throughout the utility, for the purpose of achieving optimum efficiency and the maintenance of high standards of safe operation;

Source

(iii) examine and revise its arrangements for establishing and maintaining an overall quality assurance programme for each of its plants after taking advice from independent specialist consultants.

C.R.2.2 With respect to Recommendation 1(i) and (ii), the following points need examination:

paras. 385-388	(i)	The conventional safety record of the Nuclear Generation Division (NGD) of Ontario Hydro is good. Its record of no fatalities in 125 million person-years is outstanding. But the rate of temporary total disabilities and the target rate are higher than in the heavy chemical industry. The NGD bases its practices too exclusively on internal assessments of what can be achieved.
para. 139	(ii)	Relations between Ontario Hydro and the Canadian Union of Public Employees Local 1000 have occasionally been soured by disputes.
paras. 129-131, Append. III.1,2,3	(iii)	Control of technical maintenance at the stations seems fragmented, and backlogs appear too long.
para. 141	(iv)	There are complaints that upward-directed safety recommendations are not always acted upon.
para. 141	(v)	Self-audit practised among operational staff is not adequate; abnormal events or actions with no consequences are often not recorded.
Figs. 26-29, paras. 164-183	(vi)	There appear to be undesirable differences in safety system and radiological performance between stations.
paras. 118-122	(vii)	The organisational structure of the nuclear programme appears excessively complex, with some ambiguities as regards responsibilities.
Append. III.1,2	(viii)	There is confusion in settling the status of temporary operating instructions at the stations.

Source

C.R.2.3 Although none of these circumstances in itself seriously threatens safety, the list suggests that an overhaul of operational safety culture would be in Ontario Hydro's interest--and therefore the public's.

paras. 382-395

C.R.2.4 With respect to Recommendation 1(iii), there are many references to QA in Ontario Hydro's submission to the Review; but no clear overall picture emerges. An outstanding characteristic of nuclear generating stations is that any weakness can be extremely costly in terms of money and health. For that reason, it is essential that at every stage of the programme to build and operate a CANDU (Canadian Deuterium Uranium) plant great attention be given to maintaining the highest standards of quality. The latter is needed in design, manufacture, assembly and operation, and for people and materials alike. A programme is needed from initiation to decommissioning. This is the proper dimension of the corporate QA programme, using criteria, standards, specifications, and the like. These are carried into particular effect by quality control (QC).

paras. 371-381

C.R.2.5 Ontario Hydro's manuals are explicit as to the quality of engineering, but the QA programme should be explicit for all aspects of plant design, manufacture, construction, and operation. The QA and QC programmes should have special regard for the need to obtain and maintain first-class human performance at all levels and in selection, training, and operational work. They should provide for periodic retraining of individuals. The programmes and their execution should be the responsibility of identified senior officers. They should also be on the daily agenda of all other senior officers as well as station staff.

paras. 371-381

Source

3. Pressure tube issues

Major Recommendation 2 - Integrity of Pressure Tubes

paras. 189-207 **That maximum and effective priority be given to finding a solution to the pressure tube problem, and to improved in-reactor monitoring. Investment in fuel channel research by Ontario Hydro should be increased, and greater emphasis given to the fundamental metallurgical problems, tapping expert knowledge available in other industries.**

para. 202 **C.R.3.1** The most serious technical safety-related issue in Ontario Hydro's reactors is the poor performance of pressure tubes (the inner parts of the fuel channels, in which the actual fission takes place). These tubes are parts of the high-pressure heat transport system. Any failure presents a threat of a small loss of coolant accident (LOCA). Two such failures have already occurred.

paras. 194-195 **C.R.3.2** The causes of these failures have been discovered. Some rehabilitation measures have been taken (as in units 1 and 2 at Pickering A). Much more needs to be done.

para. 198, 203 **C.R.3.3** The main threat is heavy damage to the reactor, and hence large repair and power replacement costs. There appears to be little danger that radioactive materials will escape into the environment. The public is unlikely to be affected. But there is a threat to operating and maintenance crews.

paras. 208-209 **C.R.3.4** Present annual expenditures of $42 million for research and development on the pressure tube problem ($19 million from Ontario Hydro) appear small in relation to the problem and to Ontario Hydro's revenues of $2.5 billion from nuclear power sales alone.

Source

CANDU Owners' Group analysis of research needs is excellent. In part, the fulfillment of those needs is limited by the lack of skilled specialists capable of originating or conducting original work.

C.R.3.5 Research on this problem cannot be short-term. In the
paras. search for better alloys, for example, prolonged in-reactor testing,
207, 210 over a period of years, will be necessary. So will the laboratory facilities of Ontario Hydro and AECL.

C. Other Conclusions and Recommendations

4. Research and development

Recommendation 3

That Ontario Hydro, as the producing utility, assume responsibility for the full financing of research needed to
paras. guarantee safety and efficiency in its own nuclear gener-
208-210 ating programme, purchasing facilities and staff time from AECL and other corporations and universities as appropriate.

C.R.4.1 Research and development facilities in Canada capable of mounting research into reactor design, development, modification, and testing have limitations of staff and equipment. Ontario Hydro's facilities and staff, although good, are quite limited.

C.R.4.2 Overall research expenditures on CANDU problems appear
paras. low in relation to the huge investment by Ontario Hydro and the
208-210 latter's large annual sales (over $2.5 billion from nuclear energy). Ontario Hydro's share in total expenditures seems low.

Source

C.R.4.3 The research necessary to maintain efficiency and safety must be primarily the responsibility of Ontario Hydro. In general the
Figs. 18- consumer should pay for such research, but because the research will
19, Table 3 have to go beyond the requirements of Ontario Hydro's generating programme, a contribution by the general taxpayer (including those in other jurisdictions) is appropriate. This does not lessen Ontario Hydro's responsibility to guarantee that it can attain access to research facilities essential to its nuclear programme.

C.R.4.4 Federal cut-backs have affected the programmes and availability of AECL's laboratory and engineering divisions, both of which are essential to safety-related research and development. The
para. 210 Ontario Government should ensure that these cut-backs do not adversely affect safety and efficiency within its wholly owned utility. Moreover, there are many areas of fundamental science and engineering in which Canada's universities could make a larger contribution. Certain present funding arrangements discourage this.

5. Other Ontario Hydro practices

C.R.5.1 Corporate discipline and morale appear very high, and this is a positive feature. But the impression of self-sufficiency and of
paras. professional isolation is strong. This is reinforced by Ontario Hydro's
389-395 tendency to internalise all necessary functions and skills (e.g., in contracting). Ontario Hydro should preserve the good features of this self-sufficiency, but seek to increase external contacts, especially in the safety area.

C.R.5.2 It is urgently necessary to create a means whereby closer interaction can be achieved between Ontario Hydro's excellent design and safety teams and the external scientific and technical community (which needs to be better informed). A two-way flow of information
para. 390 would enhance safety and Ontario Hydro's reputation. There is insufficient contact between Ontario Hydro's nuclear staff and the

Source

external scientific community. Much of the ignorance of nuclear affairs in the scientific arena arises from this isolation. In turn, such contacts will help the safety culture and technical performance of Ontario Hydro.

Recommendation 4

para. 390(ii) That the President of Ontario Hydro appoint a technical Advisory Committee on Nuclear Safety, similar to that already established for the nuclear fuel waste management programme, drawing on the industrial and academic communities. This committee should publish an annual report, which (with the report of Ontario Hydro's Nuclear Integrity Review Committee [NIRC]) should be laid before the Ontario Legislature.

C.R.5.3 In addition, Ontario Hydro should do everything in its power to encourage wider involvement by its professional staff in diverse scientific and technological activities outside the corporation.

6. Reactor performance

Table 1, paras. 71-94 **C.R.6.1** Ontario Hydro's 16 power reactors have had good performance records. Although units 1 and 2 at Pickering A were out of service for several years after 1983 because of technical failures, Ontario Hydro nevertheless has six of the world's top 10 reactor availabilities. The CANDU reactor has several good safety features (e.g., separation of coolant and moderator; rapid breach of calandria following a LOCA and failure to shut down, and hence quick loss of moderator; low volumes of steam for blow-down) and other less-desirable features (notably a positive void reactivity coefficient). The

Source

excellent safety record since 1971 (when Pickering A opened) owes much to good human performance.

C.R.6.2 The special safety systems, which protect the reactor fuel in the event of an accident and contain any released materials, are
paras. 95-101 shut-down systems, ECISs, and containment. The ECIS has been a costly and difficult system to install. Adequate high-pressure systems are now in place in all reactors except Pickering units 3 and 4, where they will be installed in 1988-89. Shut-down and containment systems function well. Only the shut-down systems have ever been needed to prevent accidents.

C.R.6.3 As experience has been gained, the reactors have performed more smoothly. Bruce B and Pickering B have given little trouble.

C.R.6.4 I conclude that the safety systems are effective and provide adequate protection against accident conditions. Defence-in-depth is clearly present, although Pickering A is less well protected than newer stations.

Recommendation 5

That Ontario Hydro press forward the large-scale upgrading of process and safety systems at Pickering A so that there may be no impediment to its future safe operation.

C.R.6.5 Pickering A, the oldest station, has had many problems. These have included difficulties with the control computers, the ECIS,
para. 320 198-199 and (prior to 1975) the shut-down system. Major repairs and back-fitting have been necessary since 1983 because of pressure tube failures. These have included upgrading of the shut-down system and

Source

ECIS. Units 1 and 2 are now back in service, or on the brink of it. Units 3 and 4 will receive major overhauls in 1988 and 1989. In addition, severe accident analyses done for the Review by Ontario Hydro and Argonne National Laboratory have indicated that a large LOCA with a failure to shut down would be largely contained.

Recommendation 6

That a consistent policy be established by the Atomic Energy Control Board (AECB) governing the backfitting of existing reactors. This policy should specify targets for work-force exposure. It should take account of uncertainties in safety analysis. It should also establish a firm timetable for completion of work.

C.R.6.6 Considerable debate has arisen in the past about decisions
paras. to modify or refit existing reactors. Such backfitting raises two
176-177 sorts of problems: whether it should apply to all reactors, and whether it may be counter-productive, either by weakening the design fabric, or by causing greater work-force exposure than it is ever likely to save.

7. Operating system

C.R.7.1 Most aspects of the operating system appear good. Particularly good are the technical and radiological training systems
paras. (including the AECB qualifications programme), as is the principle
124-141 that the individual staff member is responsible for his/her own radiological protection. Some apparent weaknesses were treated in paragraph C.R.2.2 above.

Source

C.R.7.2 Safety depends more on the quality and qualifications of
paras. the staff than on any other single factor. Much depends on alertness
142-143 to upset conditions and on the skill with which the operators respond.

Recommendation 7

That Ontario Hydro further refine and intensify its training and refresher courses in all aspects of reactor safety and in safety management, making maximum use of its control room simulators.

8. Risk of accidents

C.R.8.1 A severe accident in an Ontario reactor, with release of damaging amounts of radioactive substances, is very unlikely, but cannot be ruled out. Emergency measures planning requires that estimates be made of the range of credible accidents.

C.R.8.2 Abnormal incidents are common at nuclear generating
paras. stations (of the order of 700 Significant Event Reports per year).
157-163, Those with significant consequences are examined internally by the
Table 2 NIRC, and appropriate measures taken. Reports are made to AECB and the Ontario Legislature.

C.R.8.3 Of the more serious incidents, two accidents have caused
paras. significant damage to the reactors and resulted in escape of radio-
197-201 actively contaminated heavy water into the calandria and/or the reactor building. These were at Pickering A in 1983 and Bruce A in 1986 (see C.R.3.1-3 above). There was, however, no significant release of radioactive materials from containment and no measurable

Source

public exposure. Such accidents cannot be ruled out in future. Their impact is mainly economic, with some work-force exposure.

C.R.8.4 All Ontario Hydro reactors are designed to contain all but the most severe accidents, as specified by AECB. In particular, all
para. 101 reactors have access to a reinforced vacuum building designed to condense steam and retain contaminants. This is unique to Ontario.

C.R.8.5 If a severe accident were to occur, it would be quite
paras. unlike that at Chernobyl in 1986. The Chernobyl reactor had seven
318-319 times as large a coolant volume (available for blow-down) as Pickering A and used inflammable graphite as a moderator (whereas CANDU reactors use heavy water, which quenches fire). The 31 fatalities at Chernobyl included many from burns, and the spread of radioactive debris was also due in part to the graphite fire.

C.R.8.6 Other severe accidents can, however, be visualised in CANDU reactors. Two have been identified by AECB: these were failure to shut down following a large loss of coolant or a loss of regulation.

C.R.8.7 The first of these cases was analysed for the Review (for
paras. Pickering A) by Ontario Hydro and Argonne National Laboratory.
297-317 The two studies predict major damage, probably irreparable, to the reactor, with breach of the calandria and escape of large volumes of contaminated steam into containment. But the latter is expected to retain all but a small part of the available radioactive inventory. Public exposures would be quite small. The second AECB case has not been analysed.

C.R.8.8 I conclude that the chance of severe accidents is very
paras. remote at Ontario reactors, and that, if they were to occur, it is
324-330 highly likely that they would be largely contained, with minimum hazard to the public. There would, however, be severe damage to the

Source

reactors, with consequent costs and radiological penalties to clean-up and repair crews. It is desirable that this conclusion be tested for other forms of severe accidents and other reactors.

Recommendation 8

That Ontario Hydro extend severe accident analysis to:
(i) the case of loss of regulation plus failure to shut down; and
(ii) representative Bruce and Darlington reactors.

9. Emergency measures

para. 340 **C.R.9.1** If serious accidents occur, emergency measures will be required inside the plant and within the surrounding municipalities.

C.R.9.2 Ontario Hydro has assumed responsibility for in-plant measures, which are in place. In accordance with AECB requirements, Ontario Hydro also provides facilities and information to
para. 342 municipalities and engages in regular drills. Ontario Hydro's programme appears well conceived and financed ($6 million per year). It includes provision for an emergency centre and for adequate mobilisation of staff and resources.

paras. 343-347 **C.R.9.3** The external response is the direct responsibility of the Solicitor General. In 1986, the Ministry published an excellent Nuclear Emergency Plan. This provides, on paper, a means of mobilising the required personnel and equipment and ensuring operational co-operation with Ontario Hydro. It also provides for exchanges with other jurisdictions (including transboundary relations with the United States).

Source

C.R.9.4 Unfortunately, little has yet been done to give effect to
paras. this plan, in spite of a Cabinet decision to arrange for its financing
348-354 by Ontario Hydro. The professional staff involved still numbers only two. A sense of urgency is lacking. If a severe accident occurs, it will find the utility prepared and the province unready--unless prompt action is taken.

Recommendation 9

That the Province of Ontario at once appropriate the funds necessary to set in place the preparedness aspects of the Provincial Nuclear Emergency Plan.

C.R.9.5 Working Group No. 8 of the Ministry of the Solicitor
paras. General is currently analysing the accident patterns on which the
355-363 Nuclear Emergency Plan's measures should be based (e.g., evacuation, sheltering, casualty services, iodide distribution, food and water protection). The Review has taken part in this valuable exercise.

Recommendation 10

That the Province of Ontario base its nuclear emergency planning on the maximum credible releases of radioactive materials.

10. Health matters

C.R.10.1 There is no evidence that the normal operation of Ontario
Chap. V, Hydro's reactors has caused, or will in future cause, harmful effects
Annex IV in either the reactor work-force (which is by far the most exposed group) or the general public. But vigilance is required.

Source

C.R.10.2 The exposure levels of atomic radiation workers are well below AECB dose limits and compare well with the best performance
para. 223-232 in other countries. In 1985-86, work-force whole-body exposure averaged 3.9 mSv. The AECB limit is 50 mSv. Since 1979, no worker has been exposed beyond regulatory limits. The number of exposed workers per unit energy produced is among the world's lowest. But the average worker exposure is still several hundred times as great as that of the most exposed member of the public.

C.R.10.3 Epidemiological analysis of mortality among Ontario Hydro's
paras. 244-245, Table 9 atomic radiation work-force is conducted at (on an annually updated basis) the Department of Health Care and Epidemiology in the Faculty of Medicine at the University of British Columbia. This analysis shows that cancer mortality among Ontario Hydro's atomic radiation workers is only two-thirds that of the general Canadian public. It is, however, too early for all latent cancers to have been revealed.

paras. 247-249, Table 10 C.R.10.4 Epidemiological analysis of the exposed workers of AECL is similarly carried out with the assistance of the National Cancer Institute. This is a longer and larger sample (about 15 000 persons over more than a 30-yr period). It, too, shows cancer mortality to be below that in the general public (although for Chalk River employees it has tended to rise in the past 15 yr and is now level with or marginally above that of the public).

C.R.10.5 There is no comparable study of public impact in Canada. Public exposure to radiation is at least several hundred times smaller than in either AECL or Ontario Hydro work-forces. Hence, measurable effects are unlikely.

C.R.10.6 Because recent studies in England have nevertheless shown
paras. 251-253 a possible association between lymphoid leukaemias in persons under 25 yr of age and proximity to nuclear installations, every effort should be made by epidemiological means to establish whether

Source

children and young adults in communities near reactors (e.g., Pickering, Deep River) show increased leukaemia incidence or other morbidities.

Recommendation 11

para. 253 That the Government of Ontario ensure that all relevant information be provided to support AECB's feasibility study for an epidemiological analysis of cancer incidence and mortality near reactors, and to any other feasible proposal for such analyses, including effects other than cancer mortality.

para. 273 **C.R.10.7** There appears to be considerable anxiety about the rumoured health effects of atomic radiation on the general public. There is also a need for a broad forum in which health and safety issues can be debated publicly.

Recommendation 12

That the Government of Ontario create an Advisory Council on Health and Safety, with a small permanent staff, and with the funds to assist public interest groups that wish to make representations.

11. Regulation

C.R.11.1 Although regulation of the nuclear industry is within the powers of the Government of Canada, and hence beyond the scope of this Review, the importance of regulation to safety is so great, and

Source

the comments reaching us so voluminous, that the following conclusions and recommendations are offered. A more comprehensive analysis is in Appendix VII.

Annex IV (paras. 11-22) **C.R.11.2** In spite of many ill-informed allegations, the International Commission on Radiological Protection (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.

Append. VII, para. 416 **C.R.11.3** The Government of Ontario should not invade the regulatory territory now legally occupied by AECB. The legislative and legal claims of the Government of Canada to regulate Ontario Hydro's nuclear programmes are not in question.

Append. VII, paras. 396-407 **C.R.11.4** AECB is an effective regulating agency. It sets the conditions that guarantee safety to the public and the work-force and leaves it to Ontario Hydro to show that its designs and operating methods are able to meet these conditions. Its means of enforcing this mandate--the licensing and staff qualification processes--are sufficient for its purposes, provided that they are fully and promptly used. Periodic requalification of operating staff should be considered as an additional sanction.

paras. 402-407, Append. VII **C.R.11.5** AECB has chosen to restrict its regulatory actions and decisions to technical matters. It should maintain this policy, but broaden its ability to take informed account of socio-economic and environmental matters in making its decisions.

Source

Recommendation 13

That AECB retain its present powers, sanctions, and functions, but ensure that its decisions (and reasons for them) are promptly published and enforced. Its staff complement should be increased to permit a broader programme, particularly in the radiological, socio-economic, and environmental areas.

Recommendation 14

That the Atomic Energy Control Act be amended so as to increase the Board's membership,* to permit appointments of persons expert in socio-economic and environmental areas.

paras. 400-401 **C.R.11.6** The AECB's Advisory Committees on Nuclear Safety and Radiological Protection perform invaluable but little-known work in the field of nuclear safety.

Recommendation 15

That AECB's Advisory Committees on Nuclear Safety and Radiological Protection be given the resources to expand the scope, accelerate the timetable, and increase the visibility of their work.

paras. 408-415, **C.R.11.7** AECB's relations with Ontario Hydro are not ideal. Although there is much constructive exchange at the professional level,

* i.e., actual Board members, at present five. When the entire organisation, including staff, is intended, the initials AECB are used.

Source

Append. VII the basis of decisions taken by the Board is not always clear. A more explicit procedure is needed for full public accountability.

Recommendation 16

That relations between Ontario Hydro and AECB become more formal, and that the reasons for all regulatory decisions be fully documented.

paras. 414-415, Append. VII **C.R.11.8** There appears to be a legitimate desire for more public involvement, notably through public hearings, in the socio-economic and environmental implications of nuclear power facilities. AECB is not the appropriate body to satisfy this desire. Provincial statutes provide the obvious answers.

Recommendation 17

That the Government of Ontario, whenever an application is made to construct a nuclear installation, should invariably use the powers contained in the Environmental Assessment Act to make possible public hearings concerning new nuclear projects.

paras. 151-152, Annex IV **C.R.11.9** Women play far too small a role in the regulation, management, and planning of the entire nuclear industry.

Source

Recommendation 18

That every effort be made to include qualified women on the boards and in the managerial staffs of AECB, AECL, and Ontario Hydro.

12. The role of government

C.R.12.1 This Review has examined the entire question of the safety of Ontario's nuclear reactors without regard to the niceties of jurisdiction. It has made clear the fact that the provincial utility is subject to close federal regulation, and that this is a source of strength--in that it separates the regulating body from Ontario Hydro in a clear-cut way. Nevertheless, the Government of Ontario retains an important responsibility for the entire question of safety.

Append. VII

C.R.12.2 The fundamental basis of public regulation by technically expert bodies is that their work should be scrutinised by the parent governments. The Annual Reports of AECB should receive more than nominal scrutiny by the appropriate parliamentary committee. In Ontario, the strong tradition of Select Committees suggests that this would be the correct route for the Government of Ontario to follow as regards AECB's Annual Report, as well as that of the proposed Advisory Council on Health and Safety, and of Ontario Hydro's NIRC.

Minister's Report

II Summary of Technical Report*

A. General Questions

S.1 Because of decisions taken more than 25 yr ago, Ontario is heavily committed to the use of nuclear power for generating electricity. Currently, nuclear generating stations deliver half the electric power used in the province. By 1993, when Darlington Nuclear Generating Station (NGS) is in full use, the proportion will rise to two-thirds (105 000 GWh, or 69% of consumption). Installed nuclear capacity in 1993 will be 14 254 MWe.

S.2 Nuclear stations will then provide four-fifths of the baseload, the power needed throughout the day. The remaining fifth will come mainly from hydraulic stations. Peak-load additions will be provided chiefly by coal-fired stations.

S.3 Ontario's dependence on nuclear power exceeds that of all sovereign states except France and Belgium, which are at similar levels. The US 1987 level was only 17%.

S.4 The safety of nuclear power plants is within the powers of the Government of Canada, under the Atomic Energy Control Act of 1946, as amended in 1954. Ontario Hydro, which runs all of Ontario's power reactors, is subject to the regulations of the Atomic Energy Control Board (AECB), established under the above statute.

S.5 Following the establishment of Atomic Energy of Canada Limited (AECL) in 1952, a close partnership was established between Ontario Hydro and AECL (on whose Board Ontario Hydro has been represented). Between 1954 and 1966, a series of decisions by Ontario Hydro committed the utility to increasing reliance

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* The Ontario Nuclear Safety Review is written simply as "the Review."

Note: A complete description of the way in which the Review was conducted is contained in Annex VI.

on nuclear sources. It also led to the exclusive use by Ontario Hydro of AECL's CANDU (Canada Deuterium Uranium) reactors. There are now 20 CANDU reactors in use or under construction in Ontario. This is a Canadian technology that has worked well, but is not without problems.

B. Where are the Reactors?

S.6 Ontario Hydro policy has been to build nuclear generating stations with up to eight reactors at each. The Bruce and Pickering stations are this size, their eight reactors generating 6402 and 4124 MWe respectively. Darlington will have four reactors generating 3524 MWe. This contrasts with US practice of locating only one or two reactors at each station.

S.7 The Ontario practice makes possible a variety of services that would be uneconomic for a single unit. It also makes possible a safety refinement--the use of a common vacuum building, unique to Ontario, which can take and immobilise any excess gases in the event of an accident.

S.8 The province now possesses two of the world's largest nuclear generating stations, with a third under construction. One station--Pickering--is on the outskirts of Toronto. Another is only 25 km to the east. Many people thus live close to the stations and would be immediately threatened by any severe accident.

C. What are the Safety Issues?

S.9 There are two questions: are the CANDU reactors safe while operating normally? and what kinds of accidents are possible, and what would be their consequences? In both cases, the main threat is from exposure of workers and the public to dangerous radiation.

S.10 CANDU reactors are designed to make steam, which drives turbines that generate electricity. The fuel is uranium dioxide, a small part of which is fissioned (split) by neutrons in a chain reaction, which releases the required heat. The fuel is surrounded by a heavy-water moderator (to slow down neutrons) and is cooled by a rapid, high-pressure flow of heavy water through the pressure tubes containing the fuel. As the nuclei split, the fission products (usually toxic and radioactive) remain in the intact fuel. Unless the fuel overheats, and hence melts or disintegrates, the radioactive substances remain immobilised, and are later placed in safe storage.

S.11 But safety problems have nevertheless arisen in CANDU reactors. Both National Research Universal (NRU) and National Research Experimental (NRX) research reactors at Chalk River Nuclear Laboratories had serious accidents in the 1950s. There were less serious accidents--due to failures in pressure tubes--at Pickering in 1983 and at Bruce in 1986. The CANDU reactor is clearly not immune from accidents, but there have been no fatal casualties at Canadian reactors as a result of nuclear accidents. In addition, workers exposed to high doses at NRX and NRU show no increased cancer mortality.

S.12 Severe accidents have occurred at foreign plants, e.g., at Windscale, UK, in 1957, Three Mile Island (TMI), Pennsylvania, in 1979, and Chernobyl, USSR, in 1986. At Chernobyl, 31 persons died, all within the station (many from burns). An unknown number of persons in the surrounding area, and even farther afield, may contract cancer as a result of the escape of radioactive substances. A smaller escape occurred at Windscale, and a very much smaller release at TMI. These events involved different types of reactors. Could they happen at a CANDU plant?

D. Safety Measures

S.13 The CANDU reactor is isolated from its environment by massive containment structures (held below normal atmospheric pressure) designed to stop radioactive substances from escaping, following any disintegration or melting of fuel. This is the last barrier between the radioactivity and the public. In addition to containment, the following devices or systems are involved in safety management:

(i) computer-controlled, fast-acting regulating systems that keep the reactor at or near the critical state (the rate of fissioning that just maintains itself). These are necessary to control power output, and also to ensure that power inside the reactor is properly distributed. The regulating system holds the reactor inside an acceptable range of operating conditions, which are safe and also yield the power required.

(ii) shut-down systems, which are diversely designed systems that turn off the chain reaction in well under 2 s. Like the regulating systems, the shut-down systems are controlled automatically by sets of diverse sensors sampling a variety of conditions in the reactor. If abnormal conditions are detected, the chain reaction is shut down.

(iii) emergency coolant injection systems (ECISs), which flood the fuel with cool, light water, to stop it from melting or disintegrating after a large loss of coolant accident (LOCA).

S.14 The Review has examined the performance of all these systems and concludes as follows:

(i) The computerized regulating systems appear to function reliably. There were early problems in the computer control at Pickering A, but these have been overcome. Some of the computer equipment is now outdated, and replacement parts are hard to obtain. There have been no failures of regulation at either Bruce plant or at Pickering B.

(ii) The shut-down systems (SDS1 and SDS2) also display high availability. They seem to be able to shut down the reactor as designed (i.e., well within 2 s of the initial alarm). Pickering A has only one system, which has just been upgraded in units 1 and 2. This will be done for units 3 and 4 in 1988 and 1989. The single system is supported by a moderator dumping mechanism that can deal with most but not all accidents.

(iii) The ECISs are more complex, and it has been hard to show that they will cool all parts of the fuel following a LOCA. Availability has not been perfect, especially at Bruce A and Pickering A. Upgrading to high-pressure systems is now complete except for units 3 and 4 at Pickering A.

(iv) The containment systems are in a satisfactory condition and are likely to prevent the escape of radioactive materials following nearly all accidents (except for deliberately vented noble gases).

S.15 All these systems--regulating and safety alike--have to work quickly. In the event of a LOCA, the coolant in the pressure tubes will boil, creating steam voids. This will rapidly accelerate the chain reaction, requiring shut-down within 2 s. This is the positive void reactivity effect that is one of CANDU's less desirable characteristics.

S.16 These protective measures have shut down various Ontario Hydro reactors 450 times since 1971. About half of these reactor trips were due to unacceptable power changes, and half to operator errors or to falsely identified equipment malfunctions. Only 2% of the trips were due to conditions that actually threatened the fuel. The ECISs and containment systems have never been needed in earnest. All systems are diverse, contain redundancies as protection, and are routinely tested in service. I conclude that the safety systems are effective and provide adequate protection against accident conditions. Defence-in-depth is clearly present, although Pickering A is less well protected than newer stations.

E. The Pressure Tube Problem

S.17 The most serious problem to have affected Ontario Hydro's power reactors concerns the pressure tubes in which the fuel is located. These tubes have to withstand the high pressure of the heat transport system, of which they are part. They are also exposed to high temperatures and to an intense flow of neutrons. They are made of zirconium alloys that allow these neutrons to pass freely, and were expected to survive these harsh conditions for 25-30 yr.

S.18 Leaks of heavy water from these tubes (into the fuel channel's annulus) have been detected 23 times since 1971, indicating that they were not performing as expected. These leaks were easily detected, so that defective tubes could be replaced. But on 1 August 1983, a pressure tube ruptured suddenly at Pickering A. Contaminated heavy water escaped into the reactor building. It was subsequently found that many tubes in units 1 and 2 were in poor condition. Between 1983 and 1988, the reactors were refitted with tubes made of a different alloy. Meanwhile, 1030 MWe of power were immobilised and had to be replaced. The work was performed well under awkward and hazardous conditions. Total costs will exceed $425 million, and collective radiation exposure to workers was over 7 Sv (well below prior estimates, but still high).

S.19 A further pressure tube rupture occurred on 26 March 1986 at the Bruce A NGS, when the reactor was shut down. The surrounding calandria tube also ruptured. The consequences were less damaging than at Pickering A, but the event emphasised the seriousness of the problem.

S.20 Reactors in other countries normally use single pressure vessels instead of CANDU's pressure tubes, although Soviet RBMK reactors use tubes. The pressure tube technology has many advantages, but only if integrity of the tubes can be guaranteed through long working periods.

S.21 The cause of these failures is known to be the formation within the zirconium, or at stressed points within and on its surface, of enclosures or blisters of zirconium deuteride (usually called hydride). This weakens the tube. Moreover, the extent of deformation of the tube due to the neutron bombardment, and to unplanned displacement of the garter springs separating it from the calandria tube, has been larger than predicted. A major research programme is under way to find solutions.

S.22 The Review's technical consultants agreed with Ontario Hydro and AECL that such pressure tube failures have serious economic consequences, but present little threat of radiative exposure of the public.

S.23 If, however, there are major pressure tube failures in the future, there will certainly be a threat to the operational and maintenance crews in the reactor building, as well as a large refitting cost. And I am not convinced that there is no danger of public exposure, especially if the failure spreads to other fuel channels. Accordingly, maximum priority should be given to finding a solution, and to improved monitoring of the fuel channels, to avoid further surprises.

F. The Operating System

S.24 Ontario Hydro's reactors are designed and built by Ontario Hydro's own engineers and contracting staff, with input at the design stage from AECL. The process requires continuous interaction with AECB, which issues construction approvals and operating licences. AECB resident engineers are present at the station to provide continuing audit of the operating system.

S.25 The reactors are each under the direction of a Station Manager, who reports to the Nuclear Generation Division (NGD) at Ontario Hydro headquarters. The Station Manager is also directly responsible to AECB for all safety and licensing questions. In safety and radiological questions, the Station Manager is supported by specialised station staff and by various corporate groups at headquarters. The operating staff is organised by the Canadian Union of Public Employees, Local 1000, from the rank of Unit First Operator down. Union-management relationships in safety matters appear fairly satisfactory, but are not ideal: the 1985 dispute at Bruce came close to a confrontation (involving AECB) over the use of management personnel in operating positions. There are also complaints that worker safety suggestions are often disregarded.

S.26 Reviews of the operating system were carried out by an Operational Safety Review Team (OSART) from the International Atomic Energy Agency and by a consulting team drawn primarily from the oil and chemical industries. These reviews found the operating system sound, but isolated certain areas in which improvement was needed:

(i) There was a maintenance backlog at Pickering and Bruce because of inadequate staffing and resources (both reviews).

(ii) Conventional safety performance in NGD appeared inferior to that of the chemical industry. There had been no fatalities in 125 million person-hours, but NGD's temporary disability rate (although below its own target) was higher than the consultants considered acceptable (consultants).

(iii) Further developments in refresher training of operating staff were advised, as was periodic reauthorisation by AECB (consultants).

(iv) Certain refinements in radiological protection were recommended (OSART).

(v) There were some failures in communication between unionised staff and management (consultants).

Ontario Hydro's response has been prompt and effective--but has not yet met all the requirements.

S.27 The system of basic training and qualification of reactor staff is excellent. Authorisation of AECB is required for all positions with significant safety responsibility. Also excellent is the radiological training received and the principle that the individual staff member is responsible for his/her personal protection and has specified responsibility for the safety of others.

S.28 Safety depends more on the quality and qualifications of the staff than on any other single factor. The CANDU stations are extensively computer-controlled, partly because of their complexity, and partly because of the need for instant response in the case of large LOCA. The operators' role is to audit this automated process. The obvious danger is boredom and inattention. Much depends on alertness to upset conditions (which are immediately announced in the control rooms) and on the skill with which the operators respond. So far, the record at Ontario Hydro's stations is good. Equally vital is the corporate safety imperative that lies behind it--that senior management give safety its unstinted attention.

G. Exposure to Radioactivity: Health Questions

S.29 CANDU reactors produce radioactive substances in the fuel and, to a lesser extent, in the reactor fluids (moderator and coolant). The list includes very radioactive fission products (retained in the fuel, unless accidents occur), tritium, and carbon-14. The latter two substances are in part released to the atmosphere or lake. CANDU reactors produce unusually large amounts of both.

S.30 Within the reactor, neutrons are almost entirely absorbed by barriers and rarely affect workers. But strong gamma radiation is present around the reactor, with lesser amounts of beta radiation. Strict rules of protection apply in each of the defined radiological zones. Even so, there is some exposure of the work-force, especially maintenance crews. This exposure is monitored and recorded for each individual worker.

S.31 Ontario Hydro worker exposure has been observed to result in average doses in 1985-86 near 3.9 mSv/yr, comparable with the levels typical of Japan and Europe. Far fewer Ontario Hydro workers were exposed per unit energy produced. The highest 1-yr whole-body dose was 73 mSv, in 1979. Since that year, no worker at any station has been exposed above regulatory limits. Lifelong exposures are low by comparison with many other utilities. Ontario Hydro has now established target dose limits of 20 mSv/yr for Pickering and Bruce. Overall, this is an excellent record.

S.32 Exposure of the general public can occur in two ways:

(i) Under normal operating conditions, the stations are permitted to release certain radioactive substances, up to limits established by AECB. These limits are calculated so that no individual in the area surrounding the station can receive a radiation dose exceeding 5 mSv/yr. The substances include tritium, noble gases (krypton, xenon), and carbon-14. All Ontario Hydro stations reported releases at 1% or less of these limits in 1986, so that doses to the public should have been at or below 0.05 mSv per year. There is no systematic monitoring of public exposure, because releases from the stations contain less than 5% of the radioactivity that occurs naturally, which obscures the releases from the stations.

(ii) Under accident conditions, much higher exposures may occur if containment is breached, especially because highly radioactive fission products (including iodine) may be released. This has not so far happened at Ontario Hydro's stations.

S.33 The only large groups of Ontario residents who have been exposed to elevated doses from nuclear power generation are the nuclear work-forces of AECL and Ontario Hydro. Both groups have been monitored, and their health has been recorded. The Ontario Hydro data are analysed each year at the Department of Health Care and Epidemiology of the University of British Columbia (by T.W. Anderson). The AECL work-force's experience is analysed by the National Cancer Institute. The independence of the analyses is not in doubt.

S.34 In both groups of exposed workers, cancer mortality has been below that of the general Canadian public. The AECL group includes workers who received large doses during the clean-ups after the NRX and NRU accidents, and a small number of others (19) who received lifetime doses of over 200 mSv. These highly exposed groups also show cancer mortalities below expectation. The past three 5-yr periods have shown a slow rise in cancer mortality among workers at Chalk River, although values are still similar to those in the general public.

S.35 It is too early to be sure that latent cancers will not appear in some workers. So far, however, these exposed work-force groups appear to show no out-of-line cancer mortality. Because members of the general public, even those resident near power stations, receive much lower doses, it is unlikely any adverse effect will be detected among them.

S.36 Neither of these groups of workers contained any children, and few were women (most of the analysis is actually for men). The small number of exposed women shows no excess cancer mortality.

S.37 Recent analyses of persons living near nuclear installations in England and Wales similarly showed no general excess cancer and no increase in cancer. There was, however, some evidence of added lymphoid leukaemias in persons 24 yr and under. No such analysis has been attempted in Canada. Every effort should be made by epidemiological means to establish whether children and young adults in communities near reactors (e.g., Pickering, Deep River) show increased leukaemia incidence or other morbidities.

S.38 Canadian (AECB) regulations for radiological dose limits are derived from the advice of the International Commission on Radiological Protection (ICRP). Re-examination of Japanese bomb victim evidence is likely to lead the ICRP to lower its dose limits to half present values or less. Canada will probably follow suit. Ontario Hydro's practice already more than complies with ICRP guidelines and AECB regulations.

S.39 Canada, and hence Ontario Hydro, should continue to be guided by ICRP and two other internationally respected bodies, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), and the US National Academy of Sciences Committee on the Biological Effects of Ionizing Radiation (BEIR). These committees distill an international consensus and are representative of the best medical opinion world-wide.

H. Could a Severe Accident Happen in Ontario?

S.40 The Chernobyl accident killed 31 persons in the plant itself and spread large volumes of radioactive materials into the environment--minute quantities of which reached Canada. Could Ontario's reactors create a similar accident?

S.41 The answer is "no," although some other types of serious accident may occur. At Chernobyl, four factors created the problem:

(i) Operational incompetence and neglect of regulations reached astonishing heights. Ontario Hydro's responsible and well-trained shift supervisors and operators would be unlikely to behave so ineptly.

(ii) The Chernobyl cooling system involved much larger volumes of water capable of flashing into steam than does CANDU. This underlay the massive structural damage done at Chernobyl.

(iii) The Chernobyl moderator was made of large blocks of inflammable graphite, whose burning carried aloft a large part of the radioactive debris. A similar factor underlay the 1957 accident at Windscale, UK. CANDU uses heavy water, a fire quencher, for this purpose.

(iv) The Chernobyl reactor was unable to achieve rapid shut down following the power excursion, whereas early failure of the calandria in CANDU accidents would lead to rapid shut down.

The Chernobyl reactor shared one of CANDU's less-desirable characteristics--a positive void reactivity coefficient. Its regulating and safety systems turned out to be unable to cope with the upset: they functioned, but were inadequate. Moreover it lacked Ontario CANDU's massive containment system.

S.42 One possible severe accident in a CANDU could arise from a massive breach of the high-pressure heat transport system, which cools the fuel, and a simultaneous failure to shut down. The probability of such an accident has been assumed by AECB to be so low that calculation of its consequences has not been required--especially as two independent shut-down systems have been required since Pickering A was licensed.

S.43 Given public criticism of this procedure and doubts about Pickering A's ability to withstand such an accident, the Review asked Ontario Hydro and the Argonne National Laboratory to conduct parallel analyses of the case outlined in para. S.42 for the Pickering A reactors. The results, which were very similar, contained the following conclusions:

- a very rapid increase in power began immediately after the break in the inlet header (the large LOCA assumed);
- fuel melting and penetration of the pressure tubes and calandria tubes began almost immediately;
- the calandria vessel failed (in less than 4 s after the initial break);
- a massive blow-down of the hot coolant, with a strong pressure surge, ejected gases into the reactor building and containment;
- the pressure surge was unable to breach containment, although cracks appeared around the top plug of the dome;
- there was little escape of materials before these cracks resealed (in under 20 s); and
- subsequent venting of noble gases could be spread over about one week.

Independent reviews by senior consultants confirmed these results.

S.44 A severe accident of this sort would damage the reactor, probably irreparably, and might cause unsafe conditions for the reactor operators and maintenance crews. But there would probably be only minor effects on the general public. It is likely, but not certain, that similar results would hold for the other nuclear stations.

S.45 Another possible accident sequence involves simultaneous failure of the regulating system and failure to shut down. This should be analysed in the same way, as recommended by AECB. Time did not allow this further analysis as part of the Review.

S.46 It is possible that other accident sequences, perhaps including malfunctions of the monitoring and safety support systems (water, air, and electric supply in-plant), have not yet been identified. A main thrust of accident and safety analysis should be to identify such sequences. Even so, surprise can never be quite eliminated. In particular, malevolent human action remains a possibility.

S.47 In the circumstances, and given the extensive backfitting, upgrading of the ECIS, and renewal of pressure tubes carried out in Pickering A units 1 and 2, and the intention to continue much of this process in units 3 and 4 in 1988 and 1989, I see no obstacle to the station's continued operation. But it remains the weakest link in Ontario Hydro's chain of stations. Further efforts to sophisticate the upgraded shut-down system are warranted.

I. Ontario Hydro Corporate Affairs

S.48 The Review's consultants identified certain aspects of quality assurance (QA) and corporate safety culture that need Ontario Hydro's attention.

S.49 The conventional safety record of NGD does not in all ways meet the highest standards. By comparison with the chemical industry, the NGD target of six temporary total disabilities per million person-hours is not challenging. In fact, the target is satisfactorily beaten at all nuclear stations in most years. But the consultants advise that a target of one such total disability should be reachable, except during construction work. Ontario Hydro's overall performance in this area is far better than that of most Ontario industries, but should (in the consultants' view) be improved.

S.50 In contrast, NGD's record as to fatalities is remarkably good (125 million person-hours with no fatalities). The radiological record is also excellent. One consultant suggested that there was an imbalance in Ontario Hydro's overall safety culture--a bias towards radiological protection and severe hazards, and away from conventional protection and lesser hazards.

S.51 Safety in Ontario Hydro depends on ceaseless vigilance and frequent intervention by senior management. The same is true of conventional QA. Safety depends on human performance throughout the organisation. An overall assessment of Ontario Hydro's approach to QA and quality control (QC), and to quality engineering (QE), seems desirable--preferably by external critics.

J. Emergency Measures

S.52 In the event of an accident, an established set of measures will be taken by Ontario Hydro staff, and an emergency centre established in Toronto. Both at the station and at the centre, Ontario Hydro has established precise responsibilities and procedures. These are rehearsed annually and may involve surrounding municipalities.

S.53 The province assigns responsibilities in this area to the Ministry of the Solicitor General. Responsibility for emergency action of the station will be in the hands of a small planning staff, together with an identified set of officials and other parties. A formal Nuclear Emergency Plan was published in 1986.

S.54 Unfortunately, there has not yet been a formal decision to finance this plan and put it in place (although Cabinet has decided that the expenses of this procedure will be borne by Ontario Hydro). It is urgently necessary that a formal nuclear emergency planning branch be created within the Ministry of the Solicitor General, and all the preparedness provisions of the plan be effected. At present, Ontario is not ready for a severe accident.

S.55 A Working Group of this Ministry will report shortly on the reference accidents on which evacuation, sheltering, and radiological protection measures should be based. Two tiers of accidents are envisaged: one arising from possible engineering failures, and the other--much the larger--from sabotage, terrorist action, or gross negligence. Planning should clearly be based on the maximum credible accident.

K. Regulation and Public Awareness

S.56 The regulation of Ontario Hydro's nuclear activities is carried out by AECB, a statutory federal body,* and hence beyond my terms of reference. Because, however, regulation affects safety, I have offered suggestions for change.

S.57 The regulatory methods and powers of AECB are sound and should not be fundamentally changed. They follow European practice, by putting the onus for safety on the shoulders of the operating utility, subject to AECB approval. AECB sets the requirements and licenses the utility only if they are met. It would be inappropriate to move to the US model of tight prescription, with court action as the final sanction.

S.58 However, AECB has always seen its mandate as scientific and technical, whereas many of the safety issues in nuclear development are socio-economic and environmental. These matters could be considered by the Board if extra members, eminently qualified in these areas, were added (by statutory amendment). In addition, AECB's staff resources need strengthening in these areas and in public health. Proposals to reduce the staff complement are extremely unwise. The existing staff cannot effectively cover all its commitments--especially because a higher level of audit of Ontario Hydro performance is desirable.

S.59 AECB's work, and that of its outstanding Advisory Committees on Nuclear Safety and Radiological Protection, is almost unknown in Canada. AECB needs a higher profile and should also seek closer contact with concerned opinion in the

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* Where the actual five-member Board is intended, excluding the staff, "Board" alone is written.

scientific community. The advisory committees need the resources to enlarge, accelerate, and more widely disseminate their work.

S.60 The relationship between AECB and Ontario Hydro is not ideal. It depends heavily on informal discussion and exchange of correspondence. More of this exchange needs to be formal, and decisions (including reasons) need to be thoroughly documented. But the confrontational nature of the US Nuclear Regulatory Commission's (US NRC) relations with its 60 utilities would be absurd in the Canadian context. I heard several suggestions that Ontario Hydro's large size, high technical competence, and aggressive style of presenting courses of action tended to override AECB's judgements. This is certainly not the usual case.

S.61 AECB's role in the qualification of operating staff at nuclear stations is exemplary. It would be strengthened if periodic reauthorisation of staff were a requirement.

S.62 The Province of Ontario should not attempt to extend its role in the regulatory arena. On the other hand, there is an insistent demand for public participation in decisions about nuclear power. This could be met by the province in two ways:

- by more public hearings using the powers conferred by the Environmental Assessment Act; and
- by the creation of a formal Advisory Council for Health and Safety, with funds to finance public enquiries, including the expenses of intervenors.

L. Research and Development

S.63 CANDU is still a young technology and needs support from competent research and development laboratories. This is true regardless of whether further sales of CANDU reactors are achieved. Research is particularly necessary in the safety area. Recent cut-backs in research funding handicap the efforts to ensure public safety.

S.64 Responsibility for most research and development in this area has rested with AECL, a federal Crown corporation. CANDU technology was developed primarily in its laboratories, with substantial help from the Canadian General Electric Company and Ontario Hydro. AECL and Ontario Hydro have excellent research facilities, as does Canadian Westinghouse. There is, however, only limited strength in the universities (which should be strengthened).

S.65 The main thrust of safety-related research is at present towards solution of the pressure tube (fuel channel) problem. The major effort is at AECL's Chalk River Nuclear Laboratories (CANDU's original home) and Whiteshell Nuclear Research Establishment, Manitoba, where the joint waste disposal programme is also based. AECL also maintains a programme at the Mississauga laboratories of its research company. Ontario Hydro has a more limited but sound programme, as does Canadian Westinghouse.

S.66 In 1988, total Canadian research expenditures on reactors will be $117 million, of which Ontario Hydro will provide $50 million (half spent internally, and half in AECL facilities). Ontario Hydro's revenues from nuclear energy sales were $2.5 billion in 1987. Hence, Ontario Hydro's 1988 expenditures will be only 2% of sales. AECL's expenditures, at $66 million, add substantially to the total. In the fuel channel area, total expenditures in 1988 will be $42 million ($19 million from Ontario Hydro). Again, this figure is small in relation to the scale of the problem. Research is being underfunded just where the technology is most vulnerable. But part of the problem is unavailability of technically competent staff and expensive research facilities.

S.67 Furthermore, the federal cut-back (to 50%) of the research budget of AECL's research company is a serious matter for Ontario Hydro's programmes. The engineering laboratories of AECL are also important to Ontario Hydro. As long as Ontario Hydro operates CANDU reactors, it is essential that the relevant parts of AECL's infrastructure and research capability remain intact.

M. Women in Nuclear Power

S.68 There are few women at the nuclear generating stations, and there was none on either the Advisory Panel or the Review Panel of this Review. Women have in the past been excluded from work in radiological protection zones by formal regulations. I received briefs complaining that their position was still unacceptable and at variance with Ontario Hydro's affirmative action programme.

S.69 Women tend to be more critical of nuclear power in general, and of safety standards in particular. Their rarity in or absence from senior management positions, therefore, may prejudice sound judgement. I favour an increase, provided that this can be done on merit.

S.70 As regards operating positions in reactors, however, caution is needed. Women are more at risk in given radiation fields than are men, largely because of breast cancer (and recent Japanese evidence suggests that this risk is larger than previously thought). The risk is also higher for the foetus, at certain stages of development. If occupational dose limits are made low enough for men and women to work alongside in radiological zones, women will still be at greater risk, as may any unborn children (although this is not adequately understood). Although I sympathise with the wish of women's groups to *penetrate this highly paid job field, each individual should be aware of the* possible hazards before doing so.

RAPPORT AU MINISTRE

I Conclusions et recommandations*

A. Objet

C.R.O.1 Je présente mes conclusions et mes recommandations sous la forme d'une conclusion majeure, de deux recommandations majeures (avec arguments à l'appui) et de plusieurs conclusions et recommandations de nature moins générale mais ayant chacune son importance propre. J'ai indiqué, du côté gauche de la page, où trouver dans le Rapport technique ou dans les Appendices, l'argumentation détaillée correspondante.

C.R.O.2 L'évaluation prend en considération deux groupes de personnes:

- la main-d'oeuvre employée dans les centrales nucléaires; et
- la population ontarienne

et deux situations:

- l'exploitation normale; et
- les accidents

C.R.O.3 Les appendices contiennent d'autres recommandations. Ces dernières apparaissent telles que formulées par les auteurs. J'ai incorporé certaines d'entre elles aux recommandations générales. D'autres, plus spécialisées, sont soumises aux organismes appropriés pour examen.

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* Le "Ontario Nuclear Safety Review" est désigné par "la Commission".

Source*

B. Conclusions et recommandations majeures

1. Sécurité générale

1ère Conclusion majeure-Sécurité générale

le texte — **C.R.1.1 Les réacteurs d'Hydro-Ontario fonctionnent de façon sécuritaire et atteignent un niveau de performance technique très élevé. Aucun effet négatif significatif sur le personnel ou sur la population générale n'a pu être détecté. Les risques d'accidents assez sérieux pour affecter la population ne peuvent jamais être nuls, mais sont extrêmement faibles.**

C.R.1.2 Parmi les faits susceptibles de confirmer ou d'infirmer cette conclusion:

(i) La mortalité due au cancer est faible et la santé générale du personnel exposé aux radiations (surtout des hommes) est bonne d'après les observations des 20 à 30 dernières années autant à Hydro-Ontario qu'à l'Énergie Atomique du Canada Limitée (EACL). Les doses moyennes de radiation auxquelles ces groupes sont exposés sont au moins plusieurs centaines de fois supérieures aux doses auxquelles les membres du grand public sont exposés. (paras. 244-249)

(ii) Cependant, des cancers latents peuvent se manifester ultérieurement parmi les deux groupes, et une observation continue est donc nécessaire. (para. 245)

(iii) On n'a rapporté aucun accident mortel dû aux radiations parmi le personnel d'Hydro-Ontario ou d'EACL.

* paragraphes, chapitres, annexes, appendices, selon le cas, dans le rapport technique.

Source

(iv) En dépit de plusieurs accidents survenus dans les centrales d'Hydro-Ontario, aucun n'a donné lieu à la libération de quantités importantes de matières radioactives dans l'environnement; on n'a jamais eu besoin de se servir des systèmes à injection de réfrigérant au coeur du réacteur, ni des dernières barrières de retenue--les bâtiments à vide. (paras. 164-183)

(v) D'après les calculs, même dans l'éventualité d'un accident comportant une perte de caloporteur suivie d'une défaillance du système d'arrêt d'urgence dans les réacteurs les plus faibles à cet égard--ceux de Pickering A--la rétention demeurerait pratiquement parfaite, et la fuite de matières radioactives serait minime. (Table 14)

(vi) La formation technique et radiologique du personnel des réacteurs est excellente. (para. 147)

C.R.1.3 Toutefois pour assurer dans l'avenir que la performance reste sécuritaire, des changements s'imposent dans quatre principaux domaines. Le comportement des réacteurs n'a pas été irréprochable et a présenté plusieurs défaillances importantes. Leurs composants vieillissent. Certains aspects du système d'exploitation prêtent le flanc à la critique. Il faut agir au niveau de l'organisation provinciale des mesures d'urgence. La réglementation n'est pas sans poser quelques problèmes. Toutes ces questions sont débattues ci-dessous.

C.R.1.4 Une conclusion générale est que la **performance humaine--des individus et des institutions--est la clé de notre sécurité future.** Une saine attitude vis-à-vis la sécurité doit régner au sein de l'Hydro-Ontario, et elle doit être transmise à partir des échelons supérieurs vers le bas. (para. 37 (i))

C.R.1.5 Hydro-Ontario jouit d'une réputation exceptionnelle auprès des groupes professionnels et techniques dans le monde entier qui la considèrent comme l'une des compagnies d'électricité des plus exemplaires dans le monde. Cette réputation provient de sa maîtrise des sujets techniques abordés dans le présent rapport. Les groupes d'analystes à la conception, à la construction et à la sécurité sont particulièrement forts.

2. Administration générale d'Hydro-Ontario

C.R.2.1 Malgré ce qui précède, une intervention de la part du gouvernement provincial et d'Hydro-Ontario améliorerait les perspectives d'avenir quant à la sécurité et à la performance économique (les deux étant étroitement liées).

1ère Recommandation majeure-L'élément humain

Qu'Hydro-Ontario:

(i) procède, au plus tôt, à une révision en profondeur de l'organisation de son système d'exploitation, en étroite collaboration avec des consultants externes ayant une expérience internationale en matière de gestion;

(ii) commandite une étude sur les facteurs pouvant affecter la performance humaine à l'intérieur de la compagnie, dans le but d'atteindre une efficacité optimale et de maintenir un standard de haut niveau en matière de sécurité de fonctionnement;

(iii) examine et révise ses procédures relatives à l'établissement et au maintien d'un programme d'assurance qualité générale pour chacune de ses centrales, après avoir consulté des spécialistes indépendants.

Source

C.R.2.2 A l'égard des Recommandations 1(i) et 1(ii), les sujets suivants devront être examinés:

Source		
paras. 385-388	(i)	Le rapport de sécurité classique de la Direction de la production nucléaire d'Hydro-Ontario est bon. Le fâit qu'aucun accident mortel n'ait été enregistré pour 12,5 millions d'années-personnes est exceptionnel. Mais le taux d'invalidités totales temporaires, et le taux cible, sont plus élevés que dans l'industrie chimique lourde. La Direction base ses pratiques de façon trop exclusive sur des évaluations internes de ce qui peut être réalisé.
para. 139	(ii)	Les relations entre Hydro-Ontario et le local 1000 du Syndicat canadien des employés de la fonction publique ont parfois tourné au vinaigre.
paras. 129-131 Appendices III.1,2,3	(iii)	Il semble que le contrôle de la maintenance technique soit fragmentaire, et que l'accumulation de travail en retard y soit trop importante.
para. 141	(iv)	Il y a des plaintes à l'effet qu'on ne met pas toujours en pratique les recommandations adressées aux autorités au sujet de la sécurité.
para. 141	(v)	L'auto-vérification pratiquée par son personnel d'exploitation est inadéquat; il arrive souvent qu'on ne rapporte pas des événements ou des actes anormaux sans conséquences.
Figures 26-29 paras. 164-183	(vi)	Il semble y avoir des différences indésirables entre les performances des systèmes de sécurité et en matière radiologique, d'une centrale à l'autre.
paras. 118-122	(vii)	La structure organisationnelle du programme nucléaire semble excessivement complexe, et présente certaines ambiguïtés quant au partage des responsabilités;
Appendices III.1,2,3	(viii)	Il y a confusion quant au suivi donné aux directives d'exploitation temporaires dans les centrales.

Source

C.R.2.3 Même si aucune de ces circonstances ne constitue en tant que tel une menace sérieuse pour la sécurité, elles sug-
paras. 382-395 gèrent néanmoins qu'une révision des attitudes ayant trait à la sécurité des opérations serait dans l'intérêt d'Hydro-Ontario et, par conséquent, du public.

C.R.2.4 A l'égard de la Recommandation 1(iii), on fait souvent allusion à l'AQ et au CQ dans le document soumis par Hydro-Ontario à la Commission, mais aucune philosophie globale ne s'en dégage clairement. Une des principales caractéristiques des centrales nucléaires est que toute faiblesse peut être extrêmement coûteuse en termes d'argent et de santé.
paras. 371-381 C'est pour cette raison qu'à chaque étape dans la construction et dans l'exploitation de ces centrales, il est primordial de maintenir le plus haut standard de qualité. Ceci s'applique à la conception, à la fabrication, à l'assemblage et à l'exploitation, à la fois pour les gens et les matériaux. On a besoin d'un programme d'assurance-qualité depuis le début jusqu'au déclassement. Ceci caractérise l'approche corporative du programme d'assurance-qualité (AQ) qui utilise des critères, des normes, des spécifications, etc. Ces principes sont mis en pratique sous la forme de contrôle de la qualité (QC).

C.R.2.5 Les manuels d'Hydro-Ontario sont explicites quant à la qualité technique, toutefois le programme d'assurance-qualité devrait explicitement porter sur tous les aspects reliés à la conception, à la fabrication, à la construction et
paras. 371-381 à l'exploitation d'une centrale nucléaire. Le programme d'assurance et de contrôle de la qualité devrait porter une attention toute particulière au besoin d'obtenir et de garder une performance humaine de premier ordre et à tous les niveaux, y compris dans la sélection, la formation et la surveillance du personnel d'exploitation. Le ré-entraînement périodique

Source

devrait y être inclus. L'élaboration et la mise en application de ce programme devraient être confiées à des cadres supérieurs connus. Le programme devrait constituer une préoccupation constante pour les autres cadres supérieurs de même que pour le personnel des centrales.

3. Les problèmes avec les tubes de force

Recommandation majeure-Intégrité des tubes de force

paras. 189-207 **Qu'un maximum de priorité soit donné à la recherche d'une solution au problème des tubes de force, et à l'amélioration des systèmes de surveillance à l'intérieur des réacteurs. Les sommes investies dans la recherche sur les canaux de combustible menée par Hydro-Ontario devraient être augmentées et une plus grande importance aux problèmes métallurgiques fondamentaux devraient être donnée, en allant chercher l'expertise disponible dans d'autres industries.**

para. 202 **C.R.3.1** Le problème le plus grave concernant la sécurité des réacteurs d'Hydro-Ontario est la piètre performance des tubes de force (les composantes internes des canaux de combustible, dans lesquels se produisent les fissions). Ces tubes font partie du circuit de caloportage à haute pression. Toute défaillance constitue une menace d'accident à faible perte de caloporteur. Deux défaillances de ce genre sont déjà survenues.

Source

paras. 194-195

C.R.3.2 On a découvert les causes de ces défaillances. Certaines mesures de réhabilitation ont été prises (tel que la remise en état des unités 1 et 2 à Pickering A). Il y a encore beaucoup à faire.

paras. 198, 203

C.R.3.3 La menace principale est une avarie importante du réacteur, et par conséquent, des dépenses importantes entraînées par les réparations et le remplacement de l'énergie. Le danger que des matériaux radioactifs s'échappent dans l'environnement semble minime. Il est peu probable que le public soit menacé. Mais il y a des risques pour les équipes de maintenance et d'exploitation.

paras. 208-209

C.R.3.4 Le budget annuel actuel de 42 millions $ consacré à la solution du problème des tubes de force (dont 19 millions $ d'Hydro-Ontario) paraît insignifiant par rapport au problème et aux revenus de 2,5 milliards $ d'Hydro-Ontario, pour les ventes d'énergie nucléaire seulement. L'analyse effectuée par le groupe des exploitants de réacteurs CANDU, portant sur les besoins de la recherche, est excellente. Toutefois, le programme est en partie limité par le manque de spécialistes compétents capables de proposer ou d'effectuer des travaux originaux.

paras. 207, 210

C.R.3.5 La recherche sur ce problème ne peut être de courte durée. La recherche de meilleurs alliages, par exemple, exige des essais prolongés à l'intérieur du réacteur, effectuées sur plusieurs années. La participation des laboratoires d'Hydro-Ontario et d'EACL sera également nécessaire à cette recherche.

Source

C. Autres Conclusions et Recommandations

4. Recherche et développement

Recommandation 3

paras. 208, 210

Qu'Hydro-Ontario, en tant que compagnie productrice d'électricité, assure l'entière responsabilité du financement des recherches nécessaires pour garantir la sûreté et l'efficacité de ses centrales nucléaires, en ayant recours aux équipements et au personnel d'EACL, d'autres compagnies ou des universités, selon le cas.

C.R.4.1 Les institutions canadiennes pour la recherche le développement, capables d'effectuer des recherches sur la conception, la production, l'amélioration et les essais de réacteurs, sont excellentes mais limitées au point de vue personnel et équipement. Les propres installations d'Hydro-Ontario, quoique bonnes, sont limitées.

paras. 208-210

C.R.4.2 Les dépenses globales entraînées par les recherches sur les problèmes des réacteurs CANDU semblent minimes comparativement aux sommes énormes investies par Hydro-Ontario et à son chiffre de ventes annuel (plus de 2,5 milliards $ d'énergie nucléaire). La contribution d'Hydro-Ontario aux dépenses totales paraît faible.

Figures 18-19
Table 3

C.R.4.3 Les recherches nécessaires pour assurer l'efficacité et la sûreté des centrales nucléaires doivent être sous la principale responsabilité d'Hydro-Ontario. En général, le consommateur doit payer pour de telles recherches mais comme ces dernières dépassent les besoins du programme nucléaire

Source

d'Hydro-Ontario, une contribution des payeurs de taxes (y compris de ceux qui appartiennent à d'autres juridictions) est justifiée. Ceci ne diminue en rien l'obligation d'Hydro-Ontario de garantir son accès à des laboratoires de recherche indispensable à la réalisation de son programme.

para. 210 C.R.4.4 Les réductions fédérales ont affecté les programmes et la disponibilité des laboratoires de recherche et d'essais d'EACL qui sont, les deux, essentiels à la recherche et au développement sur la sécurité. Le gouvernement ontarien devrait s'assurer que ces coupures n'affectent pas la sécurité et l'efficacité des centrales d'Hydro-Ontario. Par ailleurs, il y a plusieurs domaines fondamentaux de la science et de la technique auxquels les universités canadiennes pourraient apporter une contribution plus substantielle. Les conditions actuelles de financement ne les encouragent pas dans ce sens.

5. Autres pratiques d'Hydro-Ontario

paras. 389-395 C.R.5.1 L'éthique et la discipline de la haute direction semblent très élevées, et c'est un atout pour elle. Mais l'impression d'indépendance et d'isolement professionnel qu'elle dégage est marquée. Cette impression est encore renforcée par sa tendance à s'isoler, Hydro-Ontario comblant souvent tous les postes et compétences nécessaires (par exemple en matière d'octrois de contrats). Hydro-Ontario devrait préserver les bons côtés de cette indépendance, tout en cherchant à augmenter ses contacts avec l'extérieur, particulièrement dans le domaine de la sécurité.

Source

C.R.5.2 Il est indispensable de créer, le plus rapidement possible, des moyens pour augmenter l'interaction des excellentes équipes de la conception et de la sécurité à Hydro-Ontario avec les communautés scientifiques et techniques de l'extérieur (qui ont besoin d'être mieux informées). Un

para. 390

échange d'information dans les deux sens augmenterait la sécurité et rehausserait la réputation d'Hydro-Ontario. Les contacts entre le personnel d'Hydro-Ontario et la communauté scientifique de l'extérieur sont insuffisants. L'ignorance des questions nucléaires de la part de la communauté scientifique est due en grande partie à cet isolement. En échange, de tels contacts favoriseront la culture ayant trait à la sécurité, de même que la performance technique d'Hydro-Ontario.

4e Recommandation

Que le Président d'Hydro-Ontario désigne un comité consultatif technique sur la sécurité nucléaire, semblable au comité déjà formé pour le programme de

para. 390 (ii)

gestion des déchêts nucléaires, avec des membres provenant de l'industrie et de la communauté universitaire. Ce comité devrait publier un rapport annuel, lequel devrait être déposé (avec le rapport de la Commission d'étude sur l'intégrité nucléaire) devant l'Assemblée législative.

C.R.5.3 Par ailleurs, Hydro-Ontario devrait faire tout en son possible pour encourager la participation de son personnel technique et professionnel à des activités scientifiques et techniques, en dehors de la compagnie.

Source

6. Bilan de fonctionnement des réacteurs

C.R.6.1 Les 16 réacteurs de puissance d'Hydro-Ontario ont démontré une bonne tenue. Même si les unités 1 et 2 de la centrale Pickering A ont été hors service pendant plusieurs années après 1983, à cause de défaillances techniques, six des réacteurs d'Hydro-Ontario se trouvent parmi les 10 réacteurs ayant la fiabilité la plus élevée au monde. Le réacteur CANDU (Canada Deutérium Uranium) présente plusieurs caractéristiques favorables à la sécurité (telle que la séparation du caloporteur et du modérateur; la percée rapide de la calandre du réacteur suite à une perte accidentelle de caloporteur (ou LOCA, de "loss of coolant accident") suivie d'une défaillance du système d'arrêt et, par conséquent, une perte rapide du modérateur; de faibles volumes de vapeur produite par la dépressurisation de l'eau) et d'autres caractéristiques moins désirables (notamment un coefficient positif de réactivité du vide). L'excellence du dossier de la sécurité depuis 1971 (année d'ouverture de la centrale Pickering A) est due beaucoup au bon comportement du personnel.

Table 1

paras. 71-94

C.R.6.2 Les systèmes de sécurité spéciaux qui protègent le combustible nucléaire en cas d'accident et qui retiennent les produits dégagés sont les systèmes d'arrêt, les systèmes à injection d'urgence de refroidissement (SIUR) et les systèmes de rétention. Le SIUR s'est avéré un système dispendieux et compliqué à installer. Des systèmes à haute-pression adéquats sont actuellement en place dans tous les réacteurs sauf dans les unités 3 et 4 de Pickering, où ils seront installés en 1988-89. Les systèmes d'arrêt et de rétention fonctionnent bien. Seulement les systèmes d'arrêt ont dû être utilisés pour empêcher des accidents de se produire.

paras. 95-101

Source

C.R.6.3 Les réacteurs ont fonctionné de mieux en mieux à mesure qu'on a acquis plus d'expérience. Bruce B et Pickering B ont causé peu de difficultés.

C.R.6.4 J'en conclus que les systèmes de sécurité sont efficaces et assurent une protection adéquate contre les accidents. La protection en profondeur est évidente, quoique la centrale Pickering A soit moins bien protégée que les centrales plus récentes.

5e Recommandation

Que le gouvernement fasse accélérer les améliorations à grande échelle prévues pour les systèmes de sécurité et d'exploitation de Pickering A afin d'enlever toute entrave à son fonctionnement sécuritaire futur.

C.R.6.5 Pickering A, la plus ancienne de nos centrales, a connu un grand nombre de problèmes, parmi lesquels des difficultés provenant des ordinateurs de commande, du SIUR et, avant 1975, du système d'arrêt. Depuis 1983, on a dû effectuer des réparations majeures et une remise en état des réacteurs, à cause des défaillances des tubes de force. Ces réparations comprenaient l'amélioration du système d'arrêt et du SIUR. Les unités 1 et 2 sont de nouveau en opération, ou sur le point d'être remises en service. Les unités 3 et 4 subiront une révision importante en 1988 et 1989. En outre, les analyses d'accidents graves effectuées dans le cadre des travaux de la Commission et menées par Hydro-Ontario et par Argonne National Laboratory, ont révélé que les conséquences d'un LOCA seraient en grande partie confinées.

paras. 176-177

Source

6e Recommandation

Que la Commission de contrôle de l'énergie atomique-(CCEA) établisse une politique cohérente concernant la réadaptation ("backfitting") des réacteurs actuels. Cette politique devrait prévoir des objectifs relativement à l'exposition de la main-d'oeuvre aux radiations. Elle devrait aussi prendre en considération les incertitudes dans les analyses de la sécurité. En outre, elle devrait établir un calendrier strict pour la réalisation des travaux.

C.R.6.6 Les décisions de modifier ou de réadapter les réacteurs actuels ont soulevé beaucoup de contreverses dans le passé. De telles réadaptations donnent lieu à deux genres de questions, à savoir: devraient-elles s'appliquer à tous les réacteurs, et présentent-elles des risques, soit en affaiblissant l'intégrité globale de la centrale, soit en exposant la main-d'oeuvre à plus de radiations que la réadaptation pourrait jamais épargner?

7. Système d'exploitation

C.R.7.1 La plupart des aspects du système d'exploitation semblent satisfaisants. Les cours de formation radiologique et technique sont particulièrement bons (y compris le programme de qualification de la CCEA), de même que le principe selon lequel chaque membre individuel du personnel est responsable de sa propre protection contre les radiations. Certaines faiblesses évidentes ont été discutées dans le paragraphe C.R.2.2 ci-dessus.

paras. 124-141

Source

C.R.7.2 La sécurité dépend davantage de la qualité et des compétences du personnel que de tout autre facteur. Elle dépend en grande partie de la vivacité des opérateurs en situation d'urgence, et de la compétence dont ils font preuvent pour y remédier.

paras. 142-148

7e Recommandation

Qu'Hydro-Ontario intensifie et raffine davantage ses cours de formation et de recyclage portant sur tous les aspects de la sécurité des réacteurs et de l'organisation de la sécurité, et utilise au maximum ses simulateurs de salles de commande.

8. Risques d'accidents

C.R.8.1 La possibilité d'un grave accident à l'intérieur réacteur ontarien, entraînant la libération de quantités dommageables de substances radioactives, est très peu probable, mais elle ne peut être écartée. La planification des mesures d'urgence exige que l'on évalue la gamme des accidents plausibles.

C.R.8.2 Les incidents anormaux sont fréquents dans les centrales nucléaires (de l'ordre de 700 événements significatifs rapportés annuellement). Les incidents à conséquences significatives sont analysés par la Commission d'étude sur l'intégrité nucléaire, et les mesures appropriées sont prises. Des rapports de cette étude sont remis à la CCEA et à l'Assemblée législative.

paras. 157-163; Table 2

Source

C.R.8.3 Parmi les incidents les plus sérieux, deux accidents ont causé des dommages importants aux réacteurs en entraînant une fuite d'eau lourde contaminée par les radiations à l'intérieur de la calandre ou du bâtiment du réacteur. Ces incidents se sont produits d'une part à Pickering A en 1983, et d'autre part à Bruce A en 1986 (voir paragraphes C.R.3.1-3 ci-dessus). Cependant, aucune libération importante de matières radioactives n'a eu lieu dans l'enceinte de retenue, ni aucune exposition mesurable du public aux radiations. De tels accidents demeurent inévitables. Leur impact est surtout économique, mais comporte certaines conséquences radiologiques pour la main-d'oeuvre.

paras. 197-201

C.R.8.4 Tous les réacteurs d'Hydro-Ontario sont conçus pour contenir tous les accidents sauf les plus sérieux, tel que spécifié par la CCEA. Notamment, tous les réacteurs ont accès à un bâtiment à vide armé, conçu pour condenser la vapeur et retenir les contaminants radioactifs. Ceci est exclusif à l'Ontario.

para. 101

C.R.8.5 Si un accident grave survenait, ce sera très différent de ce qui est arrivé à Tchernobyl en 1986. Le réacteur de Tchernobyl avait un volume de caloporteur (susceptible de dépressurisation rapide) sept fois plus grand que le réacteur de Pickering A et utilisait du graphite inflammable comme modérateur (alors que les réacteurs CANDU utilisent de l'eau lourde qui étouffe le feu). Parmi les 31 victimes de Tchernobyl, plusieurs sont mortes brûlées, et le déversement de déchêts radioactifs a été en partie causé par l'incendie du graphite.

paras. 318-319

C.R.8.6 Cependant, on peut imaginer d'autres accidents graves dans les réacteurs CANDU. La CCEA en a identifié deux : la défaillance du système d'arrêt faisant suite à une grosse perte de caloporteur ou à une perte du système de réglage.

Source

C.R.8.7 Le premier de ces deux cas a été analysé pour la Commission (pour Pickering A) par Hydro-Ontario et par Argonne National Laboratory. Les deux études prédisent des dommages majeurs au réacteur, probablement irréparables, avec brèche dans l'enceinte du réacteur et fuite de grandes quantités de vapeur contaminée à l'intérieur de l'enceinte de confinement. Mais on croit que celle-ci retiendrait tout le stock radioactif disponible, sauf une petite quantité. Les expositions que pourrait subir le public seraient minimes. Le deuxième cas n'a pas encore été analysé.

paras. 297-317

C.R.8.8 J'en conclus que des accidents graves sont peu susceptibles de se produire dans les réacteurs ontariens, et que s'ils survenaient, il y aurait de fortes chances pour qu'ils soient maîtrisés dans une grande mesure, et que le danger pour le public soit minime. Cependant, les réacteurs subiraient des dommages considérables, entraînant des déboursés et des conséquences radiologiques pour les équipes effectuant le nettoyage et les réparations. Il est souhaitable que cette conclusion soit vérifiée pour d'autres types d'accidents graves et pour d'autres réacteurs.

paras. 324-330

8e Recommandation

Qu'Hydro-Ontario étende l'analyse des accidents graves aux:

(i) pertes de régulation avec défaillance du mécanisme d'arrêt; et

(ii) aux réacteurs représentatifs des centrales Bruce et Darlington.

Source

9. Mesures d'urgence

para. 340 — C.R.9.1 Si des accidents arrivent, il sera nécessaire d'appliquer des mesures d'urgence à l'intérieur de la centrale et dans les municipalités environnantes.

para. 342 — C.R.9.2 Hydro-Ontario est responsable des mesures à l'intérieur des centrales, et ces mesures sont en place. Conformément aux exigences de la CCEA, Hydro-Ontario fournit également le support technique et l'information nécessaire aux municipalités, et procède à des exercices réguliers. Le programme d'Hydro-Ontario semble bien conçu et bien financé (6 millions $ par année). Il prévoit un centre d'urgence et une mobilisation adéquate de personnel et de ressources.

paras. 343-347 — C.R.9.3 La réponse extérieure est de la responsabilité directe du Solliciteur général. En 1986, son bureau a publié un excellent plan d'urgence nucléaire. Ce document procure, sur papier, les moyens de mobiliser le personnel et l'équipement nécessaires, et d'assurer la coopération opérationnelle d'Hydro-Ontario. Il prévoit également des échanges avec d'autres juridictions (y compris les relations trans-frontalières avec les États-Unis).

paras. 348-354 — C.R.9.4 Malheureusement, à date, peu a été fait pour rendre ce plan effectif, en dépit d'une décision annoncée par le cabinet de prendre les dispositions pour qu'Hydro-Ontario finance le plan. Le nombre de professionnels impliqués se limite encore à deux personnes. Le sentiment d'urgence fait défaut. Si un accident grave se produisait, on se retrouverait avec un service public bien préparé et une province mal préparée--à moins d'agir rapidement.

Source

9e Recommandation

Que la province d'Ontario affecte immédiatement les fonds nécessaires pour mettre en place les préparatifs d'alerte du Plan provincial d'urgence nucléaire.

paras. 355-363

C.R.9.5 Le groupe de travail no 8 du Bureau du Solliciteur général analyse actuellement les types d'accidents à partir desquels les mesures du Plan d'urgence nucléaire devraient être conçues (par exemple l'évacuation, les abris, les services aux victimes, la distribution d'iode et la protection de la nourriture et de l'eau). La Commission a participé à cet exercice particulièrement important.

10e Recommandation

Que la province d'Ontario base son plan d'urgence nucléaire sur le dégagement le plus élevé plausible de matières radioactives.

10. Questions de santé

Chapitre V; Annexe IV

C.R.10.1 Rien n'indique que le fonctionnement normal des réacteurs d'Hydro-Ontario ait causé, ou causera à l'avenir, des effets nocifs sur le personnel des réacteurs (qui est de loin le groupe le plus exposé) ou sur le grand public. Mais la vigilance s'impose.

Source

C.R.10.2 Les niveaux d'exposition auxquels sont soumis le travailleurs des centrales nucléaires sont de beaucoup inférieurs aux doses limites établies par la CCEA, et sont tout à fait comparables aux meilleures performances d'autres pays. En 1985-86, la main-d'oeuvre a été exposée à une moyenne de 3,9 mSv. La limite déterminée par la CCEA est 50 mSv. Depuis 1979, aucun travailleur n'a été exposé au-delà des limites réglementaires. Le nombre de travailleurs exposés par unité d'énergie produite est parmi les plus bas au monde. Toutefois la moyenne d'exposition subie par les travailleurs est encore plusieurs centaines de fois plus élevée que celle subie par les personnes les plus exposées dans la population.

paras. 223-232

C.R.10.3 L'analyse épidémiologique de la mortalité chez les travailleurs des centrales nucléaires d'Hydro-Ontario est confiée (sur une base de mise à jour annuelle) au département des soins de la santé et d'épidémiologie de la faculté de médecine de l'Université de Colombie-Britannique. Cette analyse démontre que la mortalité due au cancer chez les travailleurs de l'énergie atomique correspond aux deux tiers seulement des chiffres enregistrés pour l'ensemble de la population canadienne. Tous les cancers latents n'ont cependant pas encore pu se manifester.

paras. 244-245 Table 9

C.R.10.4 Une autre étude épidémiologique est menée auprès des travailleurs d'EACL, avec l'aide de l'Institut canadien du cancer. L'échantillonnage est plus grand et porte sur une période plus longue (environ 15 000 personnes pendant une période de plus de 30 ans). Cette analyse révèle également une mortalité inférieure à celle de la population générale (même si, pour les employés de Chalk River, elle a augmenté pendant les 15 dernières années, elle est actuellement au même niveau, ou très faiblement plus élevée que dans la population).

paras. 247-249; Table 10

Source

C.R.10.5 Il n'existe aucune autre étude comparable au Canada sur les répercussions dans la population. L'exposition du public aux radiations est au moins plusieurs centaines de fois inférieure à l'exposition subie par la main-d'oeuvre d'EACL ou d'Hydro-Ontario. D'où l'improbabilité d'effets mesurables.

paras. 251-253

C.R.10.6 Parce que des études récentes menées en Angleterre ont néanmoins révélé une association possible entre les leucémies lymphoïdes chez les personnes de moins de 25 ans et la proximité d'installations nucléaires, il faut concentrer nos efforts sur la recherche épidémiologique pour déterminer si les enfants et les jeunes adultes des communautés voisines des réacteurs (par exemple à Pickering et à Deep River) révèlent un taux plus élevé de leucémies ou d'autres maladies.

11e Recommandation

para. 253

Que le gouvernement ontarien s'assure que tous les renseignements pertinents soient mis à la disposition de l'étude de faisabilité entreprise par la CCEA en vue d'une analyse épidémiologique sur la fréquence des cas de cancers et la mortalité due au cancer dans les régions voisines des réacteurs, et à tout autre proposition pour de telles études, incluant d'autres effets que la mortalité due au cancer.

para. 273

C.R.10.7 Il semble que les rumeurs selon lesquelles la radiation atomique affecte la santé du grand public créent beaucoup d'anxiété dans la population. On devrait aussi organiser une grande tribune où les questions concernant la sécurité et la santé seraient débattues publiquement.

Source

12e Recommandation

para. 273 — Que le gouvernement ontarien crée un Conseil consultatif sur la santé et la sécurité, composé d'une petite équipe permanente et disposant de fonds nécessaires pour aider les associations qui défendent l'intérêt du public et qui souhaitent faire des représentations.

11. Réglementation

C.R.11.1 Même si la réglementation de l'industrie nucléaire relève du gouvernement canadien, et dépasse donc le mandat de la Commission, la réglementation de la sécurité est tellement importante, et les commentaires qui nous parviennent si nombreux, que nous leur consacrons les conclusions et les recommandations suivantes. Une analyse plus complète est donnée à l'Appendice VII.

Annexe IV, (paras. 11-22) — C.R.11.2 En dépit d'un grand nombre d'allégations mal fondées, la Commission internationale sur la protection radiologique (CIPR) demeure le meilleur organisme actuellement capable de déterminer les doses limites de radioactivité. La CCEA devrait continuer à fonder ses règlements sur les directives de la CIPR, sans nécessairement se conformer à son calendrier. La province d'Ontario devrait donner suite à ces directives.

Appendice VII para. 416 — C.R.11.3 Le gouvernement ontarien ne devrait pas envahir le territoire de réglementation occupé présentement par la CCEA de manière légale. Les réclamations juridiques et législatives du gouvernement canadien pour réglementer les programmes nucléaires d'Hydro-Ontario ne sont pas contestées.

Source

C.R.11.4 La CCEA est un organisme de réglementation efficace. Elle établit les conditions qui assurent la sécurité du public et de la main-d'oeuvre, et elle laisse à Hydro-Ontario le soin de démontrer que la conception de ses équipements et ses méthodes d'exploitation sont capables de répondre à ces conditions de sécurité. Les moyens dont dispose la CCEA pour faire respecter son mandat--procédures d'autorisation et procédures de qualification du personnel-- sont suffisants à cette fin, à condition que la CCEA les utilise pleinement et rapidement. Une requalification périodique du personnel d'exploitation devrait être considérée comme une obligation additionnelle.

Appendice VIII

paras. 396-407

13e Recommandation

Que la CCEA conserve ses pouvoirs, sanctions et responsabilités actuelles, mais s'assure que ses décisions (et les raisons qui les justifient) soient rapidement publiées et appliquées. Par ailleurs, le personnel cadre de la CCEA devrait être augmenté, afin de permettre une expansion du programme, en particulier dans les domaines radiologique, socio-économique et environnemental.

paras. 402-407

Appendice VII

C.R.11.5 La CCEA a choisi de limiter ses décisions et actions aux questions techniques. Elle devrait maintenir cette politique, mais augmenter sa capacité de prendre en considération des aspects socio-économiques et environnementaux dans ses délibérations.

Source

14e Recommandation

Que la loi sur le contrôle de l'énergie atomique soit amendée pour augmenter le nombre des membres du Conseil d'administration de la CCEA, afin de permettre l'engagement d'experts dans les domaines socio-économique et environnemental.

paras. 400-401

C.R.11.6 Les comités consultatifs de la CCEA sur la sécurité nucléaire et la protection radiologique rendent des services précieux, mais peu connus, dans le domaine de la sécurité nucléaire.

15e Recommandation

Que les comités de la CCEA sur la sécurité nucléaire et la protection radiologique disposent des ressources nécessaires pour étendre leur champ d'activité, accélérer le calendrier de leurs travaux et mieux faire connaître les résultats de ces travaux.

paras. 408-415

Appendice VII

C.R.11.7 Les relations entre la CCEA et Hydro-Ontario ne sont pas idéales. Même si les échanges sont constructifs au niveau professionnel, les bases sur lesquelles le Conseil d'administration de la CCEA appuie ses décisions ne sont pas toujours évidentes. Une procédure plus explicite est nécessaire pour la pleine compréhension du public.

Source

16e Recommandation

Que les relations entre Hydro-Ontario et la CCEA soient plus formelles, et que les raisons à la base de toute décision concernant la réglementation soient consignées.

paras. 414-415

Appendice VII

C.R.11.8 Le public manifeste un désir légitime de s'engager davantage, notamment par des audiences publiques, dans les discussions concernant les répercussions économiques et environnementales des installations nucléaires. La CCEA n'est pas l'organisme indiqué pour satisfaire à ce désir. Les lois provinciales y apportent des réponses évidentes.

17e Recommandation

Que chaque fois qu'une demande de construction d'une installation nucléaire est soumise, le gouvernement ontarien exerce sans exception les pouvoirs qui lui sont conférés par la loi d'évaluation de l'environnement, afin de rendre possibles des audiences publiques sur les nouveaux projets nucléaires.

paras. 151-152 Annexe IV

C.R.11.9 Les femmes jouent un rôle beaucoup trop insignifiant dans la réglementation, l'administration et la planification de toute l'industrie nucléaire.

Source

18e Recommandation

Qu'on mette tout en oeuvre pour permettre à des femmes qualifiées de faire partie des conseils d'administration et du personnel cadre de la CCEA, de l'EACL et d'Hydro-Ontario.

12. Le rôle du gouvernement

Appendice VII

C.R.12.1 La Commission a examiné l'ensemble des questions associées à la sûreté des centrales nucléaires de l'Ontario sans se préoccuper des querelles de juridiction. Elle a clairement établi le fait que la compagnie d'électricité provinciale est sujette à une réglementation fédérale serrée et que ceci constitut un avantage--du fait d'une claire séparation entre l'organisme de réglementation et Hydro-Ontario. Le gouvernement ontarien garde cependant une responsabilité importante en matière de sécurité.

C.R.12.2 La raison principale pour confier la réglementation publique à des groupes d'experts techniques est que leur travail devrait être examiné soigneusement par les gouvernements concernés. Les rapports annuels de la CCEA devraient recevoir plus qu'un examen superficiel par la Commission parlementaire appropriée. En Ontario, la forte tradition des Commissions parlementaires suggère que le gouvernement ontarien, devrait adopter cette méthode en ce qui concerne le rapport annuel de la CCEA, de même que pour celui du Conseil consultatif sur la santé et la sécurité proposé plus haut, et aussi de la Commission d'étude sur l'intégrité nucléaire d'Hydro-Ontario.

RAPPORT AU MINISTRE

II Sommaire du rapport technique*

A. Questions générales

S.1 A cause des décisions prises il y a plus de 25 ans, l'Ontario est profondément engagée dans l'utilisation de l'énergie nucléaire pour la production d'électricité. Actuellement, les centrales nucléaires fournissent la moitié de l'électricité consommée dans cette province. En 1993 lorsque la centrale nucléaire Darlington fonctionnera à pleine puissance, la proportion atteindra les deux tiers (105 000 GWh, c'est-à-dire 69% de la consommation). En 1993, la capacité des installations nucléaires atteindra 14 254 MWe.

S.2 Les centrales nucléaires fourniront alors les quatre-cinquièmes de la charge de base, c'est-à-dire de la puissance minimale nécessaire pour la journée. Le dernier cinquième sera produit principalement par les centrales hydrauliques. Les suppléments pour la charge de pointe seront surtout produits par les centrales thermiques à charbon.

S.3 La dépendance de l'Ontario à l'énergie nucléaire dépasse en importance celle de tous les états souverains, à l'exception de la France et de la Belgique qui ont des niveaux de dépendance similaires. En 1987, au aux États-Unis le niveau de dépendance était seulement de 17%.

S.4 La sécurité des centrales nucléaires dépend de l'autorité gouvernementale canadienne, sous la loi sur le contrôle de l'énergie atomique de 1946, telle qu'amendée en 1954. Hydro-Ontario, qui gère tous les réacteurs de puissance en Ontario, est soumise aux réglementations de la Commission de contrôle de l'énergie atomique (CCEA), établie en vertu de la loi mentionnée ci-dessus.

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* Le "Ontario Nuclear Safety Review" est désigné par "la Commission".

Note: La façon dont les travaux de la Commission ont été conduits est décrite au complet dans l'Annexe VI.

S.32 Le grand public peut être exposé à la radioactivité de deux manières:

(i) Dans les conditions d'exploitation normales, les centrales sont autorisées à libérer certaines quantités de matières radioactives, en respectant les limites établies par la CCEA. Ces limites sont calculées de manière qu'aucun individu dans la région environnante d'une centrale ne puisse recevoir une dose de radiation dépassant 5 mSv/a. Les substances radioactives incluent le tritium, les gaz rares (le krypton et le xénon) et le carbone-14. Toutes les centrales d'Hydro-Ontario ont fait état d'émissions à 1% ou en-dessous de ces limites en 1986, de sorte que les doses reçues par le public devraient avoir été de 0,05 mSv/a ou moins. Il n'y a aucune surveillance systématique de l'exposition subie par le public, parce que les émissions provenant des centrales représentent moins de 5% de la radioactivité naturelle, ce qui masque les effets en provenance de ces centrales.

(ii) Lors des accidents, les niveaux d'expositions peuvent être beaucoup plus élevés s'il y a une brèche dans l'enceinte de retenue, surtout à cause des produits de fission très radioactifs (incluant l'iode) qui peuvent se dégager. À date, cela n'est pas arrivé dans les centrales d'Hydro-Ontario.

S.33 Les seuls groupes importants de résidents Ontariens ayant été exposés à des doses élevées de radiations provenant de centrales nucléaires sont la main-d'oeuvre d'EACL et d'Hydro-Ontario. Les deux groupes de travailleurs ont été surveillés et leur état de santé a été consigné. Les données d'Hydro-Ontario sont analysées chaque année au département des soins de la santé et d'épidémiologie de l'Université de la Colombie-Britannique (par T.W. Anderson). L'expérience vécue par le personnel d'EACL est analysée par l'Institut canadien du cancer. Il n'y a aucun doute sur l'impartialité des analyses.

S.5 Suite à la fondation d'Énergie Atomique du Canada Limitée (EACL) en 1952, une association étroite s'est développée entre Hydro-Ontario et EACL (Hydro-Ontario a été représentée sur le Conseil d'administration d'EACL). Entre 1954 et 1966, une série de décisions prises par Hydro-Ontario ont eu pour effet d'augmenter la dépendance de l'Ontario envers les sources d'énergie nucléaire. Elles ont également conduit à l'utilisation exclusive des réacteurs CANDU (Canada Deutérium Uranium) d'EACL par Hydro-Ontario. Il y a présentement 20 réacteurs CANDU en usage ou en construction en Ontario. Il s'agit d'une technologie canadienne qui a bien marché, mais non sans difficultés.

B. Où se trouvent les réacteurs?

S.6 La politique d'Hydro-Ontario est de construire des centrales d'énergie nucléaire pouvant comprendre chacune jusqu'à huit réacteurs. Les centrales Pickering et Bruce sont de cette taille, leurs huit réacteurs produisant chacun 4124 MWe et 6596 MWe respectivement. Darlington aura quatre réacteurs produisant 3524 MWe. Ceci contraste avec la pratique américaine qui n'installe qu'un ou deux réacteurs par centrale.

S.7 La pratique ontarienne permet une quantité de services qui seraient trop coûteux pour une seule unité. Elle permet également un raffinement de la sécurité, par l'utilisation d'un bâtiment à vide commun, exclusif à l'Ontario, qui peut prendre et immobiliser tous les excès de gaz dégagés dans l'éventualité d'un accident.

S.8 La province possède maintenant deux des plus grandes centrales nucléaires au monde, et en a une troisième en chantier. Une centrale, Pickering, est située en banlieue de Toronto. L'autre est à seulement 25 kilomètres à l'est. Un grand nombre de personnes vivent donc à proximité des centrales et seraient immédiatement menacées par tout accident éventuel.

C. Quelles sont les questions sur la sécurité?

S.9 Deux questions se posent: les réacteurs CANDU sont-ils sécuritaires lorsqu'ils fonctionnent normalement? Quels sont les types d'accidents susceptibles de se produire et quelles en seraient les conséquences? Dans les deux cas, la menace principale provient de l'exposition des travailleurs et du public aux radiations dangereuses.

S.10 Les réacteurs CANDU sont conçus pour produire de la vapeur, laquelle entraîne les turbines qui génèrent l'électricité. Le combustible utilisé est le bioxyde d'uranium, dont une faible partie est fissionnée (divisée) par des neutrons dans une réaction en chaîne qui libère la chaleur nécessaire. Le combustible est entouré d'eau lourde servant de modérateur (pour ralentir les neutrons) et il est refroidi par un débit à haute pression d'eau lourde à travers les tubes de force qui contiennent le combustible. Au moment de la division des noyaux, les produits de fission (habituellement toxiques et radioactifs) demeurent dans le combustible intact. A moins que le combustible surchauffe, et donc fonde ou se désintègre, les matières radioactives sont immobilisées pour être ensuite placées dans une installation de stockage sécuritaire.

S.11 Néanmoins, des problèmes de sécurité sont survenus dans les réacteurs CANDU. Les réacteurs de recherche NRU (de "National Research Universal") et NRX (de "Natural Research Experimental") des Laboratoires nucléaires de Chalk River ont connu des accidents sérieux dans les années 50. Des accidents moins sérieux sont survenus, provoqués par des défaillances dans les tubes de force, à Pickering en 1983 et à Bruce en 1986. Le réacteur CANDU n'est certainement pas à l'abri des accidents. Jusqu'ici, il n'y a pas eu d'accident mortel dans les réacteurs canadiens suite à des accidents nucléaires. On n'a pas observé d'augmentation de la mortalité due au cancer parmi les travailleurs qui ont été exposés à des doses élevées de radiations dans les réacteurs NRX et NRU.

S.12 Des accidents graves sont survenus dans des centrales étrangères, par exemple à Windscale, en Grande-Bretagne, en 1957, à Three Mile Island, en Pennsylvanie, en 1979, et à Tchernobyl, en Union Soviétique, en 1986. A Tchernobyl, 31 personnes sont mortes, toutes à l'intérieur de la centrale (plusieurs à la suite de brûlures). Un nombre inconnu de personnes de la région environnante, et même de régions assez éloignées, pourraient contracter un cancer causé par la fuite de substances radioactives. Une fuite moins importante s'est produite à Windscale, et une autre, beaucoup plus petite, à Three Mile Island. Ces événements ont impliqué différents types de réacteurs. Cela aurait-il pu se produire dans un réacteur CANDU?

D. Les mesures de sécurité

S.13 Le réacteur CANDU est isolé de son environnement par des enceintes de retenue massives (sous une pression atmosphérique sous la normale) conçues pour arrêter les fuites de substances radioactives, suite à n'importe quelle désintégration ou fusion de combustible. Ces enceintes sont la dernière barrière entre la radioactivité et le public. En plus de la rétention, les appareils ou systèmes suivants participent aux mesures de sécurité:

(i) Les systèmes régulateurs à action rapide, commandés par ordinateur, qui maintiennent le réacteur à l'état critique ou près de l'état critique (un taux de fission qui se maintient lui-même). Ces systèmes sont nécessaires pour contrôler la puissance et aussi pour assurer que cette puissance est bien distribuée à l'intérieur du réacteur. Le système régulateur maintient le réacteur dans une gamme acceptable de conditions d'exploitations sécuritaires et il débite la puissance requise.

(ii) Les systèmes d'arrêt, de conception diverse, arrêtent la réaction en chaîne en bien moins que 2 s. Tout comme les systèmes régulateurs, les systèmes d'arrêt sont commandés automatiquement par des séries de senseurs divers échantillonnant une quantité de conditions à l'intérieur du réacteur. Si des conditions anormales sont détectées, la réaction en chaîne est arrêtée.

(iii) Les systèmes à injection d'urgence de refroidissement (SIUR) qui inondent le combustible d'eau froide, légère, pour l'empêcher de fondre ou de se désintégrer suite à une grosse perte de caloporteur (un LOCA, de "loss of coolant accident").

S.14 La Commission a analysé la performance de tous ces systèmes et arrive aux conclusions suivantes:

(i) Les systèmes régulateurs commandés par ordinateur semblent être fiables. Au début, il y a eu des problèmes de contrôle de l'ordinateur à Pickering A, mais on les a surmontés. Une partie de l'équipement informatique est maintenant démodée et les pièces de rechange sont difficile à obtenir. Aucune perte de régulation ne s'est produite à la centrale Bruce, ou à Pickering B.

(ii) Les systèmes d'arrêt (SDS1 et SDS2) démontrent également une disponibilité élevée. Ils semblent être capables d'arrêter le réacteur tel que prévu (c'est-à-dire, en bien moins que 2 s après la première alarme). Pickering A n'a qu'un système, qui vient tout juste d'être amélioré dans les unités 1 et 2. La même chose sera faite pour les unités 3 et 4 en 1988 et en 1989. L'unique système est soutenu par un mécanisme de vidange du modérateur qui peut faire face à la plupart des accidents, mais pas à tous.

(iii) Les SIUR sont plus complexes, et il a été difficile de démontrer qu'ils seront capables de refroidir toutes les parties du combustible, suite à un LOCA. Leur disponibilité n'a pas été parfaite, en particulier à Bruce A et à Pickering A. Le changement pour des systèmes à haute pression est maintenant complété, sauf dans le cas des unités 3 et 4 de Pickering A.

(iv) Les systèmes de retenue sont dans une condition satisfaisante, et ils devraient empêcher les fuites de matières radioactives faisant suite à la plupart des accidents (excepté dans le cas des dégagements volontaires de gaz rares).

S.15 Tous ces systèmes, de régulation comme de sécurité, doivent travailler rapidement. Dans l'éventualité d'un LOCA, le liquide qui se trouve à l'intérieur des tubes de force entrera en ébullition, créant un vide dû à la vapeur. Ceci accélérera rapidement la réaction en chaîne, requérant un arrêt dans les deux prochaines secondes. C'est l'effet positif de réactivité du vide, qui constitue l'une des caractéristiques les moins désirables des réacteurs CANDU.

S.16 Les mécanismes de protection ont arrêté les différents réacteurs d'Hydro-Ontario 450 fois depuis 1971. Environ la moitié de ces déclenchements ont été causés par des variations de puissance inacceptables, et l'autre moitié, par des erreurs des opérateurs ou par des défaillances de l'équipement mal identifiées. Seulement 2% des déclenchements ont été dûs à des conditions menaçant l'intégrité du combustible. On n'a jamais eu vraiment besoin des SIUR et de systèmes de retenue. Tous les systèmes sont différents, redondants par mesure protectrice, et ils sont couramment vérifiés pendant l'exploitation. J'en conclus que les systèmes de sécurité sont efficaces et qu'ils offrent une protection adéquate contre les accidents. Nous disposons certainement d'une protection en profondeur, même si Pickering A est moins bien protégée que les centrales plus récentes.

E. Le problème des tubes de force

S.17 Le problème le plus grave qu'ont connu les réacteurs de puissance d'Hydro-Ontario est celui des tubes de force qui contiennent le combustible. Ces tubes doivent supporter la haute pression causée par le système de transport de chaleur et duquel ils font partie. Ils sont également exposés à de hautes températures et à un débit intense de neutrons. Ils sont fabriqués en alliages de zirconium qui permettent aux neutrons de passer librement, et on leur a donné une espérance de survie de 25 à 30 ans, compte tenu des rudes conditions qu'ils connaissent.

S.18 Des fuites d'eau lourde ont été détectées 23 fois depuis 1971 dans ces tubes (à l'intérieur de l'anneau du canal de combustible), indiquant qu'ils ne se comportaient pas comme prévu. Ces fuites ont été repérées facilement, si bien que les tubes défaillants ont pu être remplacés. Mais le 1er août 1983, un tube de force s'est soudainement rompu à Pickering A. De l'eau lourde contaminée s'est échappée à l'intérieur du bâtiment du réacteur. On s'est rendu compte par la suite qu'un grand nombre de tubes des unités 1 et 2 étaient en piètre condition. Entre 1983 et 1988, les réacteurs ont été rééquipés de tubes fabriqués dans un alliage différent. Pendant ce temps, 1030 MWe de puissance étaient immobilisés et ont dû être remplacés. Le travail a été bien fait, mais dans des conditions difficiles et hasardeuses. Le coût total de l'opération aura dépassé 425 millions $, et l'ensemble des radiations auxquelles les travailleurs ont été exposés a été supérieur à 7 Sv (bien inférieur aux premiers estimés, mais encore élevé).

S.19 Une autre rupture d'un tube de force s'est produite le 26 mars 1986, à la centrale nucléaire Bruce A, lorsque le réacteur a été arrêté. Le tube de calandre voisin s'est rompu lui aussi. Les conséquences ont été moins lourdes qu'à Pickering A, mais l'événement a mis en lumière la gravité du problème.

S.20 Les réacteurs des autres pays n'utilisent habituellement que des cuves sous pression, au lieu des tubes de force utilisés par les CANDU, sauf les réacteurs soviétiques RBMK qui utilisent aussi des tubes. La technologie des tubes de force comporte plusieurs avantages, mais seulement à condition que l'intégrité des tubes soit garantie pendant de longues périodes de travail.

S.21 On attribue ces défaillances à la formation à l'intérieur du zirconium, ou à des points de tension à l'intérieur ou à la surface du zirconium, d'enclaves ou de boursoufflures de deutérure de zirconium (généralement appelé hydrure). Ceci affaiblit le tube. De plus, la déformation du tube causée par le bombardement neutronique, et par le déplacement imprévu des amortisseurs intertubulaires qui le sépare du tube de calandre a été plus importante que prévu. Un grand programme de recherche est en train de chercher des solutions à ce problème.

S.22 Les conseillers techniques de la Commission sont d'accord avec Hydro-Ontario et EACL pour affirmer que ces défaillances des tubes de force entraînent des conséquences économiques sérieuses, mais présentent peu de danger radiologique pour le public.

S.23 Si, toutefois, des défaillances importantes des tubes de forces se produisaient dans le futur, elles seraient certainement une menace pour les équipes de maintenance et d'exploitation oeuvrant dans le bâtiment du réacteur, et entraîneraient d'énormes dépenses de remise en état. Et je ne suis pas convaincu qu'il n'y a aucun danger d'exposition radiologique pour le public, spécialement si la défaillance s'étend aux autres canaux de combustible. En conséquence, on devrait donner un maximum de priorité à la recherche d'une solution, et à l'amélioration de la surveillance des canaux de combustible, afin d'éviter d'autres surprises.

F. Le système d'exploitation

S.24 Les réacteurs d'Hydro-Ontario sont conçus et contruits par ses propres ingénieurs et par le personnel à contrat, avec l'intervention d'EACL à l'étape de la conception. Ceci demande une intéraction constante avec la CCEA qui donne les permis de construction et d'exploitation. Les ingénieurs de la CCEA sont présents dans la centrale pour être en mesure de vérifier continuellement le système d'exploitation.

S.25 Chaque centrale a un directeur qui se rapporte à la Direction de la production nucléaire (DPN) d'Hydro-Ontario. Le directeur est aussi directement responsable devant la CCEA pour toutes les questions de sécurité et d'autorisation. En ce qui concerne les questions de sécurité et de radioprotection, le directeur est soutenu par le personnel spécialisé de la centrale et par divers groupes constitués par la haute direction d'Hydro-Ontario. Le personnel d'exploitation, à partir du premier opérateur et en dessous, fait partie du Syndicat canadien des employés de la fonction publique, local 1000. Les relations du syndicat avec la direction, en ce qui a trait aux questions de sécurité, semblent assez satisfaisantes mais ne sont pas idéales: le conflit de 1985, à Bruce, à failli se transformer en affrontement (avec la CCEA) au sujet de l'emploi du personnel cadre à des postes opérationnels. Il y a aussi des plaintes à l'effet qu'on néglige souvent les suggestions des travailleurs sur la sécurité.

S.26 Le système d'exploitation a fait l'objet d'examens par le groupe d'étude sur la sécurité des opérations (OSART, de "Operational Safety Review Team") de l'Agence Internationale d'Énergie Atomique et par un groupe de consultants venant surtout des industries chimiques et pétrolières. Ces examens ont conclu que le système d'exploitation était en bon état, à part certains points qui demandent à être améliorés:

(i) Il y avait un arriéré de travail de maintenance dans les centrales Pickering et Bruce à cause de personnel et de ressources inadéquats (selon les deux études).

(ii) La performance en matière de sécurité conventionnelle à la DPN s'est révélée inférieure à celle de l'industrie chimique. Aucun accident mortel n'est survenu en 125 millions d'années-personnes, mais le taux d'invalidité temporaire (quoiqu'inférieur à son propre objectif) a été supérieur au taux considéré acceptable par les consultants (les consultants).

(iii) Il a été recommandé de développer davantage les cours de recyclage donnés au personnel d'exploitation, de même qu'une réautorisation périodique par la CCEA (les consultants).

(iv) Certains raffinements dans la protection contre la radioactivité ont été recommandés (OSART).

(v) Il y a eu certains manques de communication entre le personnel syndiqué et la direction (les consultants).

La réponse d'Hydro-Ontario a été immédiate et efficace, mais elle n'a pas encore satisfait à toutes les exigences.

S.27 Le système de formation de base et la qualité du personnel des réacteurs sont excellents. Une autorisation de la CCEA est exigée pour tous les postes comportant une responsabilité importante pour la sécurité. Le cours de radiologie qu'est donné au personnel est excellent, tout comme le principe selon lequel chaque membre du personnel est responsable de sa protection personnelle, en plus d'avoir une responsabilité particulière envers la sécurité des autres.

S.28 La sécurité dépend plus de la qualité et de la compétence du personnel que de tout autre facteur. Les réacteurs CANDU sont en grande partie commandées par ordinateur à cause, d'une part, de leur complexité et d'autre part, de la nécessité d'une réaction instantanée lors d'un LOCA important. Le rôle des opérateurs est de vérifier cet automatisme. Le danger est évidemment l'ennui et la distraction des opérateurs. La sécurité dépend beaucoup de la vivacité des opérateurs à renverser les conditions (qui sont immédiatement annoncées dans les chambres de commande) et de la justesse de leur réaction. Jusqu'à maintenant, le dossier sur les centrales d'Hydro-Ontario est bon. Également vitale est la culture corporative en matière de sécurité qui soutend Hydro-Ontario, c'est-à-dire l'attitude des cadres supérieurs selon laquelle la sécurité requiert une attention incessante de leur part.

G. L'exposition à la radioactivité: les questions de santé

S.29 Les réacteurs CANDU produisent des substances radioactives dans le combustible et, à un degré moindre, dans les fluides qui se trouvent dans le réacteur (le caloporteur et le modérateur). Parmi ces substances, on trouve des produits de fission très radioactifs (retenus dans le combustible, sauf lorsqu'un accident se produit), le tritium et le carbone-14. Ces deux substances sont en partie libérées dans l'atmosphère ou dans un lac. Contrairement aux autres réacteurs, les réacteurs CANDU produisent ces deux substances en grande quantité.

S.30 À l'intérieur du réacteur, les neutrons sont presque entièrement absorbés par les barrières et affectent rarement les travailleurs. Mais un fort rayonnement gamma est présent autour du réacteur, ainsi qu'un rayonnement beta moins important. Des règlements stricts de protection s'appliquent dans chacune des zones de radioactivité définies. Malgré tout, la main-d'oeuvre est quand même exposée aux radiations, en particulier les équipes de maintenance. L'exposition subie par chaque travailleur est surveillée et enregistrée individuellement.

S.31 L'exposition aux rayonnements observée chez les travailleurs d'Hydro-Ontario atteignait, en 1985-86, des doses moyennes de près de 3,9 mSv/a, doses comparables aux niveaux habituellement observés au Japon ou en Europe. Mais beaucoup moins de travailleurs d'Hydro-Ontario ont été exposés par unité d'énergie produite. La dose d'exposition au corps entier la plus élevée enregistrée a été de 73 mSv/a, en 1979. Depuis, aucun travailleur d'aucune centrale n'a été exposé au-delà des limites réglementaires. Les expositions à vie sont peu élevées en comparaison avec celles qui sont subies dans un grand nombre d'autres compagnies d'électricité. Hydro-Ontario a maintenant établi l'objectif d'une dose limite de 20 mSv/a pour les centrales Pickering et Bruce. En fin de compte, il s'agit d'un excellent bilan.

S.32 Le grand public peut être exposé à la radioactivité de deux manières:

(i) Dans les conditions d'exploitation normales, les centrales sont autorisées à libérer certaines quantités de matières radioactives, en respectant les limites établies par la CCEA. Ces limites sont calculées de manière qu'aucun individu dans la région environnante d'une centrale ne puisse recevoir une dose de radiation dépassant 5 mSv/a. Les substances radioactives incluent le tritium, les gaz rares (le krypton et le xénon) et le carbone-14. Toutes les centrales d'Hydro-Ontario ont fait état d'émissions à 1% ou en-dessous de ces limites en 1986, de sorte que les doses reçues par le public devraient avoir été de 0,05 mSv/a ou moins. Il n'y a aucune surveillance systématique de l'exposition subie par le public, parce que les émissions provenant des centrales représentent moins de 5% de la radioactivité naturelle, ce qui masque les effets en provenance de ces centrales.

(ii) Lors des accidents, les niveaux d'expositions peuvent être beaucoup plus élevés s'il y a une brêche dans l'enceinte de retenue, surtout à cause des produits de fission très radioactifs (incluant l'iode) qui peuvent se dégager. À date, cela n'est pas arrivé dans les centrales d'Hydro-Ontario.

S.33 Les seuls groupes importants de résidents Ontariens ayant été exposés à des doses élevées de radiations provenant de centrales nucléaires sont la main-d'oeuvre d'EACL et d'Hydro-Ontario. Les deux groupes de travailleurs ont été surveillés et leur état de santé a été consigné. Les données d'Hydro-Ontario sont analysées chaque année au département des soins de la santé et d'épidémiologie de l'université de la Colombie-Britannique (par T.W. Anderson). L'expérience vécue par le personnel d'EACL est analysée par l'Institut canadien du cancer. Il n'y a aucun doute sur l'impartialité des analyses.

S.34 Dans les deux groupes de travailleurs exposés, la mortalité due au cancer a été plus faible que dans l'ensemble de la population Canadienne. Le groupe d'EACL comprend des travailleurs ayant reçu de fortes doses de radioactivité durant les nettoyages effectués à la suite des accidents survenus à NRX et NRU, et un petit nombre d'autres travailleurs (19) ayant reçu des doses à vie supérieures à 200 mSv. Ces groupes très exposés présentent également un taux de mortalité dû au cancer plus bas que prévu. Les dernières trois périodes de cinq ans ont démontré une lente remontée de la mortalité due au cancer parmi les travailleurs de Chalk River, quoique les chiffres demeurent les mêmes que pour le grand public.

S.35 Il est trop tôt pour affirmer que des cancers latents ne se révéleront pas chez certains travailleurs. Toutefois, jusqu'à maintenant, ces groupes exposés ne semblent pas démontrer un taux anormal de mortalité due au cancer. Étant donné que les membres individuels du grand public, même les résidents des environs d'une centrale nucléaire, reçoivent des doses beaucoup plus faibles, il est peu probable que dans l'avenir le taux de mortalité due au cancer soit aussi élevé parmi la population que chez les travailleurs exposés.

S.36 Aucun de ces groupes de travailleurs ne comprenait d'enfant, et ils ne comptaient que peu de femmes (l'étude concerne en fait les hommes). Parmi le petit nombre de femmes exposées, le taux de mortalité due au cancer ne dépasse pas la moyenne.

S.37 De récentes études effectuées auprès de personnes vivant à proximité d'installations nucléaires en Angleterre et dans le Pays de Galles ont également démontré qu'il n'y a généralement pas un nombre excessif de cancers dans ces régions, et on n'observe pas d'augmentation. Il semble y avoir toutefois une certaine augmentation des cas de leucémies lymphoïdes chez les personnes de moins de 25 ans. Aucune étude de ce genre n'a été faite au Canada. Tout doit être mis en oeuvre afin de vérifier, par des études épidémiologiques, si le taux de leucémies et d'autres maladies a augmenté chez les enfants et les jeunes adultes dans les communautés situées dans le voisinage des réacteurs (par exemple à Pickering et à Deep River).

S.38 Les règlements canadiens (CCEA) concernant les doses radiologiques limites découlent des recommandations de la Commission internationale sur la protection radiologique (CIPR). Les dernières études sur les victimes des bombes atomiques au Japon vont probablement conduire la CIPR à diminuer ses doses limites de moitié, au moins, par rapport aux valeurs actuelles permises. Le Canada fera probablement la même chose. En pratique, Hydro-Ontario est déjà au deça des recommandations de la CIPR et des règlements de la CCEA.

S.39 Le Canada, et donc Hydro-Ontario, devraient continuer à se baser sur la CIPR et deux autres organismes internationalement reconnus, la Commission scientifique des Nations-Unies sur les effets de la radiation atomique (UNSCEAR), et la Commission de l'Académie américaine des sciences sur les effets biologiques de la radiation ionisante (BEIR). Ces commissions reflètent le consensus international et elles représentent la meilleure opinion médicale au monde.

H. Un accident grave pourrait-il se produire en Ontario?

S.40 L'accident de Tchernobyl a causé la mort de 31 personnes dans la centrale même et a libéré des quantités considérables de matières radioactives dans l'environnement, dont une infime partie a été retrouvée au Canada. Les réacteurs ontariens pourraient-ils produire un accident semblable?

S.41 La réponse est "non", même si d'autres types d'accidents graves peuvent se produire. À Tchernobyl, quatre facteurs ont été responsables du problème:

(i) L'incompétence opérationnelle et le non-respect des règlements avaient atteint des niveaux incroyables. Les opérateurs et les chefs de quart biens entraînés et responsables qui travaillent pour Hydro-Ontario ne pourraient jamais se comporter de manière aussi inepte.

(ii) Le système caloporteur de Tchernobyl contenait des quantités d'eau, susceptibles de vaporisation éclair, beaucoup plus importantes que celles des réacteurs CANDU. Ceci est à l'origine des énormes dommages causés à la structure de la centrale de Tchernobyl.

(iii) Le modérateur de Tchernobyl était constitué par des gros blocs de graphite inflammable, dont la combustion a transporté au loin une grande partie des débris radioactifs. Un facteur semblable soustend l'accident de Windscale, en Grande-Bretagne en 1957. Les réacteurs CANDU utilisent l'eau lourde, qui étouffe le feu.

(iv) La défaillance rapide de la calandre des réacteurs CANDU lors des accidents de ce type, interrompt la réaction en chaîne plus rapidement qu'à Tchernobyl.

Le réacteur de Tchernobyl partageait une caractéristique moins désirable des réacteurs CANDU: un coefficient de réactivité du vide positif. Ses systèmes de commande et de sécurité se sont révélés incapables d'affronter le problème: ils ont fonctionné, mais ont été inadéquats. Il n'y avait pas de système efficace de confinement.

S.42 Un accident grave dans un réacteur CANDU pourrait survenir en cas d'une brèche importante survenant dans le système caloporteur à haute pression qui refroidit le combustible et d'une défaillance simultanée du système d'arrêt. La probabilité pour qu'un tel accident se produise a été évaluée par la CCEA comme étant tellement faible que le calcul de ses conséquences n'a pas été nécessaire, surtout parce que deux systèmes d'arrêt d'urgence indépendants ont été exigés depuis l'autorisation d'exploiter Pickering A.

S.43 Compte tenu des critiques de l'opinion publique à l'égard de cette méthode et des doutes quant à la capacité de la centrale Pickering A de résister à un tel accident, la Commission a demandé à Hydro-Ontario et à Argonne National Laboratory de mener séparément des analyses du cas présenté dans le paragraphe S.42 pour les réacteurs de la centrale Pickering A. Les deux analyses, très semblables, contenaient les conclusions suivantes:

- la puissance du réacteur augmente immédiatement après la rupture du collecteur d'entrée (dans l'hypothèse d'un LOCA important);
- presque aussitôt, il y a début de fusion du combustible et pénétration de celui-ci dans les tubes de force et les tubes de calandre;
- la cuve cède (à moins de 4 secondes après la rupture initiale);
- une dépressurisation massive du caloporteur chaud, propulse des gaz dans le bâtiment du réacteur et l'enceinte de rétention en produisant une surpression;
- la hausse brutale de la pression n'arrive pas à rompre l'enceinte de rétention, bien que des fissures apparaissent sur le pourtour du couvercle supérieur du dôme;
- une quantité minime de contaminant s'échappe avant que ces fissures se referment (en moins de 20 s);
- on procède ensuite à la décharge des gaz rares, sur une période d'environ une semaine.

Des analyses indépendantes par des consultants experts ont confirmé ces conclusions.

S.44 Un accident de cette gravité endommagerait le réacteur, irrémédiablement sans doute, et pourrait présenter des dangers pour la santé des opérateurs du réacteur et des équipes d'entretien. Les effets sur la population seraient sans doute mineurs. On peut penser, sans en être certain, que les résultats dans d'autres centrales nucléaires seraient semblables.

S.45 Une autre chaîne d'événements possible est la défaillance système régulateur, combinée à une défaillance du dispositif d'arrêt du réacteur. Cette possibilité devrait faire l'objet d'une analyse semblable, comme le recommande la CCEA. Les délais n'ont pas permis de procéder à cette recherche supplémentaire, dans le cadre des travaux effectués par la Commission.

S.46 D'autres suites possibles d'accidents, comportant une éventuelle défaillance des systèmes de surveillance et des systèmes auxiliaires de sécurité (alimentation interne en eau, en air et en électricité), existent peut-être qui n'ont pas encore été mises en lumière. Une des orientations principales de l'analyse des accidents et de la sécurité devrait être de définir de telles chaînes d'événements. Mais on ne peut pas complètement éliminer les surprises. En particulier, il faut considérer la possibilité de gestes malveillants.

S.47 Dans les circonstances, et compte tenu des travaux importants de remise en état, d'amélioration du SIUR et de renouvellement des tubes de force réalisés dans les unités 1 et 2 de Pickering, et de l'engagement de continuer une bonne partie de ces travaux sur les unités 3 et 4 en 1988 et 1989, je ne vois pas d'inconvénient à ce que la centrale soit maintenue en exploitation. Elle n'en demeure pas moins le maillon le plus faible dans la chaîne des centrales d'Hydro-Ontario. Dans tous les cas, il faudra améliorer le système d'arrêt d'urgence.

I. Administration générale d'Hydro-Ontario

S.48 Les consultants engagés par la Commission ont relevé certains aspects des usages de l'entreprise en matière d'assurance qualité et de protection industrielle qui devraient retenir l'attention d'Hydro-Ontario.

S.49 Le dossier de la sécurité industrielle traditionnelle de la Direction de la production nucléaire (DPN) d'Hydro-Ontario ne répond pas à tous points de vue aux normes les plus élevées. Comparativement à l'industrie des produits chimiques, l'objectif de la DPN, qui est de six incapacités totales temporaires par million d'heures-personnes, n'a rien d'impressionnant. De fait, cet objectif est dépassé par toutes les centrales nucléaires la plupart du temps. Les consultants affirment que l'objectif d'une seule incapacité de ce type devrait être réalisable, sauf pendant les travaux de construction. La performance globale d'Hydro-Ontario dans ce domaine est de beaucoup supérieure à celle de la plupart des industries ontariennes, mais devrait (de l'avis des consultants) être améliorée.

S.50 Par opposition, le dossier de la DPN en ce qui a trait aux accidents mortels est particulièrement bon (125 millions d'heures-personne sans accident mortel). Le dossier de la protection contre les radiations est aussi excellent. Un des consultants a exprimé l'avis qu'il y avait déséquilibre dans les méthodes de sécurité industrielle d'Hydro-Ontario, déséquilibre marqué par une concentration au plan de la protection contre les radiations et les risques graves, au détriment de la protection traditionnelle et à l'égard des risques secondaires.

S.51 A Hydro-Ontario, la sécurité du personnel repose sur une vigilance sans faille et des interventions fréquentes de la part de la haute direction. Il en va de même de l'assurance qualité traditionnelle. La sécurité dépend de l'efficacité humaine, notamment aux échelons supérieurs. Il semble souhaitable qu'on procède à une évaluation globale de la conception que se fait Hydro-Ontario du contrôle de la qualité et de l'assurance qualité, ainsi que de la qualité technique, de préférence par des consultants externes.

J. Mesures d'urgence

S.52 En cas d'accident, un train de mesures déterminé sera mis en branle par le personnel d'Hydro-Ontario et un centre d'urgence sera établi à Toronto. Hydro-Ontario a défini les responsabilités de chacun et les mesures précises à prendre, aussi bien au niveau de la centrale que du centre d'urgence. Ces exercices sont répétées annuellement, avec la collaboration éventuelle des municipalités environnantes.

S.53 Les autorités provinciales ont confié au Bureau du Solliciteur général des fonctions importantes dans ce domaine. La responsabilité des mesures d'urgence à la centrale appartient à un état-major réduit et à un groupe déterminé de représentants officiels et d'autres personnes. Un plan d'intervention en cas d'urgence nucléaire a été rendu public en 1986.

S.54 Malheureusement, il n'y a pas eu encore d'engagement formel concernant son financement et sa mise en oeuvre (mais le Cabinet ontarien a décidé que celle-ci serait à la charge d'Hydro-Ontario). Il est urgent de créer une direction officielle de la planification des mesures d'urgence nucléaire au sein du Bureau du Solliciteur général et de mettre en place les dispositions du plan pour le rendre opérant. A l'heure actuelle, l'Ontario n'est pas prête à affronter un accident nucléaire grave.

S.55 Un groupe de travail du Bureau de Solliciteur général présentera sous peu un rapport sur les accidents de référence à partir desquels les diverses mesures d'évacuation, de placement dans les abris et de protection contre les radiations devraient être prises. Deux catégories d'accidents sont envisagées: la première étant reliée à d'éventuelles défaillances techniques, la deuxième, beaucoup plus grave, visant des accidents attribuables au sabotage, au terrorisme ou à la négligence lourde. La planification doit toujours être fondée sur le pire accident plausible.

K. Réglementation et sensibilisation du public

S.56 La réglementation des activités nucléaires d'Hydro-Ontario est sous la dépendance de la CCEA, un organisme fédéral qui échappe donc à ma compétence. Comme les règlements ont une influence sur la sécurité, j'ai toutefois pris la liberté d'avancer quelques propositions de changement.

S.57 Les méthodes et les pouvoirs de réglementation de la CCEA reposent sur des bases solides et ne nécessitent pas de remaniements en profondeur. Les modalités d'intervention suivent le modèle européen dans la mesure où la responsabilité de la sécurité repose sur la société exploitante, sous réserve de l'approbation de la CCEA. Cette dernière fixe les normes et ne délivre de permis que si elles sont respectées. Il ne serait pas souhaitable de se rapprocher du système américain de consignes sévères, sanctionnées en dernière ligne par des recours judiciaires.

S.58 Toutefois, la CCEA a toujours considéré que son mandat était de nature scientifique et technique, alors que de nombreuses questions de sécurité dans l'exploitation de l'atome relèvent plutôt des domaines socio-économiques et environnementaux. Ces questions pourraient être étudiées par le Conseil d'administration de la CCEA si on ajoutait à sa composition (par voie de modification législative) des membres supplémentaires, dont la compétence serait largement reconnue. En outre, les ressources humaines de la CCEA dans ces domaines, et dans le domaine de la santé publique, devraient être renforcées. Les propositions visant à réduire l'ensemble de l'effectif sont certainement imprudentes. Le personnel actuel ne parvient déjà pas à s'acquitter de toutes ses fonctions--étant donné notamment qu'une surveillance plus serrée de la performance d'Hydro-Ontario serait souhaitable.

S.59 Le travail de la CCEA et celui, remarquable, de ses comités consultatifs sur la sécurité nucléaire et sur la protection contre les radiations, sont à peine connus au Canada. La CCEA devrait se donner une image plus dynamique et rechercher des associations avec des interlocuteurs valables dans la communauté scientifique. Il importe en outre que les comités consultatifs de la CCEA soient pourvus des ressources qui leur permettent d'accélérer leurs travaux, de leur donner plus d'ampleur, et d'en faire une plus large diffusion.

S.60 La relation qu'entretiennent la CCEA et Hydro-Ontario n'est pas idéale, puisqu'elle repose principalement sur des entretiens informels et des échanges de correspondance. Ces échanges devraient être officialisés dans une plus large mesure, et les décisions (y compris les motifs de celles-ci) faire l'objet de rapports complets, sans qu'on en vienne toutefois à reproduire le schème de relations conflictuelles qu'entretient le Nuclear Regulatory Commission des États-Unis (US NRC) avec ses quelque 60 compagnies d'électricité, situation qui n'aurait aucun sens dans le contexte canadien. J'ai reçu plusieurs commentaires à l'effet que la grande taille d'Hydro-Ontario, sa haute compétence technique et sa façon déterminée de présenter des plans d'action pouvaient contribuer à l'emporter sur les jugements de la CCEA. Ceci n'est certainement pas la norme.

S.61 Le travail de la CCEA dans l'accréditation du personnel d'exploitation des centrales nucléaires peut être donné en exemple. Ce rôle pourrait être renforcé en rendant obligatoire la reconfirmation périodique du personnel.

S.62 Le parlement ontarien ne devrait pas intervenir dans le domaine de la réglementation. Par contre, devant l'insistance du public à participer aux décisions relatives à l'énergie nucléaire, le gouvernement ontarien pourrait:

- multiplier les audiences publiques, en se prévalant des pouvoirs qui lui sont conférés par la loi sur l'évaluation environnementale ("Environmental Assessment Act");
- créer un Conseil consultatif pour les questions de santé et de sécurité, doté d'un budget pour financer des enquêtes publiques, y compris les dépenses des intervenants.

L. Recherche et développement

S.63 La technologie du CANDU, encore jeune, doit pouvoir compter sur le soutien de laboratoires de recherche et de développement dotés d'un personnel compétent, et ce, quelle que soit la fortune commerciale du réacteur. La recherche est particulièrement importante dans le domaine de la sécurité. A cet égard, il faut mentionner que les coupures récentes dans le financement de la recherche entravent sérieusement les efforts visant à renforcer la sécurité du public.

S.64 La plus grande partie des travaux de recherche et de développement dans ce domaine a été réalisée par EACL, une société d'État fédérale. C'est dans les laboratoires de cette société que l'essentiel de la technologie du CANDU a été mis au point, avec le soutien important de la Générale Électrique du Canada et d'Hydro-Ontario. EACL et Hydro-Ontario ont d'excellentes installations de recherche, comme d'ailleurs la Westinghouse Canada, ce qui n'est malheureusement pas le cas des universités dont les ressources, dans le domaine, sont plutôt limitées.

S.65 Le principal effort de recherche en matière de sécurité porte actuellement sur la solution des problèmes posés par les tubes de force (canaux de combustible). Les travaux sont concentrés dans les laboratoires nucléaires d'EACL à Chalk River (lieu d'origine du CANDU) et à Whiteshell, au Manitoba, où est également basé le programme d'élimination des déchets. En outre, l'EACL finance un programme d'étude aux laboratoires de Mississauga de sa filiale de recherche. Hydro-Ontario a un programme plus modeste, mais valable, de même que la société Westinghouse Canada.

S.66 En 1988, les recherches canadiennes sur les réacteurs nucléaires vont se chiffrer à 117 millions $, dont 50 millions $ seront fournis par Hydro-Ontario (la moitié étant dépensée à l'intérieur de la société, l'autre moitié dans les laboratoires d'EACL). Les revenus d'Hydro-Ontario provenant des ventes d'électricité produite par l'énergie nucléaire se sont élevés à 2,5 milliards $ en 1987. Ainsi donc, les dépenses de recherche d'Hydro-Ontario en 1988 ne représenteront que 2% du total de ses ventes. Le budget de recherche d'EACL, à 66 millions $, constitue un apport non négligeable. La recherche sur les canaux de combustible entraînera des déboursés totaux de 42 millions $ en 1988, dont 19 millions $ viendront d'Hydro-Ontario. Dans ce cas encore, ces chiffres sont modestes en égard à la complexité du problème. Les fonds de recherche, on le constate, manquent dans un domaine où la technologie est la plus vulnérable. Cette situation s'explique en partie par la pénurie de personnel technique compétent et le coût élevé des installations de recherche.

S.67 En outre, la réduction (jusqu'à 50%) du budget de la filiale de recherche d'EACL constitue une menace sérieuse pour les programmes d'Hydro-Ontario. En effet, les laboratoires de génie d'EACL servent également à Hydro-Ontario. Aussi longtemps que cette dernière exploitera des réacteurs CANDU, il faudra préserver l'intégrité de l'infrastructure et des laboratoires de recherche qui lui sont réservés.

M. Les femmes et l'énergie nucléaire

S.68 Il y a peu de femmes dans les centrales nucléaires et aucune femme ne faisait partie du Conseil consultatif ou du Conseil d'examen de la Commission. Dans le passé, les femmes étaient exclues par réglementation des zones exposées aux radiations. J'ai reçu des mémoires dénonçant une situation jugée inacceptable, et qui venait en contradiction avec le programme anti-discriminatoire d'Hydro-Ontario.

S.69 Les femmes tendent à être plus critiques à l'égard de l'énergie nucléaire en général et des normes de sécurité en particulier. Par conséquent, leur absence totale ou relative des postes de haute direction peut influencer la nature des jugements en ces matières. Je favorise quant à moi une augmentation de leur représentation, sous réserve qu'on le fasse au mérite.

S.70 Toutefois, en ce qui concerne le travail dans les zones d'exploitation de la centrale, la prudence s'impose. Les femmes sont plus vulnérables que les hommes à certains champs de radiation, surtout à cause du risque de cancer du sein (les résultats récents de recherches japonaises semblent indiquer que le risque est plus élevé que prévu). Les risques sont aussi plus élevés pour le foetus, à certaines étapes de son développement. Ainsi, même si les doses de radiation au travail étaient suffisamment abaissées pour que les hommes et les femmes puissent travailler côte à côte dans des zones exposées aux radiations, il n'en reste pas moins que les femmes continueront de courir des risques supérieurs, comme leurs enfants à naître (bien que le phénomène ne soit pas encore bien compris). J'appuie le projet des femmes d'accéder en plus grand nombre à ce secteur d'emploi bien rémunéré, mais je dois leur rappeler que chacune aura à évaluer pour elle-même les risques qu'elle voudra courir.

THE SAFETY OF ONTARIO'S NUCLEAR POWER REACTORS

The Technical Report

Chapter I

Introduction

A. The Problem Outlined

1. Ontario has become a major producer of nuclear electricity. Its 16 power reactors are estimated to have produced 63 800 GWh of electricity in 1987, which is about half Ontario Hydro's total output. The nuclear generating stations actually account for only about a third of the installed capacity; however, because they dominate the baseload and operate almost continually at full power, they equal the other modes of generation in total output.

2. Four more large reactors, moreover, are under construction at Darlington and will enter service between 1989 and 1992. By 1993, Ontario Hydro estimates that its total electricity production will reach 153 000 GWh, and that its 20 reactors will contribute 69%, or 105 000 GWh. Thereafter, the utility will have to meet demand by using existing conventional thermal plants, unless new sources of power are added. A high-water mark for nuclear power may hence be reached in the mid-1990s, when installed nuclear generating capacity will reach 14 254 MW.

3. To put these figures into perspective, Figure 1 shows the nuclear share of electricity among the world's industrial powers (US Department of Energy 1987). Canada as a whole ranks quite low, but only three countries--France, Belgium, and Taiwan--depend on nuclear power to a greater extent than does Ontario. By 1993, only France is likely to exceed Ontario's dependence. Ontario far outranks the United States, which is currently at 17%.

4. How did this extraordinary position come about? Canada committed itself to the peaceful use of atomic energy at the end of the Second World War. The Atomic Energy Control Act of 1946, in its Preamble, asserted that "it is essential in the national interest to make provision for the control and supervision, application and use of atomic energy." Vigorous development and promotion of atomic energy were pursued at Chalk River, initially by the National Research

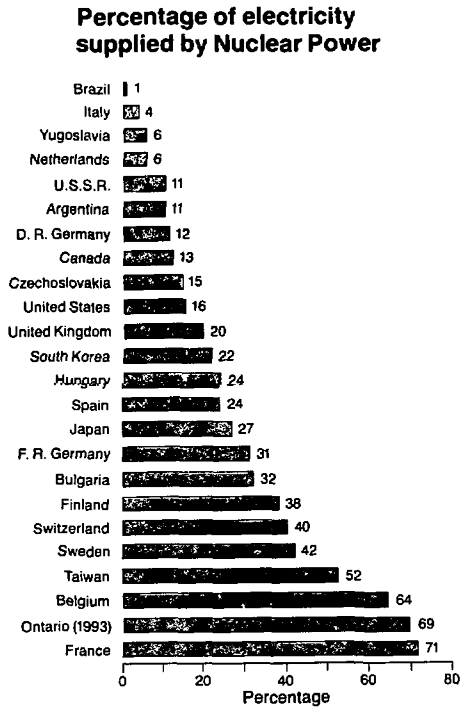

Figure 1 Ontario's stake in nuclear power: percentage of provincial consumption in 1993 expected to be supplied by nuclear stations, compared with 1987 shares in various countries.

Source: US Dep. of Energy, 1987

Council of Canada (NRCC) and then, after 1 April 1952, by Atomic Energy of Canada Limited (AECL). It has clearly been national policy for much of the post-war years to promote the peaceful use of atomic energy--or, as is now usually said, of nuclear power.

5. AECL found a ready partner in Ontario Hydro. The utility began collaborating with AECL as early as 1954* and committed itself to assist in the development of commercially viable power stations. From 1962 and 1968, respectively (until quite recently), it operated AECL's small demonstration station at Rolphton (called Nuclear Power Demonstration [NPD]; see Annex II) and the prototype at Douglas Point. With the experience behind it of building and operating large multi-unit fossil fuel stations, and the early experiences of design, construction, and operation at NPD and Douglas Point, the utility rapidly moved to the view that a few groups of large reactors could supply the entire baseload of the provincial power grid. After a brief consideration of other reactor types, Ontario Hydro committed itself (at its Pickering site) to the CANDU (Canada Deuterium Uranium) reactor. An account of the evolution of this reactor family is given by D.A. Meneley in Appendix I to this Report.

6. Figure 2 shows how the 16 existing CANDU reactors contribute to the base loading of the provincial electricity grid. Ontario Hydro occasionally has excess nuclear capacity at periods of low demand, requiring the nuclear units to operate below full power. However, because nuclear reactors have very low fuelling costs, they are used to supplement baseload hydraulic plants in supplying the continuous demand, operating whenever possible at full power. The controllers at the System Control Centre (in Toronto) can meet peak demand by bringing on stream hydraulic stations or coal- and oil-fired plants. In this fashion, Ontario has become dependent on nuclear power--generated by a single family of reactors--for much of its continuously required electricity. A utility whose very

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* In 1954, AECL established a Nuclear Power Group at the Chalk River Nuclear Laboratories (CRNL) under the direction of Harold Smith of Ontario Hydro. The group decided that W.B. Lewis' concept of a natural uranium, heavy water moderated reactor was best suited to Canada's needs (AECL submission, p. 4; see Annex I). Richard L. Hearn represented Ontario Hydro on the AECL Board from 1952 on.

Figure 2(a) Daily load curve, by source and hour of day, fcr Ontario Hydro's system on 7 December 1987 (high load period). Note key role of nuclear power in supplying the base load (continuous day-long demand).

Source: Ontario Hydro

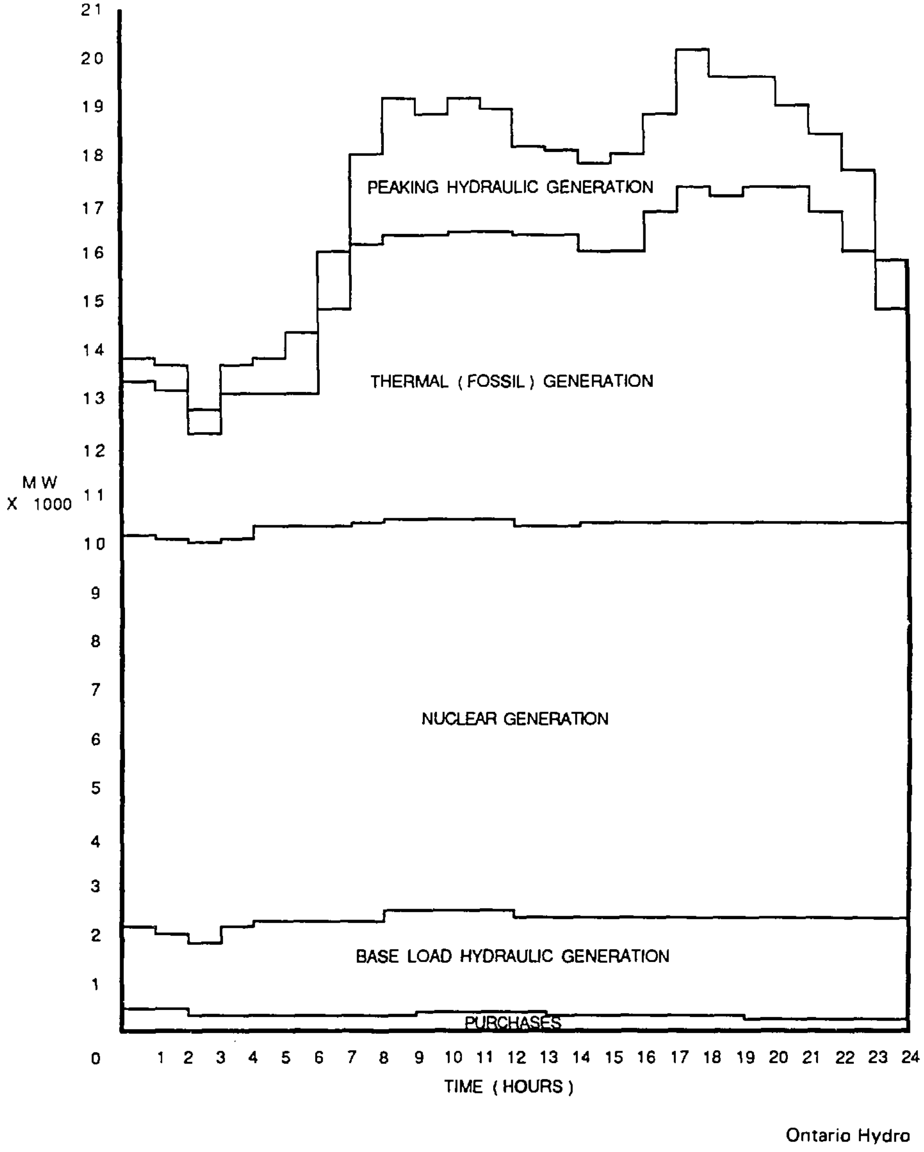
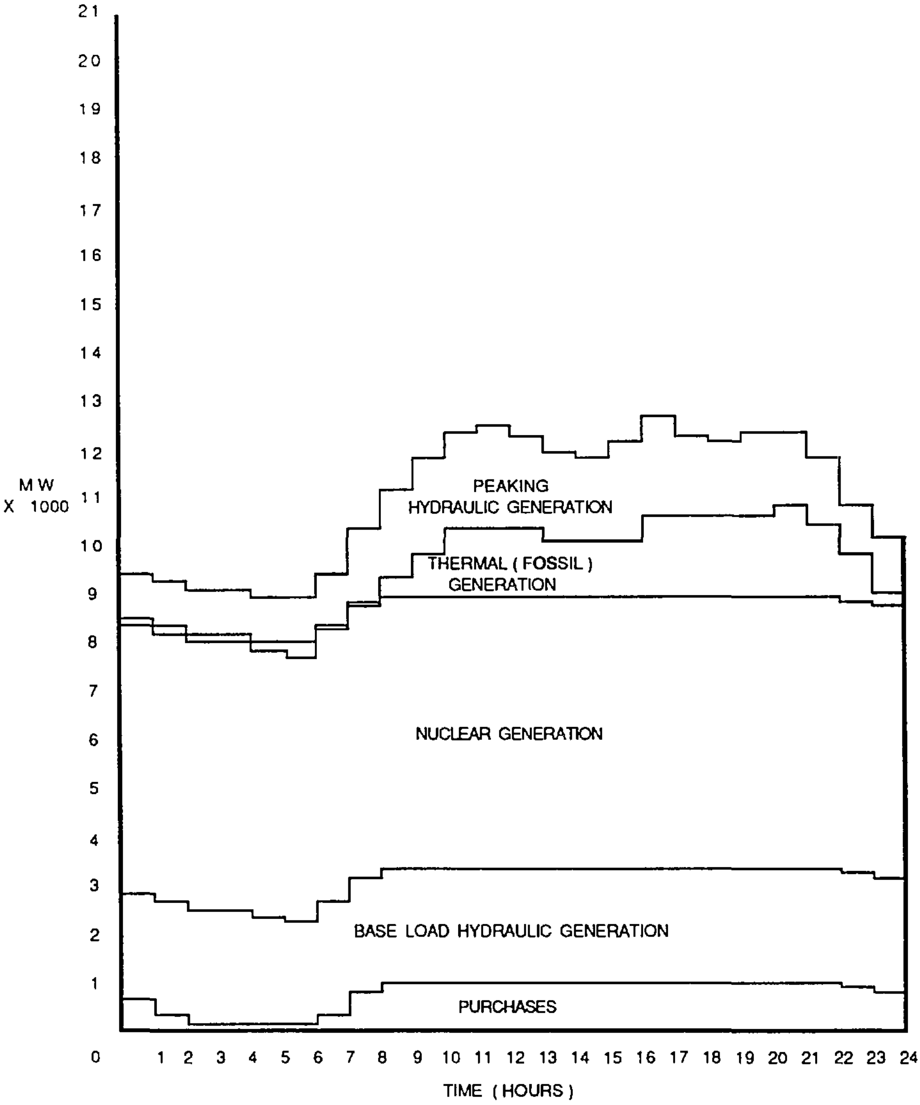


Figure 2(b) Daily load curve, by source and hour of day, for Ontario Hydro's system on 18 May 1987 (low load period). Note key role of nuclear power in supplying the base load (continuous day-long demand).

Source: Ontario Hydro



name embodies the notion of water power has turned to a vastly different source for its main supply.

7. This situation has arisen because of decisions taken and actions pursued by publicly owned corporations, acting within powers conferred on them by democratically elected parliaments. It has been public policy to develop and exploit nuclear power. Canadians are not faced, as are Americans, with a multitude of private electricity supply corporations seeking profit. Some of the rhetoric used before this Review treats AECL and Ontario Hydro as if they, too, were acting for private interests. Formally, this is not the case.*

8. Anxieties arise about this situation because of the mounting belief that nuclear power is an unsafe technology--and that disastrous harm may be caused by its wide deployment in the midst of populous southern Ontario. There may be residual memories of Hiroshima and Nagasaki. Severe accidents** at Three Mile Island (TMI) in 1979 and at Chernobyl in 1986 contributed to these fears. Could such events occur in Ontario? Even in the eastern outskirts of Toronto? Several of the Review's*** intervenors (including a Conference of the United Church of Canada) are greatly alarmed and submitted briefs to that effect.****

9. The nuclear industry is aware of this loss of confidence. AECL, in its submission to the Review (their Appendix I, p. 87), asserted that two out of three Canadians believe that the risks of nuclear power outweigh the benefits.

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* Among the early designers and builders of nuclear reactors in this country must be added the Canadian General Electric Company, a private corporation, which joined Ontario Hydro and AECL in some early projects.

** A severe accident, for the purposes of this Review, is one that cannot be contained, and which hence exposes nearby populations to radioactive materials. Safety analysts often prefer to use "severe" to denote accidents in which there is actual damage to fuel (but not necessarily with any breach of containment).

*** I have abbreviated the Ontario Nuclear Safety Review simply as "the Review" throughout the text.

**** A complete list of all briefs, submissions, and consultants' reports is in Annex I. There are frequent references to these documents in the text, without further bibliographic reference.

A poll carried out in November 1986, just before the Review was launched, showed that inherent perceived hazards, risk of accidents, TMI and Chernobyl, and the potential for human error lie behind this view. The federal Department of Energy, Mines and Resources (EMR), in a comparable survey two months earlier, found that 72% of Canadians were concerned about safe waste disposal, 68% about the occurrence of a major accident, and 61% about radioactive emissions.

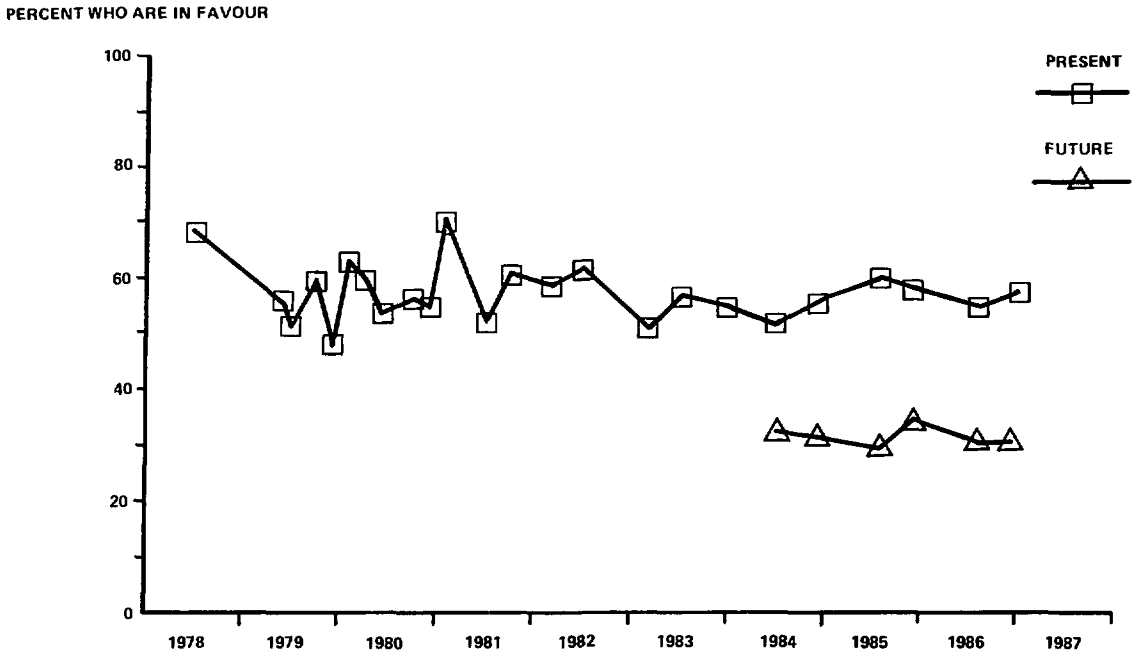
10. Ontario Hydro has been continuously sampling public opinion since 1978 (Figure 3). The results show a slightly different situation, in that support for the present use of nuclear power has fluctuated little, remaining in the 50-57% range (except for a brief downward flip after TMI). On the other hand, support for the future use of such power (sampled since 1984) is less than 30%, and if anything has tended to fall.

11. These anxieties have involved the Provincial Legislature quite deeply. The Select Committee on Ontario Hydro Affairs, under the chair of Donald C. MacDonald, MPP, conducted 16 weeks of public hearings immediately following the accident at TMI, hearing over 100 witnesses and tabling 150 exhibits. In 1980, it issued a landmark report, "The Safety of Ontario's Nuclear Reactors," containing numerous recommendations (not all of which have been acted upon) and an excellent analysis of the safety issues. It found the reactors acceptably safe, but pleaded for a far more open approach to the regulation of the industry.

12. The problem is thus that Ontario Hydro has covered most of its baseload requirements with a single technology--nuclear power. The reactors have for the most part functioned well and have won considerable admiration outside Canada, as have Ontario Hydro's radiological protection measures and system control. But serious defects have developed. These have raised fears that public safety may be jeopardised. This Review assesses the extent to which these fears are justified.

Figure 3 Fraction of respondents who supported the use of nuclear power for present (upper curve) and future (lower curve) electricity supply since 1978 (1984 for future use).

Source: Ontario Hydro



B. Origins of the Review

13. On 18 December 1986, the Ontario Minister of Energy, The Honourable Vincent G. Kerrio, wrote to me* confirming my appointment as Commissioner of the Ontario Nuclear Safety Review (see letter of appointment). He took this action in response to recommendation 3 of the Report of the Select Committee on Energy of the Ontario Legislature dated July 1986 (Government of Ontario 1986). This recommendation called for a review, on a priority basis, of "the safety of the design, operating procedures and emergency plans associated with Ontario Hydro's nuclear generating plants." Excluded from my responsibilities were "uranium mining, refining and fuel fabrication; disposal of spent nuclear fuel; decommissioning of a reactor at the end of its useful life; and the potential sale of tritium extracted from heavy water."

14. Two recent events clearly prompted my appointment: the nuclear accident at Chernobyl, and the decision by the Government of Ontario to complete the Darlington Nuclear Generating Station (NGS).

15. It was made clear to me that the Ontario government wanted a scientific and technical review, and not a public inquiry. I have complied, although I invited written input from interested parties. The Review is nevertheless primarily based on scientific and technical evidence, on which I have made personal judgements.

16. I was invited to consult expert opinion and experience on an international basis, specifically in the scientific and technical domains, and particularly from outside the nuclear industry. With the agreement of the Minister, I at once sought the help of the Royal Society of Canada, which responded willingly. It has assisted in the following chief ways:

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* Having been appointed a single Commissioner, I follow the usual practice of writing in the first person singular, unless I am clearly discussing collective judgements. Of course, I have been helped by many persons who are mentioned in the text.

- in frequent exchange of advice and criticism;
- in naming members of my invaluable Advisory Panel; and
- in providing, at the end of the work, a distinguished Panel of reviewers.

17. I have had the priceless support of a small team of dedicated professionals. The entire Review has been managed by Margaret C. Grisdale, who is highly experienced in the conduct of scientific and technical inquiries, and who has herself contributed to the analysis. Scientific direction and analysis have been in the hands of Peter M. Fraser. The French language text of the Minister's Report was prepared by Wladimir Paskievici of the Advisory Panel. Administrative support has come from Angelica Devito, assisted by Shirley Blair. The report and its appendices were processed and designed by Kartini Rivers. Marla Sheffer undertook the copy-editing. I could not have met our difficult deadlines without their help.

C. Restraints

18. The nuclear industry is so large and complex that I have inevitably ignored much of the detail offered to the Review. I am recommending that the submissions from Ontario Hydro and AECL be published as companion volumes, so that readers of the Report can have access to these rich accounts of the finer texture of the industry. But most readers will not have had my opportunity of looking closely at the stations themselves. Such inspection sharpens the curiosity. I recommend it to all who claim the luxury of strong opinions about nuclear safety.

19. Equally constraining were the proscriptions of my terms of reference. Several intervenors criticised, for example, the exclusion of waste management from the scope of the Review. Others felt that tritium sales should have been included. One or two advisers wanted far more emphasis on security. I sympathise with all these views, but was nevertheless relieved that they were excluded, simply because I could not have covered them in the time available. And I feel that this Review has really focussed on the chief anxiety in people's minds: whether or not the reactors are acceptably safe.

20. Another restraint concerns regulation, research, and development. Responsibility for policy and decisions in these areas lies with the federal government and its agencies, the Atomic Energy Control Board (AECB) and AECL. My study has left me with firm conclusions as to their future roles, yet my Report is addressed to a Provincial Minister. I have solved the problem by confining myself to an analysis of these agencies' roles in matters of safety.

21. I have avoided commenting on the role of nuclear power in future supply; on the question of safeguards--in the industry's strange language, the attempt to stop spent fuel from providing raw materials for bombs; and on the whole question of public participation--whether ordinary people can (or should) influence decisions about safety other than through their elected representatives. All these themes are subjects on which I could have reported at some length if time had allowed. As it was, I had to work very hard to cover the subjects in the terms of reference.

22. I agree with the criticism that the Review has been dominated by men. This is because it is a scientific and technical review at the expert level. There are far too few women in the industry, its regulating bodies, and the consultant community. A body of involved experts is likely to be as male-dominated as the industry itself. The Advisory and Review Panels were appointed on the advice of the Royal Society of Canada. The Society realised the deficiency at the time of the Review Workshop, but it was then too late to correct matters. On the other hand, the Review Manager was a woman, and the Review staff did its best to ensure participation by women in its work.

23. It is generally agreed that women are less well disposed towards nuclear power than are men. Several opinion polls confirm this view, although results are more complex than the stereotype suggests. The same appears to be true of heavy technology in general. Few women choose careers in these areas, and their poor representation appears to be as much due to choice as to discrimination against them. The situation in the nuclear industry is by no means unique.

24. Among the Review's paid intervenors, one group elected to prepare a brief on women in nuclear power--the Queen's University Women's Centre. Their lengthy brief is impressive. It covers three chief areas: the effects of radiological exposure on the health of women working in the nuclear generating stations; women and the decision-making structure; and the role of organised dissent (especially women's activities in such dissent). In attempting to correct the imbalances in our treatment I have made full use of this brief.

D. Made in Ontario

25. Ontario has followed a distinctive technological path in developing nuclear power. Successes and failures, if there are any, have been grown by federal and provincial bodies on Ontario soil. So have the safety standards.

26. Ontario Hydro currently operates 16 power reactors, with four more to enter service between 1989 and 1993. All are of the CANDU design, originally conceived in Peterborough by AECL, Canadian General Electric, and Ontario Hydro (the group that designed NPD-2 at Rolphton). Only three other power reactors have been built in Canada, two in Quebec (one now decommissioned) and one in New Brunswick. The two operating reactors outside Ontario are also CANDU reactors.

27. The CANDU reactors are grouped around the densely populated peninsula of south-western Ontario, so as to be near the major demand centres. There are many other power reactors close to Ontario territory. Figure 4 shows their sites and electric power ratings, in relation to the distribution of population.

28. Ontario Hydro's use of the CANDU system sets the province apart from the mainstream of nuclear power development. These reactors use natural uranium as a fuel--i.e., uranium directly as refined from the ore, containing only 0.72% fissionable uranium-235. Most other reactor types use enriched uranium, in which uranium-235 is artificially increased to 2-4%. To use natural uranium, the CANDU reactor must be supplied with heavy water (deuterium oxide), which is extracted from Lake Huron. Heavy water occurs naturally in all water bodies in

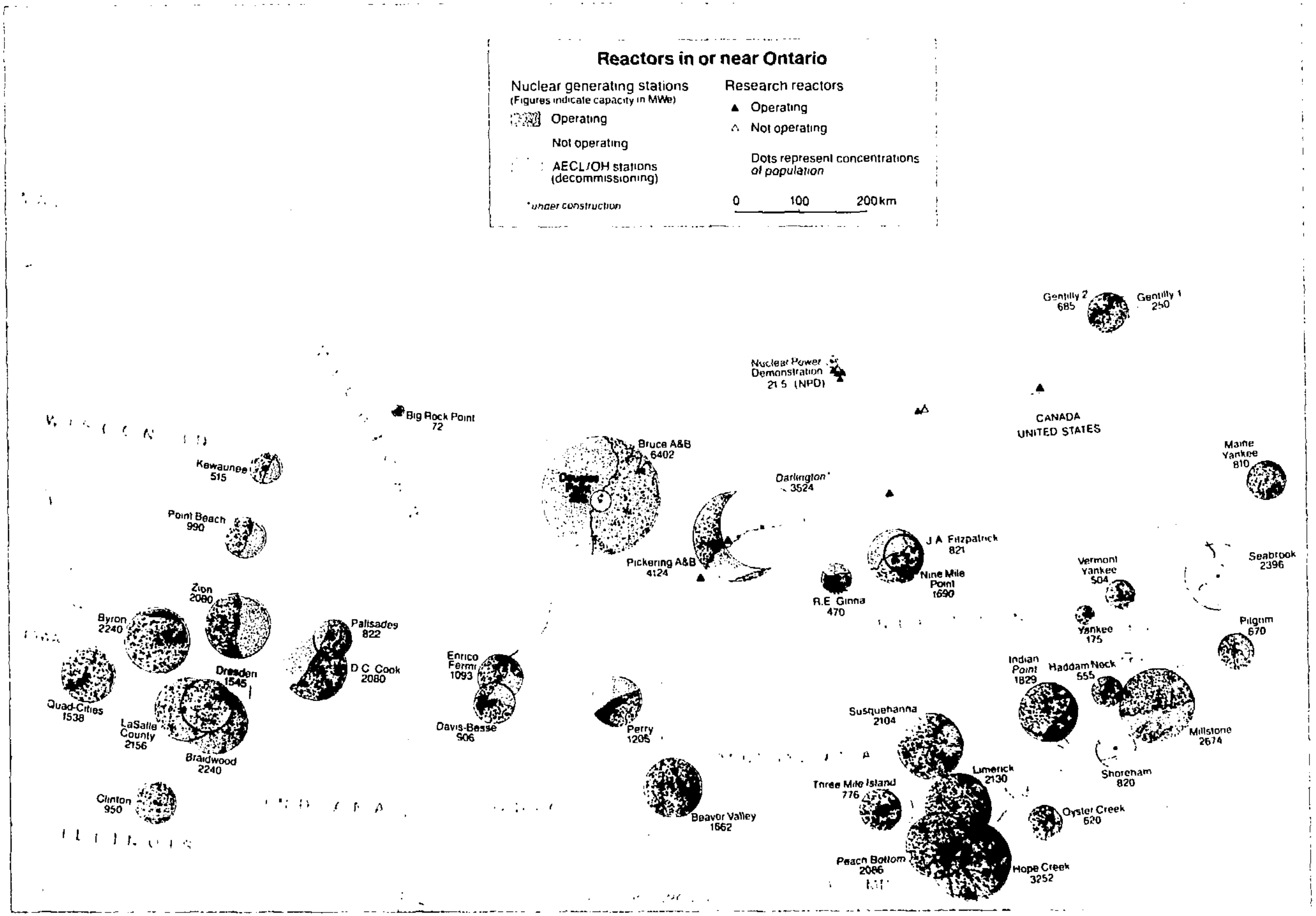

Figure 4 Sites and electric power ratings of reactors in and near Ontario. Sites of research reactors and decommissioned reactors are also shown.

Compiled from AECB and US NRC annual reports the proportion of one atom of heavy hydrogen (deuterium) to 7000 atoms of ordinary hydrogen (about 125 parts per million). Most other reactor types use ordinary water for these purposes. A few use gas as a coolant and graphite as a moderator.

29. CANDU has been successful, and its performance in some ways outstanding. But Canada has succeeded in selling similar reactors only to Rumania (which is building a five-reactor station to AECL design), Argentina, and India (its initial CANDU reactors). In addition, Canadian General Electric sold small (120 MW) CANDU reactors to Pakistan and South Korea. The United Kingdom also uses natural uranium reactors (MAGNOX), but with carbon dioxide cooling instead of heavy water, and a graphite moderator. The UK Winfrith steam-generating heavy-water reactor (SGHWR) uses heavy water as a moderator, but ordinary water as a coolant. The Soviet Union has a variety of designs. Nearly all other countries use enriched uranium light water cooled and moderated reactors. Specifically this is true of the United States, where in 1986 all but one of the 108 operating reactors were of this design.

30. The fact that our reactors are so different from the international norms has posed a problem for the Review. I have tried to use internationally recognised experts to help in the analysis. There are many questions of safety that are generic to all fission reactors, and in these areas I have consulted opinion widely outside Ontario. But a common reply from extra-provincial consultants has been a disclaimer: that the respondents do not know enough about the CANDU technology to be of assistance.

31. For obvious reasons, I have tried to avoid the use of current employees or active consultants of Ontario Hydro, AECB, and AECL as consultants. This has been a major handicap. Nearly all the real experts work for these bodies or are active consultants to them. There are few independent experts on reactor performance in Canadian universities or research organisations.

32. I have, however, had the help of several authorities now retired from Ontario Hydro, AECB, and AECL. Senior consultants have included two former presidents of AECB, D.G. Hurst and A.T. Prince; J.A.L. Robertson, formerly of AECL; and D.A. Meneley, now Professor of Nuclear Engineering at the University of New Brunswick, and formerly of Ontario Hydro. These men have world reputations and are unquestionably free agents.

33. Secondly, I received detailed submissions from Ontario Hydro and AECL on the CANDU reactors now in operation. Quite as usefully, I have discussed the strengths and weaknesses of CANDU reactors with many engineers and scientists in those corporations and have visited the nuclear generating stations and research laboratories. At no time was I conscious of any attempt to prevent me from getting at the facts.

34. The CANDU technology was first put to use in experimental power stations at Rolphton and Douglas Point, with Ontario Hydro as operator (Ontario Hydro built Douglas Point and helped in the design of NPD and Douglas Point). Since then, Ontario Hydro has managed the design and construction and operated most of the large CANDU power stations. It has done so with great success; in the world's league table of reactor availability, there have at times been six Ontario reactors among the top 10 (Table 1).

35. But problems have arisen, as they always do with new technologies. Pressure tube failures at Pickering and Bruce have led to expensive repairs, major losses of generating time, and inevitable questions about safety. The accidents were handled without danger to the public, but, coming in the wake of the TMI accident in 1979, they aroused concern.

E. Some General Comments

36. The Review attempts to answer the question: are Ontario's CANDU reactors acceptably safe? This was found to be the case in 1977 by the Royal Commission on Electric Power Planning (Porter 1978). It was also the less

Table 1

The Top Ten:
Lifetime World Power Reactor Performance
to 30 June 1987
(for reactors over 500 MW)

Country	Ranking	Unit	Type	Capacity factor* (%)
Canada	1	Bruce 5	CANDU	88.7
Canada	2	Bruce 3	CANDU	86.6
Canada	3	Pt. Lepreau	CANDU	86.5
Canada	4	Bruce 4	CANDU	85.7
Canada	5	Bruce 7	CANDU	85.5
Canada	6	Pickering 7	CANDU	85.1
W. Germany	7	Phillipsburg 2	PWR**	84.0
Belgium	8	Doel 3	PWR	83.5
Canada	9	Pickering 8	CANDU	83.2
W. Germany	10	Grohnde	PWR	82.7

* Capacity factor = $\frac{\text{actual electricity generation}}{\text{perfect electricity generation}}$.

** Pressurised water reactor.

Source: Nuclear Engineering International 1987.

(Courtesy Ray Silver
and Bridges Magazine)

unanimous conclusion of the Select Committee on Ontario Hydro Affairs of the Ontario Legislature (Government of Ontario 1980). Is the conclusion still valid, in the light of recent problems?

37. I have been impressed by five particular points:

(i) The human factor equals or outweighs the technical in the issue of nuclear safety. Human error is involved in a high proportion of all malfunctions of nuclear station systems. It was a prominent factor in the accidents at TMI and Chernobyl. Hence, the words "scientific" and "technical" in the terms of reference must be interpreted liberally. The Review could not ignore human performance, nor could it ignore regulation--which is concerned to a large extent with human factors. All major participants--designers, scientists, regulatory bodies (and their staffs), and even consumers--are capable of action or errors that may affect safety.

(ii) The senior staffs of Ontario Hydro and AECL see the growth of nuclear power as a continuing grand enterprise that depends on their loyalty and pride. This sense of achievement and of common goals still pervades the industry and is detectable even in the regulating body, AECB.

(iii) The high operating standards aimed at by both corporations rely on this camaraderie, which makes a highly disciplined operating system acceptable. Safety in reactor systems, it is held, depends on an atmosphere of confidence, responsibility, and mutual respect at all levels, from shop-floor to boardroom.

(iv) In safety questions, one must learn from experience--and especially from the recorded failures (of which the TMI and Chernobyl accidents are the most striking recent examples). Hence the design, operating, regulating, and administrative systems must always be open to change, as each lesson is learned.

(v) Although the Review is a provincially appointed body and has a mandate to examine the safety of reactors operated by a provincially owned utility, it cannot ignore the vital role played by a federal

Crown corporation, AECL, chief designers of the CANDU technology. The regulating agency, AECB, is also a federally appointed body.

F. With Whom has the Review Dealt?

38. Overwhelmingly, Canadian involvement in nuclear power lies within Ontario, Quebec, New Brunswick, Manitoba, and Saskatchewan. The first three provinces operate nuclear stations near large concentrations of population. Saskatchewan has the largest share of Canada's uranium mining and concentration. Manitoba has some involvement, because the Whiteshell Nuclear Research Establishment (WNRE) (of AECL) is at Pinawa, 90 km east of Winnipeg, and 20 km west of the Ontario border.

39. Ontario, and hence its government, is by far the most deeply involved province in the issue of nuclear safety, because of the scale of Ontario Hydro's nuclear generating programme. Overall responsibility for nuclear affairs nevertheless rests with the Government of Canada. Under the Atomic Energy Control Act, R.S.C. 1946, as subsequently amended, the federal government asserts in the Preamble that "it is essential in the national interest to make provision for the control and supervision of the development, application and use of atomic energy."

40. The constitutionality and applicability of this Act are discussed fully in a brief commissioned by the Review from Lang Michener Lash Johnston. Although private interests have challenged the Act, it has been generally conceded that the control and supervision of this industry are national (i.e., federal) responsibilities.

41. The agency responsible for the regulation of nuclear safety is thus AECB, established in 1946 under the above Act (see Appendix VII). AECB is Canada's regulating body. It has very wide powers. I have examined AECB's function in the management of nuclear safety. I appreciate the help given by its President and professional staff. (See also paras. 60-70 below.)

42. The role of the federal government does not cease with regulation. AECL is the federal Crown corporation that acts (to quote from its own brief) as "Canada's national nuclear organization." It has been the chief designer and promoter of the CANDU reactors. Although Ontario Hydro has increasingly assumed responsibility for design, construction, and operation of its nuclear stations, AECL remains a significant force in design, research, and engineering. Its laboratory facilities at CRNL, home of much of the original CANDU development work, at Mississauga in Ontario, and at WNRE, at Pinawa in Manitoba, are essential to the operations and safety of Ontario Hydro's power reactors.

43. The third institutional party is Ontario Hydro itself, the provincially owned utility that operates the reactors feeding electricity into the Ontario grid. Ontario Hydro's nuclear stations have been the principal target of this Review. I gratefully acknowledge the generosity with which I have always been met while within its offices and plants.

44. Another interested group includes the supporting industry and professions, and their associations. Most of the companies supplying Ontario Hydro and AECL are private corporations, some of which chose to submit briefs. So also did the Canadian Nuclear Association, representing the industry, and the Canadian Nuclear Society, representing individual members of the supporting professions. I also met, and received briefs from, several unions and professional associations representing the work-forces of Ontario Hydro and AECL. These encounters were especially valuable, because those who work near the reactors are those most directly concerned with safety--for their own persons, and for their jobs, which are imperilled if public confidence drops. Incidentally, it is noteworthy that AECL and Ontario Hydro employees appear to enjoy living and raising families alongside the reactors; Deep River, for example, is a flourishing community.

45. Finally, but by no means least, there is the group of independent associations and individuals who chose to intervene in the Review's work, in response to my request for help. Most of this group were strongly critical of

reactor safety and of the way the nuclear industry works. Annex I lists all the submissions made to the review by Ontario Hydro and AECL as well as briefs from the professional and industrial associations, unions, and individuals.* It also lists the reports derived from consultants selected following advice from the Advisory Panel.

46. It has been from this very large body of advice, information, and comment that I have derived my conclusions--together with my own store of personal experience and prejudice. The process has involved watching press and other media comment as well as lengthy discussion with my colleagues on the Advisory Panel and the Review staff, including the senior consultants.

47. The intervenors' briefs form a large and important body of opinion and factual information. All of them will be deposited with the provincial government with the recommendation that copies be made available to all interested parties. Some of the material is directly relevant to the Technical Report and is discussed in the text. Other parts are discussed in the appendices. The remainder has not been seen as relevant to the findings of the Report, although it has all been noted.

48. The expenses of intervenors in preparing these briefs were reimbursed by the Review. Total disbursements were $229 681.

G. What is Safety?

49. In ordinary parlance, "safety" is freedom from danger or risks. Scientists and engineers prefer to avoid the word safety, and talk instead about "risk." They assert that risks are never absent, but can be minimised by suitable action. Behind these simple truths lie long and heated arguments among scientists, and

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* I have used the term "intervenor" (disliked by some) to denote all individuals and groups who volunteered information and opinion. My budget allowed me to support financially many of these submissions. "Consultant" is the term used to denote experts from whom I commissioned studies, at my own choice.

between the technological community and the general public. The public insists that it wants to know whether things are safe, regardless of scientific arguments about degrees of risk.

50. The question before this Review, however, is the same as that posed by the Porter Commission in 1978 and by the Select Committee on Ontario Hydro Affairs of the Ontario Legislature (SCOHA) in 1980--are the nuclear reactors operated in Ontario by Ontario Hydro acceptably safe?

51. The Select Committee decided, as did the Porter Commission, that the reactors are indeed acceptably safe, although a minority disagreed. But this was before the Chernobyl accident, which reopened the public debate. I was specifically charged by the Minister with considering the implications of that accident, and with the way in which Ontario Hydro and AECL responded to it.

52. What are the risks and dangers that imperil safety? In the case of nuclear reactors, there are straightforward answers. Overwhelmingly, the risks are radiological: i.e, they arise from exposure of individuals to four classes of radiation: gamma, beta, alpha, and neutron. There is little special conventional risk. There are two distinct cases to be considered: the risks imposed by normal operations, which are largely borne by the work-force within the nuclear generating stations; and the risks arising from accidents, in which there may be exposure of members of the public.

53. The main subjects of public anxiety about safety are waste disposal (not treated here) and severe accidents--or nuclear catastrophes. A related subject is radiological hazard. Do the nuclear generating stations, while operating normally, emit clouds of dangerous radioactive substances, as the more extreme anti-nuclear activists maintain? Will the reactors continue to operate without accident far into the future?

Previous Inquiries and Reports

At intervals in the text I shall be making clear how much I owe to earlier inquiries into nuclear safety.

Within Ontario there are two reports in particular that I have found invaluable:

1. Arthur Porter, Chairman: A Race Against Time, Interim Report of the Royal Commission on Electric Power Planning (RCEPP), 1978. Henceforth this will appear as Porter 1978. This detailed analysis of Ontario's nuclear generating programme gives an excellent overview, with a treatment of waste disposal (which is ignored in the present review).

2. Ontario Legislature Select Committee on Ontario Hydro Affairs (SCOHA): The Safety of Ontario's Nuclear Reactors, 1980. This excellent overview takes account of Three Mile Island, but not Chernobyl.

UK reports of great value include:

3. Sir Brian Flowers (now Lord Flowers), Chairman: Nuclear Power and the Environment, 1976, sixth report of the UK Royal Commission on Environmental Pollution. Flowers 1976 (as it will be cited) is a veritable textbook of nuclear technology and environmental impact.

4. Sir Frank Layfield, Report on the Sizewell B Public Inquiry, 1987, 8 volumes. This work covers a public inquiry into the adoption by the Central Electricity Generating Board of the US-designed pressurised water reactor (PWR). Layfield 1987 is a monumental analysis of the entire question of nuclear safety, and of the technology and economics of the entire industry.

From US sources I have made much use of:

5. John G. Kemeny, Chairman: The Need for Change: The Legacy of TMI, 1979. Report of the President's Commission on The Accident at Three Mile Island. Kemeny 1979 raises fundamental issues about the human factor in nuclear safety.

6. US Nuclear Regulatory Commission: Report on the Accident at the Chernobyl Nuclear Power Station, 1987. NRC 1987 is a detailed analysis of the evidence bearing on causes of the Chernobyl accident.

From Atomic Energy of Canada Ltd.:

7. J.W. Howieson and V.G. Snell: Chernobyl--a Canadian Technical Perspective, 1987. Howieson-Snell 1987 covers the crucial question: how did the RBMK reactor at Chernobyl differ from CANDU?

From Ontario Hydro and Argonne National Laboratory:

8. Nuclear Studies and Safety Department and Civil Design Department, Ontario Hydro: Analysis of the Consequences of Failure to Shutdown Following a Large Loss of Coolant Accident in a Pickering NGS A Unit (Report to Ontario Nuclear Safety Review), 1987.

9. Reactor Analysis and Safety Division, Argonne National Laboratory: Assessment of Early Disruption Events during a Postulated Power Excursion Accident in Pickering a (sic) CANDU Reactor, 1987.

These two reports throw much light on the implications of Chernobyl for CANDU performance under accident conditions.

54. Running through the discussion are five principles recognising the following:

(i) there can never be absolute safety in reactor design and operation. There is always risk, for this is a potentially dangerous technology. Safety--freedom from the risk of harm--depends on two things: sound engineering design and construction; and wise human use of the equipment. If it is argued that risks can be eliminated by avoiding or abandoning nuclear technology, then it must also be admitted that all alternatives have risks as well--perhaps greater, perhaps smaller (see AECB 1987c).

(ii) Users of all such dangerous technologies must accept defence-in-depth as their guiding principle. Vital subprinciples flow from this: that it is best to prevent accidents; that if they happen they must be limited and contained; and that, if limitation, too, fails, the consequences must be limited. This idea is the basis of Ontario Hydro's submission to the Review.

(iii) The assurance of quality is absolutely cardinal to safety in nuclear technology, at all stages, and in all domains. This includes materials, operational methods, and human and institutional performance. The price of safety is unflagging vigilance.

(iv) There is some level of risk that the public finds acceptable. If no such level exists--if the public is unwilling to accept the lowest risk that can be attained--the technology must be abandoned. A corollary is that such determination has to be political, not scientific. Scientists can ascertain approximately what risks appear to be acceptable, but only elected representatives have the right and the responsibility to declare such a level to be industry's proper design target.

(v) An alternative view is that there is a level of risk best called tolerable given the level of associated benefits. Whether or not this is perceived to be the case can be roughly measured scientifically, but decisions that a risk level is tolerable should only be made politically (although each individual is clearly able to make his/her own mind up about personal tolerance).

55. D.A. Meneley (personal communication) writes:

> The fuel of a CANDU reactor accumulates large quantities of radioactive fission products--the ashes of the fission process. Under normal operating conditions the fission products are securely locked inside the fuel matrix and other barriers. The necessary and sufficient goal of nuclear power plant safety, design and operation is to ensure with a high degree of confidence that these materials will not be released beyond the plant boundary, and so will not cause damage to living organisms. Safety performance is measured by the degree to which the goal is achieved.

Thus, the central technical safety objective is always to protect the fuel--and in so doing, to protect people.

H. Where, and of What Sort, are the Reactors?

56. Annex II gives details of all the power reactors operated within Ontario, and within adjacent provinces and states. For convenience, details of New Brunswick's CANDU reactor and of small research reactors throughout Canada are also included.

57. Figure 4 shows the location of these reactors, and how that location relates to population distribution. This Review has not considered the small research reactors, none of which is operated by Ontario Hydro.

58. In practice, the reactors of most concern in this review are grouped at a small number of sites:

(i) the cluster in the Ottawa Valley above Ottawa itself, including NPD at Rolphton and National Research Experimental (NRX) and National Research Universal (NRU) reactors at Chalk River (40 km downstream). All three reactors are the property of AECL, but NPD (now being decommissioned, having fulfilled its purpose) has been operated as a demonstration of the CANDU technology, and as a training site, by Ontario Hydro.

(ii) Pickering A and B NGSs, on the eastern outskirts of Metropolitan Toronto (Pickering NGS is 35 km from Toronto City Hall). The eight reactors of these adjacent stations together generate 4124 MW net of electric power, when all are operating. Cooling water is drawn from Lake Ontario. The surrounding area is thickly populated and is becoming more so. Heavy road and rail traffic passes close to the generating stations along highways 2 and 401 and along the main lines of the CP and CN rail systems. Figure 5 shows the plant.

(iii) Bruce Nuclear Power Development, on the east shore of Lake Huron (which yields the cooling water), about 15 km north of Kincardine. The eight reactors (four in Bruce A NGS and four in Bruce B NGS) can together generate 6402 MWe net. AECL's Douglas Point reactor (206 MWe) is on the Development, but is being decommissioned. The Development also houses a heavy-water plant, which extracts deuterium oxide from Lake Huron water by chemical means (involving the use of large amounts of hydrogen sulphide, an extremely toxic gas). The surrounding area is largely rural, with some small towns and villages. Traffic density is light (Figure 6).

(iv) Darlington NGS, on Lake Ontario's north shore about 60 km east of Toronto City Hall and 25 km east of Pickering NGS. This four-reactor station is under construction. The first units will come on stream in 1989. When all are in service, the station will generate 3524 MWe net. The area is largely rural, but is traversed by highways 2 and 401 and the main rail lines of the CP and CN (the latter

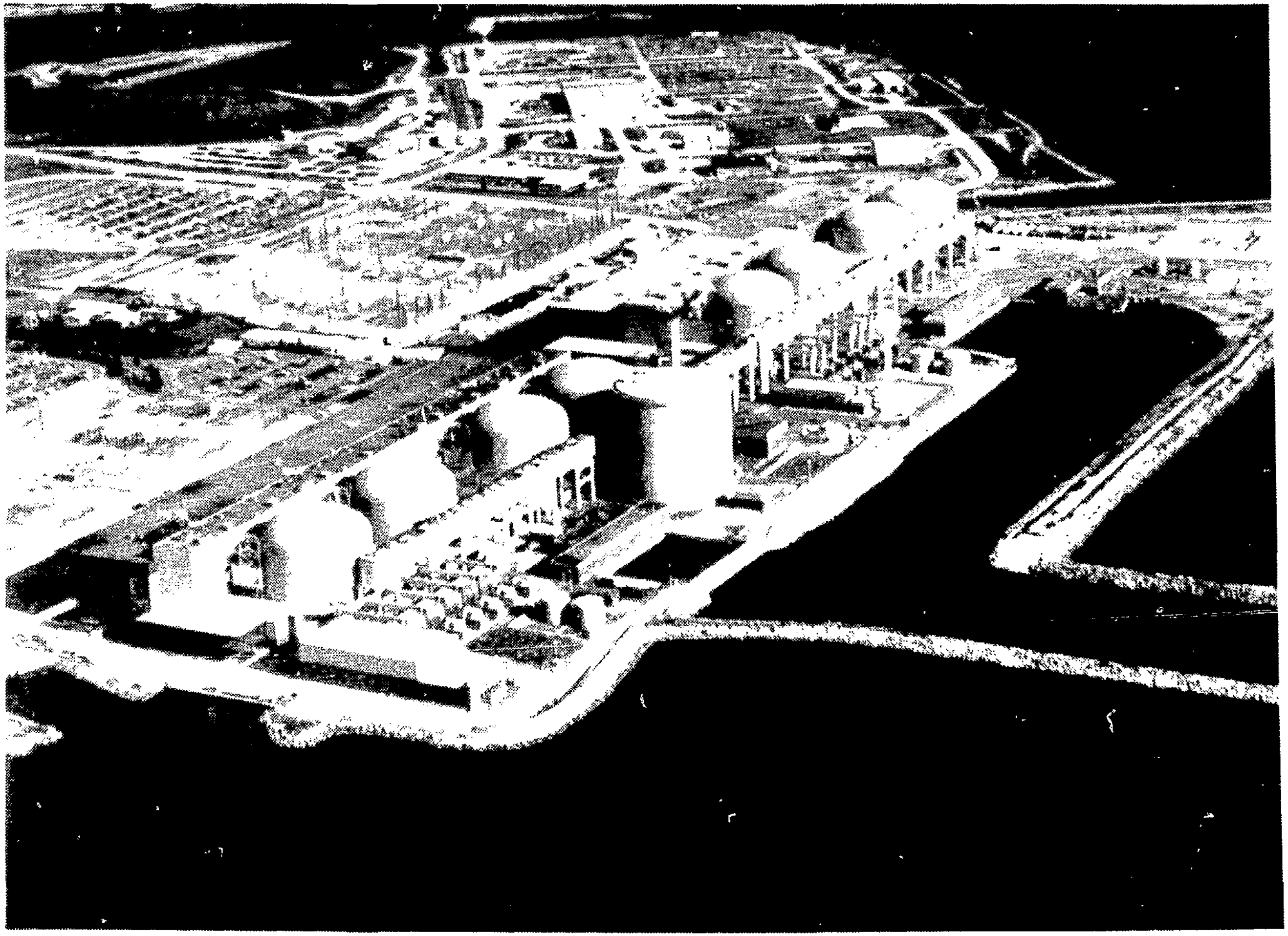

Figure 5 Pickering Nuclear Generating Station, from nearby Lake Ontario. Pickering A (units 1-4) is in the foreground, Pickering B (units 5-8) in the background. The large central circular structure is the vacuum building, with the pressure relief duct (on concrete supports) connecting it with the eight reactor containment structures.

Source: Atomic Energy of Canada Ltd.

Figure 6 Bruce Nuclear Power Development, from Lake Huron. Bruce B is in the foreground, with the vacuum building very prominent. The heavy-water extraction plant is directly beyond, with the Douglas Point reactor (now being decommissioned) on the left. Bruce A is visible in the far background.

Source: Atomic Energy of Canada Ltd.

actually crossing the site)*. Lake Ontario provides the cooling water (Figure 40, page 180).

59. All the reactors at Pickering, Bruce, and Darlington are of the CANDU type, as were NPD at Rolphton and Douglas Point at Bruce. In detail, however, there has been a considerable shift in design of these nuclear facilities as experience has been gained (see Appendix I). The reactors have also become larger.

I. The Framework of Regulation

60. Ontario Hydro operates its nuclear stations within a framework of regulation established by the Government of Canada. AECB sets the rules by which Ontario Hydro's practices are governed.

61. Regulation is an integral part of the management of safety. Accordingly, I have looked in some detail at AECB's relationship with Ontario Hydro. In arriving at conclusions, I have been guided by several bodies of material listed in Annex I. A synthesis of this material has been prepared by Margaret C. Grisdale, the Review Manager, and appears as Appendix VII.

62. The fact that a provincially established public corporation, Ontario Hydro, should find itself regulated by a federal board is a familiar situation in Canada, where complexities introduced by a federal constitution abound. Nuclear power was not foreseen by those who wrote the British North America Act. Nevertheless, the federal government has been able to establish its authority over all nuclear questions, authority that has not been seriously challenged by the provinces. In many ways, it is an advantage that the regulator serves the Queen in her federal Right, and the utility works for her in another--that of Ontario.

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* Riders on Via Rail trains will notice that their view of the station is hampered by high earthen banks. These are berms built to protect the station against possible accidents on the rail lines (and not the reverse).

63. AECB was established by section 3 (1) of the Atomic Energy Control Act, 1946, where the Preamble asserts that atomic energy is a national concern. The peace, order, and good government clause of the British North America Act (now the Constitution Act, 1867) authorises such a stance. Its validity has been upheld in the courts and appears not to be challenged.

64. In 1954, the Atomic Energy Control Act was amended so as to divorce AECB from responsibility for promoting the use of atomic energy. That responsibility thereafter rested on AECL. Since then, AECB has been simply the national regulating body, controlling "all aspects of nuclear facilities, substances and equipment, to assure that such facilities, substances and equipment are utilized with proper consideration of health, safety and security" (AECB 1987a).

65. AECB's control over nuclear generating stations depends on the approval and licensing processes, which are rigorously exercised; and the qualification of key operational staff at these facilities. These appear to be sufficient for its purposes and are certainly crucial in the preservation of safety. A body of AECB regulations, guidelines, and inspection procedures guides the conduct of business within the utility.

66. AECB regulatory authority affects every aspect of the siting, construction, commissioning, and operation of Ontario Hydro's reactors. The style of operation chosen by AECB derives from British rather than American practice. AECB differs strikingly from the US Nuclear Regulatory Commission (NRC). Several intervenors saw this as a weakness and urged a shift of AECB practice towards the US system. But Canada and the United States have very different political systems. AECB is a typical product of Canadian parliamentary democracy--one that borrows extensively from British administrative assumptions, yet has a distinctively Canadian flavour. It is far more European than American in its modus operandi.

67. AECB's practice has been to set safety performance requirements and then to leave it to the utility to design and operate the reactors. Not until AECB is satisfied that public and worker safety has been provided for will it license the

reactor for operation. This is in striking contrast to the US NRC, which prescribes many details that US utilities (currently 60) must include in their design, construction, commissioning, and operational procedures.

68. There is also an astonishing disparity in size between the US and Canadian regulating bodies--a point that was stressed by Ahearne in his review, submitted to the Review on behalf of Resources for the Future. AECB's reactor regulation branch has 4.5 employees per reactor, versus 18.5 in the US NRC. There is a federal proposal, moreover, that AECB's staff be reduced further.

69. The substance of this style of operation is that responsibility for safety is placed squarely on the shoulders of Ontario Hydro. As Grisdale remarks in her review (Appendix VII): "The question of safety begins at the time a nuclear generating station is contemplated, for it is at that time that the issue of risk and the level of tolerable risk must be confronted." The question of safety continues to loom large throughout the operation of this station, and even through its lengthy decommissioning period.

70. I received several criticisms of the system of regulation during the Review, mostly from persons who saw it as too lax, too secretive, and too cosy--i.e., as a comfortable system relying heavily on the camaraderie that unquestionably exists within the industry, and between the staff of AECB and Ontario Hydro. I do not find the system either lax or secretive, but it is certainly little-known. Only the technically competent can regulate an advanced technology, and this is achieved. I agree, however, that some further check is required: someone must watch the watchdogs. In my view, this is the duty of Parliament and the Provincial Legislature, whose Select Committees offer an adequate mechanism for ensuring that the final judgement is based on general human values, and not simply on technical evidence. I return to these questions at the end of the Report, chapter IX.

Chapter II

The CANDU Reactor System

A. Overall Characteristics

71. The CANDU reactor system* differs strikingly from the systems used in most other countries, chiefly in four ways:

(i) The fuel (uranium dioxide) is based on natural uranium,** which contains only 0.72% of fissile uranium-235. The UK gas-cooled MAGNOX reactors also use natural uranium, but in metallic form. Most other reactors use enriched uranium in which the proportion of uranium-235 in the oxide fuel is increased to 2-4% by uranium enrichment. CANDU pays a penalty (in terms of power derived per tonne of fuel) by having less fissile material in the fuel (although it yields more energy per tonne of uranium ore mined), but avoids the hazards and costs of the enrichment process.

(ii) After a start-up by external neutron sources, the fission is brought about by neutrons released by the fission itself, slowed down by heavy water*** as a moderator. The fission consumes most of the uranium-235, but also involves a small fraction of the uranium-238, after it has been converted (by neutron absorption) into fissile plutonium-239. Most US reactors are moderated by ordinary light water, which is feasible if enriched fuel is used. Graphite (crystalline carbon) is used in the UK gas-cooled reactors and in the RBMK reactors of the Soviet Union. Heavy water is also used in the CANDU primary heat transport system (for fuel cooling).

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* For more details, see Appendix I, by D.A. Meneley, and Robertson 1985.

** i.e., uranium having the isotopic composition found in natural ore-bodies, which is uniform world-wide (except at a curious ancient underground natural reactor, in Gabon, where natural forces happened to create fission-supporting conditions).

*** The oxide of heavy hydrogen, deuterium, in which one proton and one neutron form the stable nucleus of each atom. Heavy water is not radioactive, although it may transport radioactive substances in suspension.

(iii) The fuel itself is arranged in fuel channels containing pressure tubes, each connected to the primary heat transport system of the reactor. The fuel channels are in turn surrounded by the heavy-water moderator contained in a vessel called the calandria. This arrangement differs radically from the pressure vessels used in the pressurised water reactors (PWRs) and boiling water reactors (BWRs) of the United States. Pressure tubes are also used, however, in the Soviet RBMK reactors (of which Chernobyl's reactors are examples).

(iv) Remote-controlled refuelling at full power of these pressure tubes allows the reactors to operate for long periods without shut-down.

72. No other country operates reactors of this type in such numbers. Single CANDU units are in operation in South Korea, Argentina, and Pakistan, and there are multi-unit stations in India. A multi-reactor station is under development in Rumania. But the 20 present or future CANDU reactors of Ontario, plus one each in Quebec and New Brunswick, have created a body of experience and expertise unique to Canada. There is a large body of technology in which Canada can look only to her own engineers and scientists for expert advice.

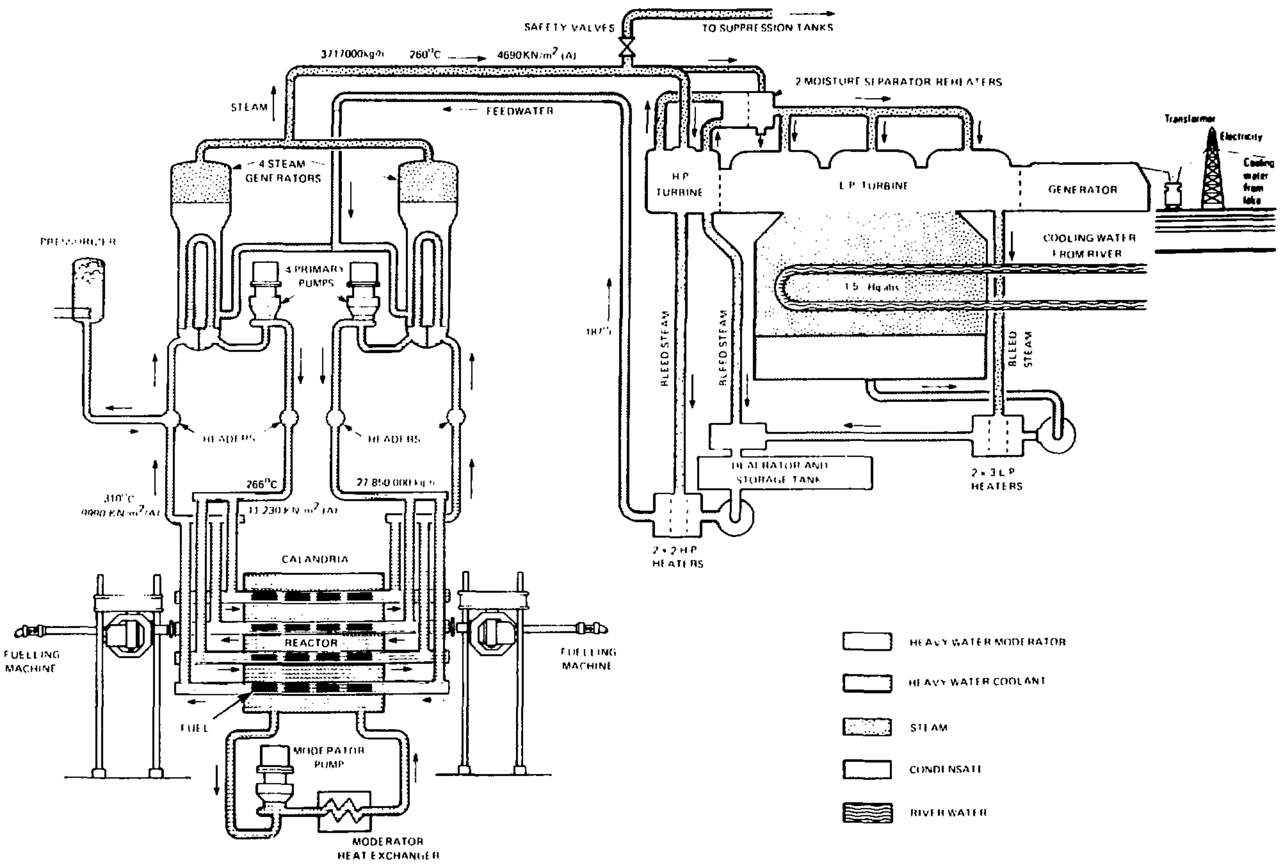
73. The reactor core is part of a larger system, all parts of which are essential to safe and economic operation. The essential components of the system (Figure 7) are these:

(i) the reactor core, within the calandria, in which the controlled fission process proceeds. The fission process releases immense quantities of heat, which is the desired product. If not removed, however, the heat becomes a hazard, by overheating the fuel. Most radiological hazard comes from the fission products produced in and contained by the fuel. This hazard is readily containable as long as the fuel bundles or elements remain intact.

(ii) the primary heat transport system, by means of which heavy water is circulated past the fissioning fuel to remove the heat, i.e., to cool the core. Any breach of the piping carrying the coolant--an event

Figure 7 Main features of the CANDU reactor system.

Source: Atomic Energy of Canada Ltd.



known as a loss of coolant accident (LOCA)--imperils the fuel, which may break up or melt.

(iii) the steam generators, where the hot heavy water of the heat transport system converts ordinary light water to steam.

(iv) the secondary heat transport system, carrying steam from the steam generators to the turbines of the generators and returning the necessary feedwater supply to the steam generators.

(v) the turbine generators, the station transformers, and switchyard, generating electricity and supplying it to the provincial grid.

(vi) the regulating and monitoring systems, whereby all the above components are kept within a desirable operating envelope.

(vii) the fuelling system, whereby fresh fuel is fed into the reactor and the irradiated fuel removed to storage.

(viii) special safety systems, which are designed to prevent the release of radioactivity from the plant as a result of any undesired excursions of the reactor from normal operating conditions (i.e., shut-down systems, emergency core cooling systems [ECCSs], and containment).

(ix) The safety support systems, such as the internal electric power supply system and cooling water and compressed air systems necessary to operate the plant.

74. Safe and economic operation of the reactor involves the proper control of all nine subsystems, in accordance with the defence-in-depth principle defined above in para. 54(ii). A large break in the primary heat transport system, for example, would quickly imperil the fuel in the pressure tubes. Failure of the electrical supply to the plant would endanger almost all aspects of its operation. A nuclear generating system must hence be controlled as a single, complex operation, in which all components are continually monitored and regulated. In this respect, a station resembles a major chemical complex or an oil refinery. Where it differs is that the consequences of failure are perceived as more serious by the general public.

75. There are two quite distinct topics to be considered. One, dealt with at once, is the reactor system as a set of hardware devices. The second is the use of that system in operations, which has to do with human factors.

B. Where do Safety Problems Arise?

76. The specific questions addressed (and answered in the indicated paragraphs) include the following:

(i) Does CANDU compare favourably or unfavourably with other widely used reactor systems, such as PWRs and BWRs, or the UK gas-cooled reactors?

See paras. 331-339, also Appendix I

(ii) Do the process and special safety systems of CANDU reactors perform reliably? Are the regulatory requirements being met?

See paras. 158-188, also Appendix II

(iii) What radiological dose does the normal operation of a CANDU reactor place upon the in-plant workers?

See paras. 223-232, also Annex III

(iv) Does the normal operation involve releases of radioactive materials (or other hazardous entities) to the environment? If so, which groups in the population are most exposed?

See paras. 233-241

(v) Are there improvements to the normal operating systems in CANDU stations that would enhance safety?

See paras. 124-148, also Appendix III.1 and III.2

(vi) Against what range of abnormal operating conditions are the stations designed to be effective?

See paras. 78-108, also Appendices I and II

(vii) Are serious accidents possible? If so, with what potential consequences?

See paras. 275-339, also Appendix II

(viii) What specific problems have already arisen in the operation of Ontario Hydro's stations?

See paras. 189-210, also Appendix II

(ix) What are the lessons to be learned from the Chernobyl and TMI accidents? Are they being acted upon?

See paras. 318-323, also Appendix VI

(x) Does Ontario Hydro learn from plant experience with much smaller break-downs or close calls?

See paras. 157-163

(xi) Are the staff at nuclear generating stations properly trained, especially as regards safety measures?

See paras. 142-148, also Appendix III.1

(xii) Does Ontario Hydro assign enough resources to nuclear generating stations to allow a sufficiently high level of maintenance?

See paras. 129-131, also Appendix III.1, III.2, and III.3

77. In addition, other questions have arisen concerning the role of AECB as the national regulating agency; the adequacy of international assessment of radiological impact; and the effectiveness of federal and provincial emergency planning.

C. On Reactivity, Criticality, and Regulation*

78. A nuclear reactor is a device whereby controlled fission of uranium-235 and plutonium-239 is achieved. Because these were the isotopes used in the first fission bombs (at Hiroshima and Nagasaki), which aimed at explosive, uncontrolled fission, it is natural that one should ask: how can control be safely achieved?

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* The word "regulation" is ambiguous. Here it refers to mechanical control, not legal regulation.

79. When fissionable material is exposed to a flux of neutrons, individual atomic nuclei divide ("fission" is used as a verb in this context), with release of much heat, two to three neutrons, and hazardous fission products (these being retained in the fuel). The neutrons travel at very high velocities. These fast neutrons are ineffective in producing further fission. If they are slowed down to thermal velocities, however, by contact with a moderator--heavy water in CANDU reactors--they become more effective and are referred to as thermal neutrons. Further fissions occur, each of which releases more neutrons. A chain reaction is thus very rapidly set up. Reactivity is the measure used in reactor physics to express the rate of increase of neutrons available to feed this chain reaction.

80. When from each fission exactly one neutron achieves another fission, the reactor is said to be critical.* Thereafter, the reactor is held in this state by means of its regulating system. The heat released by the fissions is enormous and has to be removed by the heat transport system, which in CANDU uses heavy water as the coolant. The CANDU reactors at full power generate from 1744 to 2832 MW of heat, dependent on plant rating. Very large coolant flows are required to transport this energy to the steam generators, on its way to generate electricity.

81. When a reactor reaches this critical state (criticality), it is in a condition demanding tight regulation. Normally, changes in reactivity are quite slow. But if criticality is much exceeded in the absence of regulation, effective cooling and fast shut-down are needed. Under accident conditions, a major loss of coolant and shut-down (a combination with a calculated probability of one in 10 million reactor-years) will bring about an exceedingly fast rise of power and fuel temperature. In the Pickering A reactors, for example, the reactor will become

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* Most neutrons are released almost instantly and are hence called "prompt." A very small fraction actually come from the fission products and are slightly delayed. Regulation of the reactor depends on these delayed neutrons. If the reactor is at criticality on prompt neutrons alone, it is said to be "prompt-critical." Above this level of reactivity (super-prompt-criticality) the regulating system can no longer control the chain reaction, other than to shut down the reactor.

super-prompt-critical in 2.2 s after a guillotine rupture of the coolant inlet header and a failure to shut down (Ontario Hydro 1987b). Within 4 s, it is likely that such a set of failures will lead to melting of fuel, with rupture of the fuel channels and the calandria vessel, thereby releasing radioactivity into the containment. It is hence vital that the reactor's control systems, heat transport system, and shut-down systems be continually effective and poised for action.

82. It is in this sense that CANDU reactors, like other water-cooled reactors, pose the threat of near-explosive accidents. Power excursions, to use the jargon of the nuclear engineer, were involved in the severe accidents at Chalk River (NRX) and Chernobyl. If such failures of control occur, the power may rise to tens or hundreds of times the normal level, and temperatures rise far above the melting point of the fuel--whose radioactive fission products may thus be released.

83. Yet such an accident in no way resembles what happened at Hiroshima and Nagasaki. Deliberately set nuclear explosions happen not in seconds, but in millionths of a second, because the chain reaction involves fast neutrons and proceeds unchecked. In the relatively slow fission process--actually fundamentally different from bomb processes--of a nuclear reactor, rupture of the calandria or pressure vessel means that the all-important moderator is lost, and the chain reaction thereby stopped. There will still be a great deal of heat to be disposed of, coming from decay of fission products, but the chain reaction in effect kills itself by discharging the moderator.

84. Obviously, however, a reactor power runaway remains a disturbing, even if remote, possibility. The events at Chernobyl illustrate vividly what may happen if control is lost. How is the layman to be assured that control will not be lost?

85. The answer lies in physical regulation of reactivity. Long-term reactivity control is provided by refuelling. Medium and short-term control is provided by the regulating systems, which exist in order to introduce or remove reactivity from the reactor core and to ensure optimum distribution of reactivity within

the core. The primary control devices are a series of interconnected compartments that can be filled with or emptied of ordinary water, a powerful absorber of slow-moving neutrons (see Figure 8). If this is insufficient, mechanically controlled neutron absorbers can be introduced to reduce reactivity. If the latter is too low, adjuster rods can be removed from the calandria to raise it. The combined actions of these mechanical devices make it possible to maintain an optimum distribution of reactivity throughout the calandria and to ensure that the power output (and rate of steam generation) is close to the demand from the electrical generators and power distribution systems.

86. All three components of the regulating system are under automatic control by digital computers. Redundancy is present in all cases; the sensors that detect the physical state of the reactor, the regulating devices themselves, and the control computers are duplicated or triplicated, so that a failure in one component is immediately covered by the entry of a replacement. This automation of regulation--further advanced in CANDU than in most of its competitors--is the outgrowth of a safety principle first enunciated by George Laurence, an early President of AECB (from 1961 to 1970): that nuclear operators should be given primarily an audit role, thereby freeing them from the repetitive control tasks that lead to boredom and complacency (see AECL submission, p. 15).

87. Given the characteristics of the CANDU reactor at criticality, such automation is in any case essential. But in CANDU's case, there is a further reason for prompt control: the reactors have a small positive void reactivity coefficient when operating at full power. If, for any reason, the heavy-water coolant of the heat transport system boils as it passes through the fuel channels, reactivity increases because of the growth of voids--steam bubbles--in the coolant.* Hence the power increase is accentuated by the positive feedback. The exceedingly rapid rise in temperature in the fuel following a loss of regulation and shut-down accident arises mainly from this void effect.

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* Some boiling does occur (by design) as the coolant passes through the fuel channels at Bruce A and B, and (in future) at Darlington.

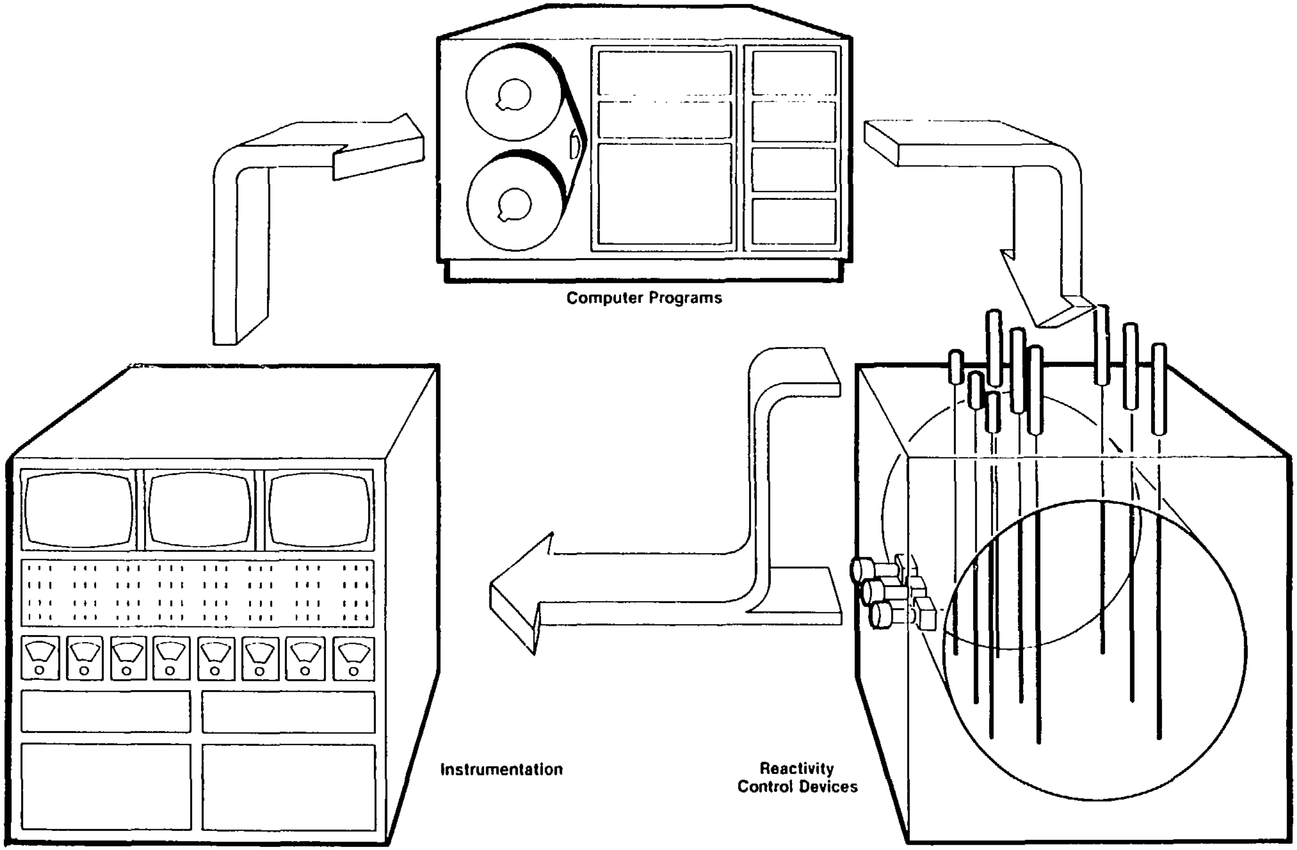

Figure 8 The regulating system of a CANDU reactor (much simplified). It consists of neutron-absorbing rods and compartments of light water (also neutron-absorbing) whose motion in and out of the calandria is controlled by computers into which monitoring devices provide a continuous record of reactivity and its changes.

Source: Atomic Energy of Canada Ltd.

88. George Laurence* also articulated two other principles, equally central in Canadian practice, requiring that there be two independent sets of systems controlling reactivity in CANDU reactors:

- process systems, which are the normal systems required to maintain production of the desired end-product, electricity; and
- safety systems,** which come into play if the regulating mechanisms are unable to hold the reactor within its envelope of safe operation.

Laurence's first principle is that process and safety systems must be independent of each other. His second principle is that safety systems must be independent of one another and must be continuously testable. If possible, they should also be diverse in nature.***

89. The Laurence principles were applied to the design and operation of the first demonstration CANDU, NPD, at Rolphton, Ontario, 40 km upstream from Chalk River on the Ottawa River. Their use has been standard practice in all subsequent CANDU reactor projects in all jurisdictions.

90. The regulating systems of a reactor are clearly process systems; the proper operation of the reactor, and hence its economic function, require them. They can also deal with a wide range of abnormal (upset), even accident, conditions.

91. If the normal range of operating conditions is transgressed, the regulating systems can and do reduce the power and may even shut the reactor down. The computer programs that govern the regulation include standing instructions to this effect. Moreover, the operators, if they see that safety is threatened, can intervene to shut down the reactor without recourse to the safety systems. This

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* I had arranged to visit Dr. Laurence in his home at Deep River, Ontario, on 14 November 1987 to discuss these questions with him. Sadly, he died a week before the visit.

** These are now usually called special safety systems, the term used below.

*** I have condensed the history of the evolution of Canadian safety principles and used up-to-date terminology in this chapter.

happened, for example, following the failure of pressure tube G-16 at Pickering A, Unit 2, on 1 August 1983. The operators shut the unit down in minutes and achieved cold, depressurised shut-down status in 1 h and 25 min after the first warning was received of the failure of the pressure tube. They used only the regulating systems to achieve this. Safety systems were not needed (Ontario Hydro submission, pp. 9-6 to 9-7).

92. The Laurence principles were based on experience gained at CRNL, operated by AECL. A failure in the NRX reactor in 1952, Canada's first and most serious nuclear accident, led to drastic rethinking of design and safety principles.

93. In the NRX accident, during a low-power experiment, a combination of mechanical failure and operating errors led to a power excursion from the normal 20-MW level to 80-90 MW. There was no containment and no independent fast shut-down system available. Extensive fuel damage occurred, and there was a considerable escape of radioactive material. Shut-down was achieved by dumping the moderator to stop the chain reaction (AECL submission, pp. 38-39).

94. To sum up, the CANDU regulating systems are designed to hold the reactor core at power levels consistent with demand, efficiency, and safe operation--essentially by automatic regulation of reactivity. If reactivity increases to unacceptable levels, the regulating systems are designed to shut down the reactor. The operator can, moreover, use the process systems to correct most abnormalities. If neither the automated regulating system nor the operator can achieve safe shut-down, the special safety systems take over.

D. Special Safety Systems

95. The special safety systems installed in CANDU reactors are described in detail by Meneley in Appendix I, pp. I61-I94. To paraphrase him in three short excerpts:

(i) Special safety systems are those that have no role in normal operation of the plant, but that are installed solely to control and mitigate the consequences of failures that may occur in the process systems during any phase of operation.

(ii) There is only one objective of any special safety system action: to keep the fission products that have accumulated in the fuel elements from escaping from the plant.

(iii) The underlying reality of any safety system design is that the most severe possible accident can occur at some probability; the objective of the design is to make this probability acceptably low. It can never be zero.

96. The special safety systems include:

- one or two fast shut-down systems (Pickering A has one, all others two)--these introduce negative reactivity into the reactor core, to shut down the chain reaction in well under 2 s (see Figure 9);
- ECCSs, whose function is to cool the fuel after a LOCA, i.e., to remove the decay heat from the fission products; and
- containment, which is a physical enclosure of the entire reactor system designed to contain almost all the fission products that may escape from damaged fuel.

97. Shut-down system 1 (SDS1) is a system of neutron-absorbing rods (28 in most reactors) that are poised above the calandria (in Pickering A there are only 11 rods in SDS1, but this has been increased to 21 in units 1 and 2 during the refitting of pressure tubes, 1984-87). The rods are held suspended by clutches that in turn are actuated by electric circuits connected with three sets of independent and technically diverse sensors monitoring critical parameters such as reactor power, heat transport pressure, and boiler water level. If any two of three sensors monitoring a parameter indicate that conditions are outside the acceptable operating envelope, the clutches are de-energised and release the rods, which fall into the reactor core--accelerated by powerful springs. It

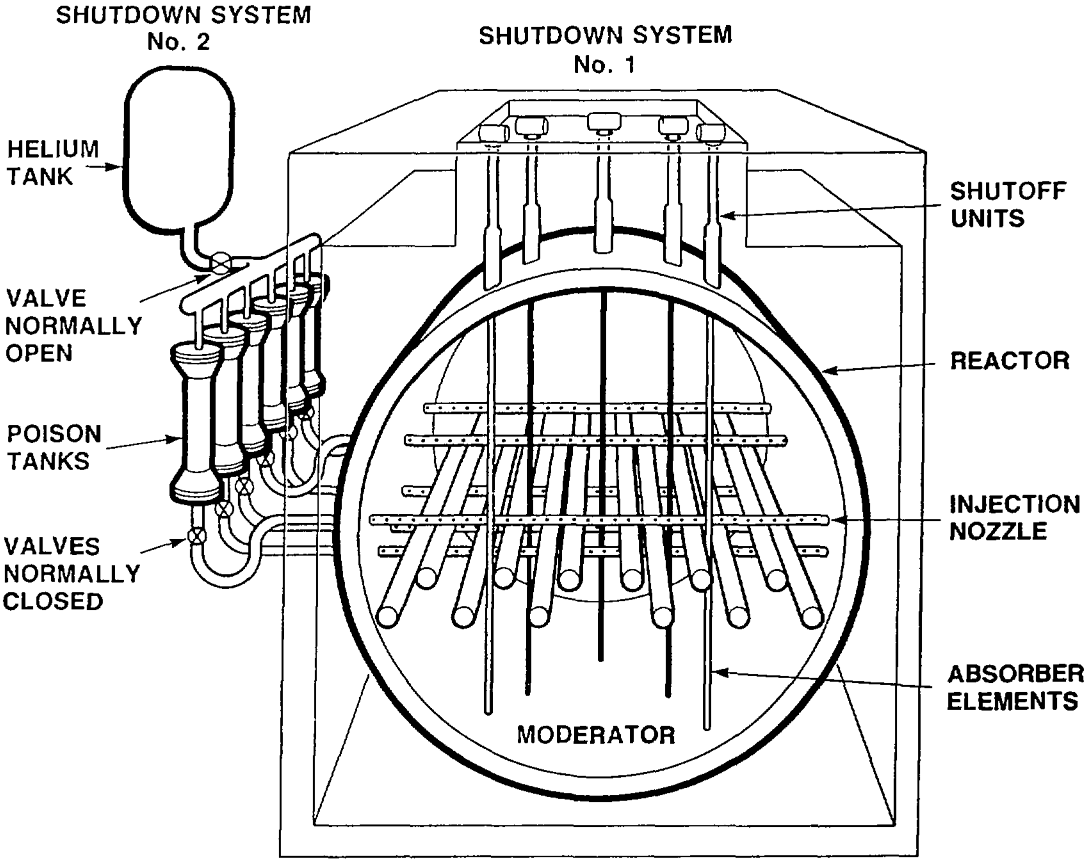

Figure 9 The shut-down systems of a CANDU reactor. SDS1 is a system of neutron-absorbing rods (shut-off units). SDS2 is made up of tanks of gadolinium nitrate, a neutron-absorbing liquid. Both can be automatically inserted into the reactor in 2 seconds or less, to stop the chain reaction.

Source: Atomic Energy of Canada Ltd.

takes only 1 s to achieve full insertion. Even a partial insertion--either of the entire set, or of only some of the rods--achieves shut-down.

98. Shut-down system 2 (SDS2) consists of a series of horizontal tubes equipped with nozzles permanently mounted within the calandria, through which a strongly neutron-absorbing solution of gadolinium nitrate can be injected into the moderator. The gadolinium nitrate is stored in tanks directly connected to the injector pipes, with no closed valve in between. It is propelled into the moderator by high-pressure helium, which is normally separated from the nitrate by an array of valves. The latter open automatically if two out of three diverse and independent sensors monitoring a number of key reactor parameters indicate conditions outside the normal operating envelope. SDS2 is fully inserted into the reactor 2 s after the initial signal and achieves shut-down well before that.

99. The two shut-down systems are quite different and are tested for performance at regular intervals. Both have achieved high reliability in recent years, failure rates having fallen to near one in 10 000 tries. Nevertheless, their performance was criticised by certain intervenors, as was the absence of SDS2 at Pickering A (where a second shut-down mechanism consisting of a slower-acting moderator dump can, in principle, cope with most accident conditions).

100. The ECCS has as its function the absorption and removal of decay heat from the fission products, after shut-down following a LOCA. In CANDU reactors, part of this cooling is initially achieved by the heavy-water moderator, which surrounds the pressure tubes and has a high capacity to absorb heat (because it is ordinarily quite cool, about 70°C). All CANDU reactors are equipped with an emergency coolant injection system (ECIS), as part of the ECCS, which, when actuated, floods the heat transport system with cold light water (see Figure 10). Two-out-of-three logic, as in the shut-down systems, tells the system when to fire. There are considerable differences between ECIS installations in the different stations. Currently, a high-pressure pumped system is being backfitted at Pickering A.

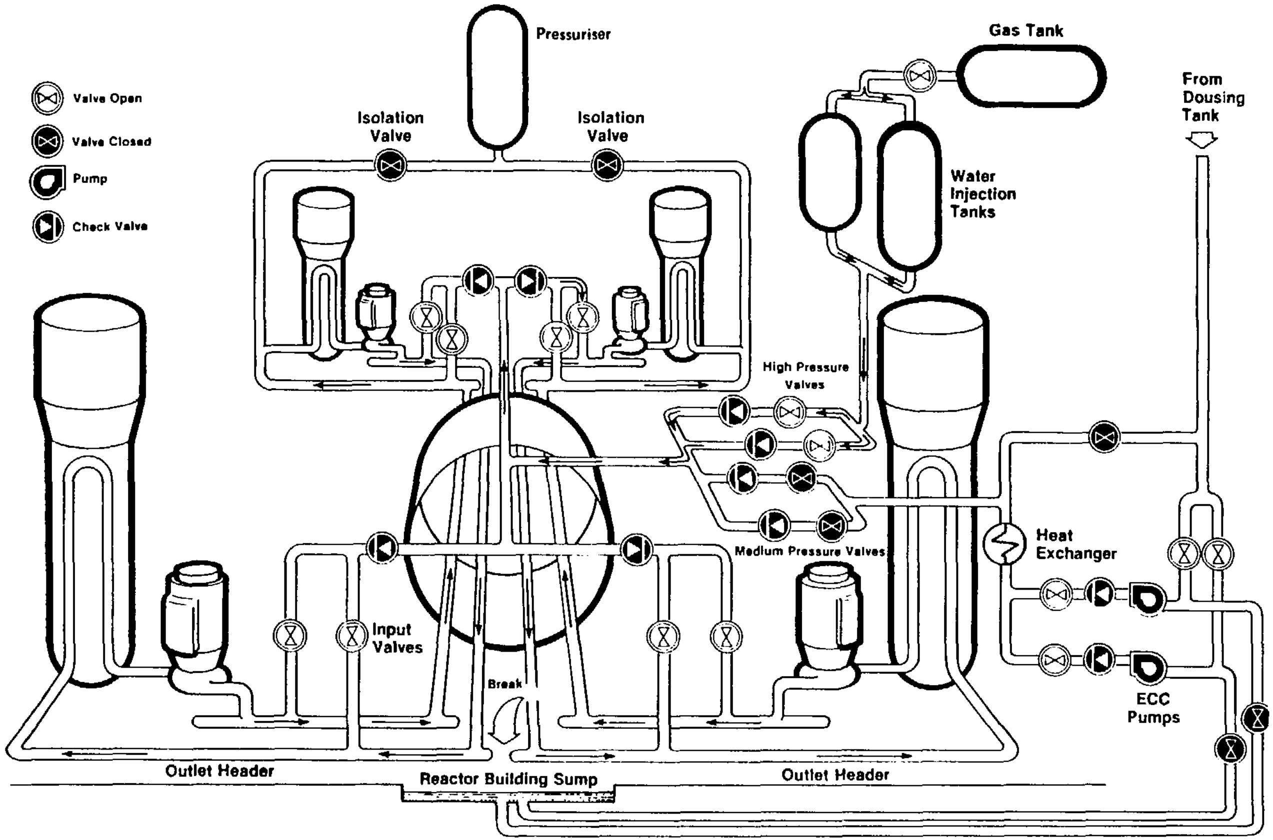

Figure 10 AECL's high-pressure emergency core cooling systems. Similar emergency coolant injection systems are now installed (or being installed) in all Ontario Hydro reactors. These systems flood the fuel channels with cold light water in the event of a loss of coolant accident. Their purpose is to remove decay heat from the radioactive fuel elements.

Source: Atomic Energy of Canada Ltd.

101. Containment is the final system preventing escape of radioactive materials to the environment. In effect, this means that the entire reactor system, and more especially its high-pressure fluid systems, should be encased in physical structures that either are permanently sealed or else can seal themselves automatically when sensor systems detect rising pressure. CANDU structures are largely (but not entirely) reinforced concrete of strength sufficient to contain all anticipated pressure overloads (see Figure 12 for a sketch of the Pickering B containment). In addition to the concrete shell around the reactor and supporting systems, CANDU containments for Ontario Hydro include a large vacuum building, which provides pressure suppression following a LOCA. All parts of the containment system normally operate below atmospheric pressure, to avoid the uncontrolled release of gases (see Figure 11). Following a LOCA, dousing systems in the vacuum building recondense steam, and any hydrogen accumulation is deliberately ignited to prevent explosive concentrations. In the longer term, excess gases are vented to the atmosphere at favourable times, all except the noble gases, which are removed by filters.

E. Other Subsystems

102. Of the remaining subsystems listed in para. 73, less need be said here--although they are all essential to the safe and efficient use of the reactor.

103. The primary heat transport system, as shown above, serves to remove heat from the fuel to the steam generators. It must remain intact. Any LOCA is an immediate threat to the security of the reactor. The heat transport system pressure boundary, including the pressure tubes, must be of the highest quality. Assurance that this boundary will not be breached is a major objective of reactor design. Much of the treatment of accident analysis given later (Chapter VI and Appendix II) has to do with hypothetical breaks in this boundary.

104. The refuelling subsystems are among the most impressive of the CANDU technology. The machines responsible, designed by AECL or Canadian General Electric, depending on the reactor, perform the tasks of refuelling and removal

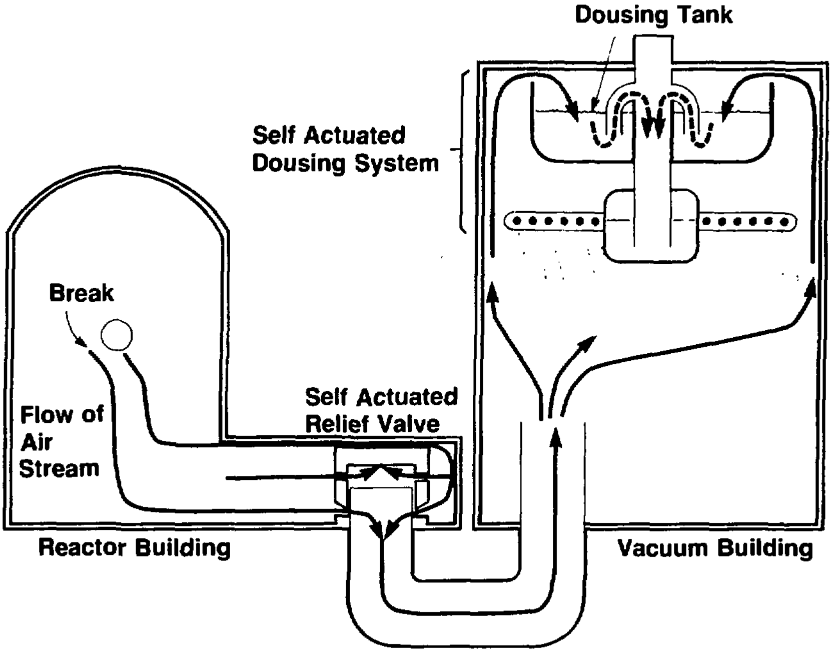

Figure 11 The negative pressure principle in CANDU containment systems. The entire reactor system is kept below normal atmospheric pressure, and the vacuum building is largely exhausted of air. Under accident conditions, excess gases--largely steam--pass from the reactor building via self-actuated relief valves and the pressure relief ducts to the vacuum building, where the self-actuated dousing system cools and condenses the steam and restores pressure to its subatmospheric value.

Source: Ontario Hydro

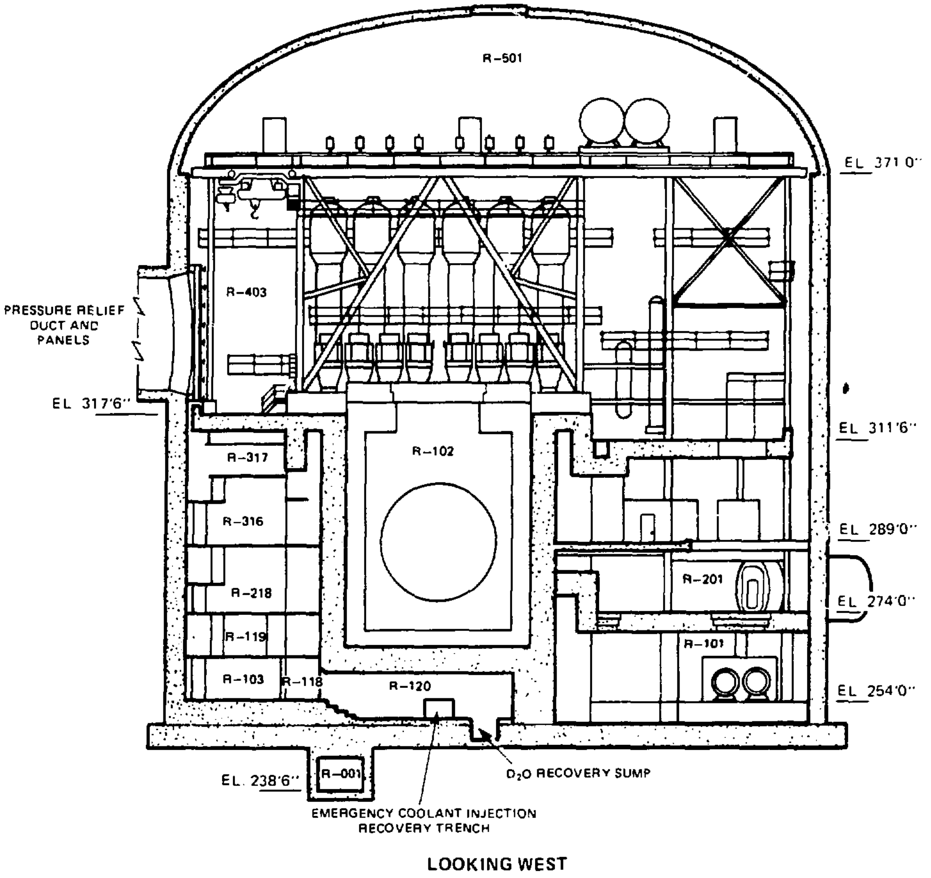

Figure 12 The Pickering B concrete containment dome design enclosing each reactor. The circular object is the calandria.

Source: Ontario Hydro

to storage of spent fuel entirely by remote control (because an intense gamma radiation field precludes human intervention). Each operation involves opening a reactor channel, thereby breaching the pressure boundary of the heat transport system, and resealing it again after the exchange of fuel bundles. There have been malfunctions in this complex operation, but in general it works well enough to allow the CANDU reactors to operate at full power for long periods.

105. The steam generator, secondary heat transport system, turbines, and electrical generators are less sensitive, in that they do not transport or use radioactive water. But they, too, are essential as heat sinks for the reactor; there can be no break in the flow of energy from reactor core to transmission line, because significant energy storage is impracticable. If a defect occurs anywhere in the subsystems that is serious enough to impede the energy flow, or if demand decreases suddenly, the reactor regulating systems must at once reduce power and adjust all other subsystems accordingly. The fundamental principle, as stated above, is that the entire system must be controlled as a single mechanism.

106. It follows that regulation (or, in the same sense, control) is absolutely central to the entire enterprise. This implies three things:

(i) There must be continuous monitoring of the physical state of all parts of the system, together with a list of key control parameters that the monitoring will address.

(ii) There must be a diverse, sophisticated, and multiple system of communication within the nuclear plant, capable even under accident conditions of carrying the monitoring signals to the control computers, as well as instructions from those computers to all the regulating and control devices.

(iii) The control computers themselves must feed information into a central control room, the brain of the station. The control room, in ordinary conditions, is the place where the operating staff can watch the computer codes carry on the entire complex operation, with little need for intervention. When things go wrong, it is equally the place where the operators must carry out the sequence of remedial measures prescribed in the manuals, or--in highly unusual circumstances--improvise wise and effective remedies for the unforeseen event. With this in mind, CANDU designers have included emergency control locations in nuclear generating station layouts.

107. The wiring diagram of a nuclear generating station is accordingly one of the most complex in all of heavy industry. This places heavy watchdog responsibilities upon the station operating staffs, especially in maintenance (to which I shall return in Chapter III). It also creates a curious paradox. Computer technology advances so rapidly, as does electronics, that the control functions of all large installations are out of date within a few years of construction. At Pickering A, for example, the control computer equipment reflects what is now a bygone age, and an upgrading has to be a high priority, not because performance is degrading, but because spare parts are getting harder to find. Hence, maintenance costs are rising. Electrical relays, still extensively used in switching, will soon be museum items. Yet there is a natural reluctance to replace proven systems of control.

108. The elaborate but massive structures just reviewed may be secured against their own weaknesses, but conceivably not against those due to external shocks--the so-called common-mode events. These include explosions, break-up of turbine blades (which may act like missiles), fires, tornadoes, plane crashes, floods, and earthquakes. All these have to be allowed for in the design process. An intervenor, R.H. Ferahian, drew our attention in his brief to the fact that Pickering A, unlike its successors, was earthquake-proofed only in terms required by the Canadian building code. Subsequent stations have been built to higher standards, almost certainly enough for the quite frequent but small quakes common in south-west Ontario. The most obvious potential victim of a beyond-design-basis earthquake in a CANDU station might well be the electrical circuitry associated with the regulatory and special safety systems. I regard this as a very low but not zero hazard.

Chapter III

CANDU Operations: the Human Element

A. Method of Analysis

109. The operational use of the CANDU reactors involves human skills, labour, and wisdom. It may also offer an opportunity for human failings, as well as for purely technical failures. In this section, I attempt to answer the question: are there improvements to the normal operating system in CANDU stations that would enhance safety?

110. Human failures have underlain several recorded reactor accidents. The operating system turned out in those cases to be imperfectly proofed against human weaknesses, carelessness, and folly. To quote John G. Kemeny (1979), in his overview of the Presidential Commission's report on the TMI accident:

> The fundamental problems are people-related . . . and not equipment problems . . . . wherever we looked, we found problems with the human beings who operate the plant, with the management that runs the key organization, and with the agency that is charged with assuring the safety of nuclear power plants.

Could similar charges be levelled against the operators of Ontario's CANDU plants?

111. To answer this question, I asked Ontario Hydro to describe the operating system in detail. They responded in their submissions with a detailed account that focussed more on specific safety measures than on the routines of normal management. Accordingly, I accepted or set in motion two specific inquiries. The first was a prior initiative of the Ontario Minister of Energy, who had proposed that the federal EMR Minister request an Operational Safety Review Team (OSART) study by the International Atomic Energy Agency (IAEA).

112. IAEA will conduct such reviews at the request of member countries, of which Canada is one. Normally the review is addressed towards the needs of a

specific utility for advice and constructive criticism. In the present case, the needs of the Review prompted the request, but the utility has already profited from the exercise. By agreement between the parties, Pickering NGS was the subject of the OSART review, whose report is reproduced here as Appendix III.2 (IAEA 1987). (Ontario Hydro's response is in Appendix III.3.)

113. An OSART review is a technical analysis from within the industry. All 12 members of the Pickering review teams were nuclear engineers or scientists with a total of 200 yr of operating experience in their own countries (which included the United Kingdom, the United States, West Germany, Japan, Italy, France, and Argentina). Ferdinand L. Franzen, of the Division of Nuclear Safety, IAEA, led the team, which visited Pickering on 1-19 June 1987. Their report was made available to me in late August 1987.

114. For the second inquiry, I asked W.J. Keough, formerly Vice-President for Refining of Esso Resources Canada, to lead a team of consultants who would compare the CANDU operating system with that of other industries, to get a critical overview from an external industrial perspective. Keough's report forms Appendix III.1. In addition, I had access to a report on the Bruce A reactors prepared by a team from the Institute of Nuclear Power Operations (INPO), a utility-sponsored group based in Atlanta, Georgia. I also received a considerable body of comment on the operating system from intervenors (see Annex I).

115. Given that the Chernobyl accident had much to do with the establishment of this Review, it is worth insisting that Kemeny's (1979) comment on TMI applies with still greater force to the Chernobyl disaster. Here again operational errors--which means more than operator errors--were largely to blame, although the design of the reactor was of an unforgiving sort.

116. A well-known nuclear advocate, J.A.L. Robertson, wrote to me that he was appalled by the number of operator errors at Chernobyl and the difficulty of explaining them to the public. Under such circumstances, Robertson felt that it would be helpful to use more familiar analogies, where apt:

> Let us suppose that a certain airline took into service a new design of jumbo jet on the assurance that it could, if necessary, land on automatic pilot. This was not, however, tested in commissioning. During a scheduled flight, with a full load of passengers and highly flammable fuel, the flight crew decided unilaterally to conduct this test, which inevitably had to be performed when the aircraft was in a highly unstable condition just on the point of stalling. To permit the test, the crew disabled the manual controls, disconnected a safety system and switched off some alarms. In doing all this somebody overlooked an altimeter adjustment.

If this had really happened, the wonder would not be that 31 people died but that anyone survived.

117. This review has encountered nothing so bizarre in the operations of the CANDU reactors. Quite the reverse, in fact: the evidence is that the operating system in Ontario Hydro stations has encouraged not only adherence to accepted procedures, but also alertness and competence in the face of the unexpected.

B. Organisation

118. Figure 13 shows the organisational diagram of a CANDU station. Each of the operational nuclear generating stations has a Station Manager, who reports to the Director of the Nuclear Generation Division (NGD), which is the chief centre of managerial activity at the corporate level. The Station Manager in turn has an internal management structure, differing slightly from plant to plant. In principle, therefore, a simple authority tree extends from the President of Ontario Hydro to the operating staff of each nuclear generating station--with the Station Manager the central figure. By analogy, the Station Manager resembles the captain of a ship at sea--responsible for the safe passage of the vessel, endowed with considerable authority, but subject to the ultimate authority of a head office (which knows much less about his ship than he does).

119. In reality, the situation is more complex. The first complexity is that certain functions necessary to the conduct of business at each station are managed centrally, and hence have independent reporting routes. A good

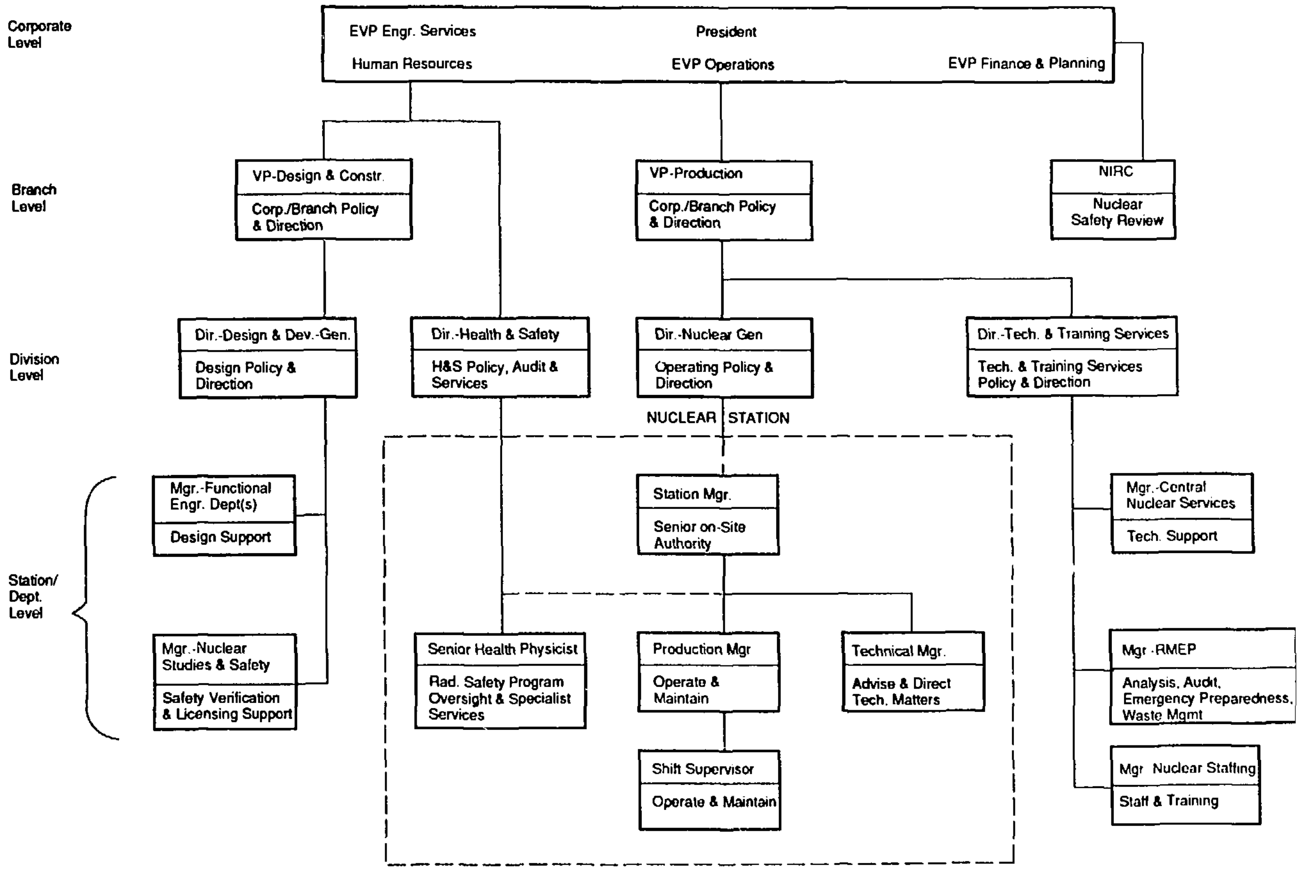

Figure 13 The organisational links of a nuclear generating station with corporate headquarters of Ontario Hydro. The diagram actually underestimates the complexity of working relationships.

Source: Ontario Hydro

example is Radioactivity Management and Environmental Protection (RMEP), whose corporate manager reports to the Director of Technical and Training Services. Another is that the health physicists at each station are responsible to the Director of Health and Safety, who is in a different part of the corporate structure. Yet another is that all engineering functions in Ontario Hydro are controlled by the Vice-President, Design and Construction, who reports to a different Executive Vice-President from the Vice-President, Production.

120. The second point is that Ontario Hydro and its nuclear generating stations are honeycombed with committees, boards, and less formal arrangements that deal with questions that do not fit the formal structure.

121. The most noteworthy is the Nuclear Integrity Review Committee (NIRC), chaired by the Vice-President, Design and Construction, and including: the Director of Nuclear Generation; the Director of Design and Development, Generators; the Director of Health and Safety; the Project Manager, Darlington; the Director of Technical and Training Services; the Group Manager, Nuclear; and a representative of AECL. This committee is charged, inter alia, with monitoring the Significant Event Reports (SERs) coming from the stations, and with reporting annually to the Ontario Legislature (see paras. 157-163).* At the other end of the seniority scale are the station-based union-management committees that watch over radiological questions on the job.

122. With some exceptions, the officials to whom I spoke expressed themselves satisfied with these arrangements, which seem to work well.

123. AECB resident engineers are present at each nuclear generating station and perform inspection, audit, and advisory functions within the established regulatory framework. They are not, strictly speaking, members of the station team. Significantly enough, I was not introduced to them in most of my own visits to the stations. I heard them described as policemen at a football game!

* NIRC needs to be more widely advertised. At the Workshop, speakers for the union movement, including a Unit First Operator, denied all knowledge of it.

In my view, they play another role: that of continuing day-to-day audit of safety performance and the provision of good advice.

C. Operating Systems at the Nuclear Generating Stations

124. The NGD of Ontario Hydro is responsible for ensuring that all the nuclear generating stations are operated efficiently and safely, within the requirements of the licence to operate granted by AECB. The operating system varies only slightly between stations (Ontario Hydro submission, pp. 5.1-5.11).

125. The functions to be managed are of four sorts: operation, maintenance, modifications, and surveillance. In more detail, NGD sees its responsibilities as falling within seven management elements:

- a defined operating envelope,* which requires that all work be performed according to rules set out in a formal document, Operating Policies and Principles, approved by AECB;
- the defined responsibilities and limits of authority for all staff involved in operations;
- the performance of all work by qualified staff and according to approved procedures;
- the use of only approved equipment and materials;
- the documentation of work activities;
- the surveillance of work and equipment, with corrections made as needed; and
- assurance that emergency preparedness is in place.

126. The Operating Policies and Principles define the work pattern in a sufficiently specific fashion. Special provision is made within them for a wide set

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* This usage derives from the word's mathematical meaning. An envelope curve is a line surrounding a family of points on a graph with two or more dimensions. The operating envelope is thus a surface surrounding (in a multi-dimensional sense) the acceptable states of the reactor or of operations. Any state outside this surface is unacceptable.

of contingencies. Changes in procedures or equipment require approval at specified levels of authority; for cases in which the assessment of public safety is involved, AECB approval is also required. Deviations from approved procedures are covered by an Abnormal Incident Manual, which tells the operator how to restore normal conditions--and also when it is permissible to act on personal initiative.

127. In Ontario Hydro (and generally in other utilities), the word "surveillance" covers the entire spectrum of inspection and technical audit functions made necessary by the need for constant vigilance and specified in the licence to operate. It includes, for example, the testing of safety systems on a systematic basis, to ensure that their performance exceeds the established targets. Other systems are also tested on a defined schedule. Station documentation is inspected and, where necessary, updated. A formal quality assurance (QA) programme ensures conformance to standards. Overall station performance is in turn reviewed by corporate senior management. Surveillance thus covers a multitude of checks on the safety and effectiveness of the entire system.

128. Overall, I gained the impression of an exceptionally well disciplined system at each of the stations I visited. Those I spoke to supported both its necessity and its acceptability.

129. Both the OSART team (Appendix III.2) and Keough (Appendix III.1) commented, however, on two aspects of station maintenance:

(i) There was a backlog of maintenance items at both Bruce and Pickering. It appears that other items were given higher priority.
(ii) Responsibility for maintenance was in several hands, without clear-cut centralised responsibility.

130. It is tempting to recommend that maintenance be recognised as a separate, self-standing function, with a single engineer responsible for co-ordinating all such activities (see Appendix III.1 and III.3). Given the complexities introduced by the presence of strong radiation fields and the need to perform certain

operations by remote control, this suggestion may be impracticable. It is, however, vital that enough financial and human resources--and priority decisions--be assigned to the maintenance function that no backlog develops. This is crucial to plant, worker, and ultimately public safety.

131. Modifications of existing equipment involve similar complexities. Pickering A units 1 and 2, for example, have just undergone extensive backfitting, inspection, and repair of equipment within the radiological zone where hands-on methods are hampered by the strong gamma field present. Large-scale activities of this sort are different in kind from modifications to single devices, especially where the latter lie outside the strong radiation fields. My judgement, based on limited exposure to this work at Pickering A, is that modifications are carried out as expeditiously and effectively as possible (to minimise radiation exposure).

D. Operating Staff and Station Support Groups

132. The key official of Ontario Hydro at each nuclear generating station is the Station Manager. He is appointed with the authorisation of AECB. He is responsible to NGD for the safe and efficient operation of the station. In addition, he is responsible directly to AECB, which must be made aware of any modifications to equipment or procedures, especially malfunctions, where public safety is involved. The operating licence makes the Station Manager responsible for safety and safety-related questions and specifies his authority and responsibilities. The latter in effect require him to maintain a high quality of plant operational and commissioning safety. As must be the case, all the station managers are highly experienced nuclear engineers.

133. The actual operation of the reactors, under the Station Manager's authority, is carried out by the staff specified in Figure 14.

134. The Shift Supervisor is normally a graduate engineer or scientist with long experience in the nuclear power industry. He requires AECB authorisation and has completed extensive technical training in order to achieve it. His authority

OPERATING STAFF STRUCTURE

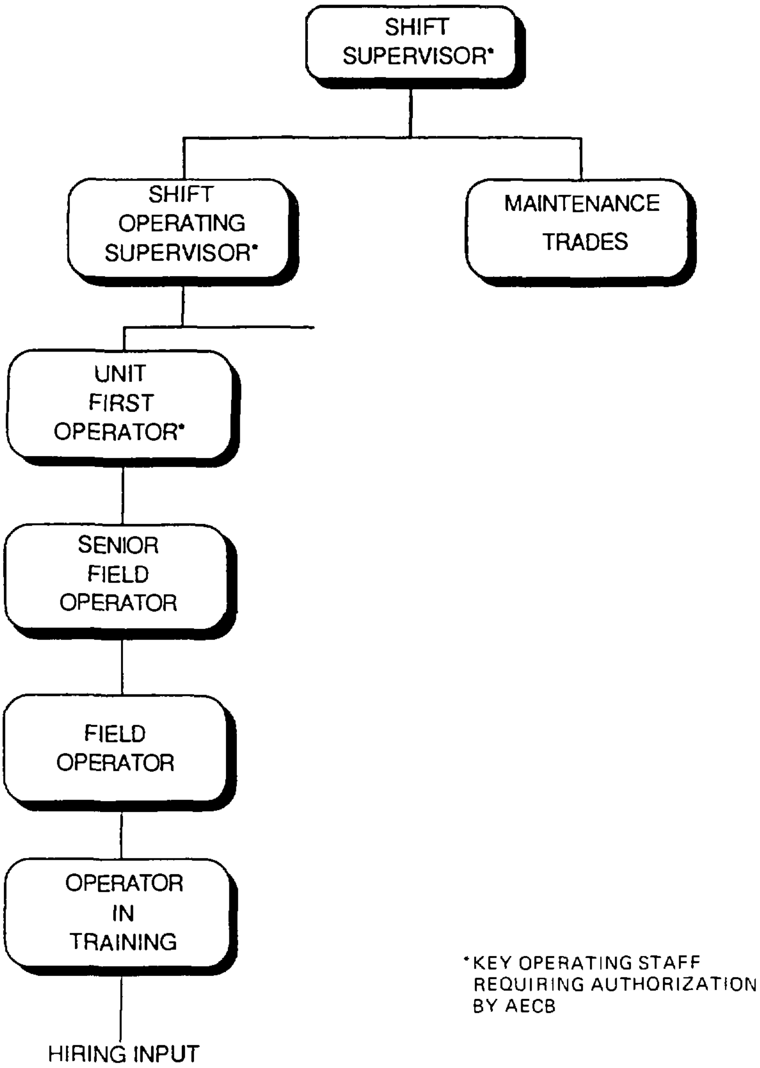

Figure 14 The levels of operating staff within a nuclear generating station.

Source: Ontario Hydro

is defined by the Operating Policies and Principles. He uses it to ensure that work proceeds on his shift in accordance with approved procedures, specifically as regards controlling of power, cooling of fuel, and containment of radioactivity. He also has important responsibilities in the event of any emergency (see Appendix VI).

135. Shift supervisors are normally drawn from the relatively youthful, technically most competent, and upwardly mobile segment of Ontario Hydro's labour force. This has had one unfortunate result: that shift supervisors often stay in their posts far too short a period. Continuity of experience therefore suffers.

136. The Shift Operating Supervisor, also an AECB-authorised position, has the task of supervising the operator work group. Normally this consists of six operators. He/she is in general drawn from the ranks of unit first operators and has passed AECB examinations.

137. The Unit First Operator is the senior shift operator in the station control room. Operating Policies and Principles place a highly significant set of duties on his/her shoulders. In Ontario Hydro practice, he/she will generally have some technical or scientific training after Grade 13 and will have completed a prolonged period of in-house training, with Ontario Hydro and AECB examinations at several stages. The position is unionised (by Canadian Union of Public Employees [CUPE] Local 1000, which briefed us on the responsibilities concerned). He/she requires AECB authorisation.

138. For some time, there was a shortage of authorised unit first operators. Only about 2% of Ontario Hydro nuclear trainees have stayed the course long enough to qualify. As a union officer lugubriously pointed out to us, it takes as long to become a Unit First Operator as it does to qualify as an MD. Although the pay is good, the duties are exacting. I was assured that the shortage had recently been alleviated. In any case, this is a position that is essential to the safe functioning of the reactors. It is vital that it be filled by men or women fully qualified for the job and satisfied with working conditions.

139. As is almost universally the case in western industrial societies, a line is drawn through this column of jobs between those performed by workers and those performed by management--the line between unionised and non-unionised establishment levels. In an Ontario nuclear generating station, this division is not aggressively visible, but it is still present. It lies immediately below the shift supervisors, who are non-unionised professionals. Unit first operators are union members. I heard some dissatisfaction with the career opportunity block that this presents. This division cannot be said to help safety management. For example, actions taken by Ontario Hydro and AECB in response to a strike threat at Bruce in May 1985 soured union-management attitudes. AECB's willingness to permit management staff to operate the reactors while a strike was in progress was much resented by the union.

140. The controlling positions listed above are supported by a team of second operators and assistant operators. I was impressed at all the CANDU stations by the clean, uncluttered, and, above all, thinly populated control rooms. But a large support staff is required behind the scenes. Each station has an effective maintenance group and a technical support group capable of providing the necessary expertise to the production staff. In addition, the corporate head office provides extensive support. The nuclear generating stations are hence large employers, as the size of their parking lots testifies.

141. In spite of the obvious virtues of this operating system, I was concerned by several things reported by the consultants: the maintenance backlog, a conventional safety record that falls short of the highest standards (see Chapter VIII), the expressed view of operators that safety suggestions do not receive adequate attention from management, and the lack of some types of self-audit. I concluded (and have recommended) that an external review of the human factors involved (well beyond the Review's analysis), and the organisational structure, would contribute to higher operational safety standards.

E. Training of Nuclear Staff

142. Given the importance of technical training in reactor operations, it is natural that Ontario Hydro should have felt that such training was properly an internal corporate responsibility. This is particularly true because of the exacting requirements imposed by AECB. The Canadian system of regulation places full responsibility for safety on the utility. For this reason alone, Ontario Hydro sees technical training as a vital internal function. As Keough says in Appendix III.1, "a well-trained crew can contain and control a problem situation, a poorly trained crew has the potential to turn a small problem into a calamity."

143. Overall responsibility for this ambitious programme lies with the corporate Nuclear Staffing Group, which plans requirements, hires staff, trains the newcomers, and places them in their first jobs. It operates a Central Nuclear Training Department at corporate headquarters, concerned with staff planning and hiring, as well as some training. The major teaching facilities are at the Western and Eastern Nuclear Training Centres, at Bruce and Pickering, respectively. These are attractive technical colleges, superbly equipped at a variety of levels. Four categories of training are provided, with programmes designed for management and professional staff (about 50 per year); nuclear operators (about 30 per year); mechanical maintainers (about 25 per year); and control technicians (about 36 per year).

144. The Ontario Hydro submission (section 6) gives a detailed outline of the programmes provided for the trainees. It is obviously thorough and involves formal lectures, demonstrations, and on-the-job training. To give some feeling for the scope and timing of the work, Figure 15 summarises the 3-yr Unit First Operator training programme.

145. All candidates for the positions authorised by AECB must pass, in addition to Ontario Hydro's internal examinations, a set of tests administered by AECB itself. Although not unique to Canada, this double jeopardy imposes a heavy strain on all trainees. In the past, the AECB failure rate was high, and there was some feeling in Ontario Hydro that the AECB's requirements were

UNIT FIRST OPERATOR TRAINING PROGRAM

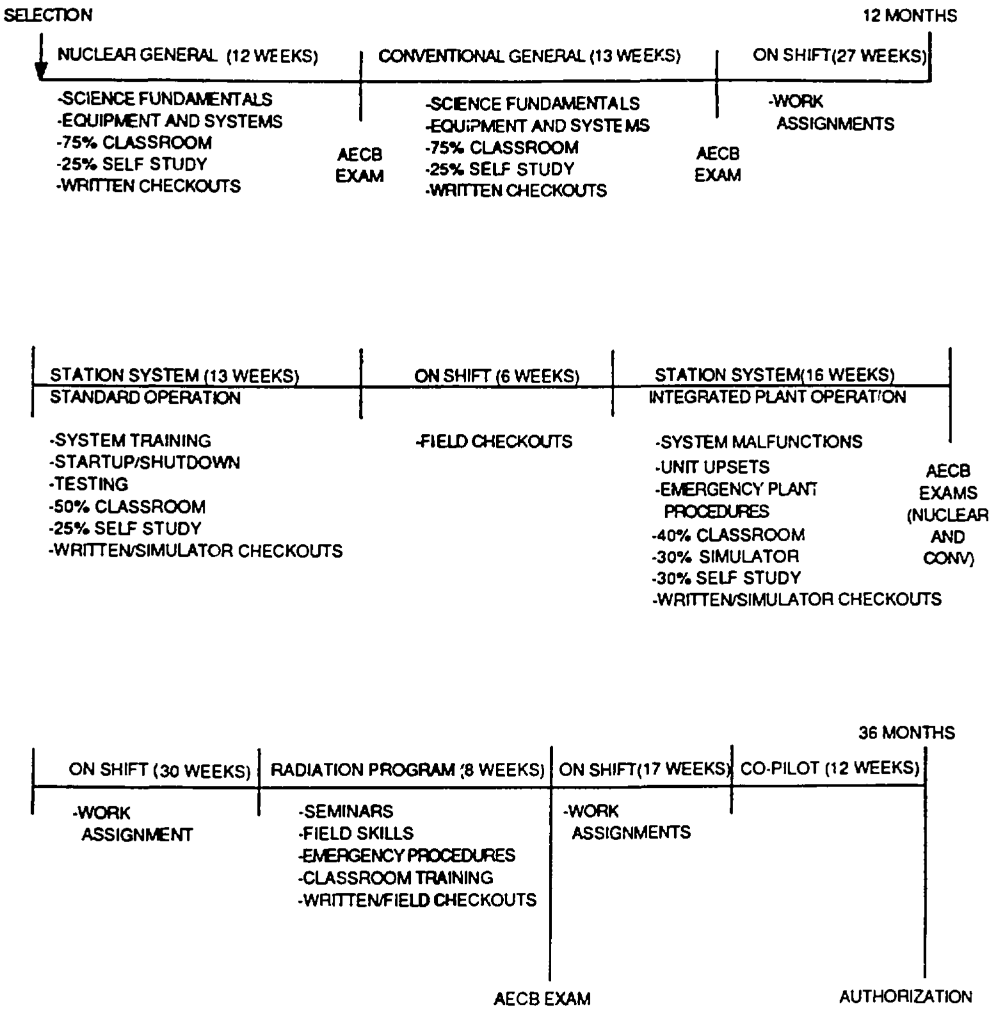

Figure 15 Ontario Hydro's Unit First Operator training programme schedule, with examination stages.

Source: Ontario Hydro

unreasonable. The passing rate has gradually improved, in spite of what Ontario Hydro perceives as increased difficulty in AECB exams (Ontario Hydro 1987a:E4-7).

146. As far as I was able, I compared the Ontario training system with those in place in the United States and United Kingdom. Those commentators who were familiar with the situation suggested to me that the level of technical competence of the Ontario Hydro nuclear staff was very high. Everything I saw and heard confirmed this assessment--especially as regards safety and radiological protection.

147. Two aspects of training struck me as most valuable:

(i) the availability at all the nuclear generating stations of full-scale control room simulators, programmed so as to expose trainees to a full range of normal and abnormal operating conditions. Such simulators are now standard equipment at nuclear stations in many countries, but were lacking, for example, at Chernobyl and TMI prior to the accidents. In spite of their high cost, such simulators are invaluable, especially in developing alertness and versatility in control room operators.

(ii) the in-depth radiological training received by all Ontario Hydro nuclear staff, each of whom is responsible for his/her own radiological dose monitoring and safety, and who will later assume responsibility for the safety of less-qualified staff. Other utilities typically employ a separate cadre of radiological technicians, a tactic that in my view lessens the competence of plant operating and maintenance staff and actually tends to increase the collective dose experience of the station.

148. Review consultants recommended that refresher courses for shift supervisors and operators be upgraded (Appendix III.1). Certainly there is a need for fairly frequent retraining in such a technical field. Ontario Hydro's (1987a:E3-3) response is that the need for "a formal, refresher training program has been

recognized and work is in progress to establish such a program." Our consultants' comment was based on conditions at Bruce B, where the simulator became available only in September 1986. No new plant should be operated without the simulator for that plant being available for training.

F. Head-office Support Groups

149. I referred above to the support provided by corporate headquarters to each nuclear generating station. This falls under three chief headings:

(i) the work of the Health and Safety Division in overseeing and assisting the radiological protection function.

(ii) work done by three Production Branch support groups. I have spoken of the Nuclear Staffing Group. The Central Nuclear Services Group assists the stations in such fields as reactor physics and fuelling, performance and reliability of equipment, inspection and maintenance, chemistry, and metallurgy. RMEP functions in the areas suggested by its title. Technical support services are offered to the stations in the following areas:

- operational analysis;
- radioactive waste;
- human performance evaluation;
- radiation dose reduction;
- emergency preparedness;
- emissions monitoring; and
- significant event report reviews.

(iii) the Design and Development Division, which provides support to the stations in design and construction, safety analysis, and safety verification. Much of the necessary engineering support is found here. The Nuclear Studies and Safety Department is responsible for safety requirements in the design phase and continues to advise operating stations on safety questions. The Nuclear Studies and

Safety Department offered this Review invaluable and highly expert assistance.

150. The strength, versatility, and self-confidence of the corporate groups are major factors in maintaining both safety and economic production at the nuclear generating stations. Ontario Hydro likes to boast of its philosophy of defence-in-depth. Nowhere does this philosophy show up more convincingly than in the support services offered to the station staff by corporate headquarters.

G. Role of Women in the Nuclear Power Industry

151. Women still play a very small role in this industry, in spite of affirmative action programmes. I should like to see this situation changed. There should indeed be more women in key positions, in Ontario Hydro (including its Board), in AECL and its Board, and in the AECB Board and staff. If the AECB staff is enlarged to include social and environmental scientists, an opportunity may be at hand. But women should hold these key positions only if by merit they are the chosen candidates. No other basis is acceptable at these levels.

152. The section of the Queen's University Women's Centre brief dealing with the decision-making structure is interesting and contains a useful review of what is known about women's opinions about nuclear power. It also records Ontario Hydro's efforts to increase the role of women in corporate affairs and in NGD. Unfortunately, its recommendations lie largely outside the Review's scope, dealing with matters without a direct safety connection, or with questions dealt with elsewhere in this Report.

Chapter IV

CANDU Operations: Safety Performance

A. The Problems Studied

153. In this chapter, I discuss the questions: do the process and special safety systems of CANDU reactors perform reliably? Are the regulatory requirements being met? What specific problems have already arisen in the operation of Ontario Hydro's stations? Sources of information and opinion at my disposal included several highly critical briefs (notably from Nuclear Awareness Project and Energy Probe) and the submissions of Ontario Hydro and AECL. A detailed analysis is presented by Peter M. Fraser in Appendix II.C, E-F.

154. Ontario Hydro admits in its submission that there has been less than perfect performance in the safety and process systems, but claims that these have improved progressively as experience has been gained and modifications made. The setbacks due to pressure tube failures in certain reactors are admitted, but Ontario Hydro expresses general confidence that these, too, will be overcome. The intervenors take a much more jaundiced view, maintaining that several aspects of performance remain unsatisfactory or have even worsened. Nuclear Awareness Project goes so far as to demand immediate shut-down of Pickering A, "on the basis of the trend to increasing event consequences due to safety and process system faults" (Nuclear Awareness Project brief, recommendation E1.5), with a similar proposal for Bruce A.

155. Process systems can be judged against the licensing requirements. Safety systems come into play only if an excursion from the envelope of acceptable conditions occurs. Hence, they must be measured in two ways: their performance under the routine testing required by the Laurence safety principles, and their performance during actual periods of abnormal operating conditions.

156. The Slee-Rubin Energy Probe brief (on reactor ageing) is critical to the following treatment, because it raises in sharp focus an anxiety that is present in all designers' and operators' minds. Can high-performance systems that are

by their nature hidden from view be kept operational indefinitely? Or do they slowly decay, as they endure years of high irradiation? Reactor ageing is not treated as a separate subject in this Report, but it is a question that underlies the whole treatment.

B. Significant Event Reports

157. An SER has to be filed by the appropriate department at the nuclear generating station concerned for each unplanned event "that causes or has the potential to cause an undesirable impact upon the Nuclear Generation Division's performance in the key effectiveness areas of worker safety, public safety, environmental protection, product quality, and product cost" (Ontario Hydro 1986a). Such a report must be filed within 48 h by the Shift Supervisor responsible, or other station officer. The report is rendered anonymous and then forwarded to NGD at corporate headquarters, as well as to a substantial list of addressees. A standardised format is used, involving identification of key effectiveness areas (defined in the quotation above), causes, consequences, and immediate remedial action taken.

158. Between 1967, when the first SER was filed from NPD Rolphton, and 31 December 1986, 6740 such reports were written by staff members of the Ontario Hydro nuclear generating stations. Over the years 1982-86, the annual number averaged 667. All these are on file and can be consulted by the public or the concerned legislator at Ontario Hydro's Public Reference Centre (at corporate headquarters) or in the library of the Legislature. I asked for, and obtained, a complete file of the reports, except for those dealing with station security and surveillance.

159. Do 6740 SERs in 19 yr, or nearly 700 such reports per year in recent years, represent cause for alarm? The answer is "not necessarily," as the reports are of very unequal weight. All the events are accidental, but many do not deserve the word "accident." One cannot count them, or arrange them in time series to identify trends, without straining credibility. Nevertheless, the

file contains a record of every safety-related abnormal event that has occurred at a nuclear generating station. Hence, it is vital to this Review.

160. An analysis of the SER file was made by the Nuclear Awareness Project, a paid intervenor to the Review. Table 2 is reproduced from their brief (their Table E1, p. E-9 of the brief). It shows how the flow of SERs has fluctuated with time, and how they have been distributed between stations.

161. One might argue, given an unchanging reporting procedure and the absence of thorough maintenance, that a time series of SERs should have a U-profile: at the outset, high values should result from faults in equipment and from lack of experience on the operators' part; in the middle years, when the reactor is in its technical prime and a good body of experience is available, values should be low; and in late years, until decommissioning, values should climb again because of wear and tear in the ageing equipment. Obviously, such a U-profile could be discerned only if standards of reporting remained uniform throughout--which is not altogether the present case--and if corrective maintenance were not performed.

162. Nothing of the sort is visible in Table 2. The Nuclear Awareness Project claims to detect an upward trend in some of the consequence classes (not shown in the table) and a decrease in others. It isolated 11 classes of event by consequence category at Pickering A and found what it believed to be a general upward trend in the years 1980-86. I very much doubt whether the effect is significant, although these were indeed difficult years at Pickering A (where units 1 and 2 were closed down in 1983 because of pressure tube failures). On the other hand, there was no obvious improvement over the period.

163. The usefulness of the SERs is that they provide an opportunity for systematic audit of safety performance. This is performed within Ontario Hydro by NIRC, which reports on the safety-related events annually to the Ontario Legislature. In my view, it would be useful if AECB also published its audits of SERs in its Annual Report.

Table 2

Number of Significant Event Reports, by Station and by Year

Year	Bruce A	Bruce B	Darlington	Douglas Point	NPD	Pickering A	Pickering B	Yearly aggregate total
1967					43			
1968				124	28			
1969				73	23			
1970				54	32	15		
1971				42	28	72		
1972				27	15	97		
1973				27	21	134		
1974				30	24	141		
1975				38	26	157		
1976				25	25	184		
1977	94			35	31	189		
1978	100			25	51	249		
1979	135			18	54	193		
1980	141			25	39	186		
1981	94	1		34	49	157		
1982	141	8		39	56	199	198	641
1983	137	33		55	48	162	188	623
1984	112	69		27	84	151	260	703
1985	158	93		2	72	134	259	718
1986	109	78	12		55	140	256	650
TOTALS	1221	282	12	700	804	2560	1161	6740

Note: Average number over the last 5 yr = 667.

Source: Nuclear Awareness Project brief (Table E-1, p. E-9).

C. Special Safety System Performance

(a) Shut-down system performance

164. Pickering A has only a single shut-down system (SDS1),* depending on the release of neutron-absorbing shut-off rods into the calandria. All other stations have SDS1 plus a second shut-down system (SDS2), which works by injecting a poison (gadolinium nitrate) into the moderator. Both are designed to be fully inserted in under 2 s, although they achieve shut-down in much less time. Both are activated by two-out-of-three logic by a series of detectors that are rapidly sensitive to abnormal conditions in the key areas of the reactor system.

165. If for some reason the effectiveness of the detectors, logic systems, or the devices themselves is reduced (but not eliminated), the shut-down system is said to be unavailable. A system is termed inoperable if it is definitely incapable of shutting the reactor down. Appendix II gives a complete list of all cases of unavailability and inoperability at all stations.

166. Fraser's analysis (in Appendix II.C [f]) shows that of 450 reactor trips since 1971 (i.e., unplanned shut-downs), 420 were caused by SDS1, and 30 by SDS2. On only 2% of these trips was there potential damage to fuel if the trip had not been effective. Of the rest, about half were due to power transients, i.e., power changes outside the acceptable envelope. The rest were due to operator error or to spurious equipment malfunction.

167. Clearly, a better measure of the performance of systems designed to be perpetually poised is their availability or operability. These measures have to comply with AECB specifications. The shut-down system at Pickering A, as mentioned above, is simpler and less effective than in all newer stations. AECB

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* At Pickering A, a supplementary shut-down capability resides in the fact that the moderator is automatically dumped (thus stopping the chain reaction) if power falls too slowly, indicating that the shut-off rod action is not up to acceptable standards.

requires that it be unavailable for less than 24 h in any one year. At newer reactors, the unavailability must be less than 8 h/yr. Both targets have largely been met. At Pickering A, there has been no unavailability since 1975. Bruce A has the poorest record, but even here significant unavailability has been uncommon. Overall, experience with the systems under test conditions has been excellent.

168. Dual system unavailability (other than at Pickering A) implies that the reactor may be unprotected. If the systems are truly independent, combining the AECB requirements for both systems requires that they be simultaneously unavailable for only 30 s/yr, or one-quarter of an hour in 30 yr (the planned lifetime of the reactor). There have been instances at Bruce A, however, of dual unavailability. Fifteen such cases are identified in the *SER* file. Most of these lasted only seconds or minutes, but there have been eight instances of over 10 min.

169. Only one instance has come to our notice in which both systems were actually inoperable, and this was when Unit 2 at Bruce A was already shut down. It arose from deliberate action by the operator to save the shut-off rods and to avoid poison injection. The relatively poor performance at Bruce A (which we noted in other systems) is a matter for some disquiet.

170. Our intervenors expressed grave disapproval of Pickering A's dependence on a single shut-down system, even taking into account the effectiveness of the moderator dump mechanism against accident sequences.

171. In general, however, the shut-down systems installed in Ontario Hydro's reactors appear to be capable of the vital task assigned to them. The ideal towards which the utility must strive is that they should never be needed in earnest. This implies constant vigilance.

(b) Emergency core cooling system performance

172. The object of the ECCS is to remove decay heat from the fuel following a LOCA--and thus to prevent fuel melting or disintegration. In CANDU reactors, the ECCS consists of two components: the moderator, which acts as a sink capable of removing some of the decay heat; and the ECIS.

173. These systems are complex (see Figure 10 above) and vary from unit to unit. Their performance has been hard to model, so that there have been several design changes to meet defects in performance that were not foreseen in the design phase. Assisting this has been a large experimental programme, notably at AECL's WNRE, where a full-scale mock-up loop is now in operation.

174. In essence, the ECIS exists to flood cold light water into the heat transport system immediately following any interruption of normal heavy-water coolant flow. It does so through a maze of pipes, headers, and channels by motive power provided by pumps and, in some cases, compressed gas. At Bruce A and B, water is injected under pressure from the accumulator initially, and then recovered and reinjected by pumps. It has been a major problem to design the systems so that they can be shown to flood all the fuel channels under a wide range of postulated upset conditions. Essentially, it has been a question of replacing the low-pressure injection system designed for Pickering A and Bruce A with high-pressure systems, a process that has involved extensive backfitting in the older reactors.

175. The ECIS has never been activated under accident conditions at any CANDU reactor. Hence, our knowledge of its reliability is based on modelling and testing. Like the shut-down systems, it is activated by sensing and logic systems that can indeed be physically tested. But flooding the fuel channels with light water would be costly and is not attempted after the commissioning phase. The available test results are hence less convincing measures of effectiveness than is desirable.

176. AECB licensing requirements set unavailability targets of one in 1000 for most stations, i.e., that each ECIS should be unavailable for 8 h or less in each year. At Pickering A the target figure during design was one in 100, or 80 h/yr, but the target was then lowered to three in 1000, or 24 h/yr. (This target was by no means reached at Pickering A, where most units had more prolonged unavailabilities in several years. The new backfitted system will be at one in 1000.) The newer stations have performed more satisfactorily. Appendix II gives details of events that have reduced availability for all reactors (not, however, inoperability--the more serious condition).

177. Relations between AECB and Ontario Hydro have been strained over the design and performance of these systems. In particular, there were differences over the ECIS of Bruce A. Details of this dispute are given in Energy Probe's brief "Reactor Aging" and are summarised in Appendix II.D, paras. 207-208. There is also an account in Ted Schrecker's analysis for Energy Probe (Energy Probe brief).

(c) Containment performance

178. Ontario Hydro's concept of containment, evident in the design process, is that a series of barriers should resist the escape of fission products. First and foremost of these are the crystal structure of the fuel, fuel sheaths, pressure tubes, calandria tubes, and fuelling machines that surround the fissioning fuel and that have to be breached if the fission products are to escape. Beyond these--and to most observers containment begins at this stage--is the series of structures surrounding the reactor vault. Most familiar to the casual observer are the concrete containment structures surrounding each reactor and the vacuum buildings into which the reactors can void excess gases and steam under accident conditions. Containment details differ from station to station, but all have in common these properties:

- they are maintained at subatmospheric pressures under normal operating conditions and are designed to withstand brief transient high pressures following accidents;

- they all contain a vacuum structure capable of receiving gaseous and particulate materials via pressure relief ducts from each reactor, during either the overpressure period or the subsequent period when pressure falls below atmospheric values;
- all can be isolated from the outside environment immediately if sensors in the reactor vaults detect high pressure or high radioactivity; and
- all are equipped to allow controlled release of certain materials (chiefly the noble gases) at favourable times (in terms of weather) following an accident.

179. CANDU containment contains other unusual features. Accumulation of dangerous levels of hydrogen, for example, is controlled by deliberate burning (not yet installed in Pickering A units 3 and 4). Considerable work has also been done to seal the floors of the vacuum buildings, because the dousing water (see Figure 11), which contains dangerous nuclides in solution or suspension, cannot be allowed to leak.

180. Fraser has analysed the containment systems' performance in Appendix II.C (c). His tables summarise unavailability times for all currently operating Ontario Hydro reactors. The AECB target unavailability for these structures is again one in 1000, or 8 h maximum per year.

181. Although there have been escapes of heavy water from fuel channels at Pickering A, there has been no case at any station in which containment isolation and vacuum building activation were needed. Again we must rely on testing for any measures of availability and performance. Such tests cannot always be frequent because some--such as tests of vacuum building operation and dousing--require shut-down.

182. Fraser's analysis draws attention to certain physical defects that have been detected, such as holes in concrete containment structures and installation and operating errors. Bruce A and B have had such troubles, including a failed vacuum building roof seal, when the two units in operation at the time were

shut down. Pickering A and B have performed almost faultlessly since 1981 and 1983, respectively.

183. I conclude, nevertheless, that CANDU containments are in a generally satisfactory condition and are likely to prevent the escape of radioactive materials following nearly all accidents (except for deliberately vented noble gases). This conclusion agrees with our own consultant's report (J.D. Stevenson and Associates). It has been confirmed for Pickering A by the severe accident analysis conducted at my request by Ontario Hydro and Argonne National Laboratory (Chapter VI).

D. Process System Performance

184. The process systems in CANDU are those required for the production of electricity, the central purpose of the generating stations. As shown above, however, they also play major roles in safety performance. They include most of the reactor hardware, together with the feedwater pick-up, the discharge of coolants to the lakes, and the apparatus required to generate electricity and to dispatch it into the provincial grid.

185. The overall performance of the nuclear generating stations has been very good by international standards. Availability of the complete system has been much higher than in most light-water and gas-cooled reactors around the world.

186. But there have been failures in the process systems, especially at Pickering A and Bruce A, the older stations. Some of these can be attributed to unforeseen complexities and design weaknesses that have since been removed. Others, however, remain unresolved; in one case--the pressure tube ruptures at Pickering A--the problem has led to actual accidents, with severe economic consequences. The Slee-Rubin brief from Energy Probe and Ralph Torrie of the Advisory Panel make the comment that the CANDU reactor does not age gracefully.

187. Nevertheless, there is also evidence that most of the process systems behave reliably, and that when faults occur (as they do in all industrial systems) they are handled promptly by the operators and maintenance staff. The file of SERs is full of such cases. Very few of these malfunctions come even close to causing true accidents, still less to releasing radioactivity. Fraser's exhaustive treatment in Appendix II emphasises these events, in accordance with our mandate. The long periods of largely event-free operation get little attention.

188. Although there have been problems at most of the nuclear generating stations with one or other of these functions, by far the most serious has been the fuel channel (pressure tube) problem. It continues to cause anxieties and has already involved Ontario Hydro in high costs. It has seriously damaged CANDU's reputation for reliability. There has also been a substantial (although smaller than feared) radiological penalty paid by the maintenance crews charged with the repairs (see para. 199).

E. The Fuel Channel (Pressure Tube) Problem

189. Figure 16 shows a cut-away sketch of a typical CANDU fuel channel, the theatre within which the reactor conducts its fundamental process of fissioning uranium-235 and plutonium-239. There are 380 such channels per reactor in Pickering B, 390 in Pickering A, and 480 at Bruce A and B (see Appendix I, paras. 21-24). All contain fissioning fuel while the reactor is on stream. All are connected to--and are hence part of--the primary heat transport system, which pumps hot, high-pressure (~10-11 MPa) heavy water through the inner part of the channel to remove heat to the steam generators.

190. The fuel channel is made up of an outer calandria tube, which is surrounded by the cool heavy-water moderator, and an inner, thicker pressure tube. Within the latter (which carries the coolant flow) are the fuel bundles containing the fissionable uranium and plutonium. The two tubes are kept separate by ordinary garter (ring) springs of the appropriate radius fitted round the pressure tube and spaced so as to minimise stress. The space between the

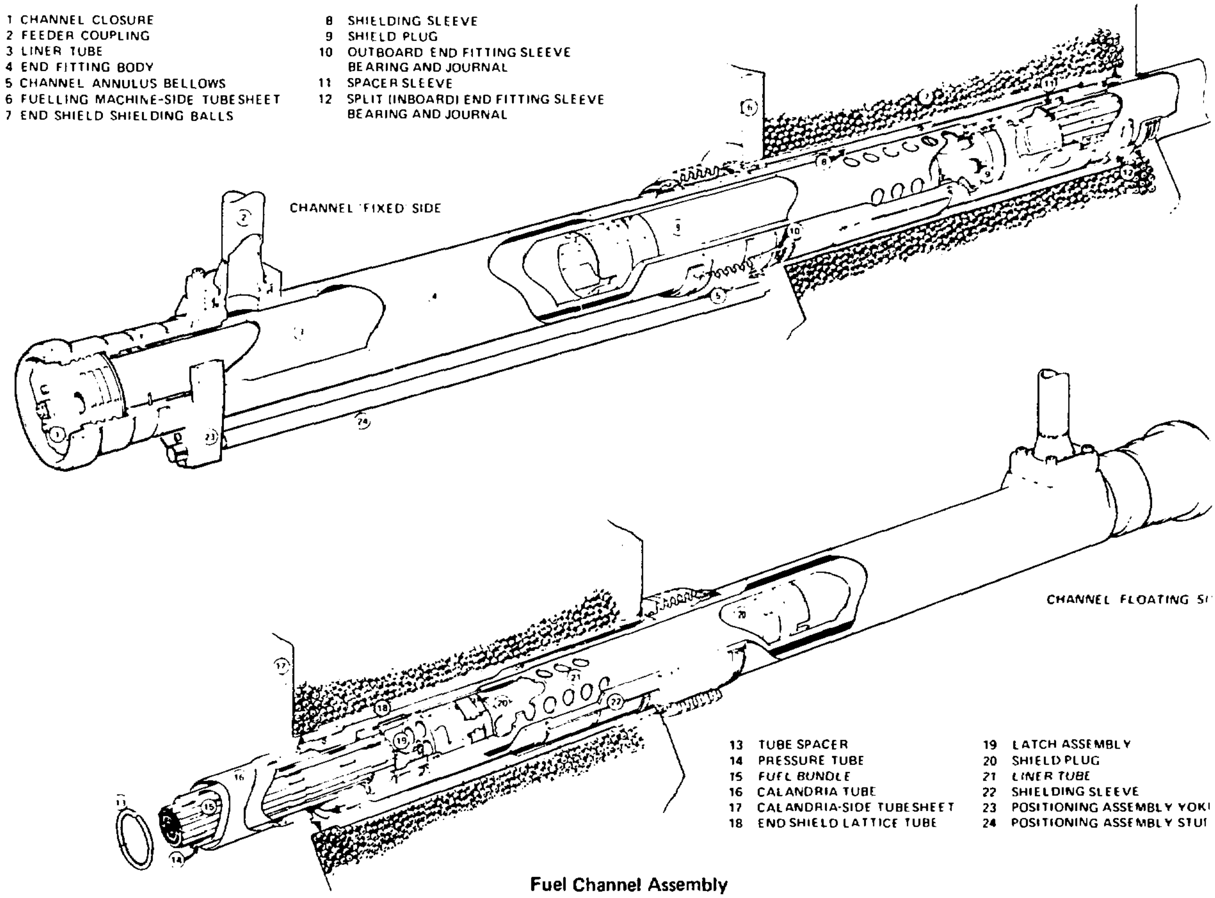

Figure 16 Cut-away diagram of a CANDU fuel channel. The pressure tube can be seen inside the thinner calandria tube, with fuel bundles exposed (lower half of diagram).

Source: Ontario Hydro

tubes (called an annulus) is occupied by dry carbon dioxide (nitrogen-14 at Pickering A, but this is now being changed) at low pressures.

191. The calandria tubes are rigidly attached to the calandria vessel, but the pressure tubes have stainless steel end fittings capable of being attached by remote control to the mobile fuelling machines, which periodically renew the 12 to 13 fuel bundles in each pressure tube. Each such opening requires elaborate measures as regards opening and resealing (so as to conserve the high pressures inside the tube), prevention of leaks, and removal of the irradiated fuel--all under computer control. The intactness of the pressure tube is monitored by detectors that test the annular gas for heavy-water vapour (whose presence indicates leaks in the tube or an imperfect fitting).

192. The pressure and calandria tubes are made of zirconium alloys. At Pickering A, units 1 and 2 were originally fitted with Zircaloy-2 (containing 1.5% tin, 0.12% iron, 0.1% chromium, and 0.05% nickel as well as the zirconium), but these have now been refitted with zirconium - 2.5% niobium, the Soviet-originated alloy system used in all the other reactors. Zirconium as a metal allows very free passage to neutrons, which are hence able to penetrate to the moderator to contribute to the overall neutron economy of the reactor. The minor components beneficially influence the physical properties of the tubes. Zirconium - 2.5% niobium has higher tensile strength and is more resistant to corrosion than Zircaloy-2; it was originally selected for its creep resistance.

193. CANDU designers realised from the outset that the pressure tubes and their interiors would be subject to very harsh conditions--notably high temperatures and pressures within the fuel channel, with much lower values of both in the calandria. Moreover, the entire assembly would be subject to intense irradiation by neutrons. It was expected that the pressure tubes would increase in length and girth (axial and radial directions). The methods of installing the tubes (use of rolled joints), isolation (use of channel bellows), and separation from the calandria tube were designed to allow for this behaviour. It was also evident that very high standards (in practice those of the American

Society of Mechanical Engineers [ASME]) of quality and QA would be required at all stages of fabrication and assembly.

194. Notwithstanding these precautions, pressure tube (and in one case calandria tube) failures have occurred. Figure 17 shows the dates and modes of failure of all such cases. An excellent account of the failures is given in the Ontario Hydro submission, section 9 (from which Figures 16 and 17 are taken). I quote from their diagnosis of the problems:

(i) delayed hydride cracking [see para. 195 below] is the only mechanism common to all pressure tube failures.

(ii) delayed hydride cracking occurs only when hydrides are present at the appropriate temperature and when either a very high tensile stress, or some lower stress together with a stress intensifying flaw, is present.

(iii) high residual tensile hoop stresses were present in the rolled joints of some reactors as a result of the rolling procedure used during installation.

(iv) some rolled joint cracks were associated with flaws, but others were simply due to the presence of very high tensile stresses.

(v) hydride blisters were present in heavily deuterided* Zircaloy-2 pressure tubes in contact with calandria tubes as a result of the mislocation of spacers during commissioning. These blisters act as flaws which initiated delayed hydride cracking in the body of the tube, remote from the rolled joints.

(vi) it is expected that zirconium - 2.5% niobium pressure tubes will be less susceptible to a blister type failure mechanism.

195. The delayed hydride cracking referred to in para. 194(i) is known to be a common feature of zirconium structures in which stress or thermal gradients exist. If there is a source of hydrogen ions, these tend to migrate along such gradients to points of maximum stress (which can be due in CANDU to rolled joint installation methods or small flaws in the material). The ions accumulate in the material or on the surface in conspicuous white blisters of zirconium

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* Technically, most of the hydrogen ions are of heavy hydrogen, deuterium; hence, the blisters are more properly referred to as zirconium deuteride.

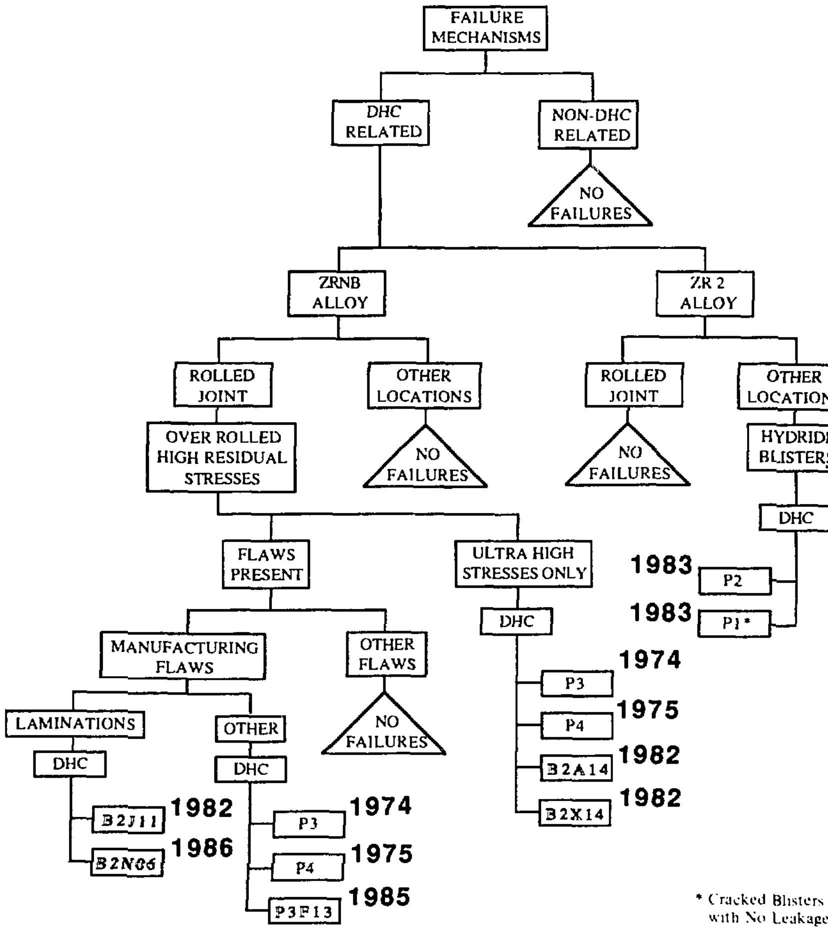

Figure 17 Failure mechanisms of all significant pressure tube failures since 1973 in Ontario Hydro reactors. All failures trace back to hydride formation in the tubes.

Source: Ontario Hydro

hydride. Small cracks occur and, after a period that may be quite prolonged, may suddenly enlarge, breaking the tube open and allowing the egress of the hot, pressurised coolant into the annular space outside the tube.

196. Although failures (leaks) of pressure tubes had occurred as early as 1974-75 (in Pickering A, units 3 and 4, in zirconium-niobium)--see Figure 17--it was two more recent events that caused most anxiety and disturbance. These were the Pickering A accident on 1 August 1983 and a less dramatic event at Bruce A on 26 March 1986.

197. The Pickering A accident occurred on 1 August 1983 when pressure tube G16 in reactor Unit 2 suddenly ruptured. A crack 20 mm wide and 2 m long formed at the bottom of the tube, ending in a 120-degree tear in the circumferential direction. Coolant escaped at about 18 kg/s and discharged from both ends of the annulus through ruptured bellows. The calandria tube, although exposed to the very high pressure of the heat transport system, remained intact. There was no preliminary warning from heavy-water vapour in the gas annulus; the comfortable assurance that a slow leak would always precede a break was thereby shattered. Delayed hydride cracking was established as the cause of the accident. It was also demonstrated that there had been a migration of the garter springs, allowing contact between pressure and calandria tubes.

198. The consequences of this accident were largely economic, although some added work-force exposure occurred. There was no escape of radioactivity from containment, nor was there damage to the reactor core. But subsequent inspection showed that many other tubes in units 1 and 2 were probably affected by hydride concentrations. The decision was taken to replace the pressure tubes in both units--a process that will have extended from 1983 until 1988, when Unit 2 will return to service (Unit 1 was started up again in September 1987). The opportunity has been taken to undertake extensive refitting of other reactor components and to increase the number of shut-off rods in SDS1 from 11 to 21. A high-pressure ECIS is now installed as well in these units.

199. The entire job on units 1 and 2 was estimated beforehand to involve a collective dose to workers of ~20 Sv. As of October 1987, only about 7 Sv of this dose had been committed. In spite of difficult working conditions, especially because of high levels of carbon-14 from the annuli, the work has been conducted with high efficiency and a much lower radiological cost than originally feared. No public exposure has occurred. Total cost is estimated at $425 million (including the cost of replacement power).

200. The event at Bruce A took place on 26 March 1986, when operators detected heavy water in the annulus of tube N6 in reactor Unit 2, indicating a leak of coolant. The tube ruptured on 28 March during a repressurisation manoeuvre aimed at locating the leak. The reactor had been shut down, and it is thought that the cooling was responsible for the extension of the crack. The crack was later shown to be 3.8 m long, with an associated flap of material. In addition--in contrast to the Pickering accident--as a result of the testing procedures used on N6, the calandria tube had cracked along its weld seam, thus allowing a small escape of coolant heavy water into the moderator. Ontario Hydro does not expect calandria tube failure with the system operating under normal conditions. The original cause was again diagnosed as delayed hydride cracking, associated in this case with a defect in the region of the rolled joint. Repairs have been effected.

201. These events have raised many doubts about the future behaviour of zirconium-niobium tubes and about the possible consequences of such failures. Two of the relevant points are as follows. First, is the conclusion reported to the Review by Ontario Hydro that zirconium - 2.5% niobium tubes are "less susceptible to a blister type failure mechanism" sustainable? Several failures have occurred in such tubes. Preliminary inspection of a tube drawn from Pickering A Unit 3 has shown a higher level of hydride accumulation than was predicted by model analysis, although no dangerous situation has been detected (Ontario Hydro, personal communication). Second, is the refitting of all the older reactors--Pickering A units 3 and 4, and Bruce A units 1-4--called for? Pickering units 3 and 4 are scheduled for shut-down and heavy maintenance in

1988 and 1989, but a decision has just been made (Ontario Hydro, private communication) to refit Pickering units 3-4 with new pressure tubes. This will modify the schedule.

202. Pressure tube failures are a crucial problem confronting the designers and operators of CANDU reactors. If it is not possible to find metallic species or alloys capable of resisting decay processes, the safety of pressure tube technology has to be seen as dubious. These tubes are part of the high pressure boundary of the heat transport system. It is fundamental to the safe operation of a reactor that the pressure boundary remain intact--as it did not, in the cases described. A serious failure is effectively a small LOCA.

203. In none of the cases of failure discussed above, and shown in Figure 17, was there a release of radioactivity from the station, nor were special safety systems needed to shut down the reactor. In each case, the consequences of the failures were less than had been estimated in the original safety analysis--except that no one could have foreseen that caution would have required the utility to endure the huge cost of replacing the pressure tubes in Pickering A units 1 and 2. No member of the public suffered, and exposure of maintenance crews was lower than foreseen. It is hence easy to conclude that future fuel channel failures, if they occur, may be costly, but will not affect safety outside the stations. Ontario Hydro's submission contains statements to this effect.

204. Although this limited optimism may be justified, I refer to Ontario Hydro's own diagnosis of the possible core damage that may be caused by future failures:

- can the failure of one fuel channel lead to a failure of any neighbouring channel? [it did not do so at Pickering A or Bruce A];
- can the resulting forces in the calandria vessel cause failure of the calandria vessel itself, which might result in the core geometry being disrupted? [again it did not do so in the cases described]; and
- can the resulting forces within the core cause the shut-down system to be impaired to such an extent that it can result in a failure to shut down the reactor or to maintain it subcritical?

In each case, investigation has given Ontario Hydro an encouraging answer (reported to the Review in its submission). But I cannot believe that the questions are yet fully answered.

205. A natural response to these difficulties is to turn to the research community for answers. This Ontario Hydro has done, largely with the help of AECL and Canadian Westinghouse laboratories. Because jurisdictions other than Ontario operate CANDU reactors, the CANDU Owners' Group (COG) has also been involved. Since the 1983 Pickering accident, a rather slow-moving research effort in this area has been intensified and accelerated.

206. I visited AECL's WNRE and CRNL (as did some of my Review colleagues). I also visited Ontario Hydro's laboratories at Kipling Avenue, Etobicoke. Much excellent work has been done and published, but it is obvious that much more needs to be done. This class of applied research is fundamental to safety. Many different aspects of the problem are under investigation in these laboratories. I looked at the following areas of research:

- research into the mechanics of hydride blistering, cracking, and fracture, together with aspects of the basic metallurgy of hexagonal and cubic metals;
- analysis of the modes and routeways of deuterium and hydrogen ingress from the coolant into the pressure tubes, and the relationship of such ingress to general corrosion phenomena;
- study of the extraordinary deformation (change of shape) of the pressure tubes under the harsh conditions of the fuel channel, including lengthening, ballooning, radial growth, creep, and garter spring displacement*;
- thermal hydraulic analysis of the consequences of sudden ruptures, including the influence of water-hammer effects (believed to have been of importance in the calandria tube failure at Bruce A);

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* which is not included in the deformation, although it has a bearing on it.

- development of techniques of non-destructive examination, whereby materials and structures can be examined for defects prior to installation, without damage to themselves; and
- the search for better alloys that may overcome the problem, using advanced metallurgical techniques.

207. The Review asked for a professional opinion from two consultants in pressure tube performance. Their answers will be published, but a summary of their findings is given here:

(i) D.J. Burns (of the University of Waterloo) confirms most of the current trends reported by Ontario Hydro and AECL programmes of research, laying stress on the garter spring problem, the need for data on hydride pick-up rates, the problems of biaxially strained seam welds, the question of Bruce's thinner calandria tubes, and the vital importance of in-service inspection techniques.

(ii) D.O. Northwood (of Windsor, Ontario) agrees with Burns in most points, but lays emphasis on the problems of retubing, discussing the criteria and inspection programmes necessary for decisions. Like all other commentators, he is anxious to know whether the Pickering A Unit 3 tube recently pulled is representative of most zirconium-niobium tubes. He also lays major stress on advances in production of these tubes, discussing reductions in iron content, new fabrication routes, and the possible use of yttrium sinks for deuterium and hydrogen. Like Ontario Hydro, he concludes that "the consequences of most failures of pressure tubes (those involving single tubes) are economic rather than safety related."

I accept much of our consultants' analyses, also taking into account a review of the AECL programme by E. Smith (1987). I remain of the opinion that the future performance of CANDU fuel channels is the most important outstanding safety-related question. The possibility of further accidents involving release of coolant has obvious safety implications for operating and maintenance crews, as well as very large cost implications. It is crucial that research and development be continued and, in some cases, intensified. The view was expressed to me that the solution may well lie in an area in which research is not currently buoyant: the metallurgical search for better alloys.

F. Reactor Research Funding

208. The budget for 1988 for the funding of all forms of reactor development is shown in Figures 18-20. It shows disquieting features:

(i) Of the $117 million for total research, only $50 million is provided by Ontario Hydro. This is only 2% of gross energy sales from nuclear plants. This seems small in relation to Ontario Hydro's enormous investment and nuclear energy sales.

(ii) Of the fuel channel budget of $43 million (see Table 3), Ontario Hydro will provide $19 million. Given the urgency of the pressure tube problem (which is a subset of the fuel channel problem), this seems a small commitment of funds to the most important issue of the day.

(iii) AECL still provides over half of all research funding. This expenditure is threatened by federal budget cutting.

209. Major operating industries that use highly technical equipment and processes have no choice but to reinvest a significant fraction of gross income in research and development. This is especially true where, as in CANDU's case, the technology is unique, and there is no large pool of foreign expertise that can be tapped. Recognising this, CANDU operating utilities and AECL have banded together in COG, which provided Figures 18-20 and Table 3. COG has done an excellent job of defining research needs (by means of numerous working groups), especially in the safety and fuel channel areas.

210. But serious problems exist that will affect safety prospects. AECL's Research and Engineering Laboratories, which are completely central to safety research, are under financial erosion by the federal government's response to the

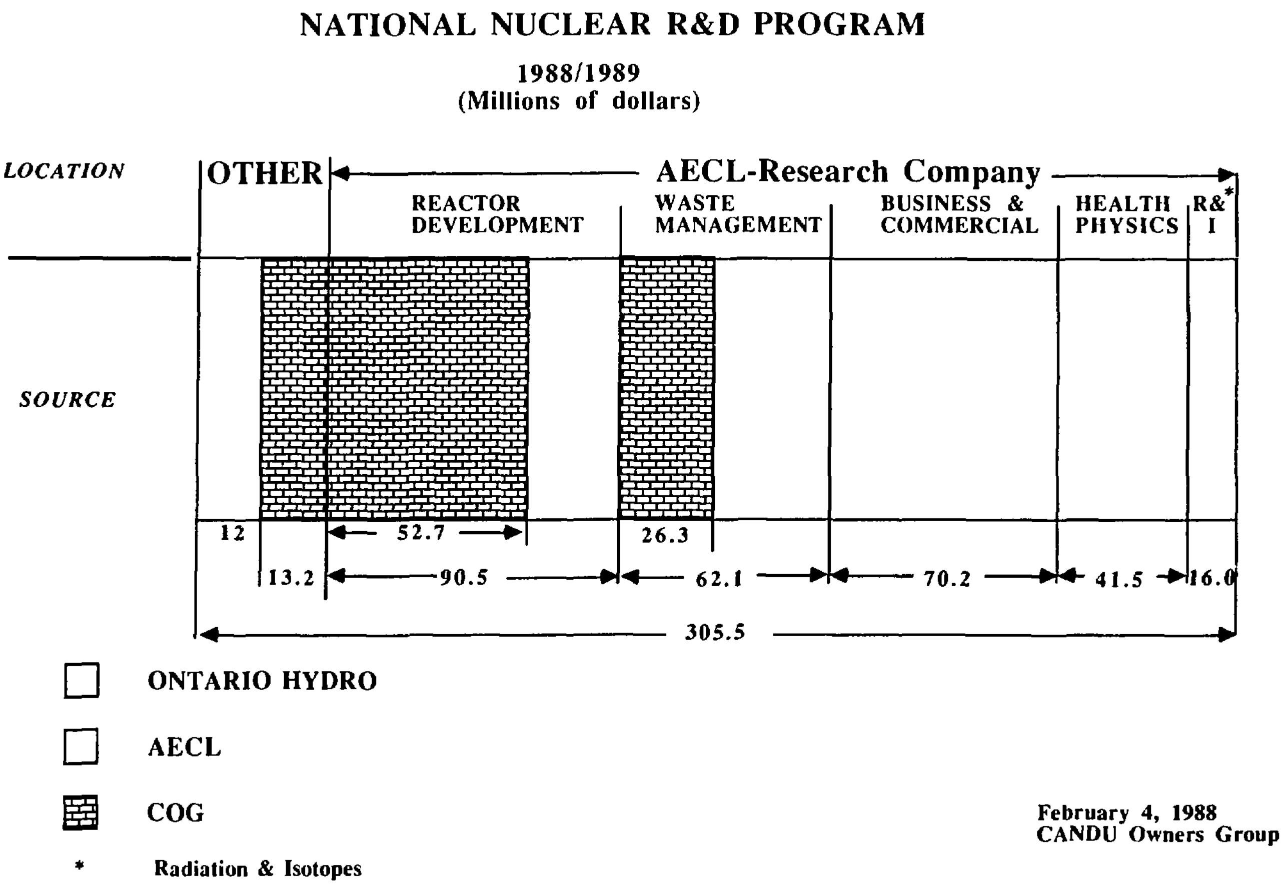


Figure 18 1988-89 budget for research and development, Canadian national nuclear programme, by function and origin. Note the CANDU Owners' Group's role.

Source: CANDU Owners' Group

AECL-Research Company
REACTOR DEVELOPMENT
1988/89
(Millions of dollars)

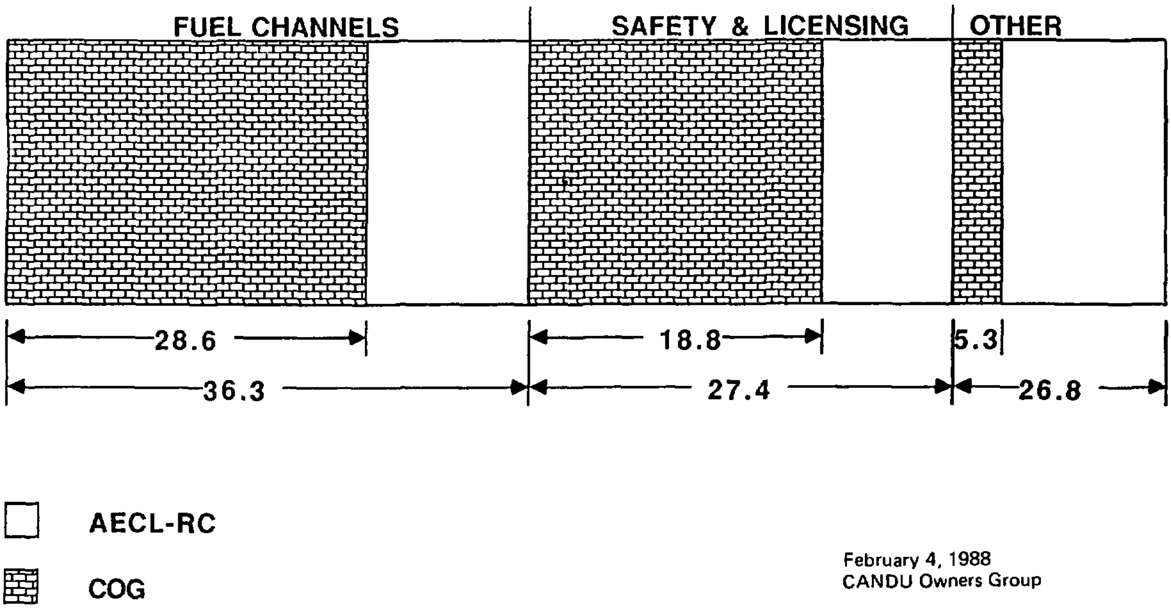


Figure 19 1988-89 AECL Research Company budget for reactor development, showing the major role of fuel channel research.

Source: CANDU Owners' Group

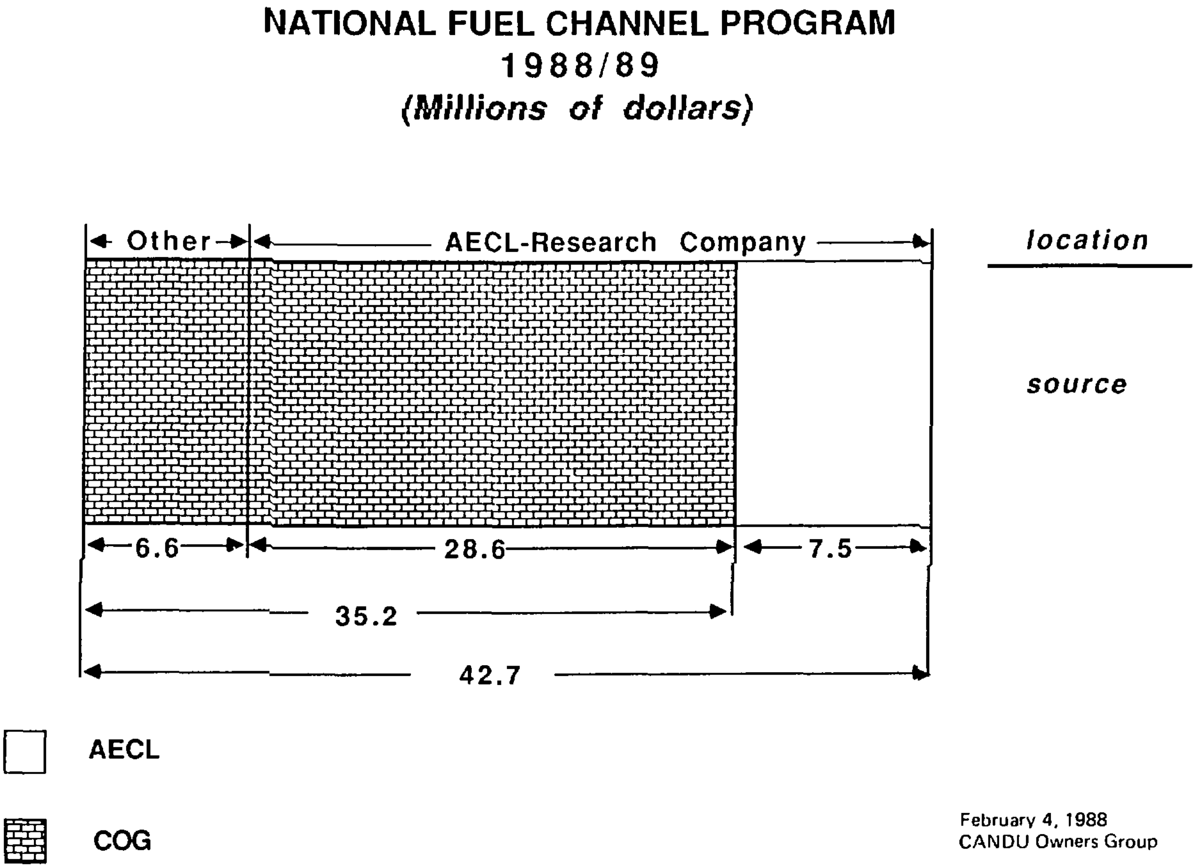


Figure 20 1988-89 fuel channel research budget, showing the overwhelming importance of AECL's component.

Source: CANDU Owners' Group

Table 3

Fuel Channel Research Budget Expenditures,
1988-89 (annual values)

	$ million
By ultimate source:	
Ontario Hydro	19.4
AECL Research Company	21.5
Other utilities	1.8
Total	42.7
By site:	
(Funding via CANDU Owners' Group)	
Whiteshell Nuclear Research Establishment (AECL)	3.9
Chalk River Nuclear Laboratories (AECL)	24.7
Mississauga, AECL Research Company	1.5
Ontario Hydro Research Laboratories	5.0
(From AECL budget)	
Chalk River Nuclear Laboratories	7.5

Source: B.R. Collingwood, CANDU Owners' Group, personal communication.

weakness of CANDU sales elsewhere. There are serious shortages of skills, and the universities can offer very limited help. Fields such as the kind of metallurgy applicable to CANDU reactors are very thinly represented in Canada and in other countries. I urge that the responsible corporations and governments try to fill these gaps over the long term: there is no short-term solution. The present COG programme could be supplemented, at least to initiate important new programmes of work in the universities (see Recommendation 3, Minister's Report I).

Chapter V

Radiological Performance

A. Background

211. Nuclear fission releases four types of radiation capable of damaging living tissues:

(i) gamma radiation, which is very short wave electromagnetic radiation, largely derived from the fission products. Such radiation can be extremely high in energy and creates an intense radiation field around the reactor core or irradiated fuel. It penetrates the body even more readily than do medical X rays, which it resembles.

(ii) alpha particles, which are heavy, fast-moving helium nuclei emitted from certain radioactive substances (and from gaseous decay products of heavy metals, notably radon). They do not penetrate the skin deeply and cannot penetrate dead skin tissue (but may invade lung and digestive tract tissues if the radioactive substances are inhaled or ingested). They are important in other aspects of the nuclear fuel cycle, but not in reactor operation.

(iii) beta particles, which are light, fast-moving electrons derived from various nuclear transitions in the fuel and fission products, and from tritium in the coolant and moderator. They may penetrate more deeply than do alpha particles.

(iv) neutrons, released at high velocities within the fuel bundles at the instant of fission, but likely to be encountered within the reactor core only after slowing by the moderator to the thermal velocities typical of gaseous molecules. Exposure to neutrons, which are heavy, is possible, although unusual, in a few locations during normal operations.

212. All four types of radiation may damage human tissues, including genetic materials, by ionising body fluids and several other probable mechanisms. All four can be stopped (i.e., absorbed as heat) by shielding substances, such as lead

and water (the radioactive spent fuel bundles stored in the nuclear generating station storage bays, for example, may be safely viewed through a few metres of clear water). Rigid rules of access, clothing, and duration of exposure apply within the specific radiological protection zones inside the reactor building. Radiological management within the plant is hence in part a design requirement--e.g., the installation of effective shielding systems--and in part a disciplinary code to limit exposure or to prevent overexposure.

213. In the times immediately following the discovery of radioactive substances, little thought was given to these hazards. In the past 60 yr, however, an immense body of knowledge has been accumulated. As it has grown, so also has our ability to protect ourselves against the threat of unwelcome side effects.

214. The nuclear power industry had nothing to do with the earlier development of radiological protection. It was the physicians who moved in this direction. The predecessor of the modern International Commission on Radiological Protection (ICRP) was created in 1928 by the International Congress of Radiology. In the 60 yr since its creation, ICRP, a purely voluntary creation of the scientific and medical communities, has led the way towards comprehensive protection against ionising radiation. The methods to be reviewed in this section are part of that comprehensive system.

215. Three situations require analysis:

- the exposure of workers and visitors inside the generating station exclusion fence during normal operations;
- the long-term exposure of persons resident near enough to the exclusion fence to be exposed to permitted releases of radioactive materials to air and water; and
- the radiological implications of incidents or accidents that allow unplanned releases of radioactive materials.

Lengthy briefs covering these and other aspects of radiological protection were submitted by three intervenor groups (CUPE Local 1000, the International

Institute of Concern for Public Health [IICPH], and Nuclear Awareness Project). I have grouped my replies in Annex IV.

B. Exposure to Radiation During Normal Operations

216. The two primary hazards in CANDU operations are gamma radiation from sources external to the body and internal exposure arising from the ingestion of tritium (chiefly as the oxide, HTO), a weak beta radiation emitter. Tritium is produced in CANDU reactors through neutron absorption by heavy water in the moderator and coolant. Normally, the tritium remains within these systems, but small amounts inevitably escape. A tritium removal plant has been built at Darlington NGS, which will ultimately allow about 80% of the tritium in contaminated materials from all Ontario Hydro's reactors to be immobilised on titanium sponge for indefinite storage.

217. Radiological protection at the stations is the responsibility of two on-site units:

(i) the Radiation Control Unit, part of the station line management, headed by the Radiation Supervisor. It provides radiation protection procedures and ensures that protection equipment and materials are available. It also provides training and on-the-job assistance.

(ii) the Health Physics Services Unit, whose head--the Senior Health Physicist--reports through a separate line to the corporate Director, Health and Safety. It provides oversight and service functions on the station, such as approving procedures, interpreting standards, and controlling dosimetry.

218. A feature of Ontario Hydro procedures is the stress laid upon individual responsibility for self-protection and for the protection of less-qualified persons. A high level of formal training, as well as progressive on-the-job learning, is required in order that individual employees may become qualified to discharge this responsibility. Training and qualification of employees are joint

responsibilities of the Senior Health Physicist and line management. To quote the Ontario Hydro submission, "trainees receive a minimum of 160 hours of formal training and progress through a period of structured experience . . . [under] actual work conditions."

219. Access to the radioactively contaminated parts of Ontario Hydro's facilities requires the wearing of dosimeters (to measure external radiation) that are colour-coded according to level of personal qualification: fully qualified staff wear green badges, which entitle the wearer to full access to the highest exposure zones and to escort unqualified persons; yellow, orange, and red badges indicate progressively lower access and escort rights.

220. Within each station, radiological zones are established, corresponding to progressively greater radiation levels as the reactor core is approached. Various barriers, interlocks, alarm systems, monitors, and cleansing apparatus exist at each human access point. Movement of materials is controlled so as to minimise contamination. Ventilation (filtered at the outlet) operates inwards towards the reactor core. The area inside containment is kept at subatmospheric pressures, so that leakages tend to be carried towards the interior.

221. Other specific measures aimed at reduction of individual and collective radiation doses include the following:

(i) design of the reactor so as to minimise the need for staff to enter high-radiation fields. As experience has been gained, it has been possible to locate essential equipment outside containment, so as to make it more accessible for maintenance and inspection.

(ii) provision of efficient clothing, tools, and equipment that minimise time spent within high-radiation fields and that to the maximum extent protect the body and prevent removal of contaminants from the inner radiological zones.

(iii) planning of work schedules and rostering of staff so as to minimise collective doses and, as far as possible, individual doses. This is especially necessary in the maintenance and construction areas.

(iv) maintenance of a thoroughgoing assessment of the doses received by all who enter the radiological zones, notably the work-force, including a permanent personal history file for all individuals.

222. This set of working methods of radiological control has enabled Ontario Hydro to achieve an acceptable standard of protection for its entire work-force. This achievement is outlined in section C. But the IAEA OSART inspection (in 1987) of Pickering NGS was not fully satisfied, although it found performance above average. Its report is reprinted in Appendix III.2. Its recommendations have been in part incorporated into my own. Appendix III.3 contains an analysis of Ontario Hydro's responses.

C. Radiological Performance at Nuclear Generating Stations Within Work Areas

223. The levels of exposure of workers inside the nuclear generating stations are much higher than those either received or authorised for the most exposed member of the public living outside the exclusion fences.

224. ICRP (1977) enunciated three general principles that underlie radiation exposure restrictions in general, and hence dose limits for in-plant workers:

(i) justification: no practice shall be adopted unless its introduction produces a positive net benefit.
(ii) ALARA: all exposures shall be kept <u>A</u>s <u>L</u>ow <u>A</u>s <u>R</u>easonably <u>A</u>chievable, economic and social factors being taken into account.
(iii) a system of dose limits that prescribes a method of combining dose received by separate organs and the whole body. In addition, no individual may be exposed to unacceptably high radiation doses.

225. Ontario Hydro's (1987c) Radiation Protection Regulations Part I, submitted to AECB in April 1987, are based on AECB regulations and ICRP recommendations and seek to limit worker exposure by specifying annual and quarterly dose

limits of exposure. These are reproduced in their entirety in Annex III. Table 4 summarises the more general limits.

226. It is possible that these April 1987 regulations may soon be overtaken by events. Current re-examinations of available observations of cancer mortality dose-effect relationships make very probable a halving of ICRP effective dose limits. If so, then AECB and Ontario Hydro will have to re-examine the situation. The UK National Radiological Protection Board (NRPB) has recommended to the UK government's Health and Safety Executive that dose limits for exposed workers "be so controlled (by suitable work practices) as not to exceed an average effective dose equivalent of 15 mSv for the most exposed groups." This is an interim step imposed while the United Kingdom, like Canada, waits for revised ICRP guidelines (UK NRPB 1987:4).

227. Figures 21-22 summarise the actual levels of dose achieved at Ontario Hydro's nuclear generating stations, taken as a group. Figure 21 shows that collective doses per reactor unit--i.e., the total dose received by the entire work-force at a single reactor--declined strikingly between 1975 and 1985. As the number of reactors increased, the collective dose per year per megawatt (electrical) declined even more sharply; in other words, the cost in terms of radiological exposure of producing a unit of electric power shrank gratifyingly.

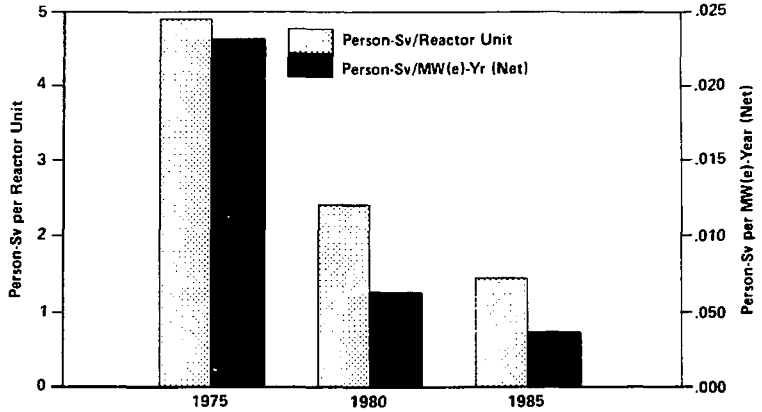
228. The comparison between countries for 1980-84 (Figure 21) shows that Ontario Hydro had high individual exposed worker dose rates (about 7 mSv/yr) by comparison with European countries and Japan. These levels have since fallen significantly (to an average of 3.9 mSv/yr in 1985-86; see Figure 22). Ontario has a lower number of exposed workers. This comparison is especially striking (in Ontario's favour) with the United States and Japan. The favourable Ontario situation arises, to quote Ontario Hydro's submission (p. 7-10), from its practice "of operating the nuclear stations with a normal staff complement and avoiding the use of large numbers of attached workers." US practice has sanctioned the use of such attached workers under contract, as a means of spreading radiological burden, but at the cost of a high collective dose. Figures 23 and 24 show the annual collective dose per reactor, and per gross megawatt-year

Table 4

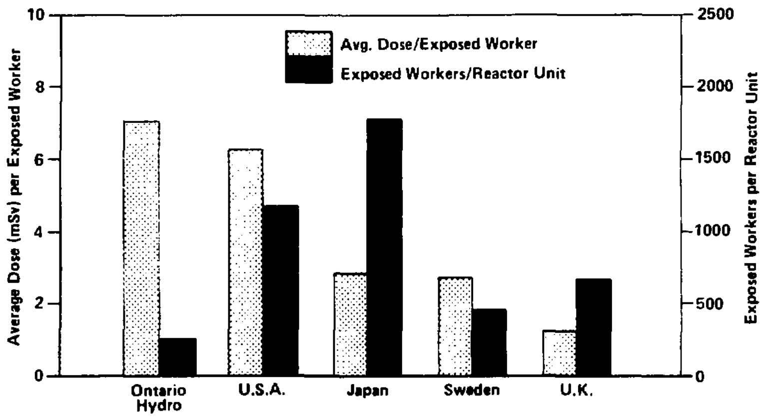
Total Dose Limits for Atomic Radiation Workers,
Ontario Hydro
(April 1987)

	Dose limits (mSv)		
	Whole body	Lens of the eye	Other organs
Any quarter	30	80	300
Whole year	50	150	500

Source: Ontario Hydro (1987c).



Collective Dose Performance



Exposed Workers and Average Doses
(5-Year Average Doses)

Figure 21 Collective radiation dose per reactor unit, average dose per exposed worker, and number of exposed workers per reactor unit, Ontario Hydro, 1980-84, versus performance in other countries.

Source: Ontario Hydro

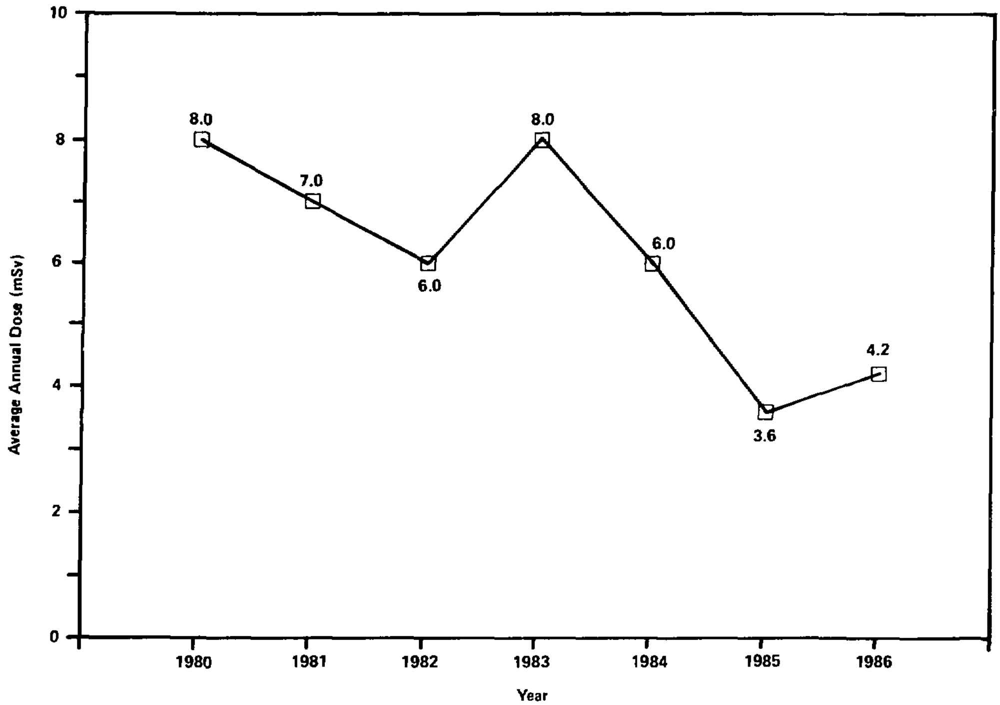


Figure 22 Average annual radiation dose in Ontario Hydro. All workers with measurable dose.

Source: Ontario Hydro

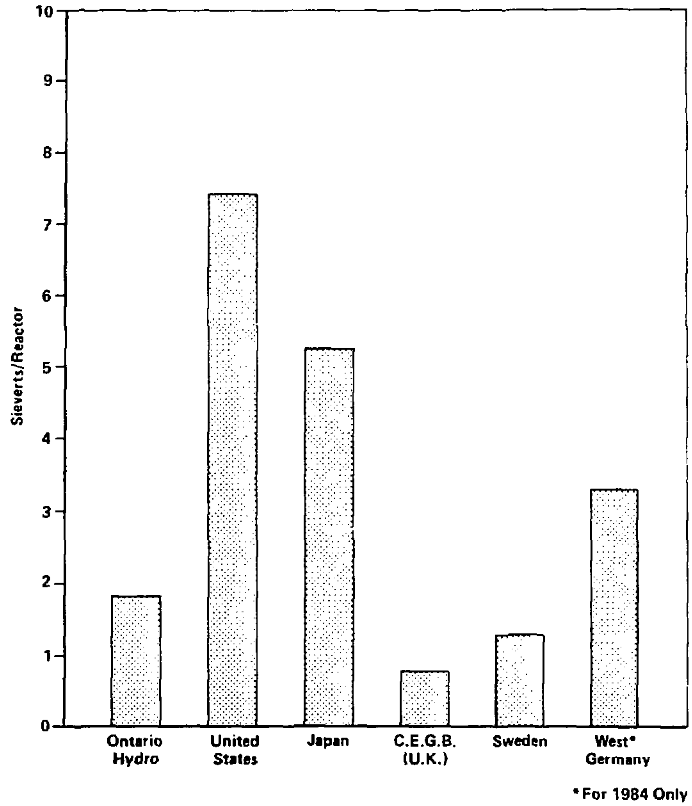


Figure 23 Annual radiation dose (Sv) per reactor, 5-yr average, 1980-84.

Source: Ontario Hydro

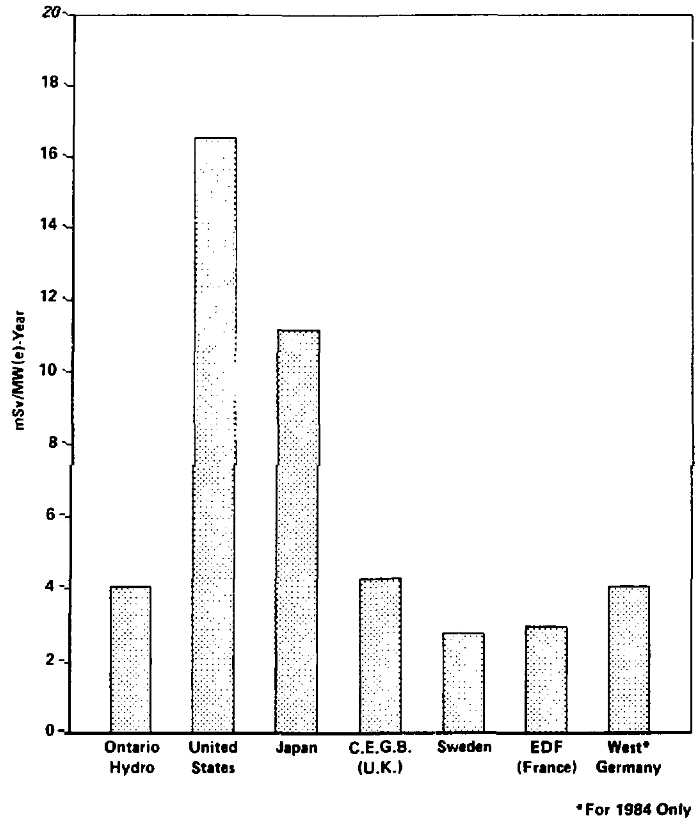


Figure 24 Radiation dose per gross megawatt-year electrical, Ontario Hydro versus various countries, 1980-84.

Source: Ontario Hydro

(electrical). Ontario's performance is respectable, but appears inferior to that of Sweden and France.

229. Individual doses to workers vary between individuals and according to place and nature of the job done. Table 5 shows the number of individuals who have exceeded the regulatory limiting dose, over the whole history of reactor operation. The highest level of whole-body exposure between 1963 and 1986 was 73 mSv (at Bruce A, in 1979). The highest extremity exposure was 1.24 Sv (at Pickering NGS, in 1984). In 1985, during the retubing of units 1 and 2 at Pickering A, one worker received a lung dose above both quarterly and annual limits as a result of exposure to carbon-14 (which presented a serious problem to the crews working in the reactor vault). There have been no whole-body exposures above the regulatory limits at any station since 1979.

230. Figure 25 shows the distribution of lifetime doses of radioactivity among Ontario Hydro radiation workers. Only 94 individuals have accumulated lifetime doses above 300 mSv.

231. These figures are not challenged by those most qualified to do so--CUPE Local 1000--and I accept them as valid. They indicate that Ontario Hydro has done an excellent job of protecting its work-force. Still more is likely to be demanded, however, in the light of new information.

232. It is obvious, however, that these exposures are much larger than is typical of the public, even of those resident near the exclusion fences of the nuclear generating stations. If prolonged exposure to ionising radiation carries with it the penalty of greater proneness to disease, that fact should show up among Ontario Hydro's work-force. The same should be true of AECL employees at Chalk River (and in the nearby town of Deep River, where many AECL staff live).

Table 5

Radiation Exposure in Excess of Regulatory Limits,
Ontario Hydro Work-force, 1963-86

	Whole-body dose		Extremity dose		Skin dose	
Station	1/4 ECY*	ECY	1/4 ECY	ECY	1/4 ECY	ECY
NPD NGS	1	3	0	0	0	0
Douglas Point NGS	16(1)**	6(1)	0	0	0	0
Pickering NGS	13(1)	5(1)	1(1)	1(1)	0	0
Bruce A NGS	3(2)	2(2)	6(3)	3(3)	3	0
Bruce B NGS	0	0	0	0	0	0
TOTAL	33	16	7	4	3	0

* ECY = equivalent calendar year (all exposures are not counted from same starting date).

** Figures in parentheses indicate the number of individuals who exceeded both quarterly and yearly limits.

Source: Ontario Hydro (personal communication), 1987.

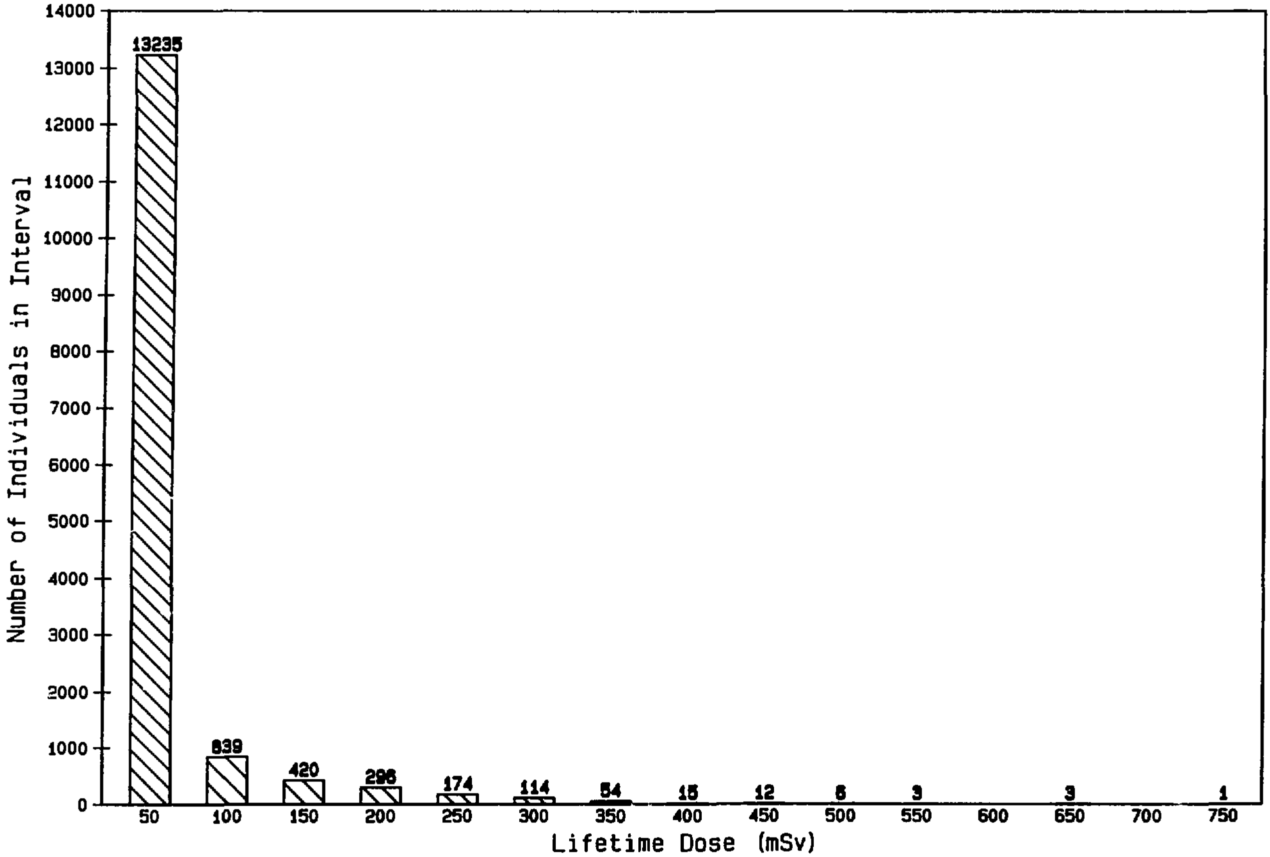


Figure 25 Lifetime radiation dose for all Ontario Hydro exposed employees, as of 31 December 1985.

Source: Ontario Hydro

D. Environmental Releases of Radioactive Substances due to Normal Reactor Operation

233. AECB regulations (which take into account ICRP guidelines) define statutory dose limits for members of the public. From these limits, derived release limits (DRLs) (or derived emission limits [DELs]) are calculated as those levels of release that, if reached, would result in the maximum permitted radiation dose to a member of the public living at the boundary of the facility, considering all environmental pathways of exposure and using very conservative (i.e., erring on the side of safety) assumptions (see Annex III).

234. Table 6 gives the AECB statutory dose limits applicable to the Ontario Hydro reactors for members of the public. In practice, these limits involve summation over all relevant released radioactive substances and over effluents to water and emissions to air. At local sites, pathways must be identified whereby these substances may reach specific human targets (in effect at the exclusion fence over land, and at the property boundary over water). Calculations are then made for each pathway using conservative values of all the input parameters.

235. Table 7 gives station-specific values of the DRLs for Ontario Hydro nuclear generating stations in operation on 31 December 1987.

236. In actual performance, Ontario Hydro's corporate target (as published in the Operating Policies and Principles) at each nuclear generating station is for releases to remain as low as possible, and in any case at or below 1% of the DRLs at all stations. If this target (which derives from AECB guidelines) is frequently or significantly exceeded, the Operating Policies and Principles call for repairs or modifications to equipment to restore matters. In the 1970s, performance at Pickering A and Bruce A was rather erratic. Since 1980, more stable levels have been reported to AECB. In the 1980s, emissions and effluents have generally more than complied (on an annual basis) with Ontario Hydro's own objectives.

Table 6

AECB Statutory Dose Limits for Public

Organ or tissue	Annual dose limits
Whole body, gonads, red bone marrow	5 mSv (0.5 rem)*
Skin, bone, thyroid	30 mSv (3 rem) (1/2 this value for children up to 16 yr)
Other single organs or tissues	15 mSv (1.5 rem)
Extremities	75 mSv (7.5 rem)

* ICRP recommends that this limit be administered so that average lifetime dose should not exceed 1 mSv.

Source: Government of Canada 1985.

Table 7

AECB Annual Derived Release Limits* for
Specified Radionuclides for Ontario Hydro Stations
Operating on 31 December 1987

	Airborne				
Station/ Component	Tritium	Iodine-131	Noble gases	Carbon-14	Parti-culates
Pickering A**	(3.8×10^5)	(0.8)	(8.7×10^4)		(1.9)
	2.7×10^5	4.2	10.4×10^4	2.7×10^3	10.8
Pickering B	2.7×10^5	4.2	10.4×10^4	2.7×10^3	10.8
Bruce A	3.8×10^5	3.3	8.3×10^4	2.1×10^3	8.3
Bruce B	6.1×10^5	3.3	44.0×10^4	2.1×10^3	8.3

	Waterborne		
Station/Component	Tritium	Carbon-14	Gross beta and gamma
Pickering A	6.2×10^5	1.55×10^2	34.0
Pickering B	6.2×10^5	1.55×10^2	34.0
Bruce A	5.3×10^5	1.38×10^2	28.0
Bruce B	5.3×10^5	1.38×10^2	28.0

* All units are TBq/yr except noble gases. (1 TBq = 10^{12} Bq = 27 Ci.) Because noble gases are inert and do not interact with the human body, one can measure the external dose from the mean gamma ray energy per disintegration rate of all noble gas radionuclides present. The unit for noble gases is gamma TBq·MeV/yr.

** At the time that Pickering B emission limits were derived, the limits for Pickering A were reviewed. The result is that new DRLs for gaseous emissions have applied from January 1983 (old numbers in parentheses). The DRLs for liquid emissions remained unchanged.

Source: Ontario Hydro (courtesy G. Armitage), 1987.

237. Figures 26-29 show the annual totals since 1982 of emissions to air of tritium, noble gases, iodine-131, and particulates, in terms of the associated radioactivity, and effluents to water of tritium and gross beta and gamma radioactivity (for carbon-14, see section F below).

238. In every case, the emissions and effluents have been at or below the corporate target of 1% of the AECB-approved DRL. This was not, however, true of NPD at Rolphton, where releases were substantially above target. NPD is now being decommissioned. These data are derived from Ontario Hydro's own monitoring, but can be compared with independent monitoring by the Ontario Ministry of the Environment and the Department of National Health and Welfare.

239. There are no firm statistics concerning actual individual exposures among the Ontario population. These are thought to be small by comparison with natural background radiation levels. It was estimated that in 1984 the total electric generation by Ontario Hydro reactors was 4.7 GWyr, and that this exposed the Ontario population to a collective dose of only 4 person-sieverts (Ontario Hydro, personal communication). Detailed estimates of exposures of individuals around Bruce and Pickering are available by specific radioactive substance (Ontario Hydro 1986b).

240. Even at the exclusion fence around each station, the gamma exposure rates from released radionuclides will usually be obscured by the natural background. Table 8 shows the typical external natural background levels across Canada, as determined by surveys.

241. The exposure of members of the public to radionuclides emitted from nuclear generating stations is also considered small by comparison with home radon and radon daughter exposures. This is believed (AECB 1987b, to be published*) to average 0.5-0.6 mSv in Toronto, although an alternative of 1.0

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* These figures may be raised somewhat before publication. They are regarded as low by several correspondents and are low by comparison with recent US NCRP (1987) estimates. I have added rough overall magnitudes for internal plus external exposures to Table 8, using these sources.

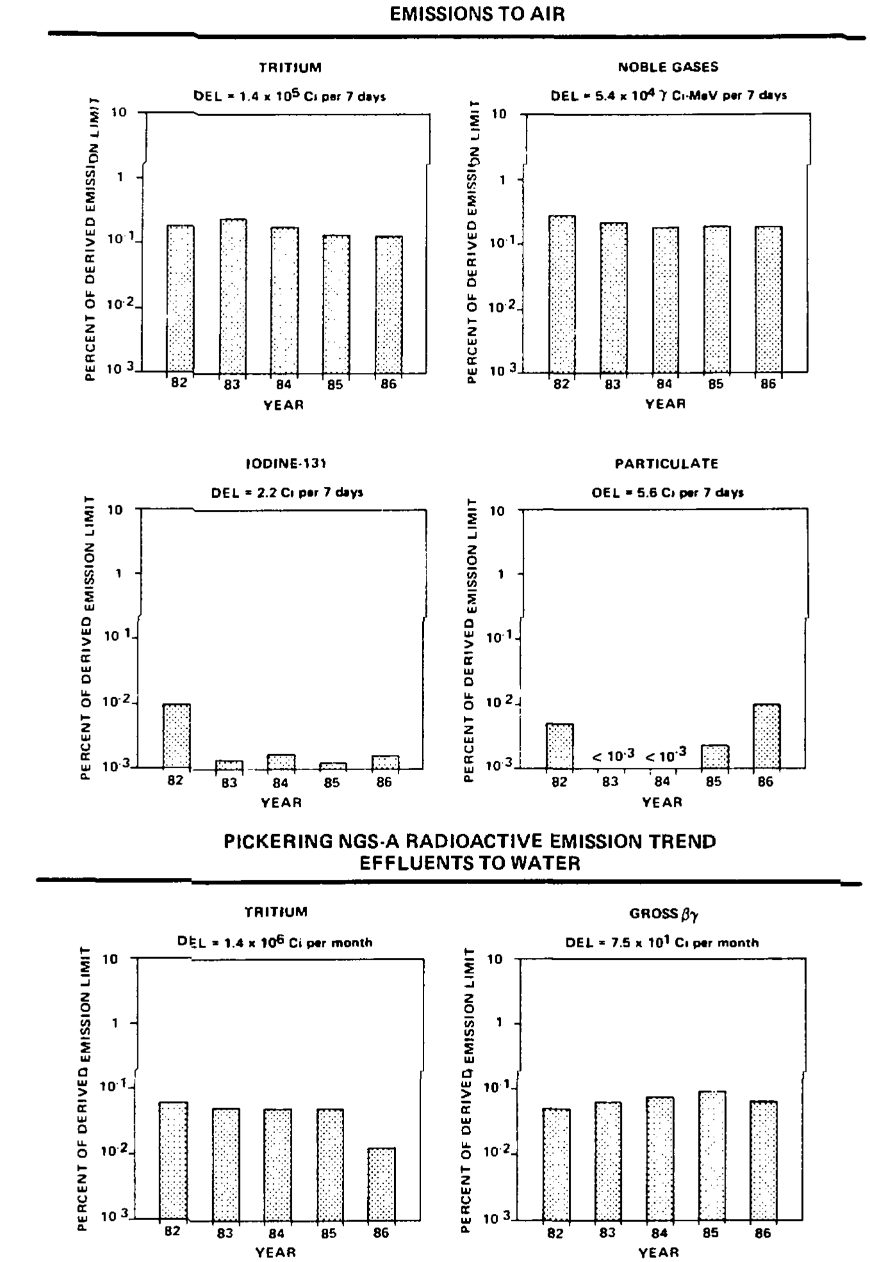


Figure 26 Observed emissions and effluents of radioactive substances, 1982-86, Pickering A.

Source: Ontario Hydro

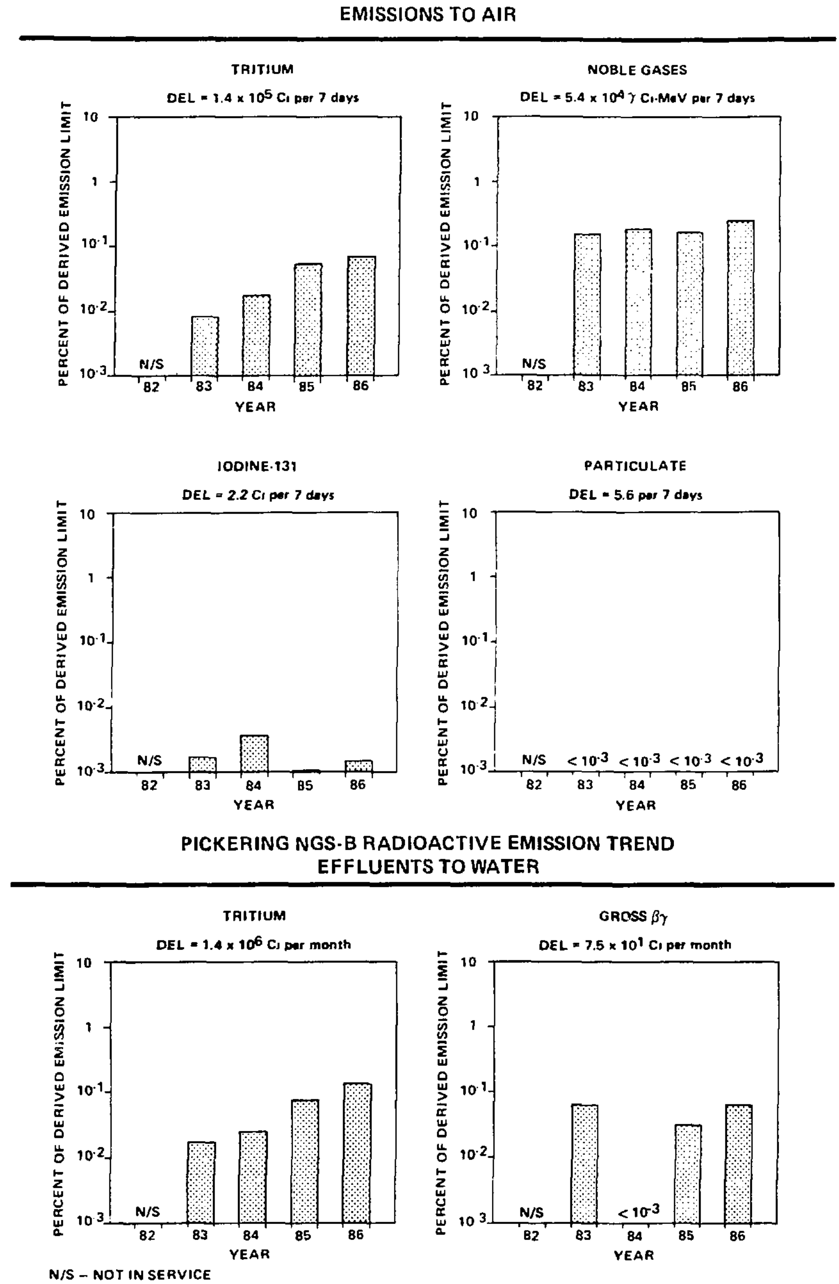
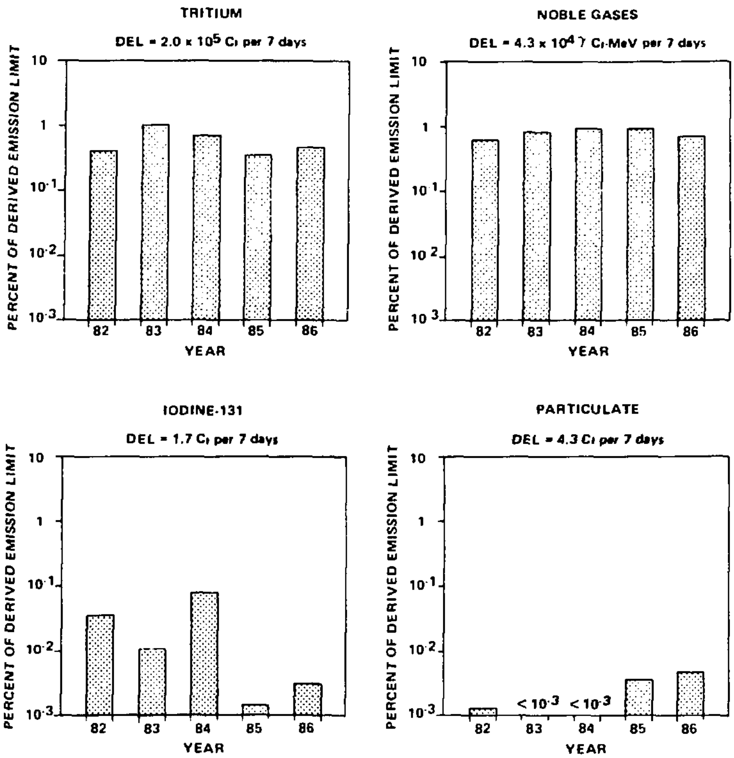


Figure 27 Observed emissions and effluents of radioactive substances, 1982-86, Pickering B.

Source: Ontario Hydro

EMISSIONS TO AIR



BRUCE NGS-A RADIOACTIVE EMISSION TREND
EFFLUENTS TO WATER

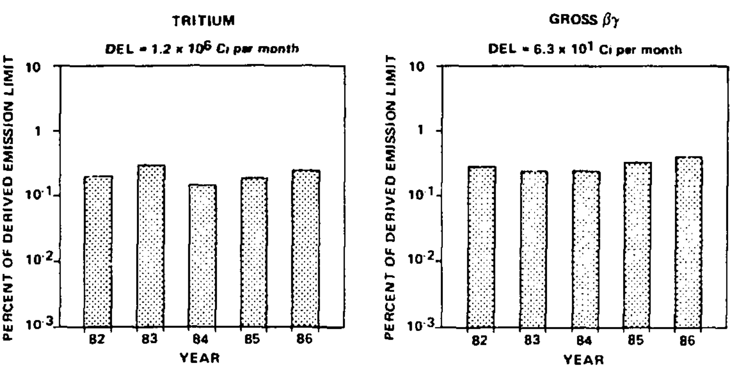
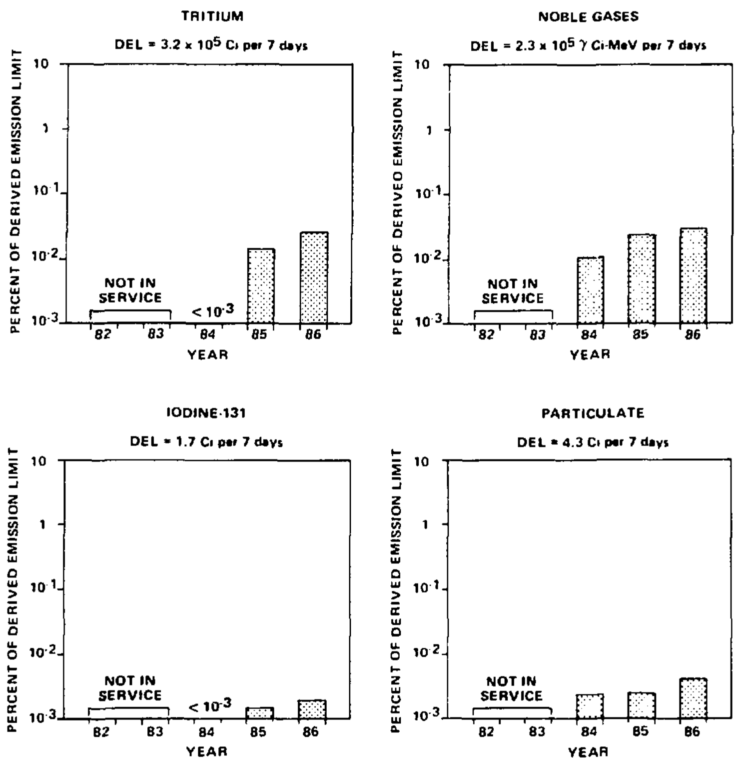


Figure 28 Observed emissions and effluents of radioactive substances, 1982-86, Bruce A.

Source: Ontario Hydro

EMISSIONS TO AIR



BRUCE NGS-B RADIOACTIVE EMISSIONS TREND

EFFLUENTS TO WATER

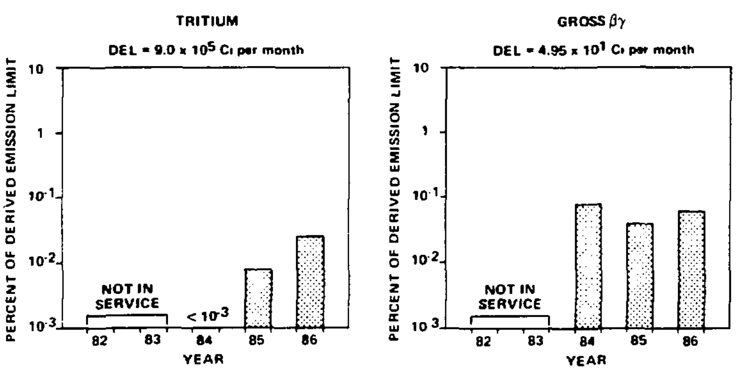


Figure 29 Observed emissions and effluents of radioactive substances, 1982-86, Bruce B.

Source: Ontario Hydro

Table 8

External Background Radiation Doses,
Canada

Locality	Dose (mSv/yr)
Calgary, Edmonton, Toronto	~0.5
Vancouver, Montreal, Halifax	~0.6
Saskatoon, Ottawa, Fredericton	~0.7
Whitehorse, Yellowknife, St. John's	~0.8
Pickering NGS	0.58
Bruce Nuclear Power Development	0.59
In comparison	
Regulated limit of annual dose from NGS emissions, at exclusion fence	5.0
Target maximum level due to radionuclide release, at 0.01 of limiting dose (for persons within 10 km of the exclusion fence)	<0.05
Total dose (for natural external and internal sources) is estimated at	~2 mSv
of which radon and thoron daughters yield	~1 mSv

Source: AECB 1987c; R.V. Osborne, personal communication; US NCRP 1987.

mSv is often accepted for radon and thoron together. Natural background plus radon and thoron daughter exposures thus exceed probable exposures due to nuclear generating station emissions at least 20-fold.

E. Epidemiological Evidence Bearing on Health Impact

242. There is little direct epidemiological evidence bearing on the question: do Ontario Hydro's reactors affect the health of members of the public? There is ample evidence, however, concerning health risks per unit dose. There are also direct studies of present and past employees of Ontario Hydro and AECL, most of whom will have received radiation doses far above those likely to be encountered by the general public. These will be examined in this section, as will some highly relevant work in the United Kingdom. The Canadian studies unfortunately do not extend to children, probably among the most vulnerable persons. Hence, the UK analysis (which does) is of special interest.

243. The dearth of analysis of public exposures and consequent health effects arises from these circumstances:

- only rarely does one find members of the public with a monitored record of radiation exposure;
- exposures to the public are so low under normal operating conditions that additional doses are well within the range of variation of natural background radiation; hence, it is difficult or impossible to measure the added doses or to determine dose-response relationships;
- only at Pickering NGS is there a large enough population close to a reactor installation for meaningful statistical analysis; and
- the high mobility of the Ontario population reduces still further the number of individuals who reside in an area near a reactor long enough to receive an appreciable dose above background levels of exposure.

It has thus seemed pointless to attempt epidemiological analyses of the general population.

244. The Ontario Hydro worker experience has been analysed by T.W. Anderson, Head of the Department of Health Care and Epidemiology in the Faculty of Medicine at the University of British Columbia (Anderson 1986).

245. Table 9 shows Anderson's analysis of cumulative mortality experience among Ontario Hydro workers, active and pensioned, by dose, 1972-85. It shows, as expected, the healthy worker effect: mortality from all causes was lower than in a comparable group of the general population. Deaths from neoplasms (cancers) were two-thirds as great as in the public at large. Anderson warns that the period of record is too short to justify the conclusion that radiation exposure has had no effect on cancer mortality. Except for leukaemia, latency in cancer incidence is typically of the order of one to two decades. Anderson's analysis also shows that mortality from all causes is well below that observed in thermal generating plants and in other Ontario Hydro work situations (where the same standards of staff selection apply).

246. A similar analysis was performed for AECL's exposed workers (by G.R. Howe, J.L. Weeks, A.B. Miller, A.M. Chiarelli, and J. Etezadi-Amoli 1987*). This cohort goes back to 1950 and includes 7548 individuals currently working for AECL and a further 7074 persons who had worked at Chalk River or Whiteshell, but who had left AECL prior to 1 January 1980. Almost 93% of the eligible group consented to the analysis and had records suitable for the study. Results showed that over three decades (1950-81), cancer mortality among males and females alike was lower than in the general population (164 deaths among AECL workers versus an expectation of 189.6 in the general population). Exposed women showed no higher mortality than did men.

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* This report is still in preparation for publication. Weeks is Senior Advisor on Health and Safety at WNRE, AECL. Howe, Chiarelli, and Etazadi-Amoli are members of the Epidemiology Unit of the National Cancer Institute (Howe is Director of the Unit), and Miller is Professor, Department of Preventive Medicine and Biostatistics, University of Toronto.

Table 9

Ontario Hydro Work-force
Cumulative Mortality Experience, by Dose:
1972-85

Effect		Dose* (mSv) 0	0.01-49	50-99	100-149	150-199	200+	Total
Neoplasms	Obs	8	10	4	2	3	1	28
(cancers)	Exp	11.31	21.34	2.74	2.18	1.66	2.56	41.79
	SMR	(71)	47	(146)	(92)	(181)	(39)	67
Circulation	Obs	12	24	1	1	1	3	42
(heart,	Exp	19.26	36.03	4.50	3.65	2.79	4.38	70.61
stroke, etc.)	SMR	61	67	(22)	(27)	(36)	(68)	59
Accidents	Obs	10	16	5	1	0	2	34
(all types)	Exp	15.83	28.19	4.51	2.82	2.15	2.58	56.08
	SMR	63	57	(111)	(35)	(0)	(78)	61
All other	Obs	2	5	0	0	2	0	9
causes	Exp	8.83	16.43	2.34	1.82	1.35	1.97	32.74
	SMR	(23)	(30)	(0)	(0)	(148)	(0)	(27)
Total	Obs	33	54	10	4	7	5	113
(all causes)	Exp	55.23	101.99	14.09	10.47	7.95	11.49	201.22
	SMR	60	53	71	(38)	(88)	(44)	56

* Observed (Obs) and expected (Exp) deaths, and standardised mortality ratios (SMRs), in all male employees of Ontario Hydro (active pensionable and pensioned, combined) from 1972 to 1985 whose names appear in the radiation dose register; by cumulative lifetime dose. Expected figures are age-adjusted by 5-yr age groups and are based on general male mortality rates in Ontario during the inter-census periods 1971-76 and 1965-81. SMRs express observed as a percentage of expected and have been put in parentheses where based on less than 10 observed deaths.

Source: Anderson 1986.

247. A recent analysis of CRNL (AECL) employees by M.M. Werner and D.K. Myers (1986) confirms and extends this result. The analysis included mortality among those who participated in the clean-up after the accidents at the NRX and NRU reactors, and among all employees whose lifetime dose equalled or exceeded 200 mSv.

248. Table 10(a) shows the mortality record among male AECL employees or retired staff between 1966 and 1985. There were 119 cancer deaths versus an expectation of 128 in the general population. Among female workers (not shown), there were six observed deaths versus an expectation of seven. Table 10(b) shows a breakdown of the overall mortality into 5-yr periods. There was a steady rise in standardised mortality ratio* (SMR) from 1971-75 to 1981-85, which might indicate the realisation of latent cancers. But none of these ratios is significantly different from unity, and hence no final conclusion can be drawn. This is also true of the cancer deaths among those who participated in the NRX-NRU clean-ups, and of the 19 deaths among employees with a lifetime dose of 200 mSv or more. In each case, the SMR is less than unity, indicating less mortality among the nuclear workers than in the general population, but the result is not statistically significant.

249. As with Ontario Hydro workers, the AECL cohort (which dates back more than three decades) shows few disquieting features. Cancer mortality, even among AECL's most exposed groups, appears, if anything, to be lower than among the general public, although the apparent rising trend since 1971-75 will have to be watched.

250. Can conclusions be drawn from epidemiological studies elsewhere? There is a small group of workers, chiefly in the United States, who claim to find such anomalies around many US installations, or among the work-force, and who look for them in other countries. Most other investigators, however, find no such association. A compilation carried out at a conference organised by the British Nuclear Energy Society (1987) showed leukaemia SMRs among radiation-exposed

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* Ratio of actual to expected deaths.

Table 10

(a) Mortality Among Male CRNL Employees who Died During Employment or After Retirement, 1966-85

Causes of death	Observed	Expected	SMR*
Cancer	119	127.7	0.93 (0.77-1.11)
Cardiovascular diseases	237	262.7	0.90 (0.79-1.02)
Violent causes	28	46.7	0.60** (0.40-1.0)
All other causes	68	90.8	0.75** (0.59-0.96)
All causes	454	527.9	0.86** (0.78-0.94)

* Standardised mortality ratio. The numbers in parentheses represent the 95% confidence limits on the SMR.

** Value is significantly lower than 1.0 as judged by the 95% confidence limits.

(b) Standardised Mortality Ratios for Major Causes of Death, Males, 1966-85, by 5-yr Intervals

Causes of death	1966-70	1971-75	1976-80	1981-85
Cancer	0.95	0.72	0.89	1.07
Cardiovascular diseases	0.85	0.78	1.15	0.81
Violent causes	0.59	0.68	0.61	0.52
All other causes	0.36	0.80	0.87	0.84
All causes	0.76	0.76	0.99	0.88

Source: Werner and Myers 1986.

workers below unity at seven out of eight major US plants (including two producing plutonium) and at two UK plants (one producing plutonium). The conference proceedings, not yet available in detail, will contain an overview of occupational exposures in most of the industrialised countries. These results are comparable with limited Canadian experience with occupational groups--but say nothing about conditions among the public in surrounding areas.

251. The most thorough analysis of public exposures seems to be that by Forman et al. (1987), of the Imperial Cancer Research Fund Epidemiology and Clinical Trials Unit at the Radcliffe Infirmary, Oxford. The analysis considered a very large number of persons exposed near UK nuclear installations over a 22-yr period. It showed conclusively that there had been no general increase in cancer mortality near the pre-1955 installations. The work involved study of the general population of all the Local Authority Areas within 16 km of these plants. The study did show, however, a significant increase in lymphoid leukaemia among persons aged 0-24 within 13 km of pre-1955 installations. There was also a suggestion of slightly increased mortality due to multiple myeloma and Hodgkin's disease among those aged 25-74.

252. D.K. Myers (personal communication) pointed out that lymphoid leukaemia is not the form of that disease most commonly associated with radiation exposure, and that there was no increase in myeloid leukaemia in the sample. He concluded that this anomaly "does not suggest a causal link with emissions of radioactive material from the nuclear installations." Forman et al. (1987) also suggested (with respect to the small number of significant associations they had found) that "several of the differences were most likely to be due to chance, diagnostic or social factors rather than to any hazard specifically related to the installations."* They felt, however, that the leukaemia excess among the group aged 0-24 was an exception and required further examination.

253. What useful parallel studies might be supportable in Canada? We do not have the dense populations typical of the United Kingdom, nor do we have their

* For a contrary view, see Crouch 1987.

intricate network of census divisions and public health data; our aggregations are larger. Only two communities suggest themselves as possible sites for such analysis: Pickering and surrounding communities, and Deep River. I understand that discussions are in progress between Ontario Hydro and the University of Toronto for a study of leukaemia admissions at the Hospital for Sick Children in Toronto. Given the low doses involved, however, it will be from analyses more tightly focussed on the nuclear generating station perimeters that evidence of any association with radioactive materials, or the lack of it, will emerge. The ACRP/ACNS (Advisory Committees on Radiological Protection and Nuclear Safety) joint subcommittee on regulatory research has indeed recommended to AECB that it should fund a feasibility study on this topic in 1988. This feasibility study will presumably consider the size of populations available for study, the sizes of population needed to get statistically significant data, population mobility, other confounding factors, and estimated costs. I strongly support this initiative.

F. The Carbon-14 Question

254. Because of their technical characteristics, CANDU reactors produce (and also emit) two radioactive substances at rates far exceeding those of other reactor types. These are tritium, which was discussed above, and carbon-14. The latter requires further discussion.

255. Carbon-14 is a very weak beta radiation emitter. It occurs in the natural atmosphere and is present in all the air we breathe (and in solution in all water). It is also present in food. Natural carbon-14 is formed in the upper atmosphere when nitrogen-14 (the main constituent of the atmosphere) encounters cosmic ray neutrons from space. After a transition, the species becomes carbon-14. It has a half-life of 5730 yr. Because it forms part of all living tissues, dead organisms contain a steadily decreasing fraction. This fact has formed the basis of the method of calculating the age of organic remains from the past 50 000 yr--an innovation by Willard F. Libby (1952) that

transformed the work of archaeologists, climatologists, and biblical scholars, among others.

256. In CANDU reactors, carbon-14 is produced in three ways (see Figure 30):

(i) Neutron activation of nitrogen-14 in the gas annulus separating each pressure tube at Pickering A from its surrounding calandria tube produces carbon-14, which escapes to the atmosphere (see Table 7 for the governing DRL). All subsequent reactors use ordinary carbon dioxide as annular gas. This reduces the problem. At Pickering A, carbon dioxide has replaced nitrogen as annular gas in units 1 and 2. Units 3 and 4 will be similarly treated.

(ii) Very small amounts of carbon-14 are formed by neutron activation in the fuel (not as a fission product) and coolant (which is heavy water).

(iii) Larger amounts are formed by neutron activation of oxygen-17 in the moderator. The activated oxygen-17 decays (after emitting an alpha particle) to carbon-14. There is also some activation in the moderator of stable carbon-13, which becomes carbon-14. About half the moderator carbon-14 is emitted to the atmosphere (within the DRL), and the rest is retained in ion-exchange resins that filter the heavy water.

257. With the removal of nitrogen-14 from the annuli of Pickering's fuel channels, the moderator becomes to an even greater extent the source of carbon-14. Measurement and capture of this element have been difficult. Figure 31 shows that CANDU reactors produce far more than do foreign reactors. Even the removal of half of Pickering A's emissions leaves the releases quite large--about 10 times that due to light-water reactors (LWRs).

258. Figure 32 shows that Ontario Hydro's reactors will in fact be the largest single source for this long-lived radionuclide in the atmosphere, even on the world scale. There is, however, another side to this. Nuclear Awareness Project (in its brief) recommended that collective doses to the entire human population

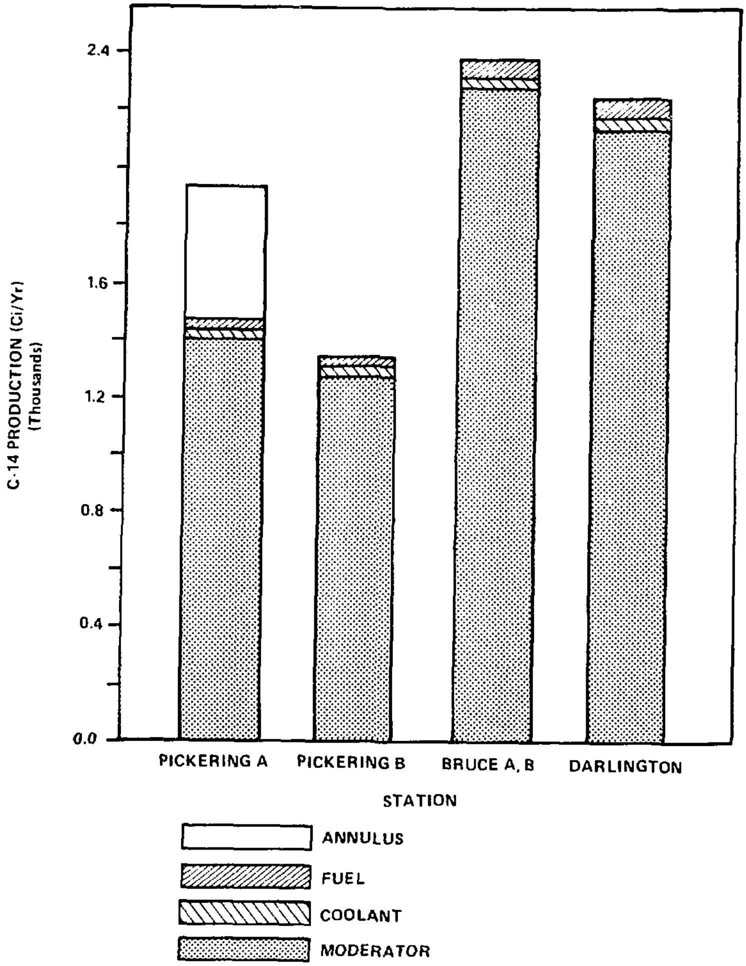
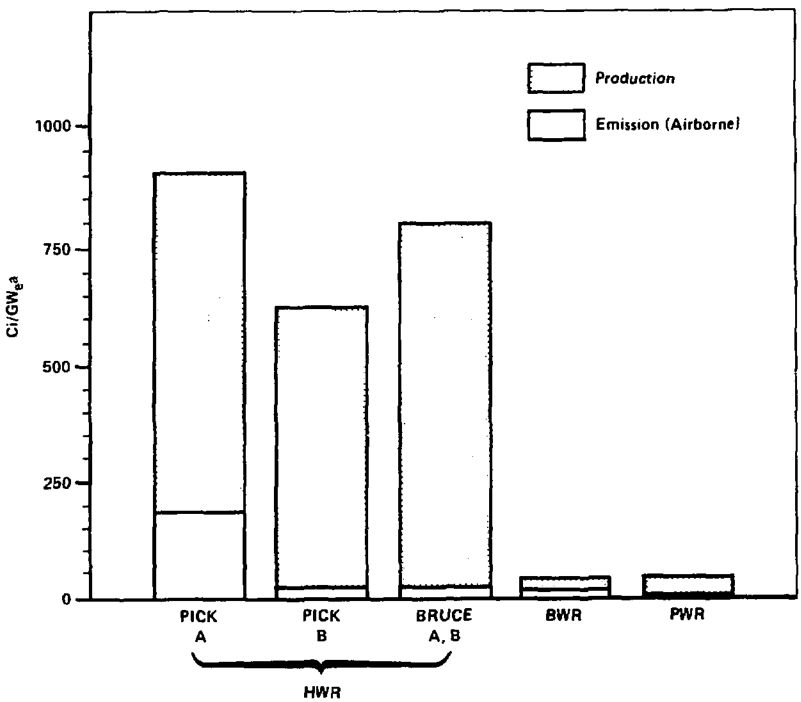


Figure 30 Calculated production of radioactive carbon-14 by station, showing origins within reactors.

Source: Ontario Hydro



HWR = HEAVY WATER REACTOR
BWR = BOILING WATER REACTOR
PWR = PRESSURISED WATER REACTOR

Figure 31 Comparison of carbon-14 production per unit energy produced, Pickering and Bruce reactors versus pressurised water reactors (PWRs) and boiling water reactors (BWRs) in other countries.

Source: Ontario Hydro

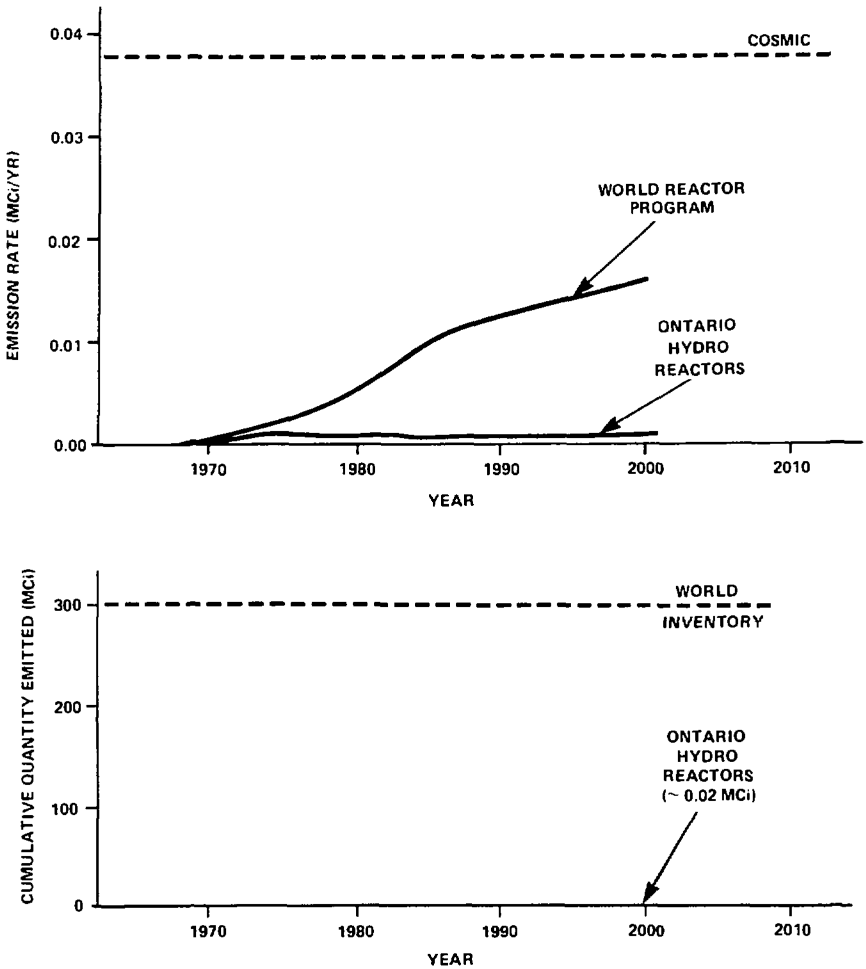


Figure 32 Carbon-14 emission trends to AD 2010. Upper diagram compares Ontario Hydro's output with that expected from overall world reactor use. Lower diagram shows the world inventory of carbon-14, mostly in the oceans. Total Ontario Hydro output is clearly very small in comparison.

Source: Ontario Hydro

should be calculated out to the effective limit of the species' radioactive life.* This demand is reasonable enough on environmental grounds. But a countervailing view arises from the fact that the natural concentration of carbon-14 has been considerably reduced by fossil fuel burning (currently at about 5 billion--5 x 10^9--tonnes of carbon per year). The carbon-14 from power reactors is hence entering an atmosphere being progressively impoverished in the natural constituent (because the burning of coal, oil, and natural gas releases no carbon-14). Ontario Hydro's contribution will amount to 0.1% of the world inventory, most of which is actually in the ocean. As a weak beta emitter, carbon-14 adds little to the normal exposure of the human body. Food is the chief route of ingress. The body contains a carbon-14 concentration similar to present levels in the atmosphere. Naturally produced carbon-14 contributes about 0.01 mSv/yr to the individual dose.

259. At Pickering A, however, considerable problems were encountered during the retubing of units 1 and 2, where carbon-14 from the annular gases raised concentrations in working areas well above the acceptable level for industrial exposure. All the repair work has hence been performed by crews who have had to wear special protective clothing and to rely exclusively on piped external air supply for breathing and ventilation. I can testify from personal experience that this work has been done under conditions of considerable difficulty.

G. Monitoring

260. I asked Science for Peace (D. Paul and B. Southern) to review the systematic monitoring of radioactivity in the Ontario environment. Four agencies routinely carry out such monitoring: Ontario Hydro, the Department of National Health and Welfare, the Ontario Ministry of Labour, and the US Department of Energy. Table 11 shows the radionuclides sampled by each and the thermoluminescent dosimetry dose by AECL. None of this monitoring is both continuous and truly external environment, as it should be. The spatial coverage is

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* This would involve at least 57 300 yr, 10 half-lives.

Table 11

Radionuclides Monitored by Various Agencies
in Ontario

Organisation	Air filtering	Precipi-tation	Tritium	Iodine	TLD*
Ontario Hydro	Yes	Yes	Yes	Yes	Yes
Department of National Health and Welfare	Yes	Yes	Yes	Yes	Yes
Ministry of Labour	Yes	Yes	Yes	Yes	Yes
AECL	No	No	No	No	Yes
Ministry of the Environment	No**	No	No	No	No
US Department of Energy	Yes***	No	No	No	No

* TLD = thermoluminescent dosimetry dose.

** Air filtration is done routinely for chemical pollution monitoring.

*** Only parameters monitored.

Source: Science for Peace brief, D. Paul and B. Southern.

good in relation to the distribution of the nuclear generating stations. Paul and Southern comment on the fact that there is a huge inventory of unexamined air filters resulting from the Ontario Ministry of the Environment's air pollution control programme.

H. Relative Sensitivity of Women to Radiological Hazards

261. The brief of the Queen's University Women's Centre followed IICPH and Rosalie Bertell in expressing dissatisfaction with the ICRP and AECB procedures in setting dose limits and recommended that more research be done by people outside the industry. It emphasised the value of work on non-lethal effects of exposure, and of better knowledge of background radiation. It urged that dose limits be pushed downwards. The authors reviewed the epidemiological evidence and concluded that: "the higher susceptibility of women to radiogenic cancers . . . must be acknowledged, and risk estimates and calculations within the nuclear industry must reflect this."

262. I agree with the latter conclusion, but feel that the authors underestimate the extent to which the industry already does this. I also agree that future nuclear reactors, if any are built, should avoid nearby metropolitan areas, to minimise exposure. I wish I could agree with the authors when they urge the monitoring of exposure among the general population. Such levels are bound, however, to be obscured by the background, and only difficult research techniques, sure to be unwelcome to the subjects, can disentangle the received extra doses from the background doses.

263. I also agree that women's extra risk is due in large part to the susceptibility to breast cancer. I am informed (R. Osborne, personal communication) that although the recent examination of Japanese bomb victim data has lowered risk factors for most specific cancers, it has sharply raised that for breast cancer. These risk factors are all approximate at the low exposure levels experienced in reactor buildings, but the reality of this extra hazard is not in doubt.

264. I agree with CUPE Local 1000 in its expressed view that exposure levels among atomic radiation workers should be set low enough to permit both sexes to work alongside one another throughout the nuclear generating stations. But this does not alter the greater susceptibility of women. Moreover, the added risks to the foetus during certain stages of pregnancy cannot be disregarded. I conclude that a woman should choose to enter this particular career path only if she has full access to information about the small but finite risks involved, to herself and possibly to her children.

265. Thirty years ago, ICRP recognised that special measures were necessary to protect the foetus because of its extra sensitivity to radiation. Because it was postulated that young women who were sexually active might be pregnant without knowing it, more restrictive limits were prescribed for "women of reproductive age." To operate within this limit, it was easiest for employers such as Ontario Hydro to decide that they would not designate any women as atomic radiation workers. This denied women access to certain jobs in Ontario Hydro and was perceived as a violation of human rights. It formed the basis of a court action, and the administrative rules of Ontario Hydro are now changed.*

I. What Does ALARA Mean?

266. The ALARA principle--that exposure to radioactivity should be as low as reasonably achievable, social and economic factors being taken into account--was enunciated by ICRP in its Publication No. 26 in 1977. In effect, ICRP sets dose limits and then tells the world's utilities that it is specifying only a minimum standard; they must judge how much better they can do, given the circumstances in which they find themselves. It is far from being a recent idea: in my own childhood I recall that road safety objectives in my native county were specified in similar terms.

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* The substance of this paragraph was provided by G.C. Butler, Canada's former ICRP representative.

267. But what is reasonable, in the Ontario context? And precisely which social and economic factors should be taken into account? This is a very rich society, which can afford the highest standards of safety. How should these standards be established? It has been AECB practice to suggest a formula that provides the working answer: that Ontario Hydro should generally aim at, for example, DRLs for radioactive materials at only 1% of the limits likely to satisfy ICRP effective dose limits. Many countries and many utilities aim at this target. Ontario Hydro meets it and beats it at most stations. Does this answer to the ALARA principle?

268. When I posed these questions to various individuals involved in the nuclear industry, I got confusing answers. One eminent designer told me that in many years of dealing with AECB, the ALARA principle had never influenced the decisions taken and had only rarely been mentioned as a factor. Another professional said that ALARA was crucial to his duties in the radiological area: that radiological work planning, so as to minimise both individual and collective doses, was a never-ending exercise in ALARA. The falling average whole-body radiation dose of Ontario Hydro employees (see Figure 22) is, in this view, proof that ALARA is an active principle, because regulations did not change during most of this period.

269. Layfield (1987) exhaustively reviewed this entire question in the Sizewell B Inquiry in the United Kingdom. Like me, he had encountered wide confusion as to the meaning, purpose, and methods of ALARA, as regards social costs and benefits, and also in relation to design principles. Layfield's conclusion, voiced while he was a member of the Review Panel, is that ALARA may defy ready articulation, but is nevertheless crucial in that it provides a consistent mode of thought--an excellent discipline for those who must make decisions.

270. In Ontario Hydro's case, I am satisfied that ALARA has been both a useful discipline and an active principle in decision making. But the weighing of cost and benefit never ceases. The problem arose, for example, in the question of a second shut-down system at Pickering A. Was it worth investing a large sum of money and incurring substantial worker radiation exposure to increase safety

marginally? The probability that a second shut-down system would ever be needed to prevent a serious accident was judged to be extremely low. A much greater gain in safety could be achieved by investing the same amount of money and worker exposure in areas where the threat to safety is higher.

271. This kind of cost-benefit and risk-benefit analysis can be quantified and applied as a formal discipline. Doing so involves assigning values to human life, health, and injury in a fashion unwelcome to many.* It also leads directly to a mechanism for making comparisons with other modes of energy production (or its avoidance, for energy conservation is in many ways a form of production). Such choices confront the province now.

272. If ALARA is a useful discipline when wise people use it, it may also become a counter-productive weapon. If applied without discretion, it may lead (Layfield 1987, p. C35-8) to ratchetting--an inevitable increase in safety standards, whether or not this is justified. "As a result," wrote Layfield, "national resources may be misallocated towards nuclear safety, and the economics of nuclear power may be unreasonably handicapped."

273. In brief, I accept the view that safety measures in Ontario reactors should continue to be based on this principle, subject to the vital proviso that what is reasonable and what is achievable should both be subject to periodic review and public scrutiny. If an Ontario Advisory Council on Health and Safety is established, as I very much hope, I should regard such reviews as being permanent agenda items--as they already are in AECB. I have formally proposed (Recommendation 12) that Ontario create such a Council, with a broad mandate to encourage wide public debate on those and other issues, and with the staff and resources to carry out its programme.

274. My Advisory Panel pointed out to me that my own treatment of the safety issue did not treat the question of the relative safety of nuclear power versus alternative sources, nor did it treat the question whether its use was justified by

* In Canada, the leading practitioner has been Ernest Siddall (for a statement of the philosophical position, see Siddall 1985).

social and economic factors. I accept these criticisms, having taken the view that these questions were beyond my mandate, and also beyond my current powers. ALARA calls for such comparisons, but in this sense I did not apply the ALARA principle to my own work.

Chapter VI

Safety and Accident Analysis

A. Introduction

275. Public fears about reactor safety focus on three central points: fear of accidents, fear of high-level radioactive wastes, and fear of radioactive emissions from the stations. The most obvious anxiety is about severe accidents.

276. The public is clearly unaware of the major effort made by the industry, and by Ontario Hydro in particular, to quantify the risks inherent in accidents (even those not expected to occur), in three distinct contexts:

- the justification of design (to show that future reactors will be built to adequate safety standards);
- the validation of operating methods (to show that normal operations will not imperil the public); and
- the prediction of the consequences of accidents.

Much of the effort and a substantial part of the costs of nuclear power go into such safety and accident analysis.

277. To provide background, I asked two authorities to write an overview of the Canadian approach to this question. J.A.L. Robertson (formerly of AECL) and D.G. Hurst have complied, and Appendix IV presents their work. Hurst is the former Chairman of the Senior Advisory Group of IAEA and a former President of AECB. The long series of Safety Guides published by IAEA owes much to his leadership.

278. Among helpful sources, Layfield provides an excellent account of the techniques of analysis available, and of their application to the specific problems of a PWR at Sizewell, in England (Layfield 1987, section 5). Fraser (in Appendix II.D) goes into considerable detail on the technical methods used in safety analysis in Canada. Several intervenors offered helpful commentaries (notably

Peter Brogden, Friends of the Earth, Nicholas Teekman, and the Department of Clinical Epidemiology and Biostatistics at McMaster University). In addition, we retained numerous consultants, among whom were D.J. Burns, D.J. Diamond, Institute for Resource and Security Studies (G. Thompson), R.E. Jervis, S.C. Lonergan and R. Goble, D.O. Northwood, J.T. Rogers, and K.J. Serdula. Finally, Ontario Hydro's safety analysts (notably R.A. Brown) provided us with invaluable help, as (under contract) did Argonne National Laboratory.

B. Canadian Methods

279. Within Canada, the clearing-house for these ideas and methods has been AECB, and especially (in recent years) its ACNS. They have evolved in relation to specific major events, e.g., the licensing of Pickering, Bruce, and Darlington as the sites of multi-unit generating stations. Thinking has changed considerably during this time. A critical review of this process was offered by Nuclear Awareness Project in its brief.

280. To a large extent, the pattern of safety analysis has been affected by the powers available to AECB in its role as licensor of all nuclear reactors in Canada. AECB exercises its powers in relation to two primary events: the granting of a construction approval for a reactor project; and the granting of an operating licence (renewable every 2 yr thereafter). In practice, several further steps are required. These include:

(i) a procedure for site acceptance, for which a Site Evaluation Report is prepared, in which economic, environmental, demographic, and geographic data are amassed by the proponent. AECB defers judgement on non-nuclear matters to other federal and provincial agencies.

(ii) a Preliminary Safety Report prepared by the proponent, a document in which quantitative safety analysis is carried to the point where AECB thinks that no further basic design change will be needed. Construction approval follows AECB analysis.

(iii) a final Safety Report, which has to be submitted prior to the issuance of the operating licence, in which safety analysis is used to show that the plant as built conforms with AECB regulations, and to seek AECB's agreement that public safety is adequately protected.

281. Throughout the lengthy period between conception of a reactor project and its entry into service, there is continuous interaction between AECB and Ontario Hydro. The procedure is defined in a series of AECB regulatory and consultative documents that make baffling reading to a stranger to the process. (One such stranger, John F. Ahearne, a consultant, referred to the regulatory process in Canada as a family affair.) Central to the procedure is the use of quantitative safety and accident analysis.

282. George Laurence encapsulated the basic ideas in the document "Reactor Siting Criteria and Practice in Canada," Document AECB-1010, published in 1965, and the basis for the Pickering A project. As revised in 1972 (Hurst and Boyd 1972a), the procedure calls for the analysis of the consequences of single failures (in process systems) and dual failures (one failure in a process system and one in a special safety system, with the changes being rung around all conceivable combinations). Out of this requirement has emerged the system of analysis now used in the siting, construction, licensing, and operation of nuclear reactors.

283. Safety and accident analysis is quantitative and mathematical. This does not deny the importance of qualitative judgement. The underlying assumption is the typical engineering and scientific view that one has a duty to be as quantitative as possible, and to make final judgements only after consideration of the best numerical estimate that is possible. In the end, quality--i.e., value-based judgement--must have precedence.

284. Numbers enter the process of safety analysis in several ways, including these:

- because certain inputs are defined in terms of specific frequency (e.g., that the sum of all process system failures should not be more frequent than one in 3 yr [~3 x 10^{-1}]; or that dual failures should not occur more often than once in 3000 yr [~3 x 10^{-4}]);

- because the upper limit of the frequency of failure of particular parts of the reactor system must be specified, wherever possible, in actual observed frequencies (e.g., frequency of a valve failure); and because the values of physical parameters like temperature and pressure are also in numerical form; and
- because the object of the analysis is to show that the calculated maximum radiological doses to the most exposed individual and to the total exposed population are less than certain reference dose limits for accident conditions specified (in numerical terms) by AECB.

285. Table 12 shows the operating dose limits and reference dose limits applied by AECB to such analyses. Obviously, value judgements have already entered the analysis. The dose limits, for example, were chosen "as those judged tolerable for a 'once-in-a-lifetime' emergency dose." The dose chosen for the dual failure situation corresponds (using ICRP's dose-response risk factors) to "about a 0.1 per cent increase in the lifetime incidence of cancer in a population of a million people."

286. Obviously, then, safety analysis is a series of sums done with numbers whose values were, in the first instance, chosen because they were assumed tolerable to the public. The basis for judgement was debate among the members of the nuclear profession, the AECB Board and staff, and a comparison with what seems tolerable elsewhere. The regulating agency has to work in such cases with no help from the legislator. Our political system passes down the responsibility of deciding what is tolerable risk to the scientific and technical community.

287. Several of our intervenors objected to the simplistic logic of these early procedures, echoing what was often admitted and said by AECB, Ontario Hydro, and AECL spokesmen--that cross-linked failures were possible; that not all so-called common-cause or common-mode failures were adequately catered for; that danger did not end with the initial event; and that numbers somehow misled.

Table 12

Operating Dose Limits and Reference Dose Limits
for Accident Conditions

Situation	Assumed maximum frequency	Meteorology to be used in calculation	Maximum individual dose limits	Maximum total population dose limits
Normal operation		Weighted according to effect, i.e., frequency times dose for unit release	5 mSv/yr whole body 30 mSv/yr to thyroid	100 person-Sv/yr 100 thyroid-Sv/yr
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 mSv whole body 30 mSv to thyroid	100 person-Sv 100 thyroid-Sv
Process equipment failure plus failure of any special safety system (dual failure)	1 per 3000 yr (Pickering A) 1 per 1000 yr (all others)	Either worst weather existing at most 10% of time or Pasquill F condition if local data incomplete	250 mSv whole body 2500 mSv to thyroid	10^4 person-Sv 10^4 thyroid-Sv

* A meteorological measure of the conditions for dispersal of contaminants.

Source: AECB 1983.

Recent practice has hence evolved towards two more sophisticated models. The first of these is the so-called safety design matrix, which makes possible a longer-term view and allows analysis of interdependencies. Introduced in 1975, and since greatly elaborated, this innovation depends on the notions of event sequence analyses, fault trees, and other concepts emerging from the developing applied science of risk analysis, which has since evolved much further. In the wake of the celebrated Rasmussen (1975) study of reactor safety in the United States, which was criticised but widely imitated, the nuclear safety analysts have moved towards probabilistic risk assessment (PRA), in which an elaborate calculus is developed that enables statistical risk parameters to be combined in a strikingly apposite fashion. This technique is being applied by Ontario Hydro (with AECB agreement) to the Safety Report for Darlington NGS (which was submitted to AECB late in 1987). Figure 33 gives some idea of the system of evaluation.

288. These analyses serve many purposes--but not that of persuading the public. They are abstruse, heavy, jargon-laden things even after the computer output has been translated into prose in the Safety Report. They are technical models, serving technical purposes--the chief of which, however, is the non-technical objective of satisfying AECB that a licence should be issued. Evolving technique makes such demonstrations progressively more realistic. Thus, a main purpose of PRA (which Ontario Hydro calls Probabilistic Safety Evaluation [PSE]) is to identify realistic accident sequences that should be analysed in the Safety Report--instead of analyses of pre-determined accidents. The important thing, according to R.A. Brown (personal communication), is to examine rigorously the design for potential failure modes, to identify the dominant risk sequences, and then to attempt to reduce the risk by working on those dominant sequences.

289. A second purpose or by-product of the fulfillment of the licensing requirement is that good safety analysis is an obvious guide to the design and operating practices of the utility. It is Ontario Hydro's practice to update the Safety Reports on its reactors with this in mind, so as to learn from experience.

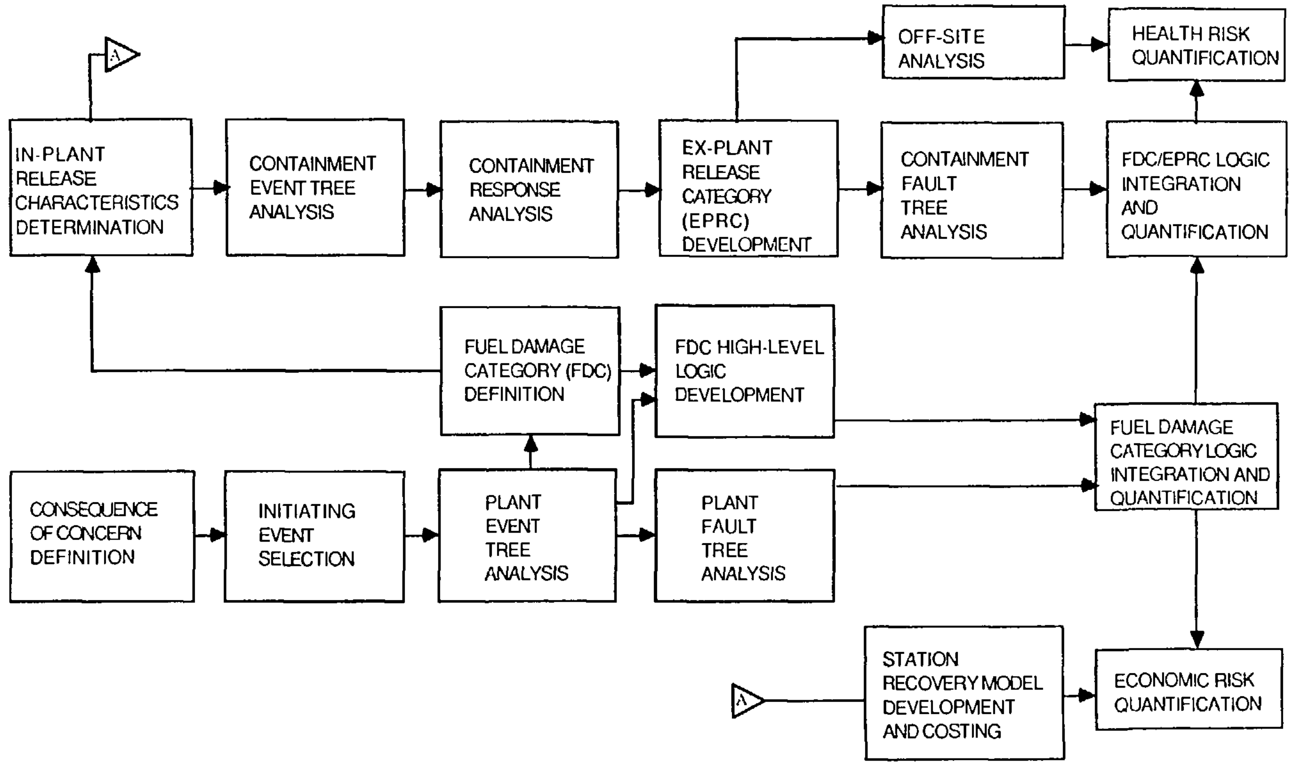

Figure 33 Task flow diagram for a typical Probabilistic Risk Assessment, in this case the Darlington Probabilistic Safety Evaluation just completed by Ontario Hydro.

Source: Ontario Hydro

290. In sum, the craft of safety analysis has provided the operators and the regulating agency with an evolving quantitative picture of the safety characteristics of Ontario's reactors. They are shown to meet certain quantitative criteria and can be modified if those criteria are made more exacting.

291. However, the question of what risk is tolerable (or what risk is acceptable)* is not answered by such analysis. It is commonly agreed that the public seems unconcerned with risks with a probability of one per million or one per 10 million per year for each individual (10^{-6} to 10^{-7} in mathematical terms). Lightning fatalities are a case in point. It can be shown by safety analysis techniques that the known risks of operating CANDU reactors are comparable, or even lower. Why, then, is there continued unease?

292. There are two answers. One is often called risk aversion, a special fear of an improbable, dreaded event. Nuclear accidents are usually called nuclear catastrophes by those who fear them greatly. Risk aversion can be and is incorporated into some schemes of risk analysis, but for obvious reasons tentatively.

293. The second is that the analysis is not believed. To some (including myself), it is quite unconvincing to deal with a probability of one failure in 10 000 or 100 000 reactor-years. This puts the observer back in Pleistocene time (loosely, the ice age), if he or she tries to gain a perspective by looking backwards. Still less can I get an intuitive feeling for calculated probabilities of one event in a million years, in spite of my training in the earth sciences (it is roughly the probability of rolling all sixes when throwing eight dice!). How can a lay person imagine, or believe, such a probability? Yet these indeed are the ordinary predictions of safety analysis.

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* See Layfield 1987, paras. 12.7-12.16, for arguments on this distinction, and para. 54 of this Report. See also Health and Safety Executive 1988, in response to Layfield.

294. To others, again including myself, there is the fear that feasible accident sequences have been overlooked, or that real hazards have been underestimated.* I am aware that these fears are widely shared by the nuclear safety analysts themselves.

295. Nevertheless, such calculations are crucial to the assurance of safety and to the liberation of qualitative methods. With numbers, however tentative, to provide a substitute for guesswork one is freer to make judgements that incorporate human values.

296. I am satisfied that the safety analyses I have seen for Ontario Hydro reactors have been well conducted. They help persuade me that the risk of living fairly close to these reactors (as I do) is personally acceptable. But the present public uneasiness will not be satisfied by design-basis calculations, or by sums done on day-to-day emissions. Only the application of such methods to the most extreme credible event has any chance of allaying public fears, as distinct from the views of scientists like myself. Several of our intervenors made this point.

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* R.A. Brown (personal communication) comments:

> This is a valid point. We have spent years worrying about the large catastrophic accidents to the point where we have designed enough safety systems to cope with them. What PRA's are showing is that it's not the large LOCAs that are risk dominant--it's the smaller accidents or problems with the safety support systems (electric, air, service water, etc.). The economic risk is dominated by the high frequency, low consequence events--but here the majority of the cost is associated with replacement energy. We are now moving to examine the problems in these less catastrophic areas.

C. Severe Accident* Analyses: the Problem of Pickering A

297. I have said already that I believe most public anxiety to arise, not from the everyday running of the reactors, but from the possibility of a Chernobyl-like event at one of the nuclear generating stations. Could such a drama overwhelm us?

298. As I came to write this chapter, a distinguished Ontario jurist** said to me: "Surely it is only a matter of time before we, too, are faced with a nuclear disaster?" Anxiety is not confined to the ill-informed. It is widespread among scientists, in the bureaucracy, and even (although usually silent) in the upper echelons of the business world.

299. The safety analyses performed for each of Ontario Hydro's nuclear generating stations as part of the design, construction, and licensing processes will satisfy most technically trained persons who learn how to read them (which at times is about as difficult as reading the scriptures in their original Greek or Hebrew). But the analyses, although competent, are almost unknown to the public. I was only dimly aware of them as I began this Review. Understood or not, they show that the best technical analysis possible finds the aggregate probability of accidents per reactor-year below one in 100 000 (10^{-5}) and, for a Chernobyl-style event, almost certainly a much lower probability. Even allowing for the fact that we have 16 reactors, soon to be 20, this is not an alarming figure--if it is understood, and still more if it is believed.

300. Several of the intervenor groups do not believe it and freely predict a Chernobyl-style event on Ontario soil. They are highly critical of Ontario

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* Here, as elsewhere in this Report, a severe accident is one that breaches containment and releases sufficient radioactive material to expose the nearby public to significant doses. Fraser (who adopts a different usage) covers this subject more fully in Appendix II.F.

** Judge Derek Mendes da Costa, formerly Chairman of the Ontario Law Reform Commission.

Hydro's failure to conduct severe accident analysis, and of AECB's refusal to require analysis of events with expected frequencies of one in 10 000 000 reactor-years or below. They are especially concerned about Pickering A, with its single shut-down system, and with one serious accident already part of its history (the pressure tube failure of 1 August 1983).

301. Following the Chernobyl accident, AECB carried out an analysis of its causes and consequences (AECB 1987d). So also did AECL (Snell and Howieson 1986; Howieson and Snell 1987) and the US NRC (1987). In general, AECB concurred in AECL's view that the CANDU design, and above all Ontario Hydro's operating procedures, would render such an event extremely unlikely. In one sense it could not happen here, in that Chernobyl's RBMK had inflammable graphite as a moderator, whereas all Ontario reactors have heavy water. Most of Chernobyl's casualties involved burns. But AECB suggested that Ontario Hydro might re-examine two possible severe accident sequences: a large LOCA, accompanied by a failure to shut down (simultaneous inoperability of all shut-down systems); and a failure of regulation from any cause, plus a failure to shut down.

302. I concluded that I could not recommend the continued operation of Pickering A, given its comparative poverty in shut-down capability, without the analysis of the first of these sequences. Accordingly, I asked Ontario Hydro to perform such an analysis and to involve the Argonne National Laboratory in the United States in a parallel study. Time and resources did not allow exploration of the failure of regulation case, although I hope that this will still be done.

303. I received the results of these analyses on 23 October 1987. I have asked that Ontario Hydro publish them as part of this Review's body of evidence. The report (Ontario Hydro 1987b) has been technically reviewed by J.T. Rogers of Carleton University and J.A.L. Robertson, formerly of AECL. It has also been submitted to AECB.

304. The analysis was performed for a hypothetical unit of Pickering A, assuming the upgrading of the shut-down system and the other component

systems already complete for units 1 and 2, and to be carried out on units 3 and 4 in 1988 and 1989. Three cases were considered, a base case (the most probable, taking pessimistic estimates of input parameters), an early terminated event, and an upper limiting case.*

305. The LOCA was assumed to be due to a guillotine fracture of the inlet header of the reactor's heat transport system. Because this creates an almost immediate fall of pressure (normally near 10 MPa), voids are formed as the coolant in the pressure tubes boils. This leads to a very rapid increase in reactivity, and hence in reactor power--a transient or power excursion in the language of the nuclear engineer. Figure 34 shows the calculated values of this transient, for the base case, for intact and broken loops (i.e., specific fuel channels, some of which have broken) and for the centre of the core. As can be seen, the transient begins only 2 s after the fracture initiating the event, and ends (as reactivity shuts itself off) at 3.7 s.

306. This analysis illustrates vividly why (in para. 87) I referred to the fast-acting characteristics of the CANDU reactors at criticality, because of the sensitivity of the chain reaction to the presence of voids (steam-filled spaces) in the pressure tubes. The need for fast-acting special shut-down systems--and for them not to fail--is also made clear.

307. From the point of view of consequences, it is the prompt phase of such an accident that matters most. At Pickering, this means the 20 s after the initial event. During this phase, there is likely to be (in addition to the power excursion) substantial disruption of the reactor core (as pressure and calandria tubes burst), and a blow-down of the heat transport system, where heavy water goes into steam. Loss of moderator stops the chain reaction, in this case after 3.6-3.9 s, but an immense amount of heat continues to be generated within the fuel by the fission products. The fuel melts near its centre line, from where

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* The range of estimates on either side of the base case is that the first channels may fail in 3.5 s (the early termination case, with early thermal interactions between the fuel and pressure tube) and 3.8 s (the upper limiting case), where this interaction is delayed.

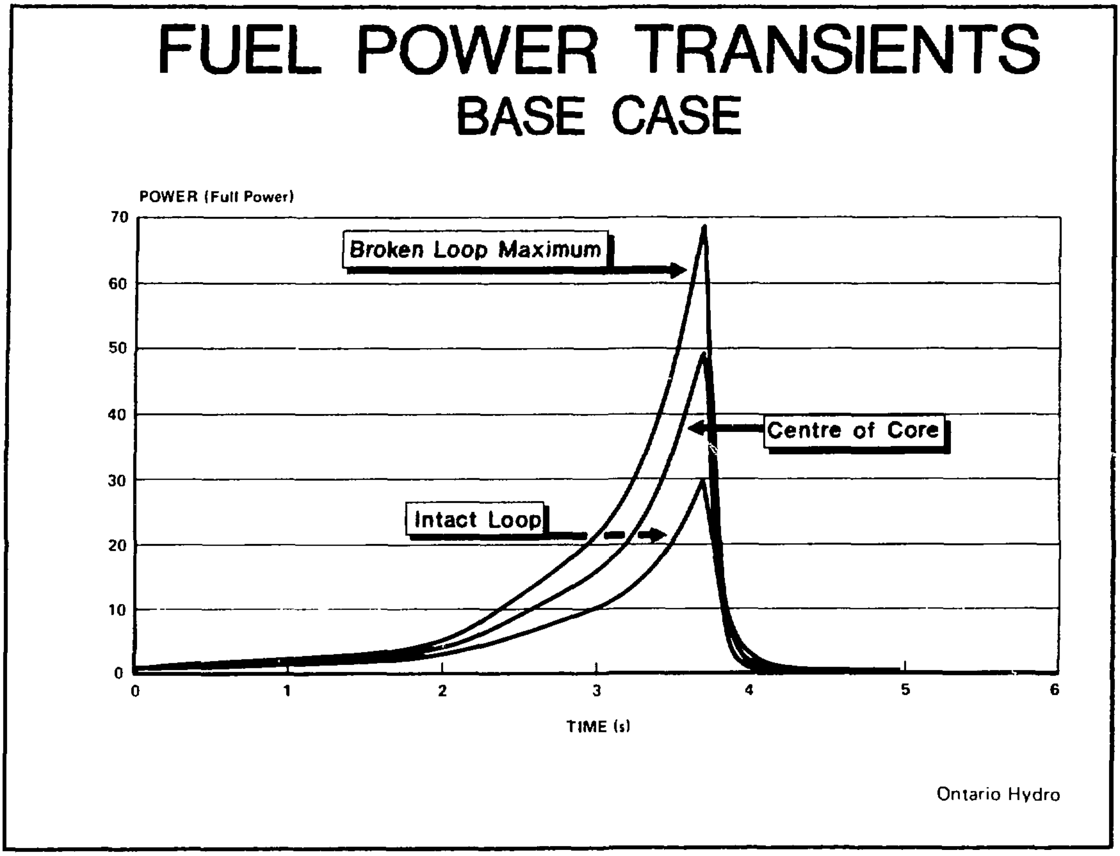


Figure 34 Fuel power transient (or excursion) at a Pickering A reactor following a major loss of coolant accident with failure to shut down. Curves show the spectacular rise of power following the initial accident, to a peak at about 3.7 s. Thereafter loss of the moderator, because of failure of the calandria seal, stops the reaction. In the broken cooling loop, the maximum is just under 70 times the normal value.

Source: Ontario Hydro

molten fuel may be ejected to impinge on the sheath. It then escapes by ejection into the annular space, and thence to the moderator (at 3.3-3.5 s). The calandria vessel is pressurised, and its integrity is broken in about 3.7-4.0 s, allowing contaminated steam to escape into the reactor vault. Table 13 summarises the calculated timing of the chief events for the three cases.

308. The line in Table 13 referring to super-prompt-criticality, at 2.2 s into the accident, reminds us that a CANDU reactor's regulating system depends on the delayed neutrons coming from the fission products (see paras. 80-81; for more detail, see Appendix I, paras. 45-52). At prompt-criticality, reached in this case at just over 2 s, the reactor is critical on prompt neutrons alone, and thereafter, as reactivity rises, the regulating system is unable to control the chain reaction: hence the power excursion of Figure 34.

309. The subsequent events predicted by Ontario Hydro's analysis are summarised in Table 13. The integrated internal consequences are set out in the following Table 14. The main points are these:

(i) Of the 390 fuel channels in the calandria, 48% will have failed by the 20-s mark in the base case, and 100% in the upper limiting case.

(ii) In all three cases, the calandria fails at the welds between the annular plate and the main shell.

(iii) The peak pressure on the containment structures during the prompt phase is in the range 150-180 kPa (normal atmospheric pressure is 101 kPa).

(iv) Reactivity falls very rapidly as moderator is pressurised, vaporised, and ejected.

(v) The containment structures remain intact in the early termination case. Minor cracks develop in the concrete reactor building dome around the top plug in the base case, with larger cracks and some yielding of reinforcement around the plug in the upper limiting case. In both the latter cases, the cracks reseal as the pressure transient passes.

Table 13

Summary of Sequence of Events During the Prompt Phase of a Loss
of Coolant plus Failure to Shut Down Accident at a Pickering A Reactor

Event description	Time (s) Base case	Early termination	Upper bound
Guillotine rupture of a reactor inlet header	0	0	0
First dryout in broken pass high-power channel	0.9-1.0	0.9-1.0	0.9-1.0
First dryout in intact pass high-power channels	1.3	1.3	1.3
Reactor super-prompt-critical	2.2	2.2	2.2
Heat transport relief valves (small valves) start to open	2.5	2.5	2.5
First dryout in intact loop	3.1	3.1	3.1
First molten fuel ejection in broken loop maximum powered channels	3.3-3.45	3.3-3.45	3.3-3.45
First channels fail in calandria in broken loop	3.7	3.55	3.85
First fuel disruption in intact loop	3.7	-	3.7
Reactor subcritical	3.74	3.6	3.89
Calandria vessel fails	~3.8	~3.65	~3.95
First channel failures in intact loop	3.9	-	3.9
Early channel failures complete	5	5	5
Broken loop depressurised below 1 MPa	~12	~20	~12
Intact loop depressurised below 1 MPa	>20	>>20	>20

Source: Ontario Hydro 1987b.

Table 14

Summary of Key Findings from Analysis of a Loss of Coolant Accident with Failure to Shut Down

	Most probable scenario (base case	Early termination	Upper bound scenario
Lead channel failure:			
No. of channels	5	3	5
Failure time	3.7 s	3.55 s	3.85 s
Failure mode	Molten UO_2/PT contact	Early molten fuel/PT thermal interactions	Delayed molten UO_2/PT contact
No. of channels failed during power excursion (% of core)	115 (30%)	45 (11%)	195 (50%)
No. of channels failed at end of prompt phase (% of core)	190 (48%)	90 (24%)	390 (100%)
Calandria vessel damage	Vessel failure at annular plate/ main shell welds	As for base case	As for base case
Peak pressure for containment during prompt phase	~160 kPa (a)	<150 kPa (a)	~180 kPa (a)
Containment envelope damage	Minor cracking of concrete around the plug structure at top of reactor building dome, cracks reseal when pressure is reduced	None	Concrete cracking with some incipient yielding of reinforcement around the plug structure at the top of the reactor building dome, cracks will reseal when pressure is relieved

Note: (a) = atmospheric; PT = pressure tube.

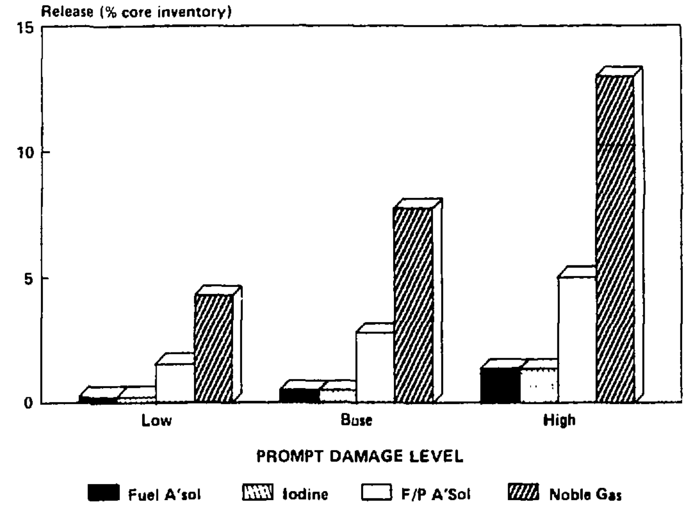
Source: Ontario Hydro 1987b.

310. If these model results are correct predictions, then a very severe accident, perhaps the most severe accident conceivable for a Pickering A reactor, will largely be contained. There will, of course, be extensive damage to the reactor, and hence repair costs that may be prohibitive, in both radiological and financial terms. It is doubtful, however, that such costs could approach those at TMI, where it has still not been possible to enter the damaged and sealed vault of the reactor involved in the 1979 accident. All clean-up has had to be done by remote-control probes (Booth 1987).

311. The off-site impact of such an accident will arise from the release of radioactive materials from the cracks in the containment (before they reseal) and from deliberate venting of the noble gases. Ontario Hydro's calculations suggest that such escapes (called the source term in the language of accident analysis) will be comparable with those predicted for lesser accidents studied during design-basis and licensing calculations. In the present case, noble gases contribute most of the dose. Specific doses to individuals are not calculated, but Ontario Hydro expects them to be less than the permitted doses under accident conditions shown in Table 14.

312. Figures 35 and 36 summarise the expected releases into containment and to the environment. The prompt phase will see substantial releases into containment of the core inventories of fuel (in particulate form), other aerosols, iodine, and the noble gases. The latter will be released to the environment at suitable times, i.e., after a period of decay, and when weather is suitable (Figure 36), but little of the rest reaches the environment. Total dose to the public will depend crucially on the weather at the time of the accident and during the episodes chosen for deliberate release (venting) of noble gases.

313. The analysis thus predicts that this very improbable accident would lead to heavy economic damage, but only minor impact on the surrounding community. This result is so favourable that it naturally raises the questions: was the analysis realistically and objectively performed? And were the results predetermined by the modelling assumptions?



Prompt Release from Plant

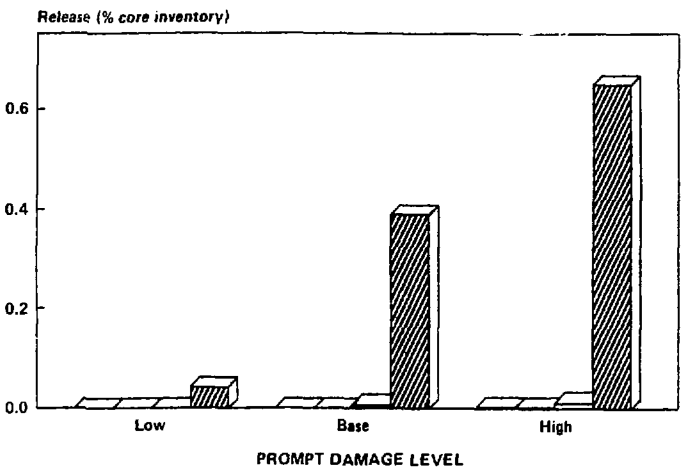
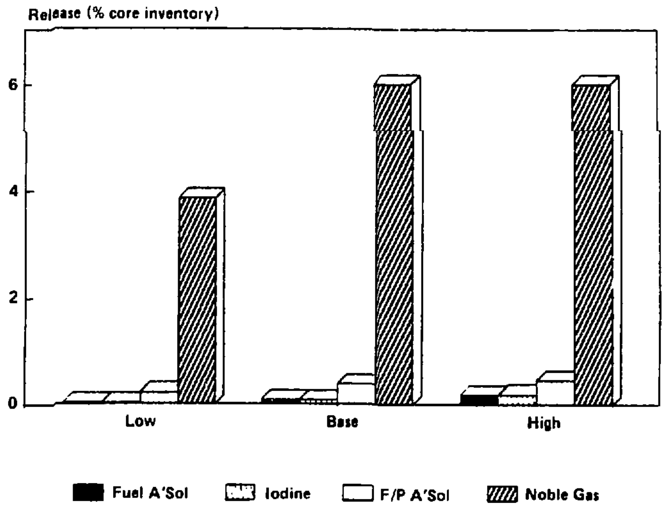


Figure 35 Prompt release (within 20 s) of the reactor core's inventory of radioactive materials, as a fraction of total inventory, following the accident sequence of Figure 34, for three scales of accident (see text). Upper diagram shows a release into containment of fission products (F/P) and fuel aerosols (A'sol). Lower diagram shows predicted releases to the environment through short-lived cracks in containment.

Source: Ontario Hydro



Cumulative Release from Plant Over Following Week

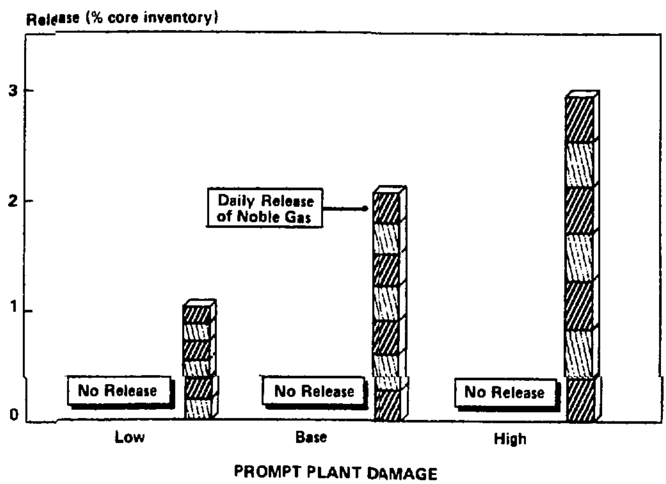


Figure 36 Subsequent releases into containment (upper diagram) of radioactive materials, as a fraction of total inventory, following the accident sequence of Figure 34. Bottom diagram shows schematically the daily release of noble gases, spread over a week (the actual timing would depend on weather). No releases other than the noble gases would be expected.

Source: Ontario Hydro

314. The parallel analysis of the central part of the exercise by Argonne National Laboratory (presented as Appendix H of the Ontario Hydro report) used quite different codes and was based on a very different body of experience. Nevertheless, its results (Argonne National Laboratory 1987) parallel those of Ontario Hydro in many particulars and differ from them in no important way. Especially striking is that the sequence and timing of events during the prompt phase (to which Argonne largely confined itself) are very similar.

315. J.A.L. Robertson (a specialist in CANDU fuel performance) points out (personal communication, as consultant to the Review) that the differences between Argonne's model of the fuel failure mechanisms and that of Ontario Hydro's analysis are substantial, and that these differences should now be systematically compared. I agree; these differences could otherwise cast doubt on the validity of the modelling. On the other hand, to quote Robertson, "the fact that both analyses yield a very similar final conclusion, viz., no serious leak of radioactive material, from such different assumptions concerning the detailed mechanisms, could be reassuring." Again, I agree.

316. J.T. Rogers (Canada's leading academic student of accident analysis) finds the analysis "a major advance in the understanding of severe beyond-design-basis accidents in CANDU reactors." He finds no major errors or omissions, and adds, "I am confident that the occurrence of such an accident in a Pickering NGS-A unit, improbable though it is, would not present a major hazard to the public, with the resulting public dose being within the AECB limits for a dual failure accident" (personal communication, as consultant to the Review). In other words, the result of this imagined severe accident is no more severe than those calculated for a less serious event already examined. I have incorporated some of Rogers' formal recommendations into my own Report.

317. I conclude that this thorough Canadian exercise in beyond-design-basis accident analysis was well conducted, given the severe time constraints that I was forced to impose. It answers some of the anxieties raised by our intervenors and, in my view, justifies continued operation of Pickering A (as rehabilitated, see para. 198). But caution is needed in extending this conclusion to

other CANDU reactors, on the following grounds. The reactors at Bruce and Darlington are or will be larger than those at Pickering A and B. This implies a larger source term, i.e., inventory of radioactive materials capable of release. There are also differences in reactor physics and calandria design that might (not necessarily would) make it harder to terminate the power excursion quickly at these larger reactors. On the other hand, the population potentially exposed at Bruce and Darlington is very much lower than at Pickering. In due course, I hope that AECB will require such extreme-case analyses for all CANDU reactors. I should add the obvious corollary to the first point: that smaller reactors (such as AECL's CANDU 300) may present even lower risks than those now in operation, whatever their relative cost.

D. Why are the Predicted Consequences at Pickering A so Different from Those Observed at Chernobyl?

318. This question was considered by Ontario Hydro and answered in these terms:

(i) The process of channel failures in Pickering promotes a very rapid termination of the power excursion by rapid displacement of liquid moderator. At Chernobyl, solid graphite moderator could not be this readily displaced. Furthermore, the first channels to fail at Chernobyl promoted rapid, coherent failure of all remaining channels by shearing of their outlet connections. This acted to increase the magnitude of the power excursion and the resultant fission energy generation. This autocatalytic process does not apply to the Pickering reactors.

(ii) The major energy discharge from a damaged reactor in this type of accident is associated with blow-down of the heat transport coolant. Because of the small volume of coolant in a Pickering reactor coolant system, relative to the Chernobyl reactor, the energy discharge is an order of magnitude lower in Pickering.

(iii) The large volume of the Pickering containment, coupled with a design that is based upon minimising pressure differentials between internal ımpartments, limits the damage potential associated with the energy release during the accident.

The first two factors are illustrated graphically in Figure 37, which shows Ontario Hydro's calculated values of the main mass and energy parameters. Clearly, the Pickering A event is a pygmy by comparison with that at Chernobyl, primarily because of the much lower mass of coolant available at Pickering for the destructive blow-down, and because of the very quick termination of the power transient due to loss of moderator. That, plus the use of an inflammable moderator at Chernobyl, accounts for the better survival expectation of Pickering.

319. Howieson and Snell (1987) concluded, in their AECL analysis of the Chernobyl event, that no new processes or failure modes had been revealed, and that Canadian design and operating practices precluded the inadequacies of the Soviet RBMK reactor and its operators. Only the positive void reactivity coefficient was a common factor. As the Ontario Hydro - Argonne analysis has pointed out, the CANDU design presumes the need for highly efficient, fully computerized control systems, and also for a fast shut-down system or systems. Pickering A is the least well protected CANDU station in this respect, yet in its updated form it appears, in this analysis, to be capable of containing almost all the released fission products except, as usual in such cases, the least damaging--the inert noble gases.

320. Given this favourable result, I feel that Pickering A should continue to operate, given also:

- the extensive rehabilitation of each reactor, including its detection systems;
- the enhanced capability of SDS1 being installed in units 3 and 4 (and already installed in units 1 and 2);
- the excellent availability record of SDS1 since 1975; and
- the upgrading of the ECIS, now fully installed in units 1 and 2, and to be installed in units 3 and 4 in 1988-89.

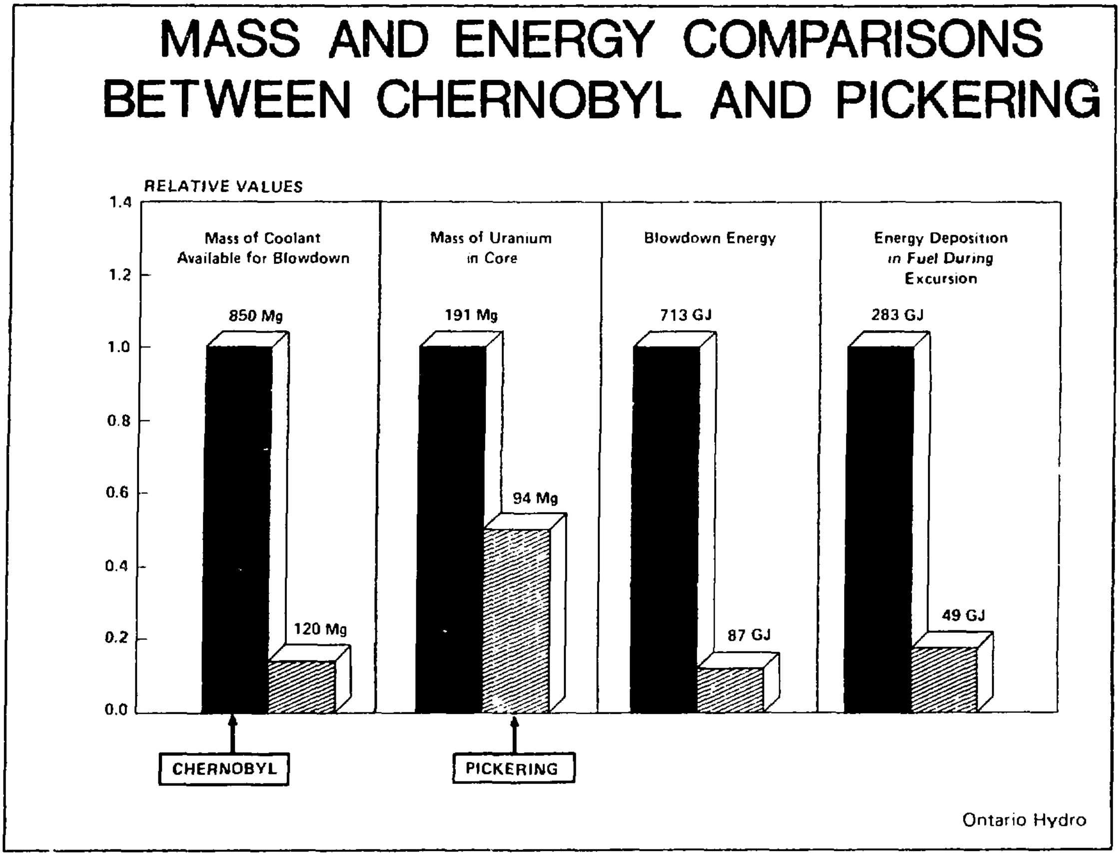


Figure 37 Comparison of mass of coolant, mass of uranium, energy available for damaging blow-down, and energy released during an actual accident at a Pickering A reactor and a Chernobyl RBMK reactor. The potential for catastrophic accidents at Pickering is clearly much lower.

Source: Ontario Hydro

321. I assume in this judgement that inspection of the pressure tubes in units 3 and 4 will be pressed forward, and that all necessary action will be taken to prevent (if possible) further accidents involving their rupture.

322. I am also convinced that Ontario Hydro should proceed at once to the analysis of the second severe accident sequence postulated by AECB--the failure of regulation case.

323. In addition, it may be wise to consider a further sophistication of the Pickering A shut-down systems. The number of shut-off rods has been increased from 11 to 21. Suggestions have been made that these could be divided into two independent groups, with diverse detection and logic systems. This would further enhance the protective system.

E. Potential Consequences of Even More Severe Accidents

324. In Chapter VII, I explore the need for an effective emergency measures organisation outside the nuclear plants. To organise effective measures, the responsible body will need an estimate of the maximum credible accident. A Provincial Working Group is considering this separately, but it is appropriate here to consider the potential consequences of accidents going beyond the bounds of the Ontario Hydro - Argonne exercise just considered.

325. The Review appointed consultants to analyse this problem. Reports were received from the Institute for Resource and Security Studies (Gordon Thompson) and from investigators with the McMaster Institute for Energy Studies (S.C. Lonergan) and the Center for Technology, Environment and Development, Clark University (R.L. Goble and C. Cororaton). The McMaster-Clark analysis was addressed specifically to Pickering A.

326. The McMaster-Clark analysis applied the Melcor Accident Consequence Code System (MACCS) to two accident scenarios for a Pickering A reactor. This computer code requires as input the reactor core inventory of radioactive

materials; release fractions for the two accident scenarios; five sets of weather conditions and three wind directions; health effects probabilities; data on land use, population, and land and crop values; and estimates of decontamination costs (using US values). Outputs include prompt fatalities expected; early injuries; cancer deaths; health costs; and property damage and costs. The output is specific to sectors around the nuclear generating station. The two scenarios considered included:

- a design-basis accident analysis provided by Ontario Hydro (based on its emergency measures assumptions), involving release of only a small fraction of the core inventory of radioactive materials (2.2% of noble gases, with very small values for iodines, cesiums, and other fission products); and
- a much more severe accident modelled on the assumptions adopted in case PWR-2 of the Rasmussen (1975) report, involving releases of 90% of noble gases, 77% of iodines, 50% of cesiums, 30% of tellurium, 6% of strontium, and 2% of ruthenium.

Several other scenarios were run, but not analysed in detail.

327. As might be expected from the sweepingly different source terms, the two scenarios produce equally contrasted sets of consequences. Table 15 shows estimated health effects for the two analysed cases. In case 1, the plume of radioactive releases (on the PWR basis) is carried directly across Metropolitan Toronto under conditions likely to maximise the exposure of individuals within the sector, and to maximise accompanying contamination effects. Case 2 shows the predictions of the same code when applied to the Ontario Hydro design-basis accident. Obviously, the use of the US PWR scenario produces a catastrophic result, whereas the Ontario Hydro design-basis accident, although far from negligible, gives a much smaller penalty (including no fatalities).

328. The Ontario Hydro - Argonne analysis described in section C above clearly resembles in its consequences the design-basis accident of the McMaster-Clark analysis. Although both are very unlikely, they are much more probable

Table 15

Health Effects from a Catastrophic Accident at the Pickering Nuclear Power Plant

	Case No.	
Health effect	1*	2**
Prompt fatalities	37.5	0
Early injuries		
Prodromal vomiting	811	0
Lung impairment	320	0
Hypothyroidism	4880	0
Cancer deaths	9700	3.8
Lung cancer	1370	1.03
Breast cancer	3020	0.429
Gastrointestinal cancer	3020	1.44
Leukaemia	768	1.09
Bone cancer	39	0.287

* Case 1: Effect of releases of radioactive materials on the scale of case PWR-2 in the Rasmussen analysis, involving escape of most of the inventory of fission products, with plume directed across Metropolitan Toronto.

** Case 2: As in case 1, but with releases as predicted by Ontario Hydro design-basis scenario.

Sources: Rasmussen 1975; Lonergan, Goble, and Cororaton, consultants' report (their Table 7).

than the hypothetical case represented by case 1. The fact that the moderator is lost very early in a CANDU accident (because of calandria failure) automatically restricts the scale of severe accidents that are credible in Ontario reactors. Accident analysis suggests that although the probabilities of scenario PWR-2 in a PWR and of the design-basis accident in a CANDU reactor are not dissimilar (of order 10^{-5} per reactor-year, perhaps lower for the CANDU case), the probability of losing a high fraction of radioactive inventory from a CANDU reactor core is much lower.

329. A useful feature of the McMaster-Clark study is a sensitivity analysis. The most significant result is that prompt use of emergency measures, such as evacuation, greatly reduces both health and economic impacts.

330. It appears, in sum, extremely unlikely that catastrophic accidents of the type examined in the McMaster-Clark study will occur in Ontario. But there may be other beyond-design-basis accidents that will involve serious consequences going well beyond those discussed in this chapter. These are being analysed by Working Group No. 8 of the Ontario Ministry of the Solicitor General. They are outlined in Chapter VII. These beyond-design-basis accidents include the remote possibility of a partial or complete melt-down--i.e., a rise of core temperatures to the point where widespread fusion of the fuel occurs, with the latter migrating downwards under gravity to the floor of the reactor building or beyond, with a risk of consequent steam explosions. Fraser deals with this unlikely event in Appendix II.F.

F. Would Other Types of Reactors Help Safety?

331. I have not examined the concept of inherent safety in reactor design, on several grounds. First, the terms of reference call for an examination of CANDU reactors, which are not inherently safe. Second, I am dubious about the notion of inherent safety. And third, I am not competent to pass judgement on so complex a technological issue.

332. Reactors do exist for which inherent safety is claimed. All are small, with low power output. Most depend on large coolant volumes and are designed so that as core temperatures rise, reactivity decreases, and ultimately the reactor shuts down with no external intervention. Ontario Hydro's submission (section 15) reviews the few working examples. AECL's Slowpoke reactors (see Annex II), used mostly for research, are in this category.

333. At the time of decision concerning the building of Pickering A, Ontario Hydro appears to have considered the possibility of using US PWRs and enriched uranium in lieu of CANDU. This raises the question: was CANDU a wise choice?

334. From the standpoint of safety, there appears to be little to choose between the two designs, different though they are. The evidence is reviewed by Meneley in Appendix I.

335. PWRs use a single pressure vessel, with no separation of moderator and coolant. They can be regulated safely without computerized systems (although these are becoming standard). There is little or no boiling in normal operation, and void reactivity coefficients are small and negative. Hence, CANDU's positive void effect, with its need for very fast shut-down, is avoided. Unlike CANDU, however, PWRs are extremely sensitive to breaks in the secondary heat transport system, and for this reason also need fast shut-down systems.

336. The Achilles' heel of PWRs, mercifully highly improbable in CANDU, is the possibility of a melt-down (the China Syndrome). A major break of the pressure vessel (in which the reactor is contained) would release a large volume of steam that would be sure to break containment and cut off fuel cooling. Melting of fuel could create further opportunities for explosive steam formation and the possibility that the fuel could penetrate the containment floor and encounter ground water that would vaporise. CANDU's systems make this worst conceivable accident scenario exceedingly unlikely.

337. It was nevertheless the view of most analysts with whom I discussed the comparative advantages of CANDU that one should not seek to justify its use solely on safety grounds. CANDU is as safe as it is because of the ingenuity of its regulating and shut-down systems, and in spite of the positive void reactivity coefficient, the very fast increase in reactivity if voids occur. Severe accidents have been avoided by good design characteristics and shut-down methods, combined with excellent computer control of regulation and generally good operating procedures: good human performance in design and operation has been the key.

338. It is not obvious that the present configuration of CANDU and its fuel are optimal as safety features. The economic performance of the fuel would improve with a low degree of enrichment in uranium-235 (far below, needless to say, the degree required for weapons manufacture). There is also the possibility, admittedly remote, that advanced fuel cycle research may make possible the use of thorium-232/uranium-233 technology. If work continues on either of these possibilities, there may be an improvement in inherent safety. I am told, however, that it will not be possible, even with enriched fuel, to avoid the positive void reactivity effect (R.A. Brown, personal communication).

339. In short, AECL and Ontario Hydro have made the most out of a good but not perfect option. I am left with the conviction that high human performance has been the key to the success of Canada's nuclear power programme. I see no reason why CANDU should be abandoned--but neither can I see why its present characteristics should be treated as sacred.

Chapter VII

Emergency Measures for Nuclear Accidents

A. The Problem Defined

340. If a reactor gets out of hand and accident conditions arise, there is an immediate need for emergency measures. These are of three kinds:

- restoration of the reactor to safe conditions, which is the responsibility of the operators in the control room and the other staff on duty at the time;
- emergency procedures within the station to protect workers and equipment and to prevent or minimise danger to the public; and
- emergency measures in the civil community around the station and (in severe cases) farther afield.

341. As demonstrated in para. 329, these emergency measures can do much to mitigate the consequences of an accident.

342. Responsibility for the first two kinds of emergency measures lies clearly with Ontario Hydro, which has evolved a set of procedures covering both needs. These have taken shape in response to AECB requirements, to planning within Ontario Hydro, and to actual experience of accidents or emergencies in the nuclear generating stations. The Ontario Hydro submission deals explicitly with these procedures. The key principle involved is that the on-site operating organisation must be able to respond immediately and effectively, using the staff on duty at the station. As far as I can judge, this principle is honoured. Ontario Hydro annual expenditures on emergency procedures are close to $6 million.

343. Responsibility for the third kind of emergency measures--the main subject of this chapter--is with the Province of Ontario, which published a formal Nuclear Emergency Plan in June 1986. Federal government responsibilities also arise, because the consequences of an accident may not be confined within

provincial boundaries and may also involve other countries. A Federal Nuclear Emergency Response Plan is in place and was actually tested by the 1986 Chernobyl accident.

344. Emergency planning is defined in what follows by the words used by Energy Probe in their brief (by Paul Muldoon and Andrea Jenkins): planning and preparedness designed to prevent, mitigate, and minimise the potential effects of an off-site release of radiation to persons, property, and the environment.

345. In Ontario, this mandate is discharged by the Ministry of the Solicitor General (whose much larger responsibility is the Ontario Provincial Police). At this time (February 1988), this Ministry still has only two professional staff in nuclear emergency planning. The Ministry's brief to the Review outlines provincial policy. In view of its importance to the present argument, I have included this brief in the present Report as Annex V.

346. The legal responsibility to prepare a nuclear emergency preparedness plan lies with the province, as specified by the Ontario Emergency Plans Act (Section 8) of 1983. This differs from that for all other types of emergency, where the responsibility lies with the municipalities. The Solicitor General is responsible for the administration and implementation of the plan. The plan itself, Part I of which was published in 1986, is admirable. But its administration and above all implementation will require substantial resources in people and money. These have not been provided.

347. A key decision taken by the Provincial Cabinet was that these necessary resources should be "provided by Ontario Hydro in the form of an annual subvention, which would be used to hire the required staff and meet the operating expenses" (Ministry of the Solicitor General brief, pp. 6-7). Inquiry reveals that this has not yet been done. In any case, it is a bad principle. The province should fund its own programme itself. If it chooses subsequently to tax the utility, it can of course do so.

348. The Ministry of the Solicitor General's brief ends with these words:

> This plan still requires to be translated into tangible preparedness to deal with such an emergency. The Province is confident that, with the assistance of Ontario Hydro, a high level of nuclear emergency preparedness will soon be established for the people of the province.

Nine months later, this confidence looks misplaced. So far the only parts of the plan that conform to requirements are those organised by Ontario Hydro. Most of the rest remains to be started. The utility is ready. The province is not.

349. Discussions with officials and intervenors suggest that this paradox arises from the widely shared belief that a severe accident in Ontario is unlikely, and that money should not be spent in large amounts on structures that will probably never be used. I heard this view expressed by employees of Ontario Hydro, the province, and AECL. But this is not the policy of any of these groups, and it is certainly not my own view. A severe accident is indeed unlikely, but the province must equip itself to deal with the possibility--and with the overspill from any severe accident on the US side of the border.

350. The provision can be best made by creating within the Ministry of the Solicitor General a small, nuclear preparedness branch, with responsibility for giving effect to the arrangements outlined in the brief to the Review (Annex V), and thereby giving substance to the excellent plan now part complete, part still in evolution.

351. The plan envisages the provincial role as one of mobilisation, public information, and administration. The implication is that technical and scientific matters will be coped with by Ontario Hydro and AECB. This is too much to ask. It neglects the fact that the province and its institutions--notably the hospitals and universities--already possess considerable skills in the technical area. These will be needed if an accident occurs. I found it quite hard to determine the actual level of available skills, e.g., the capacity of the hospital system to absorb radiological casualties.* A nuclear preparedness branch should

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* Another Provincial Working Group is currently making such an assessment.

have the technical competence to mobilise these skills in a matter of hours--and should prepare itself and them in depth beforehand.

352. There is no close parallel between Ontario and Illinois, except that both have many power reactors (Illinois has 13, Ontario currently 16). But a comparison says something about the scale of the Ontario proposal. The Illinois Department of Nuclear Safety, with responsibility for all radiation areas, has a staff of 205 persons. In addition, a wing of the Emergency Services and Disaster Agency (which covers all types of emergency response, seen as a state function in Illinois) is responsible for the state response in all nuclear accidents. All this is over and above what is done by or on behalf of the US NRC.

353. I attended the US NRC's emergency exercise at the Zion Nuclear Plant in Illinois on 24-26 June 1987 and was struck by the highly evolved response of the State of Illinois:

- in Illinois, the cost of the state organisation to provide for nuclear emergencies is borne by the utilities; and
- in Illinois, in contrast to Ontario, the state has acquired the technical capacity to monitor the public safety related aspects of the performance of its nuclear utilities.

I do not suggest that Ontario should imitate Illinois, but only that the disparity in the scale of involvement is unreasonable, even in Ontario's more streamlined and centralised situation.

354. I consider it a matter of urgency that the province proceed at once to implement its own plan, which means agreed organisation and commitment of money and staff on the required scale.

B. For What Accidents Should the Province Prepare?

355. It is crucial to decide what kind of accident justifies emergency preparedness. The public requires that planning for nuclear emergencies should be carried out for much lower probabilities than is the case for most other hazards. Should the emergencies be those provided for in the design of the reactors, the licensing of which depends on design-basis accident analysis? Or should the province allow for much more extreme events?

356. To answer these questions, the Ministry of the Solicitor General in 1987 established Provincial Working Group No. 8, with K.G. McNeill as chairperson. Its specific mandate was to "review the issue of the upper level of emergency planning and preparedness in Ontario, and make recommendations thereon." Its chairperson has sat ex officio on the Advisory Panel of this Review. The Review has in turn been represented ex officio on the Working Group. The province should clearly be guided by what it advises. I shall not try to pre-empt its report (which is due in 1988). In what follows, I have been extensively guided by the tenor of the Working Group discussions, and by advice from its chairperson.

357. An earlier Working Group (in 1982) recommended that the maximum accident for which detailed planning was necessary was one that would give a dose of 250 mSv to an unsheltered person who remained stationary at the plant's exclusion fence, 1 km from the reactor. This recommendation was based on the assumption of sound engineering practice and the operating experience of the time, together with the fact that CANDU moderator systems act as additional heat sinks. Also implicit was the view that events with probabilities of one event or less per million reactor-years could be neglected. Calculations on these bases predicted that two emergency planning zones should exist around each CANDU:

- a primary detailed planning zone, of radius 10 km around the reactor, within which evacuation or sheltering was a possible need; and

- an outer or secondary zone, out to 50 km from the reactors, in which ingestion pathway analysis, food and water control, and radiological monitoring were the probable responses.

358. The 1982 recommendations had as a goal that accidents up to and including those resulting in a dose of 250 mSv per person should produce no statistically significant increase in latent cancers in any one geographical sector of 5000 persons living around the reactor. In addition, the purpose was to avoid serious economic loss to many persons at a radiological dose level that would be less than 2% of that which an in-plant worker could legally receive each year. The dose of 250 mSv, incidentally, excluded any early mortality or morbidity.

359. Since that time, much has been learned from further estimates of possible escapes of radioactive substances, severe accident analyses, and the actual experience of Chernobyl. These have made more precise the scale of accident that should be planned for.

360. Discussions in Working Group No. 8, taking these developments into account, have focussed on two tiers of accidents:

- a tier of accidents in which engineering design considerations suggest a range of maximum doses from 100 to 1000 mSv; and
- a tier of larger accidents, in the range of maximum doses of 1000 to 10 000 mSv, arising from gross error or deliberate action by individuals or groups.

361. The second tier of accidents allows for comprehensive planning that takes into account terrorist action or sabotage. I have been made aware of some of the security precautions in place at CANDU stations, but for obvious reasons shall not discuss them here.

362. I agree with several intervenors that planning should be based on the maximum credible accident. The latter probably lies in the larger tier defined above. If this is so, calculation suggests that beyond the 10-km detailed

planning zone there would be no early morbidity, and probably no formal call for evacuation. It is very likely, however, that voluntary evacuation would take place. If this involves a substantial part of Metropolitan Toronto, the resulting traffic tie-ups might handicap access to the Pickering A NGS site, as well as necessary evacuation and first-aid services within the 10-km zone. Clear thinking, good planning, and public education are obviously necessities.

363. It would be premature to say more at this time. But the province urgently needs to equip and staff a nuclear preparedness branch; there will be measures that should be taken immediately on receipt of the report of Working Group No. 8.

C. Is There a Danger from US Reactors?

364. In the Muldoon-Jenkins brief from Energy Probe, there is an analysis of the legal and administrative problems that arise from the fact that there are several US reactors close to Ontario's borders, and vice versa. The mutual obligations that this places on the various provincial, state, and federal governments are analysed in the brief. Appendix VI, by A.T. Prince, describes the formal relationships.

365. Of the US reactors (see Figure 4 and Annex II), Enrico Fermi 2 in Michigan, south of the Detroit metropolitan area, includes part of Essex County, Ontario, in its primary zone (defined by US authorities as extending 16 km from the reactor). The Provincial Nuclear Emergency Plan includes a specific plan for action in the event of an accident at Fermi.

366. The Davis Besse plant (Ohio), and the Ginna, Nine Mile Point, and Fitzpatrick plants in New York have secondary zones (out to 80 km in US regulations) that include Ontario territory. That of the Perry plant (Ohio) touches the Ontario shore line of Lake Erie. In reverse, both Darlington and Pickering are well within 80 km of New York territory; the south shore of Lake Ontario is about 55 km from both. In the secondary zones, if the above thinking about severe accidents is confirmed, an emergency might require food and drink control, radiological monitoring, and vital reporting functions. Hence, international co-operation is needed to ensure that the need is met.

367. The mechanisms of such international exchanges lie beyond the scope of this Review, although they have been discussed by Prince in Appendix VI and criticised sharply by the Muldoon-Jenkins Energy Probe brief.

368. A serious accident at one of several US reactors does indeed pose a threat to Ontario's population. Downwind fall-out of radioactive materials would probably occur in such a case, and the most probable displacement of such fall-out is to the east, north-east, or south-east. It is unlikely, however, that such fall-out would approach the scale of the Chernobyl event. Ontario Hydro's reactors pose a smaller threat to US territories.

369. Clearly, the nuclear emergency planning agency in Ontario must take account of such possibilities. Fortunately, the long-established links between the utilities across the border make working contacts easy. What appears lacking at present, aside from the tiny nucleus of planning staff in the Solicitor General's staff, is any sense of urgency about the problem.

D. Meteorological Monitoring and Modelling

370. Monitoring and modelling the weather around a nuclear station following a release of radioactive material is important for estimating accurately where that material will go. Environment Canada has argued in its submission that present provisions for monitoring and modelling of the weather around Ontario Hydro's nuclear generating stations are inadequate. This view is supported by the work of a consultant, S. Karpik. I agree and endorse their recommendations.

Chapter VIII

Design, Quality Assurance, and Safety Culture

A. Preliminaries

371. It is one thing to build and operate a nuclear generating station and another thing altogether to ensure that everything is well done. Safety depends on assurance as to quality--of materials, design, system, people, and institutions.

372. QA is a recognised procedure in engineering, as is the related idea of quality control (QC). Going with these activities is the need to establish standards, to which practice can adhere. But if engineers have long accepted such notions, the same cannot be said of some other industries, and of many human institutions. Some professions are reluctant to curb the freedom of their individual members. The individual is seen, within limits, as sovereign.

373. Emphatically, this easy-going reliance on individual wills and consciences will not do in the nuclear generating industry. Tight discipline is required of all who work in it and contribute to its performance. QA--the audit of quality in material and human performance--is as necessary as the financial audit of business transactions. If quality is not actively scrutinised, it vanishes.

374. In its submission, Ontario Hydro discussed the material side of this issue in some detail, and the AECL submission also covers part of the ground. In a review of these submissions, J.A.L. Robertson (writing personally as a consultant) argued strongly that the maintenance of quality in the performance of institutions was as important as material QA for safety. Can Ontario Hydro's divisions concerned with building and operating the stations ensure that their performance will remain at least as high as it is now? Can the Ontario public be sure that this will be done?

375. *The evidence is equivocal. There were obviously, for example, design* flaws in the RBMK reactors of the Soviet Union. These escaped detection--or, worse, evaluation--during the design phase. And there were major lapses of

good operational practice at Chernobyl and TMI, revealing both institutional and personal weaknesses (at Chernobyl) and poor training (at TMI). Adequate systems of QA should have revealed these flaws beforehand. What is not obvious, however, is that such flaws--if revealed--would have been corrected by corporate management. Is Ontario in a similar position?

B. Ontario Hydro's Design and Construction Processes

376. The Ontario Hydro submission presents an account of its procedures governing design and construction. It is out of the question for me to summarise one of Canada's most elaborate civil and mechanical engineering enterprises. Nevertheless, I present Figure 38, which shows the responsibility tree governing the process, together with Figure 39, identifying the corporate bodies (by initials) that exercise the various responsibilities.

377. Noteworthy in Figure 38 is the prominent place given to the column of verification responsibilities. It is important that the Nuclear Studies and Safety Manager has responsibility for design requirements, and for verifying that these requirements are met at two levels--the design and construction levels, and engineering design changes after operation begins. Moreover, there is a flow-back of such quality checks to NIRC, the body responsible for defining the risk objectives and policies in the pre-design phase. An outsider can only stand and marvel at the complex organisational tangle that is Ontario Hydro, but in this case it seems to work, and work well.

378. Early in the study, I abandoned all hope of following through the details of the construction phase (although I had the priceless opportunity of seeing Darlington being built). Certain immediate impressions, however, can be recorded:

(i) Ontario Hydro acts as its own contractor over most of a project's scope and history. As such, it is one of Canada's largest contractors. This is justified by the highly specialised QA and design requirements

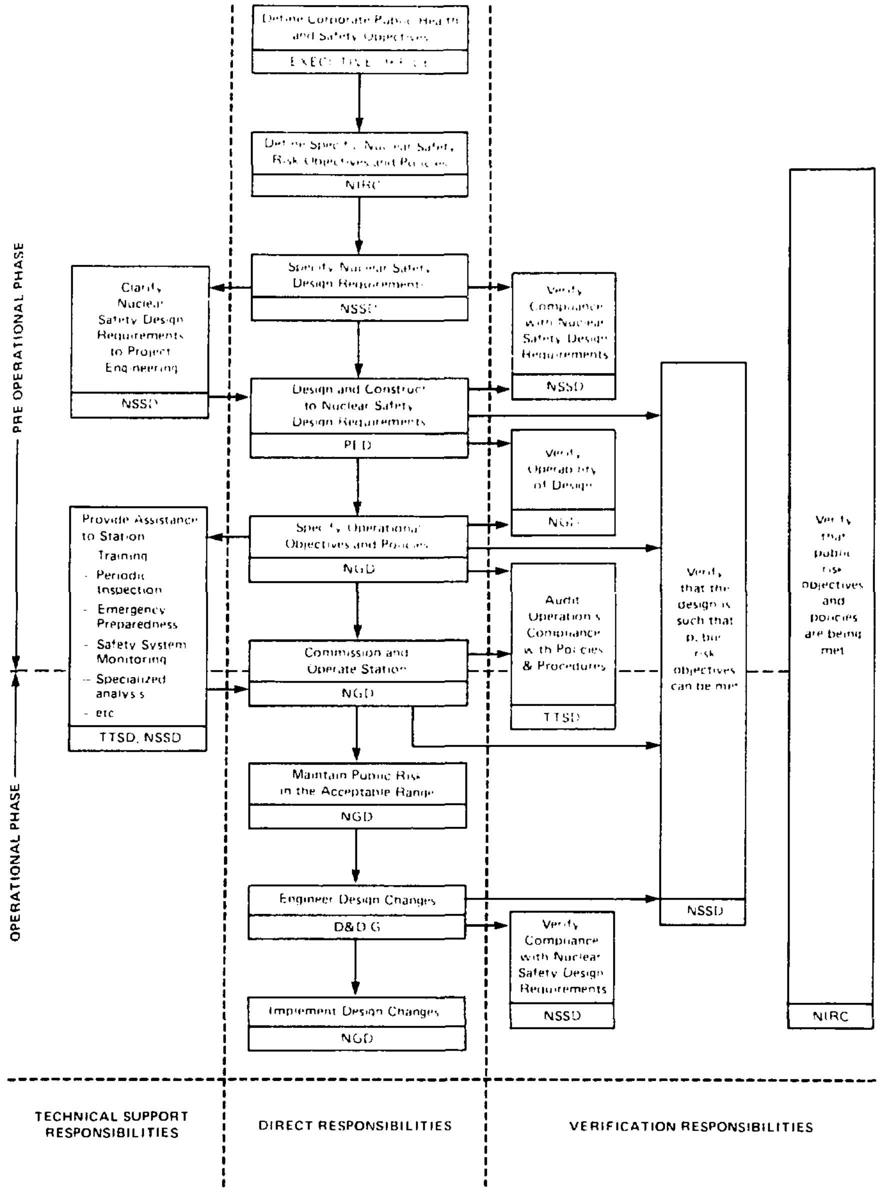


Figure 38 Public risk management framework, Ontario Hydro, defining roles of specific units (identified by initials) and showing the quality assurance role of Nuclear Studies and Safety Department (NSSD) and the Nuclear Integrity Review Committee (NIRC).

Source: Ontario Hydro

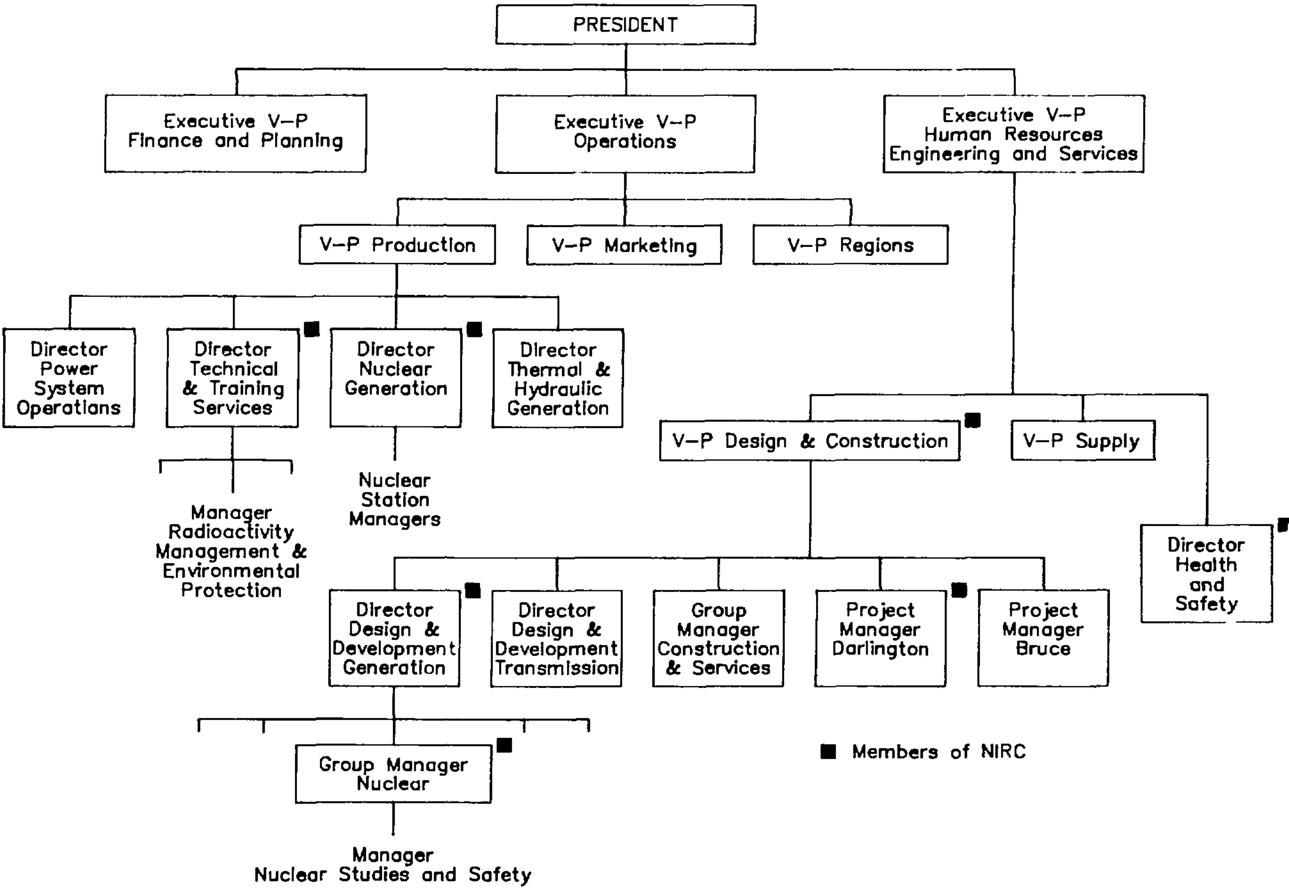


Figure 39 Senior management structure of Ontario Hydro, showing President's access to Nuclear Integrity Review Committee members.

Source: Ontario Hydro

of the nuclear programme. This Review has avoided anecdotal colour, but two tidbits should not be withheld: that Darlington NGS contains as much poured concrete as 17 CN Towers (the Tower being the world's tallest free-standing building); and that the Liebherr crane erected at Darlington (see Figure 40) merely to lift the calandrias into position can lift objects to 50 m, and cost $8 million.

(ii) The method of ensuring standards of material, equipment, installation methods, and adherence to standards is specified in Ontario Hydro's Quality Engineering Manual, which provides the detail required for effective QA programmes. This specifies (in detail) which industrial standards shall apply to each element in the construction. The ASME Manual of Standards appears to govern much of the content, but the Canadian Standards Association has over the past few years, in conjunction with AECL, extended the set of available standards to materials subject to radiation fluxes (including protective materials). Thus, the Ontario Hydro engineers and project staff have available the raw material of adequate audit and inspection.

(iii) AECB enters into the process chiefly by requiring certain suitable QA procedures, notably at the crucial design stage (which it audits). Ontario's Ministry of Consumer and Commercial Relations maintains on-site inspection of pressure vessels. But AECB resident inspectors arrive only as Ontario Hydro's operating staff are installed.

(iv) Materials testing and inspection have to be carried out at high levels of technical sophistication. AECL's laboratories and Ontario Hydro's facilities have both proved innovative in meeting Ontario Hydro's specialised needs, as have certain private suppliers. The problem becomes intensified when remote-control techniques, or non-destructive testing, have to be applied to areas with high radiation levels. Especially intriguing to me were the methods of testing pressure tube materials, and in-reactor inspection of fuel channels.

379. It is unquestionably true that mistakes made in the construction stage, if undetected, can endanger safety for the lifetime of the plant; like cancer, such mistakes may take decades to emerge. My own anxieties lie chiefly in three

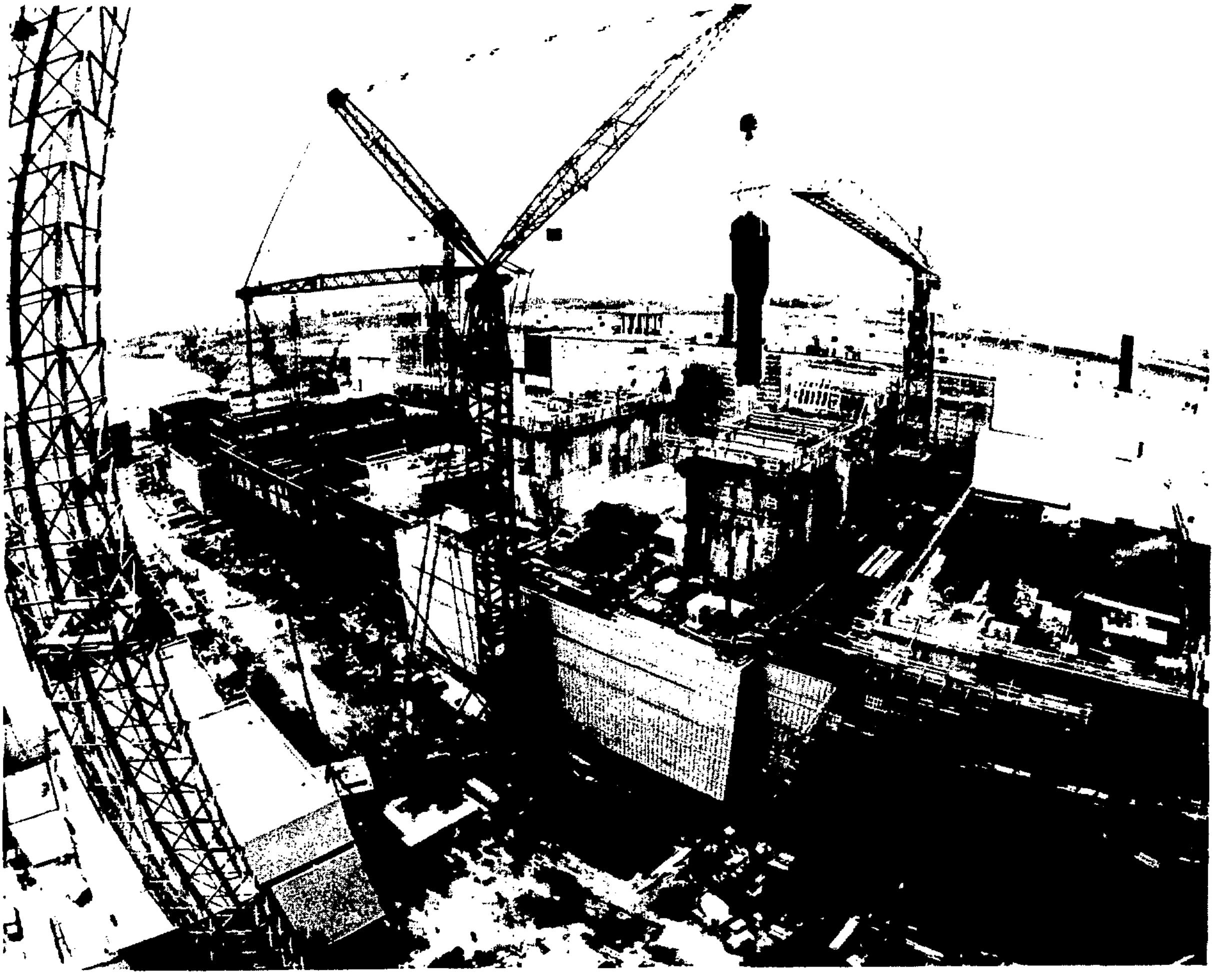


Figure 40 The Liebherr crane lifts a boiler into position at Darlington Nuclear Generating Station, under construction in 1987.

Source: Ontario Hydro

areas--the efficient functioning of pumps and valves, which is crucial to safety as well as to normal operation; the integrity of the plant's electrical systems, including those outside the reactor building; and the reliability of the entire regulatory and computerized monitoring systems--notably the control software, which AECB does not benchmark or verify in detail. Lying behind many of these concerns is anxiety as to whether or not enough is known about the properties of materials after prolonged irradiation.

380. Energy Probe, in two of its briefs, questioned the usefulness and need for the Nuclear Liability Act, a federal statute of 1976. In particular, one of its spokespersons at the Review Workshop expressed concern that this Act may shield contractors and suppliers to Ontario Hydro against the consequences of careless performance on their part. Lang Michener (personal communication) assure me, however, that the Act applies only to third-party liability and nuclear damage. Unless the contract between the operator and contractors or suppliers specifies otherwise, the latter would still be liable to the operator for loss or damage to the nuclear facility, and for all damage arising from a non-nuclear incident. This suggestion from Energy Probe hence appears groundless.

381. All my questions in these areas were willingly and convincingly answered, but I remain uneasy. The means adopted by engineers to minimise such unease is to emphasise the need for vigilant QC and inspection of work during the construction phase--plus constant testing afterwards. I agree, and wish that it was half as easy to do likewise in the arena of human performance. Elsewhere, I recommend that Ontario Hydro examine this entire area, perhaps with the aid of competent external consultants.

C. Ontario Hydro's Safety Culture

382. In its submission, Ontario Hydro made an excellent showing as to techniques and procedures for ensuring safety among its employees and its customers (the clients outside the exclusion fence). There can be no doubt about Ontario Hydro's dedication to maintaining safety. What is not discussed in

any depth is the corporation's safety culture, the expression used by industrial engineers to comprehend the entire atmosphere surrounding the maintenance of safety, informal as well as formal. To use another cant phrase of the day, the hidden safety agenda also affects the outcome, perhaps decisively.

383. Of the corporate attributes that influence safety, immense size is certainly central. Ontario Hydro is enormous, with 32 500 employees in 1987 and overall revenues from energy sales of $5.274 billion (47.5% of which came from nuclear reactors). Another is that it has no competitors and enjoys (or suffers from) an ill-defined relationship with the provincial government. Both circumstances have permitted Ontario Hydro to develop an idiosyncratic structure, system of operation, and attitude towards public needs. Ontario Hydro has many critics who point at these idiosyncracies with accusing fingers. I found, by contrast, that Ontario Hydro's peers outside Canada regarded its performance--including safety record--as admirable and viewed its freedom from undue governmental supervision with envy.

384. Two criticisms made by informed commentators deserve notice. One is that Ontario Hydro is technology-driven--that its unquestioned technical competence leads it to prefer technological initiatives and expanding power consumption to policies derived from more pessimistic socio-economic analysis. Another criticism is that the corporation is effectively isolated and self-sustaining, with neither the desire to develop nor the means of achieving a close working relationship with other institutions. Do such attitudes, if real, detract from safety?

385. The Review's small team of industrial consultants, led by W.J. Keough, came to the conclusion that employee safety was, indeed, adversely affected by these corporate attitudes. Some aspects of the safety culture appeared admirable--e.g., the decision to make individual workers responsible for personal radiological protection, and the defence-in-depth attitudes towards design. But a significant flaw concerned conventional safety in NGD, which is not as good as that of some other heavy industries. The officials to whom the consultants spoke seemed little aware of standards in other industries or of the existence of

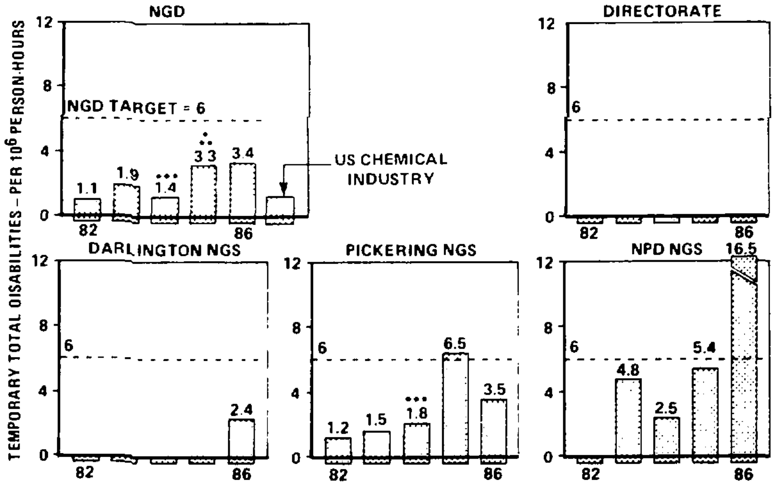
a large body of experience available to NGD. The consultants also commented unfavourably on two other questions. One was the fact that operator errors that had no consequences (because the design of the reactor corrected them) mostly went unreported. The other was an apparent lack of self-audit procedures.

386. To illustrate the point concerning conventional safety, Figure 41 shows the performance of NGD in temporary total disabilities since 1982. NGD sets a target of six per million person-hours worked, which Keough (personal communication) finds undemanding. Clearly, NGD usually has little trouble meeting its self-imposed target, both as a department and at each of its generating stations. But the US chemical industry (shown in Figure 41) does substantially better, although it, too, handles dangerous materials.

387. Two inferences may be drawn from this comparison: conventional safety at NGD stations might well be improved; and the radiological record (see Chapter V) is already excellent, because it gets more attention.

388. The point is made by the consultants that such disparities often serve as indications of imperfect overall corporate safety culture. All concerned at Ontario Hydro have unconsciously put more effort into radiological than into conventional protection (this being true of the work-force and its union representatives). A sound safety culture should resist such unbalanced attitudes. It should also be highly sensitive to comparable experience in other industries.

389. I have derived the same conclusion from my own contact with Ontario Hydro's technical staff. I saw much to admire and in no way question the zeal, dedication, and competence of the nuclear scientists and engineers who have designed and run these reactors. But I was struck by their seeming isolation from other professions and from the general public. They have ready contact and exchange with AECL and, to a lesser extent, with AECB. A large Ontario Hydro contingent attends the annual meeting of the Canadian Nuclear Association. And Ontario Hydro is justly praised for the close links it has with other utilities. But I have not encountered such contingents at events of more general scope. Nuclear engineers are far too prone to seek out their own company.



*MEDICALLY TREATED INJURIES AT BNPD-S ON OCTOBER 31, 1985 AND NOVEMBER 5, 1985 ARE NOW CLASSIFIED AS TEMPORARY TOTAL DISABILITIES

**MEDICALLY TREATED INJURY AT BNGS-A ON DECEMBER 22, 1985 IS NOW CLASSIFIED AS A TEMPORARY TOTAL DISABILITY

***TEMPORARY TOTAL DISABILITY AT PNGS ON SEPTEMBER 7, 1984 WAS REPORTED IN 1986

NUCLEAR GENERATING DIVISION
FREQUENCY OF TEMPORARY TOTAL DISABILITIES – TRENDS

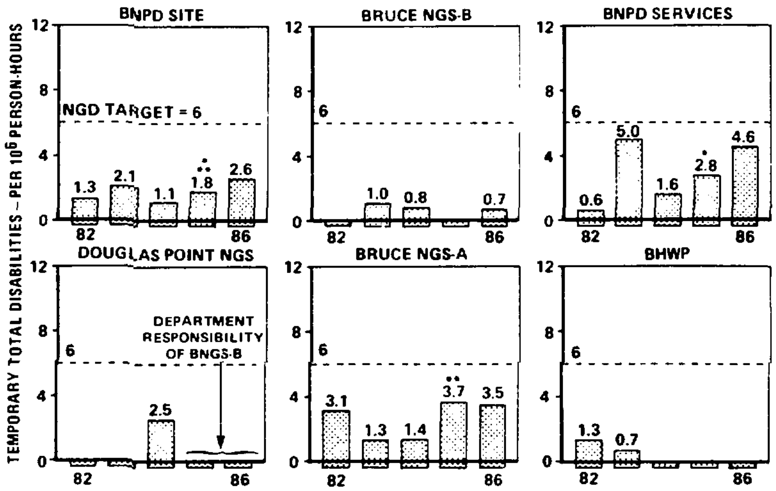


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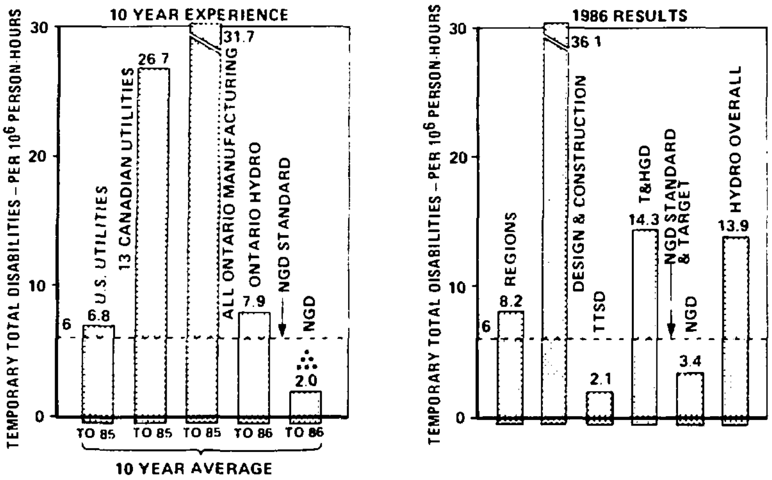
Figure 41(a) Conventional safety record of temporary total disabilities, Ontario Hydro Nuclear Generation Division, in terms of performance elsewhere–with that of the US chemical industry added.

Source: Ontario Hydro, W.J. Keough



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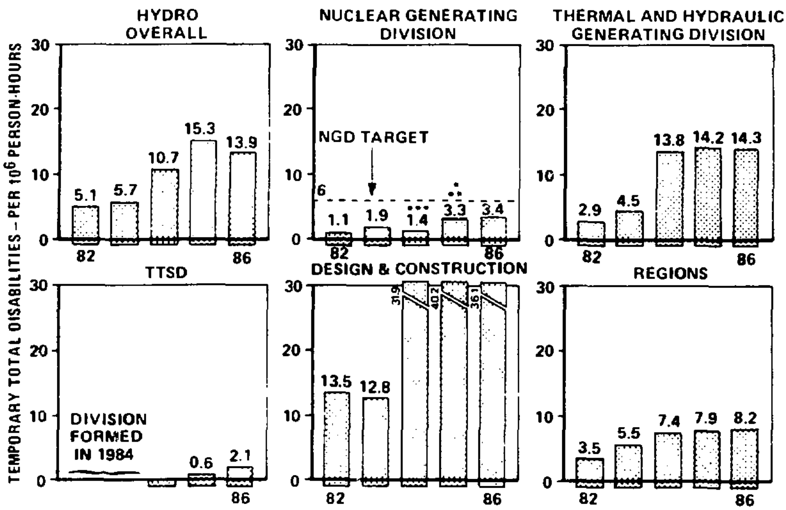

•MEDICALLY TREATED INJURIES AT BNPD-S ON OCTOBER 31, 1985 AND NOVEMBER 5, 1985 ARE NOW CLASSIFIED AS TEMPORARY TOTAL DISABILITIES
••MEDICALLY TREATED INJURY AT BNGS-A ON DECEMBER 22, 1985 IS NOW CLASSIFIED AS A TEMPORARY TOTAL DISABILITY
•••TEMPORARY TOTAL DISABILITY AT PNGS ON SEPTEMBER 7, 1984 WAS REPORTED IN 1986

Figure 41(b) Conventional safety record of temporary total disabilities, Ontario Hydro Nuclear Generation Division, in terms of performance elsewhere--with that of the US chemical industry added.

Source: *Ontario Hydro, W.J. Keough*

390. This isolation hurts both ways. It is a hindrance to the performance of NGD and its colleagues in Design and Construction and in Health and Safety. But it is equally a hindrance to the external scientific community, which is largely unaware of the problems of maintaining nuclear safety (or efficient electricity production). I find this isolation potentially disastrous. It should be bridged as soon as possible. The details of such bridge building must be left to others, but these areas seem to me to need immediate attention:

(i) socio-economic questions arising from the choice of nuclear power to dominate baseload provision. No adequate body exists to bring together Ontario Hydro with external authorities in these areas. In the same way, AECB deliberately confines itself to technical matters. The overwhelming bias of the industry towards a technical perspective thus limits discussion of crucial social and economic questions that arise in the safety area--e.g., what are the implications of massive emergency evacuation schemes? And what do "net benefit" and "reasonably achievable" mean in the ALARA principle?

(ii) the case of nuclear safety itself. The ACNS of AECB has marked out the territory and does a good job in helping AECB think clearly about safety regulations. But Ontario Hydro also has an urgent need for closer links with the external scientific, medical, and industrial communities. The President should appoint a Technical Advisory Committee on Nuclear Safety analogous to that already in place on the Nuclear Fuel Waste Management Program, to serve as a bridge in this direction.

(iii) public opinions, attitudes, and perceptions concerning Ontario Hydro's nuclear programme. I am aware of Ontario Hydro's extensive public information programme and its own soundings of public opinion. But it needs disinterested advice in this area from specialists in the academic, corporate, and other fields. In particular, it needs advice on how to maintain constructive contact with the community of intervenors tapped by this Review (e.g., at the Workshop). The way to deal with harsh criticism may well be to invite more of it.

391. A major objective of such interactions with outsiders is to ensure that the safety culture of Ontario Hydro keeps pace with events, takes into account the performance of others, and can judge public attitudes shrewdly. All these things are done now by Ontario Hydro staff, and often well done. The need is to improve them and to ensure that they do not deteriorate as time passes.

392. This is a crucial time for provincial decisions as regards Ontario Hydro as a whole, and as regards nuclear power in particular. Decisions will soon have to be made with respect to future supply increases and the role of further nuclear construction in meeting such increases. Assurance of quality in the nuclear power programme will be much affected by the decision concerning future supply sources.

393. If a decision is taken to build no more reactors, there is bound to be a gradual change in the hidden safety agenda. Sweden now confronts this problem. By public choice, the industry has been instructed to phase out its nuclear programme by the year 2010. This implies two ageing processes: ageing of professional staff, with a run-down of career prospects, thus discouraging the entry of new individuals; and the ageing of all reactor equipment. The staff scientist, Peter M. Fraser, visited the Swedish utilities and reported that they were tackling this problem in a good bureaucratic way: by looking for a change of public heart, so that the reactors would, after all, stay active. Poor morale of staff during a run-down of nuclear power is not an argument for retaining such power: that ought to be decided on other grounds. But a decision to build no more reactors, or to phase out existing reactors, is bound to have this negative effect, and the province should take it into account.

394. How does a large institution ensure that its present high standards endure or improve? How can Ontario Hydro achieve this? These are not rhetorical questions. Other public utilities have seen their competence wither away, just as private corporations have degenerated without any good reason. The Tennessee Valley Authority, 50 yr ago a pioneer in the provision of public power, is in just such a position. Its reactors (five in number) are now all out of service

because it can no longer meet regulatory standards, nor find qualified staff. Could this happen to Ontario Hydro?

395. The answer is "yes," if complacency is allowed to govern its policies. Complacency is the Achilles' heel of large, self-contained bodies such as Ontario Hydro. The Review's consultants used this term after their all too brief contact with Ontario Hydro's programme. I should not be so harsh. What I saw was a confident, competent, and self-sufficient organisation with a great deal to be proud of. But pride and complacency are first cousins. I should advise Ontario Hydro's Board of Directors to be aware of its achievements--and be wary of the future.

Chapter IX

Regulation

A. Can AECB Be an Effective Regulator of Ontario Hydro?

396. Partly through the powers conferred on it by the Atomic Energy Control Act, and partly by agreement with other provincial and federal agencies, AECB has become an effective regulator of Canada's entire nuclear industry, especially as regards radiological exposure. This small federal agency thus stands as the principal watchdog for nuclear safety.

397. The Review received six briefs dealing with the role of AECB*, and with what the intervenors and consultants perceived as its inadequate methods and resources. Favourable comment came mostly from the industry. Nearly all the intervenors wished to see AECB's role altered. Most of this material, analysed exhaustively by Margaret Grisdale in Appendix VII, goes beyond the defined scope of this Report. Grisdale's analysis is accompanied, however, by a series of conclusions and recommendations covering the entire body of intervenor opinion. Some have been incorporated into my own recommendations. The rest will be communicated to the appropriate Minister and to the presidents of AECB and AECL.

398. The main thrusts of intervenor criticism were as follows:

- that AECB's self-imposed restriction to scientific and technical matters is unrealistic (given the need to make judgements concerning such questions as ALARA, acceptable or tolerable risk, and net benefit);
- in particular, that staff resources should be increased to enable wider treatment of radiological risk and environmental issues (I agree and have so recommended);

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* Specifically, the following: Adams and Jerrett; Ahearne (for Resources for the Future); CELA; Energy Probe (Schrecker); Lang Michener Lash Johnston; and Ontario Hydro (see Annex I for details).

- that Board membership should be enlarged to allow wider representation of skills and interests (again I agree and have so recommended);
- that AECB's working methods are too informal and non-prescriptive, relying on extended negotiations with Ontario Hydro; most of the intervenors clearly preferred the US NRC model of detailed prescription, backed up by severe sanctions and tight inspections (with court action a common solution);
- that the revolving-door phenomenon (the easy movement of staff between AECB, AECL, and Ontario Hydro) threatens objectivity;
- that AECB is insufficiently democratic, e.g., that it still operates behind mostly closed doors, shuns public inquiries at the siting, construction approval, and licensing stages, and regards Ontario Hydro, and not the public, as its client;
- that there is an excessive dependence on unwritten agreements, ad hoc decisions, and a balancing of economic benefits against risks (as the ALARA principle indeed requires);
- that there is no arm's-length relationship with the utility, and that AECB relies on persuasion, not sanctions (which in any case it lacks); and
- finally, that AECB is virtually invisible to the public.

B. Is AECB Sufficiently Visible?

399. The answer is clearly "no." Most Canadians have never heard of it. Very few could name its President or describe his duties. AECB follows the honourable public service tradition of remaining in the background: to be, as a commentator said at the Review Workshop, possibly good but definitely grey. Successive presidents of AECB have shunned the limelight, and the staff is not encouraged to go out on the hustings. AECB's public reference room is one of the least used in Ottawa*. The average citizen is entirely unaware of the watchdog function performed on his/her behalf. In fact, outside the nuclear

* In the first seven months of 1987, seven persons used the room.

community itself, AECB is almost unknown among influential groups in Canada--and usually confused with AECL when the subject is raised.

400. The same is [illegible]e of AECB's two key safety-related Advisory Committees, ACNS and ACRP. These highly expert bodies offer AECB excellent advice and prepare definitive statements for publication. Recent examples include: ACNS-4, "Recommended General Safety Requirements for Nuclear Power Plants" (AECB 1983); ACNS-10, "Alternative Electrical Energy Systems--A Comparison of the Risks of Occupational and Public Fatalities" (AECB 1987c); and (unpublished, but available in draft to the Review), AC-1, "Recommended de Minimis Radiation Dose Rates for Canada" (AECB 1987b). The work of these committees is admirable, and the reports are as good as anything I have seen, but they remain little read, are circulated primarily within the nuclear community, and are slow to appear even within this restricted circle.

401. Neither committee, moreover, seems to feel that it has a responsibility to reply to the frequent allegations by anti-nuclear groups that risks are being underestimated, and disquieting evidence ignored. In many ways I support the committee attitude, which is a normal scientific position. But it leaves a vacuum on the public scene, which extreme opinions rush in to fill. The result is doubt, anxiety, and bewilderment in the public's mind. Politicians, confronted with this vacuum, have no clear way of getting a dispassionate judgement. I have already said (in Chapter VIII, para. 390) that Ontario Hydro needs public input in the areas of socio-economic impact, of nuclear safety, and of public opinion. A similar need exists at the federal level, but the existing committees do not, and probably should not, attempt to play this role.

C. Should AECB Remain a Purely Technical Body?

402. The restriction of AECB to technical and scientific matters is self-imposed. Nothing in its Act requires it to eliminate socio-economic considerations. Indeed, much of the mandate requires it. But the practice of confining the

scope of its work so that it can be done by scientists and engineers is firmly established. Membership of the Board itself tends to confirm this stance.

403. In my judgement, the restriction is wise, given the tight budget and limited staff available. But the work of AECB would be strengthened if two measures were taken. One is to add additional Board members drawn deliberately from other walks of life--from the bench, from the media, from the universities (not necessarily the humanities and social sciences), from labour, and perhaps from that little-considered pool of talent, the voluntary agencies. The second measure would be to create within the AECB staff significant strength in environmental and socio-economic matters. I do not feel that ACRP and ACNS can function adequately without stronger staff resources at headquarters. Obviously, the overall size of the Board and its staff is a powerful constraint when enlargement of role is being considered.

404. There is, however, an obvious need for a better-informed debate on all questions related to nuclear safety. This requires a far wider perspective than AECB alone can provide. Advice on mechanisms that might be effective could, perhaps, be obtained from bodies such as the Science Council, the Institute for Research in Public Policy, and the Royal Society of Canada.

D. Does AECB Have Sufficient Powers?

405. Intervenor opinion was very skeptical of AECB's ability to discipline Ontario Hydro, given the latter's large size and obvious technical dynamism. As I pointed out above (in Chapter I, para. 65), AECB's clout resides in two functions: the authorisation of operating staff (which it examines exhaustively), and the granting of construction approvals and operating licences (the latter being a repetitive process). AECB senior officers feel this to be sufficient.

406. The striking reality of regulation in this system is that it requires a prolonged two-way discussion between the officials of Ontario Hydro and those of AECB. In part, this is by word of mouth, and hence goes unrecorded. The

rest consists of voluminous correspondence (some of which I have examined). It seemed to several of our intervenors and consultants that such a procedure invites all kinds of misfortunes: e.g., a degree of collusion between the two bodies of officials (this word was actually used at our Workshop), and the failure to record much of the substance of the debate, which handicaps future decisions or enforcement measures. Grisdale summarises these anxieties in Appendix VII-C.

407. She concludes, and I concur, that the power to license, coupled with the threat of unfavourable publicity if the utility does not comply with licence requirements, is adequate to achieve AECB's objectives. Moreover, the authorisation of several levels of nuclear generating station staff depends on the ability of the individuals concerned to get past the high obstacle of AECB examinations. I agree with AECB that these two mechanisms enable it to enforce its mandate.

E. The Character of AECB

408. The remaining points of criticism summarised in subsection (a) above are more in the realm of public administration than that of nuclear safety. The central questions are these: would Canada be better off with a US NRC-based system of prescription, sanctions, and litigation? Or would it be better to stay with our present system of collegial debate? And does democracy demand public participation at every level of decision making?

409. On the first question I am sure that the answer is "no"; we are better off with our present system, although it needs modifying. AECB's present role and procedures fit in well with normal Canadian political patterns. They enable experts to regulate experts, without the lawyers intervening. I prefer to trust the integrity of experts rather than the wisdom of court decisions (in a technical field such as this). That is why the Atomic Energy Control Act exempts AECB from judicial review. It is a wise provision.

410. On the other hand, John F. Ahearne (whose judgement I respect) says in his brief (on behalf of Resources for the Future) that our system is too collegial, too familial. It depends too much on informal, uncodified agreements and conventions. And there is too great a disparity in resources between Ontario Hydro and the watchdog. I agree with these criticisms and recommend that the failings be removed.

411. Those who argue that the US NRC system is superior overlook many things. One is the character of our parliamentary democracy. In my view, the Parliament of Canada has neglected the area of nuclear safety (unlike the Ontario Legislature). But that is no reason for abandoning the system. A second overlooked circumstance is that Canada has the luxury of a very limited number of nuclear utilities, of which Ontario Hydro is by far the largest--in contrast with the US NRC's 60. The United States has little choice but to proceed as it does. Canada does not need such elaboration.

412. Support for this view comes from a recent analysis by James M. Jasper (1987), a former colleague of Ahearne in Resources for the Future, Inc., the Washington economic and social research group used by the Review as a commentator. Jasper, a sociologist on the staff of New York University, points out that France, the country most committed to nuclear electricity, enjoys a technically excellent nuclear supply (without significant accidents at its PWRs), a successful and advanced technique of public consultation, and a favourable price structure. France relies on a regulatory system strikingly like Canada's, as does the United Kingdom (see Appendix V, by W. Paskievici). A key to the French success, Jasper maintains, is the very high standard of technical performance maintained in the national utility, Electricité de France (as is true of Ontario Hydro). He contrasts this with the poor standards of the US utilities, which, he says, often see nuclear power as just another way of boiling water. He accuses the US utilities of poor management, poor economic performance, and poor scientific standards--in short, a poor system to imitate. Fortunately, Ontario Hydro does not do so.

413. To return to Ahearne's critique, I support these views:

(i) Relations between Ontario Hydro and AECB should become more formal, and decisions taken--and the reasons for them--should be more thoroughly documented. But there need be no increased use of prescriptive or legalistic methods on AECB's part.

(ii) AECB needs more resources. Its present prospect of a shrinkage of staff (in response to the Nielsen Task Force recommendations) has to be reversed. There is a clear demand that the Board itself be enlarged and broadened in scope, and that staff numbers and areas of expertise be increased. To reduce AECB's resources at this time would be ludicrous.

414. As regards AECB's alleged lack of public involvement, and the often-expressed feeling that there should be direct public participation in its decisions, I have mixed feelings. Much of the cry for public participation seems to me to be an assault on representative democracy. Canada and Ontario both embarked upon nuclear power as a public enterprise, and all the actors--Ontario Hydro, AECL, and AECB--have publicly established mandates to develop, use, or regulate nuclear electricity. None, in my judgement, has abused its mandate. But some members of the public say that they feel totally excluded from decisions that affect their lives. There is a need to bring them into the decision-making framework.

415. Within Ontario, given AECB's dislike of public hearings at the site, such access might well be given by means of the public hearings process specified by the Environmental Assessment Act. Given that public concerns with future nuclear projects are socio-economic and environmental rather than technical, this seems like a suitable mechanism. Ontario should finance the work of intervenors at such hearings, especially those that are critical of the nuclear industry. The best ways of disarming criticism are to invite it, to accept it when it makes sense, and to reject it when it does not.

416. I explicitly reject the suggestion made to me in several briefs that the Province of Ontario should enter the field of nuclear regulation. In the first place, the constitutional right of the federal government to regulate this industry

is well established and is supported by the courts. Second, there is every advantage (pointed out in several places in the text) in having the regulator and the utility in different jurisdictions. And third, the pool of available staff is already too small. One regulator is quite enough.

Annex I

Table A-1

List of Written Submissions From Consultants and Intervenors

Organisation or individual	Consultant (C) Paid intervenor (PI) Relevant letter (R) Unpaid volunteer (V)	Subject of submission
ACT for Disarmament	PI	"The collapse of values": the impact of a nuclear accident on the Regional Municipality of Durham, and portions of Victoria, Peterborough and Northumberland counties
Action for Social Change	PI	The social and political dimensions of nuclear reactor safety
Adams, Thomas, and Michael Jerrett	PI	The Atomic Energy Control Board: its role and performance in the regulation of nuclear reactor safety
Atomic Energy of Canada Limited (AECL)	V	AECL's work and facilities
Behavioural Team	C	Design quality assurance in nuclear generating stations
Bercha International Inc.	PI	The bridge between public perception and expert assessment of nuclear safety
Biron, K.V., and J.W. Richmond	C	Safety evaluations for the Ontario Nuclear Safety Review
Brogden, Peter	V	Nuclear safety and the public, attitudes, public information and participation; reactor safety design philosophy and the philosophy of risk
Burns, David J.	C	A review of the safety-related issues of the failure of the pressure tubes and fuel channels used in Ontario Hydro's CANDU nuclear reactors
Canadian Environmental Law Association (CELA)	PI	Regulatory control of nuclear safety
Canadian Nuclear Association and Organization of CANDU Industries	V	The role of suppliers in nuclear plant safety

Table A-1 (cont'd)

Organisation or individual	Consultant (C) Paid intervenor (PI) Relevant letter (R) Unpaid volunteer (V)	Subject of submission
Canadian Nuclear Society	V	The perspectives of individuals working in the nuclear industry on a safe nuclear power system
Canadian Union of Public Employees (CUPE), Local 1000 (Ontario Hydro employees' union)	PI	Comment on the safe operation of Ontario Hydro's nuclear generating stations
*Chalk River Technicians' and Technologists' Union, CLC Local 5186	V	Comment on nuclear reactor safety in Ontario
Church and Society Committee, London Conference of the United Church of Canada	PI	A popular education brochure
*Deep River, Town of	V	A nuclear community's perspective
Diamond, David J.	C	Analysis of reactivity transients
Durham Nuclear Awareness	PI	Ready or not . . . a critique of Ontario's off-site nuclear emergency plans
Eaves, Connie	C	A critical appraisal of formal submissions to the ONSR on radiological protection
Energy Probe (four separate briefs)	PI	The hazards of old reactors Transboundary impacts of nuclear reactor accidents: emergency planning and liability The Atomic Energy Control Board: assessing its role in reactor safety regulation Risks, nuclear safety, and the Ontario Nuclear Safety Review

Table A-1 (cont'd)

Organisation or individual	Consultant (C) Paid intervenor (PI) Relevant letter (R) Unpaid volunteer (V)	Subject of submission
Environment Canada	V	The rationale for Environment Canada's involvement and role in the nuclear area, and the major programmes and activities of the Department with respect to environmental protection and emergency preparedness
Federation of Engineering and Scientific Associations (FESA)	V	The general approach taken towards nuclear safety and licensing in Canada, and the professional environment in which nuclear reactors are designed, analyzed, licensed and operated in Ontario
Ferahian, R.H.	PI	A critique of earthquake design requirements of Ontario's nuclear power plants
Franks, C.E.S.	R	Nuclear energy and development in Canada
Friends of the Earth (two separate briefs)	PI	Newspaper coverage of Ontario Hydro's reactor problems, August to December 1983 Scientific risk assessment and the nuclear power debate in the Province of Ontario
C.H. (Don Mills) [letter simply signed C.H.]	R	Safety of the design of Ontario Hydro nuclear generating stations, the location of nuclear generating stations, and alternatives to nuclear power
Human Factors North	C	An assessment of human factor issues in the safety of Ontario Hydro's nuclear generating stations
I.M.P.A.C.T. Group Ltd.	V	A nuclear emergency alert communication system
Institute for Resource and Security Studies	C	Severe accident potential of CANDU reactors

Table A-1 (cont'd)

Organisation or individual	Consultant (C) Paid intervenor (PI) Relevant letter (R) Unpaid volunteer (V)	Subject of submission
International Institute of Concern for Public Health (IICPH)	PI	Biological and environmental consequences of nuclear accidents, the adequacy of emergency measures, reactor safety design philosophy, women and nuclear safety and comments on AECB, ICRP and UNSCEAR
Jervis, R.E.	C	Radionuclide releases from CANDU reactor containment in upset conditions
J.T.L. Consulting	C	A review and assessment of Ontario's nuclear emergency planning
Karpik, Stephen R.	C	A critical review of the Province of Ontario's Nuclear Emergency Atmospheric Dispersion Model (NEADM)
Keough, W.J.	C	Surveying operational safety
Lang Michener Lash Johnston	C	The legal, regulatory and constitutional framework within which Ontario's CANDU nuclear reactor plants operate
Lonergan, S.C., and R. Goble	C	An estimation of the off-site economic consequences of a severe accident at the Pickering nuclear generating station
McMaster University, Department of Clinical Epidemiology and Biostatistics	PI	Nuclear safety in Ontario: a comprehensive framework for decision-making and a critical review of quantitative analyses
Meneley, Daniel A.	C	A technical description of Ontario Hydro's CANDU reactors
Monitoring and Assessment Research Centre (MARC)	C	Intervention levels

Table A-1 (cont'd)

Organisation or individual	Consultant (C) Paid intervenor (PI) Relevant letter (R) Unpaid volunteer (V)	Subject of submission
New Democratic Party of Ontario, Brian Charlton, M.P.P.	V	Composition of ONSR, nuclear safety and public attitudes, public participation and information, the use of "acceptable risk," cost of nuclear safety, emergency planning, international context of nuclear safety, and operator error
Northwood, Derek O.	C	A review of the safety-related issues of the metallurgy of the pressure tubes used in Ontario Hydro's CANDU nuclear reactors
Nuclear Awareness Project	PI	Aspects of reactor safety
Ontario Federation of Labour	V	The broader nuclear safety issues
Ontario Hydro	V	Ontario Hydro's nuclear programme
Paskievici, W.	C	An overview of the regulation of the French nuclear industry, of the French nuclear reactor safety philosophy, and of the French reaction to the Chernobyl accident
Port Elgin, Town of	V	Design, operating procedures and emergency plans of Ontario Hydro's nuclear generating stations
Prince, A.T.	C	A review of nuclear emergency measures affecting Ontario, and other related matters
Queen's University Women's Centre	PI	The impact of the nuclear industry on women, and the impact of women on the nuclear industry
Resources for the Future (John F. Ahearne)	C	A comparison of nuclear power regulation in Canada and the United States
Robertson, J.A.L. and D.G. Hurst	C	Nuclear safety philosophy in Canada
Rogers, J.T.	C	Comments on severe accident analysis, quality assurance, risk, and licensing of nuclear reactors

Table A-1 (cont'd)

Organisation or individual	Consultant (C) Paid intervenor (PI) Relevant letter (R) Unpaid volunteer (V)	Subject of submission
Safety Institute, McCrae Lyceum	R	The preliminary education of the nuclear work force
Science for Peace (two separate briefs)	PI	Radioactive air monitoring: a survey of Ontario
		Environmental and agricultural consequences of a major nuclear power plant accident
Serdula, K.J.	C	Review of accident analyses for Ontario Hydro's Pickering "A" and Bruce "A" nuclear generating stations
Sharp, Christopher	PI	Emergency planning: an environmental and behavioural perspective
*Society of AECL Professional Employees	V	Nuclear safety: beyond the technical details
Solicitor General, Ontario Ministry of the	V	Nuclear emergency planning and preparedness in Ontario
Stevenson and Associates	C	An evaluation of Ontario Hydro nuclear generating station containment and containment systems
Teekman, Nicholas	PI	A review of nuclear sources of hydrogen ions and the effect of hydrides on CANDU zirconium niobium pressure tubes
Urbanprobe Associates Limited	PI	Gaming simulation techniques for the planning of emergency evacuation procedures
Velan Inc.	V	Valve technology related to nuclear plant safety
Woodway Resources Limited	R	The need to develop instrumentation and know how to deal with radioactive radiation related emergencies [sic]

* Financial support by ONSR restricted to the payment of expenses incurred in travelling to Workshop in September.

Annex II

Table A-2

Power Reactors In or Near Ontario and Research Reactors in Canada*

A. POWER REACTORS

Plant	Type	Location	In-service date	Net power (MWe)	Status as of October 1987
AECL/Ontario Hydro nuclear generating stations					
1. Nuclear Power Demonstration (NPD)	CANDU	Rolphton (Ottawa Valley)	1962	21.5	Decommissioning, shut down 24 July 1987
2. Douglas Point NGS	CANDU	Bruce Township (Lake Huron shore)	1968	206	Decommissioning, shut down 4 May 1984
Ontario Hydro nuclear generating stations					
3. Pickering A NGS	CANDU	Pickering (Lake Ontario shore)			
Unit 1			1972	515	Returned to service after 1983-87 outage in September 1987
Unit 2			1971	515	Will return to service in 1988, after outage since 1983
Unit 3			1972	515	Operating. Spring 1989 outage scheduled for retrofits, inspection, and routine maintenance (90 d)
Unit 4			1973	515	Operating. Summer 1988 outage scheduled for retrofits, inspection, and routine maintenance (112 d)
4. Pickering B NGS	CANDU	Pickering (Lake Ontario shore)			
Unit 5			1983	516	Operating
Unit 6			1984	516	Operating
Unit 7			1985	516	Operating
Unit 8			1986	516	Operating

Table A-2 (cont'd)

Plant	Type	Location	In-service date	Net power (MWe)	Status as of October 1987
5. Bruce A NGS	CANDU	Huron Township (Lake Huron shore)			
Unit 1			1977	759	Operating**
Unit 2			1977	769	Operating**
Unit 3			1978	759	Operating**
Unit 4			1979	769	Operating**
6. Bruce B NGS	CANDU	Huron Township (Lake Huron shore)			
Unit 5			1985	835	Operating
Unit 6			1984	837	Operating
Unit 7			1986	837	Operating
Unit 8			1987	837	Operating
7. Darlington NGS	CANDU	Town of Newcastle (Lake Ontario shore)			
Unit 1			1989	881	Advanced construction phase
Unit 2			1989	881	Advanced construction phase
Unit 3			1991	881	Under construction
Unit 4			1992	881	Under construction
AECL power reactor					
8. Gentilly 1	CANDU/ BLW	13 km east of Trois-Rivières	1971	250	Decommissioned 1986 (AECL)
Other Canadian power reactors (not AECL or Ontario Hydro)					
9. Gentilly 2	CANDU	13 km east of Trois-Rivières	1983	640	Operating (Hydro Québec)
10. Point Lepreau	CANDU	39 km south of Saint John	1983	640	Operating (New Brunswick Electric Power Commission)

Table A-2 (cont'd)

Plant	Type	Location	In-service date	Net power (MWe)	Status as of October 1987
Illinois State power reactors					
11. Dresden Station		Morris			
Unit 2	BWR		1970	772	Operating
Unit 3	BWR		1971	773	Operating
12. Zion Plant		Zion			
Unit 1	PWR		1973	1040	Operating
Unit 2	PWR		1974	1040	Operating
13. Quad Cities Station		Cordova			
Unit 1	BWR		1973	769	Operating
Unit 2	BWR		1973	769	Operating
14. La Salle County Station		Seneca			
Unit 1	BWR		1984	1078	Operating
Unit 2	BWR		1984	1078	Operating
15. Byron Station		Byron			
Unit 1	PWR		1985	1120	Operating
Unit 2	PWR		1987	1120	Operating
16. Braidwood Station		Braidwood			
Unit 1	PWR		1987	1120	Operating
Unit 2	PWR		1988	1120	Under construction
17. Clinton		Clinton			
Unit 1	BWR		1986	950	Operating
Michigan State power reactors					
18. Big Rock Point	BWR	Charlevoix County	1965	72	Operating
19. Palisades	PWR	Van Buren County	1971	882	Operating

Table A-2 (cont'd)

Plant	Type	Location	In-service date	Net power (MWe)	Status as of October 1987
20. D.C. Cook	PWR	Berrien County			
Unit 1			1975	1020	Operating
Unit 2			1978	1060	Operating
21. Erico Fermi	BWR	Monroe County	1986	1093	Operating
New York State power reactors					
22. Nine Mile Point	BWR	13 km north-east of Oswego			
Unit 1			1969	610	Operating
Unit 2			1988	1080	Operating
23. J.A. Fitzpatrick	BWR	13 km north-east of Oswego	1975	821	Operating
24. Indian Point	PWR	40 km north of New York City			
Unit 2			1974	864	Operating
Unit 3			1976	965	Operating
25. R.E. Ginna	PWR	20 km east-north-east of Rochester	1970	470	Operating
Northern New England States power reactors					
26. Main Yankee	PWR	Wiscasset, Maine	1972	810	Operating
27. Seabrook		Seabrook, New Hampshire			
Unit 1	PWR		-	1198	Opening deferred
Unit 2	PWR		-	1198	Opening deferred
28. Vermont Yankee Station	PWR	Vernon, Vermont	1972	504	Operating
Ohio State power reactors					
29. Davis-Besse	PWR	30 km east of Toledo	1977	906	Operating

Table A-2 (cont'd)

Plant	Type	Location	In-service date	Net power (MWe)	Status as of October 1987
30. Perry	BWR	35 km north-east of Cleveland	1987	1205	Operating
Wisconsin State power reactors					
31. La Crosse (Genoa)	BWR	La Crosse	1969	48	Operating
32. Point Beach Station		Two Creeks			
Unit 1			1970	495	Operating
Unit 2			1972	495	Operating
33. Kewaunee Plant	PWR	Kewaunee	1974	515	Operating

B. RESEARCH REACTORS

Station/Unit	Operator	Location	Start-up date	Heat output (W)	Status as of 31 March 1987
NRU	AECL	Chalk River, Ont.	1957	137 000 000	
NRX	AECL	Chalk River, Ont.	1947	42 000 000	In hot stand-by condition since 1986. Operates 4-8 h weekly
Swimming Pool	McMaster Univ.	Hamilton, Ont.	1959	5 000 000	
Pool Test Reactor (PTR)	AECL	Chalk River, Ont.	1957	100	
Zed 2 Experimental Reactor	AECL	Chalk River, Ont.	1957	150	
ZEEP	AECL	Chalk River, Ont.	1945	10	Retired 1970
Slowpoke Demon-stration Reactor	AECL	Whiteshell, Man.	1987	2 000 000	Developmental, now at criticality
WRI	AECL	Whiteshell, Man.	1965	60 000 000	Closed down, 1985
Slowpoke II	AECL	AECL - Tunney's Pasture, Ont.	1971	20 000	Retired 1984
Slowpoke II	Univ. of Toronto	Toronto, Ont.	1976	20 000	

Table A-2 (cont'd)

Station/Unit	Operator	Location	Start-up date	Heat output (W)	Status as of *31 March 1987*
Slowpoke II	École Polytechnique	Montreal, Que.	1976	20 000	
Slowpoke II	Univ. of Edmonton	Edmonton, Alta.	1977	20 000	
Slowpoke II	Saskatchewan Research Council	Saskatoon, Sask.	1981	20 000	
Slowpoke II	AECL	Kanata, Ont.	1984	20 000	
Slowpoke II	Royal Military College	Kingston, Ont.	1985	20 000	

* Excluding US military reactors.

** *These units can produce 300 MWt of steam in addition.*

Annex III

Ontario Hydro
Radiation Protection Regulations, Part 1
Submission to AECB, April 1987

Limits

1. The dose limits **do not include** dose equivalent received by a worker from background sources, or from medical diagnostic or therapeutic procedures.

2. The dose limits **do include** any dose equivalent received by a worker, as a consequence of his or her occupation, from all sources of ionizing radiation.

3. The dose limits specified **do not apply** to ionizing radiation received by a person carrying out emergency procedures undertaken to avert danger to human life. However, all doses shall be kept as low as is feasible and unnecessary exposure shall be avoided.

4. In determining the dose received, the contribution from sources of ionizing radiation both inside and outside the body shall be included.

Dose Limits - Atomic Radiation Workers (ARWs)

5. Administrative and procedural controls shall be established to ensure that these limits are not exceeded.

6. Whole body: the total of all effective doses shall not exceed:

   (a) 30 mSv during any quarter ECY;
   (b) 50 mSv during any ECY.

7. Lens of the eye: the total of all doses shall not exceed:

   (a) 80 mSv during any quarter ECY;
   (b) 150 mSv during any ECY.

8. Other organs or tissues: the total of all doses shall not exceed:

(a) 300 mSv during any quarter ECY;
(b) 500 mSv during any ECY.

Exceptions to Dose Limits - ARWs

9. Emergency action to avert extensive facility damage or to prevent development of unsafe situations: the single or accumulated dose to a person, added to the dose already received by that person in the current ECY, should not be allowed to exceed 100 mSv.

10. Special planned exposures: the AECB, in response to an application made in advance, may permit an ARW a single or accumulated dose up to twice any of the annual dose limits for ARWs. However, the AECB shall not be requested to issue such a waiver unless:

(a) there are extraordinary circumstances where no appropriate alternative is available; and
(b) the ARW has been informed of the implications of the exposure for his or her own health and has consented in writing to the waiver being applied.

Waivers shall not be arranged for ARWs who are known to be pregnant.

Dose Limits - Workers Other than ARWs

11. Administrative and procedural controls shall be established to ensure that these limits are not exceeded.

12. Whole body: the total of all effective doses shall not exceed 5 mSv during any calendar year.

13. Organs or tissues: the total of all doses shall not exceed 50 mSv during any calendar year.

Dose Limits - Members of the Public

14. Whole body: the total of all effective doses shall not exceed 5 mSv during any calendar year.

15. Organs or tissues: the total of all doses shall not exceed 50 mSv during any calendar year.

Dose Limits - Pregnant Workers

16. Administrative and procedural controls shall be established to ensure that these limits are not exceeded.

17. Abdomen of a pregnant ARW, or any pregnant worker: the total of all doses of radiation shall not exceed:

- (a) 0.6 mSv during any two week dosimetry period in which the worker's supervisor is aware of the pregnancy of that worker;
- (b) a total of 10 mSv after the supervisor is informed of the pregnancy of that worker.

Facility Emission Limits

18. Authorized emission limits shall be established for radionuclides likely to be released from a nuclear facility.

19. Operating targets for emissions shall be established.

Dose Rate Limits in Facilities

General radiation background

20. Zone 1 shall have a general radiation background as low as possible and in any case shall have an average monthly radiation field level less than **0.025 mSv/h.**

21. Under normal operating conditions, areas which are usually occupied or are occupied for long periods of time, should have a low general radiation background. The long term exposure of personnel who are normally in or frequently passing through the areas shall be considered.

22. The following guidelines on general dose rates apply for design purposes:

Area	mSv/h
(a) Average dose rate, accessible area	.01
(b) Average dose rate, shutdown area	.04
(c) Maximum dose rate, shutdown area	.20

Loose β/γ Surface Contamination Limit - Default Value

Location	$\mu Ci/m^2$
Controlled (rubber) areas	5
All other areas	non-detectable

23. Loose surface contamination should not normally exist or be tolerated outside of designated areas such as rubber areas. If loose contamination levels within a controlled area exceed the limit, decontamination should be carried out.

Annual Limits on Intake and Corresponding Derived Air Concentrations

24. The Annual Limits on Intake (ALIs) and corresponding Derived Air Concentrations (DACs) quoted in this table are the accepted values as of October 6, 1986.

Approved Annual Limits of Intake (ALIs)
and
Derived Air Concentrations (DACs)

GASES

Radionuclide	ALI (μCi)	DAC ($\mu Ci/m^3$)
H-3 (HTO)	6.8 x 10	2.0 x 10
H-3 (HT)	--	2.7×10^5
C-14 (CO_2)	2.2×10^5	1.0×10^2
C-14 (CO)	1.8×10^6	7.0×10^2
C-14 (hydrocarbons)	--	1.0×10^4
I-131	3.5 x 10	1.5×10^{-2}
I-133	1.9×10^2	7.8×10^{-2}
I-135	8.9×10^2	3.8×10^{-1}
I - (mixed fission products)*	2.5 x 10	1.0×10^{-1}

* The following relative abundance of iodine isotopes is assumed: I-131 (1.00), I-132 (1.45), I-133 (2.00), I-134 (2.04), I-135 (1.81).

Annual Limits of Intake (ALIs) and Derived Air Concentrations (DACs)

PARTICULATES

	Radionuclide	ALI (μCi)	DAC ($\mu Ci/m^3$)
Fission	Sr-89	1.0×10^2	4.3×10^{-2}
	Sr/Y-90	3.2	1.4×10^{-3}
	Zr/Nb-95	1.4×10^2	5.0×10^{-2}
	Ru-103	4.9×10^2	2.0×10^{-1}
	Ru-106	8.9	3.7×10^{-3}
	Cs-134	1.4×10^2	5.9×10^{-2}
	Cs-137	1.9×10^2	8.1×10^{-2}
	Ba/La-140	2.2×10^3	9.3×10^{-1}
	Ce-141	4.9×10^2	2.0×10^{-1}
	Ce-144	1.1×10	4.7×10^{-3}
Alpha	Pu-238	6.8×10^{-3}	2.8×10^{-6}
	Pu-239	5.9×10^{-3}	2.5×10^{-6}
	Pu-240	5.9×10^{-3}	2.5×10^{-6}
	Am-241	5.9×10^{-3}	2.5×10^{-6}
	Cm-242	2.7×10^{-1}	1.1×10^{-4}
	Pu-242	5.9×10^{-3}	2.5×10^{-6}
	Am-243	5.9×10^{-3}	2.5×10^{-6}
	Cm-244	1.1×10^{-3}	4.7×10^{-6}
	U (nat)	4.1×10^{-2}	1.7×10^{-5}
Activation	C-14 (particulate)	6.2×10	2.6×10^{-2}
	Cr-51	1.4×10^4	5.6
	Mn-54	6.8×10^2	2.8×10^{-1}
	Fe-55	2.1×10^3	8.6×10^{-1}
	Co-58	3.8×10^2	1.6×10^{-1}
	Fe-59	3.8×10^2	1.6×10^{-1}
	Co-60	1.9×10	8.0×10^{-3}
	Zn-65	2.4×10^2	1.0×10^{-1}
	Sb-124	1.8×10^2	7.5×10^{-2}
	Sb-125	2.7×10^2	1.1×10^{-1}
	Eu-152	1.5×10	6.1×10^{-3}
	Eu-154	8.4	3.5×10^{-3}
	Eu-155	1.1×10^2	4.6×10^{-2}

Annex IV

Comments on Special Interest Group Intervention

1. Several intervenor groups were financed by the Review to submit critiques of the performance outlined in Chapter V. The more significant responses will be discussed below.

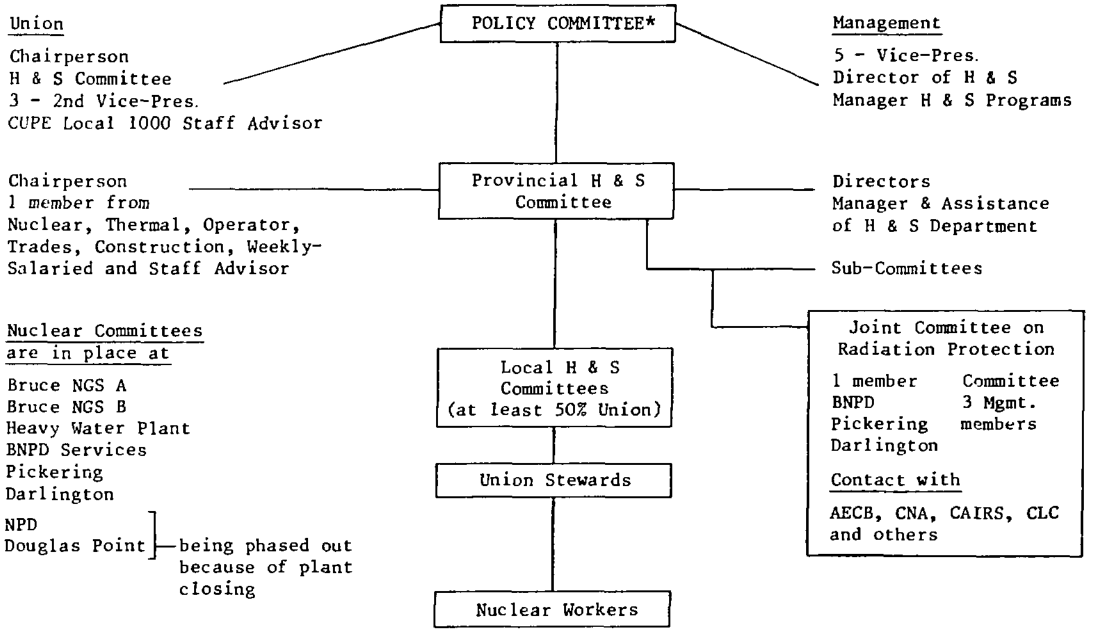
(a) CUPE Local 1000

2. This union represents most persons in Ontario Hydro whose work involves daily exposure to ionising radiation. The exceptions are management staff, certain construction trades, and professional groups. The CUPE Local 1000 submission was especially thorough. Because it represents the views of the persons most likely to be adversely affected, its recommendations merit close attention.

3. CUPE has a collective agreement with Ontario Hydro that provides for an effective relationship between the corporation and the union in health and safety questions and also assumes full consultation with the appropriate provincial and federal regulating agencies. Figure 42 below shows the elaborate committee structure that is in place to facilitate this consultation. Clearly, the structure extends, as it should, from the executive suites to the shop-floors. The Joint Committee on Radiation Protection has close connections with external bodies, and the union is appropriately represented on the committees of AECB, the Canadian Nuclear Association, and other relevant bodies. The local Joint Health and Safety Committees at each generating station work effectively.

4. The union submission speaks of "a problem with jurisdiction" as regards the respective roles of the federal Department of Labour (specifically part 4 of the federal Labour Code), the provincial Ministry of Labour, and AECB, but also says that they "are well on the way to straightening it out," in relation to the respective roles and responsibilities of themselves, the provincial authorities, and Ontario Hydro.

HEALTH AND SAFETY STRUCTURE
FOR
ONTARIO HYDRO



*This title is unacceptable to Ontario Hydro, who agree, however, that such a committee exists

Figure 42 Health and safety structure for Ontario Hydro, showing formal links with Canadian Union of Public Employees Local 1000.

Source: CUPE Local 1000

5. In general, the union says that "there is a working system for health and safety. It is successfully operating in various degrees . . . but improvements are necessary. . . ."

6. It accepts Ontario's adoption of the ICRP ALARA principle (which is that radiation exposure should be as low as reasonably achievable), but is uneasy about the word "reasonably" (as I confess I am). It notes the apparently good health record of the nuclear generating station cohorts. Ontario Hydro's overall corporate industrial safety record lies in the range of eight to nine fatalities per 100 million person-hours worked. The NGD's achievement therefore looks remarkable: there have been no fatalities in 125 million person-hours worked. Moreover, general health in the work-force appears good.

7. Nevertheless, the union is cautious, pointing out that the healthy worker effect is at work; the work-force is in part self-selected and in part corporation-selected in such a way that better-than-average health is likely.

8. Among other areas of concern, CUPE lists the following:

(i) It agrees that the individual worker effective dose limit should remain at 50 mSv, its present value, but argues for an "authorised limit" of 12.5 mSv, which should be "policed to ensure that no one receives higher doses year after year." Any individual exceedance would have to be reported to AECB.

(ii) Ontario Hydro has adopted a "target limit" for Pickering NGS individual annual doses of 20 mSv. CUPE would like this target to be applied to all Ontario Hydro stations (it has just been implemented also at Bruce A).

(iii) Female workers (few at present in radiological protection zones) should be protected during the early weeks of pregnancy. Because women also face greater hazards than men because of the breast cancer hazard, "the limit should be set lower for everyone to protect the female worker."

As regards this final point, R.V. Osborne of AECL (personal communication) offers this comment:

> Irrespective of where any single limit is set there will be a difference between the sensitivities of males and females to breast cancer induced by radiation (just as there are differences, in both directions, for other cancers). The limits were set taking such differences into account. It might also be noted that the major health hazards are believed to be induction of cancers plus induction of genetic disease in the children and grandchildren of exposed workers. Although the risk of radiation-induced cancers is higher for females than for males, recent UNSCEAR reports indicate that the risk of induction of genetic disease in offspring of *the female parent* is probably zero to 40 percent of that for the male parent.

I cannot improve on this authoritative assessment.

(b) The International Institute of Concern for Public Health (IICPH)

9. A second paid intervenor whose submission dealt mainly with radiological protection was IICPH, whose principal spokesperson is Dr. Rosalie Bertell. The IICPH submission is a composite document touching on several related questions, most of which are outside the Review's terms of reference. Dr. Bertell is well-known for her crusading work to improve--as she sees it--standards of radiological protection world-wide. The submission contains 32 detailed but loosely co-ordinated recommendations.

10. The IICPH submission was circulated, like its companion documents, to Ontario Hydro and AECL for comment. Both corporations responded in depth and detail. These responses were sent to Dr. Bertell, who has replied. I have discussed the main points of contention with a variety of authorities, including Dr. Arthur Upton, Chairperson of BEIR-5; Dr. Gordon Butler, Canada's former long-term ICRP and UNSCEAR representative; Dr. Robert Haynes of the Advisory Committee to the Review; and the competent staff of AECL and Ontario Hydro. I also received detailed comments from Dr. Connie Eaves of the British Columbia

Cancer Research Centre in Vancouver. All these have been taken into account in what follows.

11. Dr. Bertell's main thrust is that the available evidence on dose-response relationships resulting from radiation exposure is being misinterpreted by the scientists who dominate the regulating and standard-setting bodies, most notably ICRP. She is especially critical of the role played by physicists in establishing protective standards and argues that medical and health professionals are being excluded from a proper role in the regulating bodies. She is also critical of AECB, because it lacks staff with such qualifications. She herself is a mathematician and biometrician.

12. I cannot agree with the submission's recommendation "that Canada no longer rely on ICRP, UNSCEAR or BEIR as the scientific support for radiation protection standards."

13. On the contrary, it is essential that Canada be guided by the findings of these bodies. They are accepted by the world scientific community as the best clearing-houses for the empirical data that are available, as the authoritative bodies to judge the meaning of the evidence and (in the case of ICRP) to suggest standards for safe exposure. Canada, Ontario, and Ontario Hydro need not be bound, in a legal sense, by what these bodies find, but they would be ill-advised to abandon them as the best sources of advice and intellectual authority.

14. IICPH's doubts about ICRP take the form of allegations that ICRP is biased by the origins of its members. IICPH asserts that ICRP is dominated by physicists and medical administrators, many of them "involved in national atomic energy development," and that ICRP cannot therefore be considered free of all "bias, conflict, or government pressure" (IICPH submission, p. 11). Persons qualified in occupational and public health "have been excluded from membership since its conception in 1950."

15. In fact, ICRP's work is done principally by four expert committees, whose composition does include eminently qualified individuals in the appropriate

disciplines. The committee chairpersons are also members of ICRP itself. Two of the individuals specifically mentioned by IICPH as having been "deliberately excluded" by ICRP have in fact served on these committees and are among the authors of ICRP documents. Second, scientists of sufficient eminence to be appointed internationally serve in their personal capacities. Regardless of their affiliations, they are expected to use their scientific skills objectively, and the whole ethos of science dictates that they try to do so. I believe that they succeed.

16. They succeed, however, in spite of criticisms. Some observers are dissatisfied by what they see as ICRP's failure to take immediate stands on vital issues, and for what they perceive as its self-imposed concentration on defining dose limits. Others dislike its self-perpetuating scheme of membership. But few would accuse it of ignoring evidence to protect vested interests.

17. A concentrated campaign is under way to discredit this invaluable voluntary agency. The attacks range from articles in The Economist to published petitions signed by several hundred scientists, including many biologists. The demand is that the limiting effective dose recommendations be decreased by a divisor of five, 10, or even more. I agree with the editorial opinion of Nature (London) (Vol. 329, pp. 185-186, 1987):

> To respond as [ICRP's] critics ask by promptly tightening the present limits would be as damaging of its reputation and effectiveness as if it caved in to a demand from the nuclear industry that the limits should be moved in the other direction.

Nature (London) adds, however, (and again I agree) that:

> If it seeks to retain its influence, it had better change its style . . . . ICRP is slower than it should be to respond to changing circumstances, and given to behaving as if its recommendations should be regarded as mosaic tablets, to be accepted by all concerned with only the most laconic of explanations.

18. Although its style is indeed laconic, and its pronouncements are often made ex cathedra, in a way that I myself find austere, ICRP without any doubt

represents the consensus of those most qualified to make such judgements, according to the accepted standards of science. The same is true of UNSCEAR and BEIR-5.

19. I believe that this comment is also valid for Canada's national situation in radiological protection. Our own institutions are responsible and highly competent, yet they are in danger of losing public support because of unsubstantiated but widely disseminated criticisms.

20. The problem of confidence is further complicated by delays in the revision of ICRP dose limits. These depend heavily but by no means exclusively on cancer mortality statistics among Japanese victims of wartime nuclear explosions in 1945. It is now believed that the survivors of these attacks were actually exposed to 20-30% lower effective doses than was earlier assumed. An entirely new dosimetry has been established (Fry and Sinclair 1987; Preston 1987). It follows that the dose-response estimates have to be changed, but this will take time. "The changes in the risk coefficients," writes R.V. Osborne (personal communication) "will depend more on the new mortality data, on the value(s) assigned to the relative biological effect for neutrons, and on the model(s) used to apply the risk coefficients. The general feeling now is that the risk estimates may increase. Various factors have been bandied about; a factor of two (for the general public--the change for workers is likely to be smaller) is often quoted; but there are no definitive analyses yet of all the relevant new information." Very similar comments were made to me by G.C. Butler (personal communication) and Arthur C. Upton, chairperson of BEIR-5 and a member of the relevant working group of ICRP. It will still be many months or even years before this decision reaches Canada's regulating bodies in the form of firm recommendations.

21. More positively, I agree with IICPH that "more sensitive human health monitoring" ought to be carried out "in the vicinity of nuclear installations with special emphasis on health of newborns and young children." I agree in principle that such studies should be conducted by competent medical scientists (including epidemiologists). If there is any chance that the health of children is adversely

affected by the nearby presence of a nuclear reactor, that fact should be established or authoritatively refuted.

22. An argument repeatedly brought forward by Bertell (and reiterated in the IICPH recommendations) is that the ICRP, UNSCEAR, and BEIR emphasis on cancer mortality as the main measure of the impact of ionising radiation is misleading. A range of other diseases or morbidity data should also, in her view, be matched against radiation exposure. In particular, she has argued that prolonged exposure to low-level radiation may lead to premature ageing of tissues and increased leukaemia incidence in certain populations (which she claims to have detected in various US regions). I agree that an epidemiological study of such claims should be considered in the Ontario context (although I am aware of the difficulties in the way), and unmistakably under the aegis of an independent expert group. AECB's ACRP has indeed put such a proposal on its active agenda.

(c) Nuclear Awareness Project

23. This group submitted to the Review two critiques of radiological performance:

- a paper entitled "Tolerable Costs: an Approach to Radiation Standard-Setting"; and
- an analysis of radioactive emissions from Ontario's nuclear generating stations, including useful graphs and tables.

24. The first of these papers is a closely researched and argued attack on what the Nuclear Awareness Project sees as the looseness and inadequacy of the Canadian standard-setting process. Much of the content again goes far beyond the scope of the Review. Nevertheless, I believe that it raises some issues that deserve debate elsewhere, probably at the national level (as AECB is, by implication and by direct statement, under attack).

25. The second paper is a useful presentation, largely visual, of how the nuclear generating station emissions actually performed between 1973 and 1986, together with some comments on environmental monitoring at Pickering NGS. It identified certain reporting complexities or errors, which Ontario Hydro (1987a: 20-22) has confirmed or explained. The paper also analyses radioactive emissions and effluents in relation to gross energy output.

26. The Nuclear Awareness Project's recommendations include:

- "a full reassessment of the health and environmental costs of radioactive pollution," including virtually all the matters covered in Chapter V;
- "the establishment of new radiation standards for human beings and the natural environment based on qualitative cost-benefit analysis"--the recommendations include individual dose limits, collective doses integrated over the lifetime of the radionuclides, and the adoption of "authorised" limits in place of the ALARA principle;
- "the immediate establishment of interim dose limits," including maximum annual exposures of 20 mSv for exposed workers and 1 mSv for the public; also authorised limits of 10 mSv for workers and 0.05 mSv for the public;
- reform of AECB, together with the creation of an Ontario-based independent council "to assess the present and future costs of radioactive pollution"; and
- the conduct at federal or provincial level of "a qualitative cost-benefit analysis of nuclear power and to recommend new radiation standards based on this analysis"--federal environmental thinking with respect to the best practicable technology for treating emissions (I have rephrased this point) should be taken into account.

27. Ontario Hydro and AECL responses to these recommendations are highly critical. In general, I disagree with the tenor of the recommendations--essentially because the record shows that radioactive emissions to the environment from reactors under normal operating conditions are and will continue to

be small by comparison with natural radioactivity levels, a condition that will hold until there is a severe accident. But I am sure that the entire question of the adequacy of radiological dose limits needs further public scrutiny.

Annex V

Brief on Nuclear Emergency Planning and Preparedness in Ontario

Ministry of the Solicitor General, 12 August 1987

1.0 Historical Background

1.1 While the Federal Government is responsible, through the Atomic Energy Control Board, for the licensing and regulation of nuclear facilities in Canada, the responsibility for public health and safety is that of the provinces, and they are responsible for the protection of their populations in the event of a nuclear accident.

1.2 The first nuclear power reactor went into operation at Pickering in 1971. Ontario has had an emergency plan to deal with the consequences of a nuclear accident since the early 1970s. The first such plan was revised in 1979 following the Three Mile nuclear accident in the U.S.A., and a new plan was adopted in early 1980.

1.3 When this new plan was tried out in several exercises it became apparent that it suffered from many weaknesses. It was decided in 1982 to take a fresh look at nuclear emergency response, and produce a comprehensive new plan for it.

1.4 Another reason for this fresh approach was the prospect of an Emergency Plans Act being adopted in the province. This Act, which became law in 1983, provides for nuclear emergencies to be treated differently from others. Whereas, in the case of other emergencies, municipalities are primarily responsible for planning and response (with the Province furnishing assistance upon request), in the case of nuclear emergencies, it is the legal responsibility of the Province of Ontario to prepare a plan and to implement it.

1.5 This new planning effort, begun in 1982, proceeded at a slow pace because of the limited resources available for it. However, in 1986 Part I of the new Provincial Nuclear Emergency Plan was adopted by the Government of Ontario and promulgated. The Solicitor General of Ontario was made responsible for the administration and implementation of this plan.

1.6 In April 1986 a massive nuclear accident took place at the Chernobyl plant in the U.S.S.R. As a consequence, the Province has reviewed the subject of nuclear emergency planning and preparedness, and taken some important decisions based upon the implications of the Chernobyl accident. These are described in their appropriate context below.

2.0 Scope of the Problem

The scope of the problem which nuclear emergency planning and preparedness in Ontario is required to deal with can be expressed in terms of the various sources of hazard:

(a) There are 21 nuclear power reactors operating or under construction in Ontario, located in 4 sites.
(b) There are 2 large research reactors located in one site in Ontario.
(c) There is 1 nuclear power reactor in the U.S.A. within 16 km (10 miles) of Ontario.
(d) All the above reactors require plans and preparations to protect people from direct exposure to radiation resulting from an accident at them.
(e) There are 6 nuclear power reactors in the U.S.A. within 80 km (50 miles) of Ontario.
(f) There are 7 other nuclear reactors in the 4 adjoining jurisdictions.
(g) Chernobyl showed that a severe nuclear reactor accident anywhere in the world could potentially affect Ontario.
(h) The reactors at (e) through (g) all require plans and preparations for protection against exposure from radioactive contamination of the environment, especially of the food chain.
(i) In addition, a nuclear weapon accident anywhere in the world could pose a hazard to people in Ontario.

3.0 Aim of Nuclear Emergency Planning and Preparedness

The aim of nuclear emergency response planning and preparedness in Ontario is two-fold:

(a) To safeguard the health, safety and well-being of the people of Ontario, and their property, in the event of a nuclear accident anywhere which might affect them.
(b) To protect Ontario's large investment in its nuclear industry by, firstly, contributing to the maintenance of public support for the program, and secondly, in case of an accident, minimizing the possibility of adverse public reaction afterwards by demonstrating an ability to effectively protect people from harm and risk.

4.0 Goals for Nuclear Emergency Planning and Preparedness

The Provincial Cabinet, on March 25, 1987, prescribed the following goals for nuclear emergency planning and preparedness in Ontario to achieve the above aim:

(a) All nuclear emergency plans should be finalized and issued.
(b) All technical and operational procedures should be completed.
(c) Thereafter, all of these plan and procedure documents should be kept under continuing review by qualified personnel.
(d) All operational control centres for nuclear emergency response should be selected, organized and equipped at the minimum level required for immediate readiness.
(e) All preparations required to achieve an adequate level of operational readiness should be completed.
(f) An annual exercise program should be observed so that every nuclear facility plan is exercised (both onsite and offsite) at least once every year.

(g) A program of annual refresher training should be instituted for key personnel.

5.0 Analysis of the Prescribed Goals

5.1 Plans and Procedures

To cover the nuclear facilities at which an accident could affect Ontario, there is a requirement for the development of a set of 10 Provincial plans. An additional 6 municipal and 6 agency plans need to be developed with Provincial input, guidance, review, co-ordination and approval. Approximately 44 procedural manuals have to be prepared. The plans of at least 5 other jurisdictions have to be kept under review.

5.2 Advance Preparations

To enable plans to be rapidly and effectively implemented, it is necessary to work out in advance as many of the details of implementation as possible, and then to make the required preparations. It is also necessary to set up the basic infrastructure required for the execution of the plans. The mechanism set up under the Provincial Nuclear Emergency Plan to create and maintain emergency preparedness is one Provincial and a number of regional preparedness committees, each of which is chaired by a Provincial representative, and the accomplishment of whose task is the responsibility of the Province. Approximately 70 different municipalities, departments, agencies and organizations are represented on these committees, each of which is required to make certain preparations under various plans and procedures, and whose work is to be guided, co-ordinated and monitored by the Province.

5.3 Public Education

Another aspect of advance preparation is the institution of a program of public education for the populations living around nuclear facilities. The Provincial policy on the subject calls for a comprehensive and continuing program to be carried out for each nuclear facility. While the implementation of the programs is the responsibility of the nuclear facility operators, the Province monitors, regulates and participates in them.

5.4 Infrastructure

The main infrastructure required to be set up is a number of emergency centres, which need to be selected, organized and equipped at the minimum level required for operational readiness. These centres are: 9 operations centres, 5 information centres, 3 traffic control centres, 10 monitoring and decontamination centres, and 23 reception/evacuee centres.

The other important element of the required infrastructure is telecommunications.

5.5 Exercises and Training

Once plans and procedures are developed, and necessary advance preparations made, it is essential to train the personnel who will fill the various positions in the emergency response organization. The best form of training is practice drills and exercises, which simulate as closely as possible a real emergency. To exercise plans and preparations adequately, and ensure response readiness, it is necessary to hold an exercise every year for each designated nuclear facility, which would practice the emergency response organization for that area. These exercises have to be conducted by the Province. The Provincial response organization should participate in full in one such annual exercise, while taking part on a reduced scale (enough to ensure realistic Provincial interaction with the municipal organization) in the others.

Because of the turnover of personnel, and the large gap (one year) between exercises, it is necessary to conduct refresher training of key personnel at regular intervals. This is best done through audiovisual aids, workshops, table-top exercises etc.

5.6 Review and Updating

It is necessary to keep under continuous review all the plans and procedures prepared to deal with a nuclear emergency, and to ensure that they are kept up to date in the light of operational and technical developments and changes. A great deal of study and research is under way in many areas which have a bearing on nuclear emergency planning and preparation, and it is vital to keep abreast of this.

The Provincial Nuclear Emergency Plan has set up a number of technical committees to advise on various technical aspects. To be effective, these committees need adequate guidance and support.

6.0 Present Status of Planning and Preparedness

A considerable amount of work remains to be done to achieve the goals set for nuclear emergency planning and preparedness in Ontario. The conceptual framework for this effort has been developed. This would enable a response to be improvised should an emergency occur before all preparations are complete. However, this is considered to be only an interim stage, which should be ended as soon as possible. The development of the prescribed response capability is now mainly dependent upon the provision of adequate resources.

7.0 Resources for Nuclear Emergency Planning and Preparedness

Taking into account the direct relationship between resources allocated and results achieved, the Provincial Cabinet, when setting the goals for nuclear emergency planning and preparedness in Ontario, made them contingent upon adequate resources being provided. After considering various options for the provision of these resources, Cabinet decided that these should be provided by Ontario Hydro in the form of an annual subvention, which would be used to hire the required staff and meet the operating expenses of the Provincial program.

There is ample precedence for this. Nuclear utility operators are required to support emergency preparedness in many jurisdictions. This decision of Cabinet has been conveyed to Ontario Hydro.

8.0 Other Post-Chernobyl Actions

The Province has also initiated the following actions in the emergency preparedness area as a result of its review of the implications of the Chernobyl accident:

(a) A working group has been set up to review the issue of the upper level of emergency planning and preparedness in Ontario, and make recommendations thereon. This will enable the Province to decide whether any change is needed in the size of the zone around nuclear reactor facilities within which detailed emergency planning and preparedness is carried.

(b) Another working group has been set up to make recommendations on what Ontario needs to do to establish a capability and a plan to deal with acute radiation casualties which may occur as a result of a nuclear accident.

(c) The Province is also undertaking an in-depth review of the security status of nuclear reactor facilities, and will institute improvements where necessary.

9.0 Conclusion

Ontario has an excellent conceptual plan to ensure the safety of its inhabitants in the event of a nuclear accident anywhere in the world. This plan still requires to be translated into tangible preparedness to deal with such an emergency. The Province is confident that, with the assistance of Ontario Hydro, a high level of nuclear emergency preparedness will soon be established for the people of the province.

Annex VI

Description of the Ontario Nuclear Safety Review (ONSR)

Margaret C. Grisdale

1. The Review was established on 18 December 1986 with the appointment by the Minister of Energy of Dr. F. Kenneth Hare as a one-person commission. In so doing, the Minister was responding to recommendation 3 of the July 1986 report of the Ontario Legislature Select Committee on Energy. The terms of reference of the Review were specific, namely an assessment of the design and operation of Ontario Hydro's CANDU reactors and the emergency measures associated with the operation of these reactors. Excluded from the terms of reference of the Review were uranium mining, refining, and fuel fabrication; disposal of spent nuclear fuel; decommissioning of nuclear reactors; and the potential sale of tritium extracted from heavy water.

2. The original date by which Dr. Hare was to report to the Minister of Energy was 31 December 1987. Because of administrative delays at the outset of the Review, essentially the provision of appropriate office accommodation, the reporting deadline was extended to 29 February 1988. The original budget of $1.5 million was increased to $1.9 million to cover the extended period of the Review. Dr. Hare worked closely with the Royal Society of Canada in conducting this work and was assisted by a full-time staff of four (a staff scientist, a manager, an administrative assistant, and a secretary) and an advisory panel.

3. The Royal Society of Canada, the national interdisciplinary academy of scholars, supported the Review in several ways. Its senior officers assisted the Commissioner in clarifying the way in which he would approach the subject. Advisory Panel members were selected by the Commissioner in consultation with the Royal Society, and half the members of the Advisory Panel were Fellows of the Society. The Society monitored the method and progress of the Review by means of a liaison committee established for this purpose, regular written progress reports by the Review, and semi-regular personal meetings with the Commissioner and staff. The Review Commissioner was solely responsible for the conclusions and recommendations of the Report. The Society, however, appointed a panel of three external reviewers to examine the Report before presentation to

the Minister. These reviewers were asked to ensure that in the Report the Review's terms of reference were addressed, that scholarly methods were employed in assessing the facts, and that the recommendations were sustained by the text.

4. The Advisory Panel was composed of eight members, biographical sketches of whom appear at the beginning of the Report. The original radiation specialist, Dr. Douglas Grahn, was forced to resign early in the Review by the pressure of other professional obligations. He was satisfactorily replaced by Dr. Robert Haynes. Five meetings of the Advisory Panel were conducted, usually with some of the senior consultants and the Chairperson of the Ministry of the Solicitor General Working Group No. 8 in attendance. The Advisory Panel was particularly helpful in establishing the issues upon which the Review should focus and the way in which topics of interest should be pursued. Members of the Advisory Panel also advised the Commissioner on an individual basis on matters pertaining to their special interests. Several members of the Advisory Panel undertook consulting assignments (with the approval of the Ministry of Energy), and nearly all Advisory Panel members chaired sessions at the Review Workshop.

5. Although the Commissioner was cognisant of the relevance of human psychology to the issue of nuclear power safety, the Review focussed on the technical and scientific aspects of safety. The topics identified for detailed investigation were risk, reactor design and accident analysis, consequences of nuclear accidents, emergency planning, the operation of Ontario Hydro's nuclear generating stations, and regulation of the nuclear power industry in Ontario.

6. The expert advice required by the Review in these specialised, often highly technical fields was obtained by engaging consultants. The Commissioner endeavoured to engage these consultants on an international basis in order to fulfill his mandate to "obtain the views of experts who are not associated with the nuclear industry," and to "consult widely to obtain a cross-section of technical and scientific views and information." This, however, proved to be a challenge. Expertise in CANDU technology is largely confined to Canada, and

most of the experts of the high calibre sought by the Review are employed by the Canadian nuclear industry. The Commissioner and staff sought advice within the Canadian, American, British, and European scientific communities to identify qualified candidates, and these were carefully screened and assessed before appointment. Well-qualified, independent specialists from Canada and the United States who met the Review's requirements were eventually identified and appointed.

7. Contracts were awarded to 37 consultants, and approximately one-third of the total Review budget was spent on consulting services. The chief criterion for selection was excellence. Five of the consultants were identified as "senior consultants," who worked closely with the Commissioner and staff in establishing the direction of the research and the need for other consultants.

8. The Commissioner made known his desire to hear from all with an interest in the Ontario nuclear power industry and its safe operation. Advertisements in which written submissions were invited were placed on two occasions in The Globe and Mail and La Presse, and individual letters of invitation to make submissions were sent to industries; industry organisations; labour organisations; governments and government departments at the municipal, provincial, and federal levels; medical associations; journalists; and citizens' groups considered to have interest in the subjects of the Review. The availability of $250 000 for intervenor funding was announced in these invitations. Most of this sum was eventually granted to 19 individuals or groups to assist with the preparation of 21 briefs. Submissions were also made by several organisations, individuals, and government departments, notably Ontario Hydro and AECL, who prepared major documents without any financial assistance from the Review.

9. In the course of its operation, the Review established an extensive network of contacts (see the lists attached to this annex) and built up a large collection of reference documents. The latter, which includes books, reprints, and technical reports, was key-worded, catalogued with the use of a computer program designed for this purpose, and stored in the Review office. Copies of the computer print-out of the material on hand were made available to all with

an interest in the subject, and the material was freely available for use in the Review office. Members of the technical community within Canada and abroad were unfailingly generous in providing literature. The Review is particularly grateful to AECB, AECL, the Canadian Nuclear Association, and Ontario Hydro in this respect. The help provided to the Review in the collection of information by IAEA, the UK Nuclear Installations Inspectorate, and the US NRC also deserves acknowledgement.

10. Although the Commissioner and members of his Advisory Panel were scientists familiar with the concept of nuclear power, some of them required detailed technical instruction in the way the CANDU system functioned. This was accomplished by means of seminars conducted for them by Ontario Hydro, AECL, British Nuclear Fuels Limited, and the UK Central Electricity Generating Board (see list 6).

11. The Commissioner and senior staff endeavoured in the course of the Review to contact on an international basis the senior members of the nuclear power industry and its regulators and to visit as many major nuclear power installations as possible. They were assisted in these endeavours by some members of the Advisory Panel. All Ontario Hydro nuclear power sites were visited, some of them more than once. Representatives of the Review travelled to Austria, the Federal Republic of Germany, France, the Netherlands, Sweden, the United Kingdom, and the United States (see lists 1 and 2). Although this travel was demanding of the scarce time available to the Review, it helped to offset the Review's inability to engage as many international consultants as initially envisaged by the Commissioner. It also enabled the Review to meet and to consult many more members of the international scientific, technical, regulatory, and industrial communities than it would have, had it attempted to bring such representatives to Toronto.

12. A Workshop was conducted by the Review in Toronto on 24-26 September 1987 to which the authors of more than 60 briefs (a complete list of these appears in Annex I) were invited, along with observers from organisations with an interest in the Review. Although it had been established at the beginning of

its work that the Review would not conduct public hearings, it was felt that some public participation in the Review would be desirable. The Workshop presented this opportunity and provided a forum for the discussion of views presented to the Review in writing. Most of the briefs received were duplicated and distributed in advance of the Workshop. Briefers were given the opportunity to make short, oral presentations that were followed by discussion. The Review accommodated the large number of presentations within the 3-d period by conducting two parallel sessions throughout most of the Workshop. Discussion was intelligent and lively, although often not conclusive, and the Review appeared to succeed in bringing together the major participants in the nuclear power debate (the industry, the regulator, and the opposition) in a calm and open atmosphere.

13. An important contribution to the work of the Review was made by OSART of IAEA that reviewed the operation of the Ontario Hydro Pickering NGS. This OSART review was conducted at the invitation of the Government of Canada and supported by the Ontario Ministry of Energy and by Ontario Hydro. The team visited the Pickering NGS during the first three weeks of June 1987 and reported orally on its findings on 19 June. Its written report was submitted to the Government of Canada in late summer, and a copy provided to the Review. This report was made public at a special session of the Workshop, at which the team leader, Dr. Ferdinand Franzen of the IAEA, presented the highlights. Although there was some criticism of the OSART report and the method of its release by some public interest groups present at the Workshop, the Review found the report and Dr. Franzen's presentation to be useful. It forms Appendix III.2 to this Report.

14. A process of rebuttal, clarification, and expansion of views presented to the Review ensued following the Workshop. Ontario Hydro undertook the preparation of written critiques of all the briefs. AECL presented a supplementary brief on the role of the nuclear power station designer and provided a detailed critique of the submission made to the Review by IICPH. Copies of written critiques of briefs were sent by the Review to the authors concerned. Some counter-rebuttals resulted.

15. This exchange of ideas was most helpful to the Review in synthesising the wide variety of often-conflicting opinion with which it was presented. The Commissioner and staff were assisted in reading, analysing, and synthesising the material presented by the senior consultants, particularly by J.A.L. Robertson. This process of weighing and evaluating ideas and information continued throughout the autumn and the writing of the Review Report.

16. The Report was written by the Commissioner and based partly on papers in technical or specialised areas of the Review prepared by senior staff and consultants. A first draft of the Report was presented to the Advisory Panel on 18 December. The discussion that took place at this meeting helped the Commissioner to identify the principal issues upon which the recommendations of the Report should be based and the areas of the Report that required strengthening. Some minor changes to the text were made following the meeting, and copies of a revised manuscript were forwarded to the three Royal Society of Canada reviewers before Christmas.

17. The reviewers met in Toronto during the period 3-5 January 1988, conducting private sessions, sessions with the Commissioner and staff, and a session with the Commissioner, staff, Advisory Panel, and senior consultants. During this meeting, several areas of the Report that required further strengthening and revision were identified. The reviewers were unable to endorse the Report until these changes had been made and until they had had a further opportunity to examine the text. Although the revision of the manuscript proceeded expeditiously, the busy schedules of the reviewers made it impossible for the Royal Society to convene a second meeting until 10-12 March 1988.

18. The Commissioner reported orally to the Minister of Energy on 29 February 1988. Final changes to the text were made immediately after the second review meeting, and the Report, together with the reviewers' comments, was presented to the Minister of Energy.

19. Throughout the final three months, Review and Ministry of Energy staff consulted about the printing of the Report and companion volumes. Arrange-

ments were complete by the time the manuscript was presented to the Minister, and the printing process began immediately.

20. The work of the Review generated little interest on the part of the news media. Hydroscope, the internal publication of Ontario Hydro, conducted an interview with the Commissioner, and Mr. Ray Silver took advantage of a meeting with the Review to record some of the Commissioner's thoughts for Nucleonics Week. The Globe and Mail's reporter responsible for nuclear issues spoke to Review staff on a couple of occasions, but mainly to confirm facts related to other stories. The only general-circulation newspaper to request an interview with the Commissioner was The London Free Press. Several attempts were made to make the media aware of the Review. The Ontario Ministry of Energy conducted a press conference and issued a media release on 19 December 1986 to announce its establishment. As indicated above, the Review ran newspaper advertisements on two occasions to announce its existence. It also issued a media release concerning the presentation of the OSART report at the Workshop. The latter did, in fact, result in a large media presence at the event and in the widest publicity that the Review received in the course of its operation.

21. The Review proceeded smoothly despite the diametrically opposing views held in the nuclear power debate, the emotional climate in which this debate takes place, and the technical and regulatory complexity of the use of nuclear power. Full and willing co-operation was provided by all approached by the Review. As indicated above, AECB, AECL, the Canadian Nuclear Association, and Ontario Hydro were more than generous with technical information. Energy Probe also responded willingly to requests for information, as did numerous individuals within the technical community and the organised anti-nuclear-power lobby groups. The Advisory Panel members, senior consultants, and Royal Society of Canada officials were always available to provide assistance when required. Most important of all to the success of the Review, the Commissioner was able to assemble a loyal, committed, and enthusiastic staff. A great deal of dedicated effort went into the Review, and it was the desire of all who contributed to the preparation of the Report that it would succeed in providing

unbiased answers to the many questions concerning the safety of the production of nuclear power in Ontario.

Annex VI* - List 1

Site Visits Conducted by the ONSR**

Austria

International Institute of Applied Systems Analysis (IIASA) (2 July, PMF; 12 August, MCG, FKH)

Canada

Ontario Hydro
- Pickering B Nuclear Generating Station (16 February, PMF, MCG, FKH)
- Construction site of Darlington Nuclear Generating Station (19 February, PMF, MCG, FKH; 23 July, AP)
- System Control Centre, Toronto (14 April, PMF, FKH)
- Rolphton Nuclear Power Demonstration (29 April, PMF, MCG, FKH)
- Bruce Nuclear Power Development (10 July, MCG, FKH)
- Research Laboratories (15 September, PMF, FKH)
- Pickering A Nuclear Generating Station--restricted area (17 September, FKH)

Atomic Energy of Canada Limited
- Engineering Company Laboratories, Mississauga, Ontario (6 April, PMF, FKH; 8, 9 June, AP)
- Chalk River Nuclear Laboratories (28 April, PMF, MCG, FKH)
- Whiteshell Nuclear Research Establishment (11, 12 June, PMF, FKH)

New Brunswick Hydro
- Point Lepreau Nuclear Generating Station (18 June, PMF)

Federal Republic of Germany

Institute for Reactor Safety Garching bei Munchen (7 July, PMF)
Karlsruhe Nuclear Research Centre (8 July, PMF)
Julich Nuclear Research Facility (9 July, PMF)

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* AP - full Advisory Panel
PMF - Peter M. Fraser (Staff Scientist)
MCG - Margaret C. Grisdale (Review Manager)
FKH - F. Kenneth Hare (Commissioner)
WP - Wladimir Paskievici (Consultant)
JDMcG - John D. McGeachy (Consultant)

** All dates are 1987.

Annex VI - List 1 (cont'd)

The Netherlands

KEMA (14 July, PMF)

Sweden

Studsvik Nuclear Research Centre (22 June, PMF)
Swedish Radiation Protection Institute (SSI) (24 June, PMF)
AESA Atom (25 June, PMF)
Swedish Meteorological and Hydrological Institute (16 July, PMF)

United Kingdom

CEGB Sizewell A Nuclear Power Station (6 August, MCG, FKH)
CEGB Sizewell B Nuclear Power Station, site (6 August, MCG, FKH)
BNFL Sellafield Fuel Reprocessing Plant (7 August, MCG, FKH)

United States

GPU Three Mile Island Nuclear Generating Station (26 March, PMF, MCG, FKH)

Annex VI - List 2

Contact Visits Made by the ONSR*

Austria

Dr. E. Yaremy, Department of Nuclear Safety, IAEA (26 June, PMF)
M. Jacques Gignac, Canadian Ambassador and Permanent Representative to IAEA (11 August, MCG, FKH)
Dr. L.V. Konstantinov, Deputy Director General, Department of Nuclear Energy and Safety, IAEA (11 August, MCG, FKH)
Dr. Morris Rosen, Director of Nuclear Safety, IAEA, and Dr. E. Yaremy, Department of Nuclear Safety, IAEA (11 August, MCG, FKH)
Dr. Christopher Herzig, Department of Administration, IAEA (12 August, MCG, FKH)

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* All dates are 1987.

Annex VI - List 2 (cont'd)

Canada

Atomic Energy of Canada Limited
President and senior officials (27 February, MCG, FKH)
Mr. Gordon Brooks (8 July, MCG, FKH)
Drs. A.M. Marko, R.V. Osborne, D.K. Myers (12 November, MCG, FKH)
Atomic Energy Control Board
President and senior officials (12 February, MCG, FKH)
Technical staff (16 April, PMF)
Senior officials (27 April, MCG, FKH)
Senior officials (18 August, PMF, MCG, FKH, and consultants)
President and senior official (3 December, MCG, FKH)
Canadian Nuclear Association
Acting President and Vice-President (30 January, MCG)
President and Vice-President (7 July, MCG, FKH)
Ontario Hydro
Chairman (10 February, FKH)
President (12 March, MCG, FKH)
Waterloo University scientists (17 February, PMF)
McMaster University scientists (18 February, PMF)
Dr. Gordon Butler (27 July, MCG, FKH)
Assistant Auditor General of Canada and senior officials (3 September, MCG, FKH)
Mr. J.A.L. Robertson (13 November, MCG, FKH)

France

Electricité de France and representatives of French nuclear regulatory agency (29 June, WP)
Electricité de France: M. Pierre Tanguy, General Inspector for Nuclear Safety, service central de sûreté des installations nucléaires; M. David Levy, PWR Division (29 June, WP)

Sweden

Dr. Bjorn Kjellstrom (22 June, PMF)
Director General and senior officials, Swedish Nuclear Power Inspectorate (SKI) (23 June, PMF)

United Kingdom

Sir Frank Layfield, Q.C. (3 August, MCG, FKH)
Central Electricity Generating Board, Chairman (4 August, MCG, FKH)
Monitoring and Assessment Research Centre, University of London, Dr. Burton Bennett (4 August, MCG, FKH)

Annex VI - List 2 (cont'd)

United Kingdom (cont'd)

Lord Flowers (4 August, MCG, FKH)
British Nuclear Installations Inspectorate, H.M. Chief Inspector and senior officials (5 August, MCG, FKH)

United States

Argonne National Laboratory (26 May, PMF)
Clark University (7 May, PMF)
Federation of American Scientists (24 March, PMF)
Massachusetts Institute of Technology (6 May, PMF)
National Academy of Sciences, Washington (19 March, MCG, FKH; 24 March, PMF; 6 May, PMF)
Nuclear Information and Resource Service (24 March, PMF)
Nuclear Regulatory Commission
Chairman (19 March, MCG, FKH)
Technical staff (24 March, PMF; 6 May, PMF)
Pennsylvania Emergency Management Agency (27 March, PMF)
Resources for the Future (24 March, PMF)
Union of Concerned Scientists (24 March, PMF)
Dr. Arthur Upton (14 October, FKH)

Annex VI - List 3

Informal Meetings Conducted by the ONSR* at its Toronto offices

Mr. F.B. Ali, Ontario Ministry of the Solicitor General (27 January)

Senator Michael Kirby, Goldfarb Consultants (23 February)

Dr. Arthur Porter (26 January, 13 February)

Messrs. Norman Rubin and David Poch, Energy Probe (30 March)

Professor O.J.C. Runnalls, University of Toronto (10 February)

Mr. L. Ray Silver (4 June)

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* All dates are 1987 except where indicated.

Annex VI - List 3 (cont'd)

Mr. Ronald Smith, Manager of Royal Commission on Electric Power Planning (13 February)

The Hon. Charles Caccia (22 May)

Dr. L.V. Konstantinov and Dr. Morris Rosen, IAEA (dinner in Toronto, 17 June)

Dr. Richard Wilson (7 October)

Mr. Tom Kierans, Energy Options and Staff (6 November)

Mr. Barry Collingwood, CANDU Owners' Group (4 February 1988)

Annex VI - List 4

Conferences Attended*

Canadian Nuclear Association Annual Conference, Saint John, N.B. (14-17 June, PMF)

Nuclear Weapons and the Law Conference, Ottawa (15, 16 June, FKH)

International Atomic Energy Agency Conference on Reactor Safety and Reactor Ageing, Vienna (29 June - 3 July, PMF)

Annex VI - List 5

Field Exercise Attended*

United States Federal Field Exercise II, Zion, Illinois (24-25 June, FKH, JDMcG)

* All dates are 1987.

Annex VI - List 6

Seminars Conducted on Behalf of the ONSR*

Atomic Energy of Canada Limited, Chalk River (28 April)

Atomic Energy of Canada Limited, Mississauga (8, 9 June)

Atomic Energy of Canada Limited, Whiteshell (11, 12 June)

Ontario Hydro (23 July) - at Darlington
(29 July) - follow-up to 23 July session, at 700 University Avenue

U.K. Central Electricity Generating Board (Sizewell A Station Manager) (6 August)

British Nuclear Fuels Limited (7 August)

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* All dates are 1987.

Annex VII

Glossary

1. Technical Terms

accident analysis - quantitative analysis performed to simulate the consequences of postulated nuclear reactor accidents.

actinides - heavy elements with an atomic number greater than 88. The name is derived from actinium, the first of the series that includes uranium (U) and plutonium (Pu).

adjuster rod - a rod of neutron-absorbing material inserted into or removed from the reactor core to "adjust" reactor power or reactivity.

alpha particle - a particle consisting of two protons and two neutrons emitted *from some radioactive substances, e.g., plutonium-239.*

annulus - the gap in the fuel channel between the pressure tube and the calandria tube.

annulus bellows - fuel channel component surrounding the end fitting at the end shield, which forms a plug at the end of the annulus.

availability - the fraction of time that a component or system is able to function. Availability also means the probability that a component or system will be able to function at any point in time.

backfitting - installation of additional equipment or systems subsequent to the completion of the original station.

background radiation - the natural ionising radiation of the environment, including cosmic rays from outer space, naturally radioactive elements in the ground, and naturally radioactive elements in a person's body.

baseload - the supply of electricity needed to meet the minimum demand for electricity during a period of time.

becquerel - a unit of radioactivity equal to one disintegration per second. It is a measure of the rate at which a radioactive material decays. Abbreviated Bq. See also **curie**.

beta particle - electrons emitted from the nuclei of some radioactive substances, e.g., tritium and carbon-14.

beyond-design-basis accident - an accident not considered when setting the design requirements for equipment and systems at a nuclear generating station.

blow-down - the period during a loss of coolant accident when coolant is discharging from the heat transport system and prior to the injection of emergency coolant.

boiling water reactor (BWR) - a nuclear power reactor cooled and moderated by light water. The water is allowed to boil in the core to generate steam, which passes directly to the turbine.

calandria (vessel) - a cylindrical reactor vessel, which contains the heavy water moderator. It is penetrated from end to end by hundreds of calandria tubes which provide sites for the pressure tubes.

calandria tube - a tube, welded to the calandria vessel, surrounding the pressure tube in each fuel channel.

CANDU - a Canadian-developed nuclear power reactor system, which uses a pressure tube reactor, heavy-water moderator, and natural uranium fuel. The moderator is separate from the reactor coolant and is maintained cool and at low pressure. The pressure tubes, centrally located within each calandria tube, contain the fuel and the high pressure coolant as it passes through the reactor.

chain reaction - a reaction that initiates its own repetition. In a nuclear fission a neutron induces a fissile nucleus to fission, thus releasing several neutrons. To sustain the reaction, at least one of these neutrons must induce another fission.

channel bellows - see **annulus bellows**.

code - a large computer program, e.g., the program that controls the reactor hardware.

collective dose - the sum of the doses received by a group of exposed individuals.

commissioning - those activities performed subsequent to installation but prior to plant operation that are intended to show that equipment and systems meet their design requirements.

common-mode event - an event that can simultaneously affect several plant systems at one or more reactors at a time. A loss of electrical power and an earthquake are examples of such events.

containment - the reinforced concrete structure(s) that houses the reactor and its closely related systems. It is designed to suppress and contain the results of a fracture of the reactor coolant piping.

coolant - a liquid or gas that is circulated through the core of a reactor to extract and carry away the heat resulting from the fission process.

core - the central region of a reactor where the nuclear chain reaction takes place, and heat is thereby generated.

cosmic rays - radiation emanating from high energy sources outside the earth's atmosphere.

creep - the elongation of pressure tubes due to neutron bombardment. Creep resistance is a measure of how quickly the tube lengthens.

critical - an assembly of nuclear materials is critical if it is just capable of supporting a nuclear chain reaction.

critical (or criticality) - a reactor is critical or achieves criticality when the fission chain reaction becomes self-sustaining.

critical mass - the amount of fissile material needed to sustain a chain reaction.

cross-link - the consequential effect of the operation or failure of a component or system on one or more other components and systems.

curie - a measure of the rate at which a radioactive material disintegrates. A curie is the radioactivity of one gram of radium and is named after Pierre and Marie Curie, the discoverers of the radioactive elements radium, radon and polonium. One curie corresponds to 3.7×10^{10} disintegrations per second. Historical unit, replaced by the "becquerel."

daughter (radioactive) - the nucleus remaining following the radioactive decay of that nucleus.

decay - disintegration of a nucleus through the emission of one or more particles.

decommission - a process of permanently closing down a nuclear generating station, including the disassembly of the station components and the removal of spent fuel.

defence-in-depth - the provision of one or more back-ups to minimise the effect of the failure of safety-related equipment.

delayed hydride cracking - the fracture of hydride concentrations, especially on the outside surface of pressure tubes.

delayed neutrons - neutrons that are emitted after a delay from one of the fission products. Delayed neutrons account for 0.7% of the neutrons created in the fission process, but are fundamentally important for controlling reactor power. cf. **prompt neutrons.**

derived release limit - the calculated (yearly total) quantity of radionuclides that, if emitted from a nuclear facility, could result in a radiation dose equal to the regulatory dose limit of 5 mSv/yr to exposed members of the public.

design-basis accident - a type of reactor accident considered in setting design requirements for plant equipment and systems.

deuterium - "heavy" hydrogen; a hydrogen nucleus consisting of a neutron and a proton. cf. **tritium.**

dose - a measure of the biological damage caused by exposure to ionising radiation (measured in sieverts or rems). Note: formally, the term "dose" is now used to describe the amount of ionising radiation energy absorbed per unit mass (measured in grays or rads). What this report has referred to as dose is now called "dose equivalent."

dosimetry - the science of measuring dose.

dousing - a system that sprays cold water from the roof of the vacuum building (reactor building in CANDU 600) to condense the steam released from a broken pipe in the heat transport system.

dryout - a condition when a heated element ceases to contact the liquid surrounding it, resulting in much less efficient heat removal.

dual failure - the malfunction of a process system occurs simultaneously with the malfunction of a safety system.

dumping (the moderator) - rapid draining of the moderator.

effective dose equivalent - the summation of doses to individual organs using weighting factors recommended by ICRP.

effective dose limit - the prescribed limit for effective dose (equivalent).

electron - an elementary particle carrying one unit of negative electrical charge and having a mass equal to 1/1836th of the hydrogen atom. Electrons determine the chemical behaviour of elements. Their flow through a conductor constitutes electricity.

emergency core cooling system - see **emergency coolant injection system.**

emergency coolant injection system - a special safety system designed to inject cool water into the heat transport system following a pipe rupture.

end fitting - end fittings are located at each end of each fuel channel in the CANDU reactor. They are part of the heat transport system piping and are attached at one end to the pressure tube and at the other to a feeder pipe.

enriched fuel - nuclear fuel containing more than the natural abundance of fissile atoms.

enrichment - increasing the fraction of fissile atoms in nuclear fuel.

environmental qualification - the process of ensuring that essential safety equipment will be available to operate under the conditions present in the reactor building following a reactor accident.

exclusion boundary - an area (nominally of 1-km radius) around a nuclear generating station under control of the reactor owner.

failure - a change in the characteristics of a component or system such that it is unable to carry out its function.

fall-out - airborne radioactive material that has deposited.

fast breeder reactor (FBR) - a reactor in which fast neutrons sustain the fission chain reaction. The fuel is enriched, and a blanket of fertile material surrounding the core captures neutrons to become fissile.

fast neutrons - neutrons (resulting from fission) that are not slowed down by a moderator.

fault - a malfunction of a component or system.

fault tree - a deductive logic diagram that illustrates the structures and functions of a system and that defines the minimum conditions necessary to cause failure of the system. By assigning probability values to the components of the system, an estimate of the probability of system failure can be defined.

feeder - heat transport system pipe going from the reactor header to the fuel *channel end fitting.*

feedwater - the light-water supply to the steam generator, which is boiled to make steam for the turbine generator.

fertile material - potential nuclear fuels that can be transformed in a reactor into fissile material by neutron capture. Thorium-232 converts to uranium-233, and uranium-238 to plutonium-239.

fissile material - nuclear fuels in which the nuclei, when hit by neutrons, fission and release energy plus two or more neutrons, which can result in a chain reaction. Uranium-233, uranium-235 and plutonium-239 are examples of significant fissile materials, but only uranium-235 occurs naturally in relatively large quantities.

fission - the splitting of a heavy nucleus into two parts (see **fission products**) accompanied by the release of energy and two or more neutrons. It may occur spontaneously or be induced by capture of bombarding particles, particularly neutrons.

fission products - the smaller nuclei formed by the fission of heavy elements. Over 300 different stable and radioactive fission products have been identified. They represent isotopes of some 35 different chemical elements, ranging from zinc-72 to gadolinium-160.

fuel bundle - an assembly of fuel elements (fuel sheaths containing nuclear fuel pellets) and end plates, ready for insertion into a reactor.

fuel channel - the set of components, consisting of the pressure tube, calandria tube, and end fittings, in which the reactor fuel is located.

fuel element - small unit of fuel contained within the fuel bundle.

fuelling machine - equipment used to load and unload fuel bundles. CANDU fuelling machines are remotely controlled and load the fuel while the reactor is operating.

fuel sheath - tubing into which fuel pellets are inserted and sealed to create a fuel element.

gamma rays - high-energy, highly penetrating, short-wavelength electromagnetic radiation. They are emitted during the fission reaction and by the nuclei of many radioactive atoms during radioactive decay.

gas-cooled reactor - a nuclear reactor in which a gas, such as carbon dioxide, is used as the coolant.

genetic effects - see **hereditary effects.**

gray - the SI unit for dose of ionising radiation. One gray is absorbed when one joule of energy is imparted to each kilogram of matter by ionising radiation. One gray equals 100 rads. Abbreviated Gy.

grid - the interconnected network of electrical power supplies and users.

guillotine fracture - a clean transverse break of a pipe.

half-life - the time in which the number of nuclei of a particular type is reduced by radioactive decay to one-half.

header - a coolant pipe where water to/from the fuel channels is dispersed/collected.

heat exchanger - a piece of apparatus that transfers heat from one medium to another. A typical example is the steam generator in the CANDU system, where the hot pressurised water coolant is used to convert ordinary water into steam to drive the turbine.

heat sink - a body capable of absorbing the heat produced in the reactor.

heat transport system - the system of pipes, valves, pumps, and vessels that contains and circulates the coolant fluid through the reactor and transports the heat from the reactor fuel to the steam generators, where the heat is (normally) removed.

heavy water - water in which the hydrogen atoms consist of deuterium, the heavy stable isotope that is present to the extent of 150 parts per million in ordinary hydrogen; used as moderator and coolant in CANDU nuclear reactors.

hereditary effects - effects that produce changes to egg or sperm cells and thereby affect the offspring.

high-level wastes - the irradiated fuel is the most important high-level waste. Also included are other items such as recovered fission products and certain ion-exchange resins.

hydride blister - a high concentration of deuterium, especially on the outside of a pressure tube.

inoperable - a safety system is inoperable if it is not functioning and cannot be made to function through actions of the operator.

ion - an atom that has gained or lost one or more electrons and thus become electrically charged.

ion exchange - a process used to modify the chemical characteristics of a fluid that contains dissolved solids by replacing harmful ions in the fluid with chemically beneficial or neutral ions. In general, the fluid is passed through a resin bed, the resins being of a type that will contribute the desired types of ions and attract and retain the undesirable types from the fluids.

ionisation - the transformation of an atom or group of atoms from its normally electrically neutral state to an electrically charged state by gaining or losing one or more of its orbital electrons.

ionising radiation - radiation that, when interacting with material, deposits sufficient energy to eject orbiting electrons from atoms and thereby create ions.

irradiated fuel - fuel that has been exposed to irradiation in a nuclear reactor. If irradiated to its maximum economic life, it is also termed "spent fuel."

isotopes - nuclei of the same chemical element that differ in mass.

joule - the international unit of energy, equivalent to that contained in one kilogram of mass accelerated to one metre per second. Converted to electrical units, 3.6 million joules equal one kilowatt-hour.

jumper - an Ontario Hydro term applied to any temporary alteration to the mechanical, instrumental, or electrical systems.

kilowatt-hour - a quantity unit of energy, e.g., electrical power delivered at a sustained rate of one kilowatt for a period of one hour.

light water - ordinary water.

loop - a closed circuit of heat transport system piping.

loss of regulation accident - a reactor accident in which the power control (regulating) system malfunctions, resulting in a change in reactor power.

loss of coolant accident - a nuclear reactor accident in which the coolant drains out from the heat transport system.

low-level waste - this is a general term to describe the reactor wastes that arise in the day-to-day operation of the station. It includes such items as water purification filters, certain ion-exchange resins, wiping cloths, protective clothing, etc. Regardless of its general category, each type of waste product is dealt with according to the problem it presents.

megawatt (MW) - one million watts (or one thousand kilowatts). A unit used to indicate the power rating of very large energy-producing (or using) equipment, e.g., generating stations, nuclear reactors, boilers, engines, etc.

melt-down - a nuclear reactor accident in which some or all of the reactor fuel melts and cannot be contained within the heat transport system.

moderator - a substance used to slow down neutrons emitted during nuclear fission (heavy water in the case of the CANDU system).

motive power - mechanically driven power, e.g., by pumps.

natural radiation - see **background radiation.**

natural uranium - uranium whose isotopic composition as it occurs in nature has not been altered (0.7% by weight of uranium-235).

negative reactivity - see **reactivity.**

neutron - an uncharged (neutral) nuclear particle with a mass nearly equal to that of the proton and associated with it in the nuclei of all atoms except ordinary hydrogen (hydrogen-1).

neutron activation - neutron absorption by an element to create a new radioactive isotope.

noble gas - one of the inert gases, i.e., helium, neon, argon, krypton, xenon, or radon.

nuclear energy - the energy liberated by a nuclear reaction such as fission.

nuclear fuel cycle - the sequence of some or all operations in which uranium is mined, fabricated into fuel, irradiated in a reactor, stored, reprocessed to yield uranium and plutonium for reuse as fuel, and ultimately stored as waste.

nuclear fusion - the formation of a heavier nucleus from two lighter ones with the simultaneous release of large amounts of energy, e.g., two nuclei of deuterium can fuse to form a helium nucleus.

nucleus - the positively charged core of an atom. All nuclei are made up of protons and neutrons, except for ordinary hydrogen, which has no neutrons. The nucleus contains almost the whole of the mass of the atom, but occupies only a minute part of its volume.

operating envelope the set of conditions of the coolant and of reactor power in which the reactor is designed and licensed to operate.

planning zone - a zone surrounding a nuclear generating station for which a response to a nuclear reactor accident has been planned.

plutonium (Pu) - a heavy radioactive metallic element with an atomic number of 94 whose principal isotope plutonium-239 is a major fissile material. It is produced artificially in reactors through neutron absorption by uranium-238.

poison - any non-fissile, non-fertile substance having a high capacity for neutron capture. Various forms of poison are introduced into the reactor core to decrease the reactivity, or are removed from it to increase reactivity. They thus form part of the regulating system and the safety shut-down system.

poison injection - shut-down system 2. Neutron absorbing material is injected into the moderator to stop or "poison" the chain reaction.

positive void reactivity coefficient - an effect where an increase of reactor void caused by coolant boiling leads to an increase in reactor reactivity (or power).

power excursion - an unplanned reactor power increase.

power runaway - a reactor power increase that cannot be checked by regulating or shut-down systems.

pressure tube - the components of the heat transport system in the reactor core inside of which the fuel bundles reside. Pressurised heavy-water coolant flows through the pressure tube to remove the heat generated by the fuel. See also **pressure tube reactor.**

pressure tube reactor - a nuclear reactor in which the fuel is located inside a large number of high-strength tubes that penetrate the calandria (which also contains the moderator at low pressure). Pressurised coolant passes through the tubes to remove the heat from the fuel. See also **CANDU.**

pressurised water reactor (PWR) - a power reactor cooled and moderated by light water in a pressure vessel surrounding the core. The water is pressurised to prevent boiling and is circulated in a closed primary loop through a heat exchanger that generates steam in a secondary loop connected to the turbine.

primary zone - the zone surrounding a nuclear generating station for which there exists an evacuation plan.

probabilistic risk assessment - a method of calculating both the frequency and consequences of reactor accidents.

process system - any of the plant systems required for operation in any state expected during the life of the plant, i.e., all plant systems except for the special safety systems.

prompt criticality - reactor is able to maintain criticality using only the prompt neutrons.

prompt neutrons - neutrons released instantly from a fissioning nucleus accounting for 99.3% of all the neutrons released. cf. **delayed neutrons**.

proton - a nuclear particle with a charge equal in size and opposite in sign to that of the electron. Its atomic mass is approximately 1836 times that of an electron. It comprises the nucleus of the ordinary hydrogen atom, whose mass number is defined as one. It is a constituent of all nuclei.

quality assurance - a planned and systematic pattern of all means and actions designed to provide adequate confidence that items or services meet specified requirements and will perform satisfactorily in service. Quality assurance includes quality control.

quality control - those actions that provide a means to measure and regulate the characteristics of an item or service to establish requirements.

rad - the unit dose of ionising radiation. One rad is absorbed when 100 ergs of energy are imparted to each gram of matter by ionising radiation (see **rem**). Historical unit, replaced by "gray."

radiation - the emission and propagation of energy through space or matter in the form of electromagnetic waves and fast-moving particles.

radiation field - intensity of ionising radiation at a particular location.

radioactivity - the spontaneous decay of an unstable atomic nucleus into one or more different elements or isotopes. It involves the emission of particles or spontaneous fission until a stable state is reached. Note that radioactivity produces the radiation--the two terms are not equivalent.

radiological zones - zones of classification of radiological hazards for the purposes of radiological protection.

radionuclide - a general term used to describe radioactive nuclei.

radon - a natural element of atomic number 86--a heavy radioactive gas being a product of the decay of radium. Radium, and therefore radon, is present in most heavy rock formations in the earth and is more prevalent in uranium-bearing ore.

radon daughters - the short-lived radioactive products of the decay of radon gas.

reactivity - a measure of the departure of a reactor from criticality. A positive value means that the release of neutrons is increasing and that the power will rise, and a negative value means that the release of neutrons is decreasing, the power is falling, and the chain reaction could die out.

reactor - an assembly of vessels, systems, and equipment to contain a quantity of nuclear fuel and moderator, so arranged that a controlled chain reaction based on nuclear fission can be sustained and the heat can be removed.

reactor building - the building enclosing the reactor and all components of the heat transport system.

reactor core - mechanically, the structural elements in the reactor that locate and contain the nuclear fuel. In the nuclear physics sense, it includes additionally the fuel and the moderator associated with each fuel cell (fuel channel). See also **reactor**.

redundancy - characteristic of equipment that duplicates the essential function of other equipment to the extent that either is capable of performing the same function.

reflector - in CANDU, the outer region of the moderator, beyond that actually needed for neutron moderation, which serves to return neutrons to the core and to reduce neutron leakage from the reactor.

regulating system - reactor power control system.

regulation - reactor power control.

rem - the abbreviation for Roentgen Equivalent Man, the unit of an absorbed dose of ionising radiation in biological matter. It is the absorbed dose in rads multiplied by a factor that takes into account the biological effectiveness of the radiation. Historical unit, replaced by "sievert."

retubing - replacement of the pressure tubes of a nuclear reactor.

risk - an activity with the potential for causing harm. In **probabilistic risk assessment**, risk is defined as the product of the frequency of a harmful event and the harm caused. **Acceptable risk** refers to an activity that has been willingly accepted by those bearing the risk once the benefits of that activity and the alternatives to that activity are considered. **Tolerable risk** refers to activity undertaken with the acquiescence of the risk bearers, but not necessarily with their conscious acceptance.

risk aversion - a special fear of an improbable, dreaded event.

Roentgen - the unit of exposure to gamma or Xrays. Named after Wilhelm Konrad Roentgen, the discoverer of Xrays in Munich in 1895.

rolled joint - the connection between the pressure tube and the end fitting is rolled to fit snugly, rather than welded.

safety analysis - see **accident analysis**.

safety culture - a set of attitudes among designers, managers, and operating staff at a nuclear generating station that encourages practices that foster the safe operation of the station.

safety design matrix - a method of probabilistic risk assessment employed by AECL for a limited range of postulated nuclear reactor accidents.

safety support systems - essential process systems that are required for the proper operation of safety systems. Electrical power is an example.

secondary zone - the emergency planning zone outside the **primary zone** where measures such as sheltering, restriction of foods, and similar measures short of evacuation are planned should a nuclear reactor accident occur.

serious process failure - any failure of equipment or procedure that, in the absence of special safety system(s) action, could lead to significant release of radioactive material from the nuclear generating station.

severe accident - 1. An accident leading to a large release of radioactive material from a nuclear generating station. 2. An accident that leads to a destruction of the core structural integrity.

shielding - a mass of material that reduces radiation intensity to protect personnel, equipment, or nuclear experiments from radiation injury, damage, or interference.

shut-down - termination of the chain reaction in the reactor.

shut-down systems - the special safety systems capable of terminating the chain reaction in the reactor rapidly.

shut-off rod - a neutron-absorbing rod normally kept out of the reactor core that can be rapidly inserted into the core. The entire set of these rods comprises shut-down system 1.

sievert - the SI unit of absorbed dose equivalent of ionising radiation in biological matter. It is the absorbed dose in grays multiplied by a modifying factor that takes into account the biological effectiveness of the radiation. Abbreviated Sv.

significant event report - report documenting an unusual event at one of Ontario Hydro's nuclear generating stations.

single failure - in accident analysis, a **serious process failure**.

slow neutrons - neutrons that have been slowed down by a moderator so as to increase the probability of their collision with a fissile nucleus and induce fission.

source term - composition and quantity of materials likely to be released to the environment during a postulated serious nuclear accident.

special safety systems - systems designed to limit or mitigate the consequences of plant process failures and thereby limit the releases of radioactivity to the environment and the public within acceptable limits. These systems are the shut-down systems, emergency coolant injection system, and containment system.

spent fuel - nuclear fuel that has been irradiated in a reactor to the extent that it is no longer economical as a power producer, i.e., during irradiation fissionable isotopes are consumed and fission product poisons are accumulated. Term is used interchangeably with "irradiated fuel."

statutory dose limit - the maximum dose allowed by AECB regulations.

steam generator - a vessel consisting of a large number of tubes. The heavy-water coolant flows through the tubes transferring heat through the walls of the tubes to boil the feedwater and produce steam to drive the turbine generator.

super-prompt-critical - reactor reactivity in excess of the fraction of the delayed neutrons.

surveillance - the set of inspection and technical audit activities undertaken during the operation of a nuclear generating station.

switchyard - site at a nuclear generating station where the electrical connection between the electricity generated by the turbine generators and the power grid occurs.

thermal neutrons - neutrons (resulting from fission) that have been slowed down by passage through a moderator.

thermal reactor - a reactor in which thermal (slow) neutrons sustain the chain reaction. Thermal reactors contain a moderator.

thermoluminescent dosimetry - a technique for measuring radiation exposure.

thorium (Th) - a heavy, slightly radioactive metallic element with an atomic number of 90 whose naturally occurring isotope thorium-232 is fertile and the source, when irradiated in a reactor, of uranium-233.

transient - an unplanned upset to steady operation of the reactor process systems.

trip - reactor trip, i.e., shut-down system action.

trip setpoint - value of a plant process variable, e.g., reactor power, which must be exceeded as measured by the appropriate detectors for a trip to occur.

tritium - a radioactive isotope of hydrogen with a mass number of three. It has one proton and two neutrons in its nucleus. It is formed in nuclear reactors; also in nature by cosmic radiation.

turbine generator - the machine that converts the mechanical energy of the steam created in the steam generator to generate electrical power.

two-out-of-three logic - a method whereby two detectors out of three are needed to read above their trip setpoints for a reactor trip to be activated.

unavailability - the fraction of time that a component or system is unable to perform its specified function.

uranium (U) - a heavy, slightly radioactive metallic element with an atomic number of 92. As found in nature it is a mixture of the isotopes uranium-235 (0.7%) and uranium-238 (99.3%). The artificially produced uranium-233 (see **thorium**) and the naturally occurring uranium-235 are fissile. Uranium-238 is fertile.

vacuum building - a building maintained at very low pressure that, when activated, will release air, steam, etc. from a damaged reactor unit and reduce the pressure within containment to less than atmospheric pressure. Part of the containment system.

void - vapour or gas, particularly when mixed with liquid in a pipe or enclosed space.

void (reactivity) coefficient - coefficient representing the relationship between the fraction of void present in the reactor core to the reactor reactivity.

zirconium - a naturally occurring metallic element with an atomic number of 40. The material is used extensively in the construction of in-core reactor components because it has a very high corrosion resistance to high-temperature water and low neutron absorption.

2. Acronyms and Abbreviations

ACNS	Advisory Committee on Nuclear Safety (of the Atomic Energy Control Board)
ACRP	Advisory Committee on Radiological Protection (of the Atomic Energy Control Board)
AECB	Atomic Energy Control Board (Canada)
AECL	Atomic Energy of Canada Limited
ALARA	as low as reasonably achievable
ASME	American Society of Mechanical Engineers

BEIR	(Advisory Committee on the) Biological Effects of Ionizing Radiation
Bq	becquerel
BWR	boiling water reactor
CANDU	Canada Deuterium Uranium (reactor)
CEGB	Central Electricity Generating Board
Ci	curie
COG	CANDU Owners' Group
CRNL	Chalk River Nuclear Laboratories
CUPE	*Canadian Union of Public Employees*
D&D-G	Design and Development Generation
DEL	derived emission limit
DRL	derived release limit
ECCS	emergency core cooling system
ECIS	emergency coolant injection system
EMR	Energy, Mines and Resources Canada
GWh	gigawatt-hour
GWyr	gigawatt-year
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection (international society of radiologists, members from 59 countries, budget of $150,000.00. p/a, funding from governments and other national sources, about 2 full-time staff)
IIASA	International Institute of Applied Systems Analysis
IICPH	International Institute of Concern for Public Health
INPO	Institute of Nuclear Power Operations
J	joule
LOCA	loss of coolant accident

LWR	light-water reactor
MACCS	Melcor Accident Consequence Code System
MAGNOX	magnesium oxide reactor
MeV	mega electron volts
MWe	megawatt-electrical
NAS	National Academy of Sciences (USA)
NGD	Nuclear Generation Division (Ontario Hydro)
NGS	nuclear generating station
NII	Nuclear Installations Inspectorate (UK)
NIRC	Nuclear Integrity Review Committee (of Ontario Hydro)
NPD	Nuclear Power Demonstration reactor Nuclear Power Development (Bruce)
NRC	Nuclear Regulatory Commission (USA)
NRCC	National Research Council of Canada
NRPB	National Radiological Protection Board (UK)
NRU	National Research Universal reactor (Chalk River Nuclear Laboratories, AECL)
NRX	National Research Experimental reactor
NSSD	Nuclear Studies and Safety Department
ONSR	Ontario Nuclear Safety Review
OSART	Operational Safety Review Team (of the International Atomic Energy Agency)
OTA	Office of Technology Assessment (USA)
PRA	probabilistic risk assessment
PSE	probabilistic safety evaluation
PWR	pressurised water reactor
QA	quality assurance

QC	quality control
RMEP	Radioactivity Management and Environmental Protection Department
RSC	Royal Society of Canada
SCOHA	Select Committee on Ontario Hydro Affairs of the Ontario Legislature
SDS	shut-down system
SER	significant event report
SGHWR	steam-generating heavy-water reactor
TLD	thermoluminescent dosimetry dose
TMI	Three Mile Island Nuclear Generating Station of the General Public Utilities System, USA
TTSD	Technical and Training Services Division
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
WNRE	Whiteshell Nuclear Research Establishment

3. Scientific Units

Table of Physical Quantities and Units

Quantity	Unit	Symbol	Relation to other units
length	metre	m	1 m = 3.281 ft
	(also mile)	(mile)	1 mile = 1.609 km
mass	kilogram	kg	1 kg = 2.205 lb
	(also tonne)	(t)	1 t = 1000 kg
time	second	s	
	(also day, hour, year, etc.)	(d,h,yr)	
force	newton	N	1 N = 1 kg m/s^2
frequency	hertz	Hz	1 Hz = 1/s
pressure (1)	pascal	Pa	1 Pa = 1 N/m^2
temperature	degree celsius	°C	
energy	joule	J	1 J = 1 Nm
	(also watt-hour)	(Wh)	1 Wh = 3.6 kJ
power (2)	watt	W	1 W = 1 J/s
electric current	ampere	A	
electric voltage	volt	V	

Notes: (1) Atmospheric pressure is about 10^5 Pa; 1 bar = 10^5 Pa.
(2) Electrical power output is sometimes given the symbol We (1 We = 1 VA) to distinguish it from the thermal power output of a power station Wt.

Table of Radiological Quantities and Units

Quantity	Unit	Symbol	Conversion factor to old units
activity (1)	becquerel	Bq	1 Bq = 2.7×10^{-11} curie
absorbed dose (2)	gray	Gy	1 Gy = 100 rad
dose equivalent (3)	sievert	Sv	1 Sv = 100 rem

Notes: (1) Activity is the rate of transformation (also known as rate of decay) of a radionuclide. 1 Bq is 1 transformation (or decay) per second.
(2) Absorbed dose is the amount of energy imparted to unit mass of matter (such as tissue) by ionising radiation. One gray equals one joule per kilogram.
(3) Dose equivalent is the quantity obtained by multiplying the absorbed dose by a factor to allow for the different effectiveness of various ionising radiations in causing harm to tissue.

Table of Multiples and Submultiples of Units

Factor (1)	Prefix	Symbol
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n

Note: (1) 10^6 is 10 multiplied by itself six times, i.e., 1 000 000. 10^{-3} is $1/10^3$, i.e., 0.001, or one in a thousand.

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