Canadian Nuclear Society Société Nucléaire Canadienne

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Editorials

Research

The word "research" covers a lot of territory, from the trivial to the sublime. It can mean investigating the popularity of a politician. It can mean investigating the origins of the universe. However, with all its meanings, it is generally accepted as being an activity of vital importance to all industrialized societies.

Let's apply the modifier "scientific" to the word "research" and define the term as that activity which seeks to explain in detail the workings of the physical universe. While this limits the compass of the word "research" somewhat it's still wide enough that answers to the questions "what is scientific research?" and "why should we do it?" will vary greatly.

The general public may see scientific research in vague terms of lab-coated individuals pottering about with expensive and complex equipment, foul smelling liquids or oozing Petri dishes, content to spend their days tracking down the next decimal point. But their instincts about its importance to society and its inherent worth are often surprisingly acute.

Politicians tend to speak of "research-and-development" in "science-and-technology" and appear to view such activities as best left to the boffins. Politicians rationalize these imperfectly understood activities in terms of "innovation", ergo jobs, ergo votes. This can give rise to serious problems, since governments are the principal paymasters of scientific research – and should be instigators as well.

Scientists and engineers, as a group, usually define "scientific research" in terms ranging from a necessary support function for industry to pure, untrammelled intellectual endeavour.

The need for scientific research – the search to understand things and how they work – pervades our society. One particularly obvious area and one which is often (imperfectly) identified by the politicians is applied research in support of industry. Such "goal-oriented" work has obvious and readily measurable benefit and, more importantly, produces results on a timescale of the same order of magnitude as that of the political life-cycle. But such research doesn't exist and can't be maintained in isolation from other, less clearly "goal-oriented" work. Indeed, the former absolutely depends on the existence of ongoing research programmes of less specificity to provide intellectual foundations and a training ground for future recruits.

Such research meets four principal needs:

- Dealing with existing and recognised problems – five billion people all tinkering with an environment they don't fully understand can get themselves into difficulties. When these difficulties are resolved they don't necessarily stay that way since new kinds of tinkering can introduce new kinds of problems. And the problems themselves must be understood before we can even begin to work towards solutions. This takes a systematic and disciplined approach by a body of people interested and trained in the appropriate subject area. Getting – and keeping – such a body of people is a long-term business and requires a long-term commitment.
- Creating and capitalizing on opportunities – all countries have different resource endowments, climates, industrial developments and aspirations. Opportunities and strengths will exist but the time-scale and cost of coaxing them out may well be beyond the commercial or corporate horizon – the Canadian reactor system is a good example. National needs and national opportunities exist but meeting those needs and realizing those opportunities requires investment (financial and intellectual) in research.
- Looking ahead for future problems – we need to develop "early detection" of possible developing problems before they get big enough to bash us over the head. There is a need to poke, probe and postulate continuously. We must remain on the alert for the unexpected – whether favourable or unfavourable (perhaps with somewhat more emphasis on the latter). Such probing requires the application of several disciplines and isn't an instant operation. Putting a bunch of boffins in a lab and adding money won't produce immediate results. It takes time.
- Maintaining the ivory tower – we need research that has as its sole object the pursuit of knowledge for its own sake, open enquiry that follows things wherever they lead and does not have to justify itself on a traditional balance sheet. Ironically enough, it it this kind of research that ultimately supports all the others. Without a purely inquisitive approach, scientific research would simply degenerate to a matter of forcing things to fit to a current (and inevitably circumscribed) frame of reference and would lead to stagnation and decay.

Near the end of his life, Alfred North Whitehead lamented the decline in speculative thought as one of this century's greatest tragedies. Although he was talking about philosophy there is no reason to suppose that he would have been any less despondent about current trends in research policy.

For the Record

The year 1987 was a good one for reactor anniversaries. The NRX reactor at Chalk River was forty years old as was the GLEEP reactor at Harwell. The Nuclear Power Demonstration reactor at Rolphton, Canada's first electricity generating nuclear reactor reached its 25th year of operation. And was shut down for decommissioning.

As a concept demonstration, training machine and test bed, the reactor has served Canada well. And while its 25 MW electrical output might seem a bit paltry alongside that of its descendants at Pickering and Bruce, that 25 MW has been supplied with a reliability that is good by any standards and must be counted as outstanding for a concept demonstration machine.

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Editorial

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Current plans for NPD do not appear to include any provision for preservation of any part of the installation for historical purposes. While it is probably true that preservation of a complete reactor is impractical, it would be a great shame if the only record of this first Canadian nuclear generating station were a blue metal plaque stuck on a post at the side of Highway 17.

A possible approach might be preservation of the control room – either at the site, where it might ultimately form the centrepiece of a museum devoted to Canadian nuclear engineering and technology, or reconstructed at one of Canada's science museums. A more modest undertaking would be preservation of the central "control island" or console. At the very least it should be ensured that the station is thoroughly documented through maintenance at a central archive of all plans, photographs and technical literature so at least there'll exist an unequivocal record of what the thing looked like and how it worked.

All these options will require expenditure of money and effort and, from a rational point of view, such expenditure is useless. As useless, for example, as preservation of the *Cutty Sark* or the *Rocket* in England. Or preservation of all those old aeroplanes up at Rockcliffe near Ottawa.

For CNS members, NPD represented a major step in the evolution of the enterprise in which very many of us have been involved for many years. For Canadians it represents a major milestone in Canadian scientific and engineering achievement. It deserves a more palpable record than a laconic metal plaque. Anybody interested?

Electricity May Be Dangerous to Your Health

Cause and effect is a well established notion. It is also one of the touchstones of science. If a cause and effect relationship between two things cannot be shown, then that relationship may turn out to be a scientific one night stand.

Things are coming to a head with cause and effect, however. In some cases, such as the cause and effect between smoking and various diseases, a watertight proof is still not available, despite great masses of data. In other cases, such as the electromagnetic fields from power lines as a cause of cancer, articles are now appearing in which the "growing evidence" is discussed, despite the almost complete lack of such evidence.

The problem, of course, is that there is no logical connection between a "cause" and an "effect". In fact, they are ordered in that sequence only because that is the time sequence in which they occur. If there is no such logical connection, then it is impossible to "prove", in logical terms, that there is a connection at all. This is the device exploited so well by the tobacco industry.

Such a state of affairs seems contrary to ordinary horse sense. Everybody knows that there are causes and that these causes have effects. The question then becomes, "What are the scientific criteria by which 'cause and effect' is considered to be proved, and how do scientists go about proving it"? If you have a rigorous answer to this, publish it without delay. You will be famous next week.

The piece of information missing from all this is the correlation. One can correlate X to Y and if the correlation is good then one can suppose that the two have something in common. This doesn't mean that there is a necessary "cause and effect" linkage. Considerably more evidence is needed before that statement can be made.

The supposed connection between electromagnetic fields and cancer is a good case study. The fields involved are not only those from high voltage lines but also from distribution systems. There does seem to be a correlation between these fields and the incidence of cancer. What this means is far from clear. Fields of this sort are far too weak to ionize atoms although this is not the only mechanism by which cancer can be induced. Some changes in the behaviour of calcium ions, and other aspects of cell chemistry seem to result from exposure to electromagnetic fields but the significance of these changes is not clear. Ambiguities remain. Quantifying the exposure to electro-magnetic fields is in a primitive state. Work that would shed more light on the connection between such exposure and the occurrence of cancer, such as studies of the health records of people who use electric blankets, has not yet been done. All that exists at the moment is an unqualified correlation.

The danger here is that one can fall into the unsavoury position of denying that the case is proven, and in the process appearing thereby to have already made up one's mind that it will never be proven, or will soon be disproven. In fact, nobody knows.

"Nobody knows". This is too often taken to mean that we are on the edge of a cliff and must stop what we are doing immediately before we all fall off. (Already in the US, large court settlements have been granted to people exposed to the fields from high voltage power lines, on the strength of a correlation which might indicate "cause and effect".) Although nobody knows what the specific correlation between exposure to electro-magnetic fields and cancer means, there is plenty of other information in the game. About 30% of all male cancer can be attributed to smoking, and about another 40-50% is thought to result from other living habits (consumption of alcohol, sexual practices, diet and other factors). A few percent might be due to environmental pollution, while possibly 5% is attributable to all the chemical and physical insults we are exposed to occupationally. A hundred years ago there were virtually no man-made electro-magnetic fields; today we are bathed in them. Over the same period, life expectancy has increased dramatically, despite the increase in exposure to electro-magnetic fields and to many known anthropogenic carcinogens. Whatever the role of electro-magnetic fields in carcinogenesis, it seems unlikely that it is unusually potent and at the same time has gone undetected this long.

Being vigilant for unsuspected causes of scourges is important. Having found indications of one, it is also important to assess it fully and with an open mind. People taking unconsidered action out of fear to avoid a cliff which may be imaginary is an unlovely sight. The possibility that they may avoid the perceived cliff only to hurl themselves over a real one is much more disturbing.

FYI

Nuclear Moratorium Recommended in Canada

The recently issued Report of the Standing Committee (of the House of Commons) on Environment & Forestry entitled "High Level Radioactive Waste in Canada: The Eleventh Hour" has recommended a "moratorium on the construction of nuclear power plants in Canada . . . until the poeple of Canada have agreed on an acceptable solution for the disposal of high level radioactive waste."

Buried amongst the 15 recommendations are several eclectic items: "the Federal government should step up its efforts to determine the extent to which various renewable energy vectors or sources can meet the demand for energy"; "introduce reforms at the AECB for a consultation mechanism to require public participation in making decisions on moral or ethical questions . . ." and that the "AECB . . . be responsible to Environment Canada rather than to the Department of Energy Mines & Resources".

The report was tabled in the House of Commons on January 19, 1987 and nothing has been heard since.

Dr. Bill Hancox, Acting President of AECL's Research Company, has indicated in a news release that "AECL encourages and supports the committee's recommendations for a full and open debate about waste disposal. However, it is necessary to point out that there is no urgency to have an agreed upon solution . . . (since) . . . all the used fuel from Canada's 20 nuclear plants is safely stored at the reactor sites, and can remain at those locations for at least 50 years."

Dr. Hancox added: "On the basis of 10 years' research on the permanent waste disposal concept, AECL believes nuclear fuel waste can be isolated from the environment such that the hazard to present and future generations will be negligible. The Committee's recommendation for a moratorium on the construction of nuclear power plants is unnecessary and very short sighted. A moratorium is not needed because research to develop an acceptable permanent disposal method is well advanced".

NRPB Recommends Dose Limit Reduction

The British National Radiation Protection Board has recommended a near-fourfold reduction – from 50 mSv to 15 mSv – in the annual occupational dose limits for atomic radiation workers. The recommendation, made to the British government's Health and Safety Executive, is based on recently revised assessments of cancer rates among atomic bomb survivors at Hiroshima and Nagasaki.

The NRPB has also recommended a halving of the public exposure limits to 0.5 mSv annually.

By this action the NRPB appears to be dissenting from the position adopted by the International Commission on Radiological Protection, which body has not yet suggested any dose limit revision in light of the revised assessments.

Darlington Probabilistic Safety Evaluation Issued

A comprehensive risk assessment study of the Darlington Nuclear Generating Station (NGS) known as the Darlington Probabilistic Safety Evaluation (DPSE) was issued December 1987. This study reflects Ontario Hydro's practice of applying new approaches to the review of the safety of its nuclear stations. Probabilistic methods have been applied in the past, but this is the first application of fully-integrated event tree/fault tree risk assessment methods to a multi-unit CANDU reactor design.

The DPSE was initiated with the following principal objectives:

- To provide a thorough safety design verification of the Darlington NGS using probabilistic methods.
- To identify those initiating events and accident sequences that dominate public risk and economic risk to the utility.
- To provide for a comprehensive and realistic information base for the preparation of commissioning and operating procedures and for the training of operating personnel in handling accident situations.
- To provide those system reliability and event sequence assessments required as part of the licensing process.

The work undertaken in the area of plant modelling included a number of noteworthy features indicating the extent of the DPSE plant analysis.

- A systematic review of Ontario Hydro operating experience to identify and quantify the frequency of potential initiating events.
- Event tree analysis leading to multiple levels of fuel damage.
- A high degree of detail in the fault tree modelling of safety-related systems, with the objective of characterizing the specific interdependencies between these systems and their service systems, including electric power, instrument air, cooling water, and instrumentation and control.
- The development of study-specific methods to identify and quantify failures involving human error.
- The development of new methods and procedures to aid fault tree modelling, integration and presentation. The DPSE has quantified the risk from accidents affecting fuel in the core except for those involving the potential for severe core damage and loss of the containment function leading to a large off-site release. The estimated mean risk is 9×10^{-6} Sv/yr to the individual at the site boundary and 6×10^{-2} person-Sv/yr to the surrounding population out to a distance of 100 km, for the four-unit station. These risks are low and should be found acceptable. Dominant contributors to this risk are sequences which can lead to the bypass of containment because the leakage path from the heat transport system is directly outside containment. The DPSE has calculated the sum frequency of all those events with the potential for a large off-site release, which is estimated to be 8.2×10^{-7}/reactor-yr.

The mean on-site economic risk is estimated to be $10M/reactor-yr. This value is found to be small when compared to the annual costs of power production. The major component of consequence is the cost of replacement power for lost production. The dominant contributions to risk are loss of coolant accidents which require emergency coolant injection to prevent fuel failures. The D_2O recovery system is the most important mitigating system, as far as economic risk is concerned. Its failure potential contributes to about 30 per cent of the total risk.

The process of risk assessment, encompassing detailed system modelling and systematic search procedures for dependencies, was found to be a powerful method of design review.

The overall conclusion that can be drawn from the DPSE Study is that the quantified accident category frequencies and risks are low and should be found acceptable.

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La SNC procure aux Canadiens intéressés à l'énergie nucléaire un forum où ils peuvent participer à des discussions de nature technique. Pour tous renseignements concernant les inscriptions, veuillez bien entrer en contact avec le bureau de la SNC, les membres du Conseil ou les responsables locaux. La cotisation annuelle est de $50.00, $25.00 pour les retraités, et $15.00 pour les étudiants.

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TAC Report on Nuclear Fuel Waste Programme Issued

The Eighth Annual Report of the Technical Advisory Committee (Chairman: L.W. Shemilt) which assesses the scientific and technical progress made within the Canadian Nuclear Fuel Waste Management Program has been issued.

The Committee notes that the general concept of a multibarrier system involving geologic media and engineered systems is based on known technologies and current scientific knowledge and has gained strong international scientific and engineering support as currently the most feasible and practical. TAC continues to endorse the full investigation of the concept of nuclear fuel waste disposal.

The Canadian research programme, based on both laboratory and extensive geoscientific field investigations, is designed to provide the scientific and engineering base from which can be made an assessment of the ultimate safety of the concept. The programme results are to be presented through a Concept Assessment Document.

The programme results are to be presented through a Concept Assessment Document (CAD) and the process for evaluation of CAD will clearly ensure that all parties including regulatory bodies, government departments, the scientific community, the general public and interested groups have the opportunity to provide views on the results of this complex undertaking of research on nuclear fuel waste disposal.

On an overall programme basis, TAC commends the significant achievements in the range and quantity of publication in the refereed scientific literature, and pays tribute to the policy of full freedom of information which is a prominent aspect of the total programme.

NEA/OECD Report on Radiological Impact of Chernobyl Accident

As a consequence of the Chernobyl nuclear plant accident in 1986, people living in member countries of the Organization for Economic Co-operation and Development (OECD) are not likely to have been subjected to a radiation dose significantly greater than that received from one year of exposure to the natural background radiation, a new report from the Nuclear Energy Agency (NEA) of the OECD concludes. As a result, the report says, the lifetime average risk of radiation-related harm for the individual members of the public has not changed to any noticeable extent by the accident. It further states that the number of potential health effects (cancers and genetic effects) that can be derived by calculating collective doses will not constitute a detectable addition to the natural incidence of similar effects within the population.

Agreement on Conceptual Design of Fusion Reactor

Delegations of the world's four major fusion programmes have agreed to recommend to their respective governmental authorities the start of collaborative work on a design study of an international fusion reactor. The agreement was reached at a meeting held in Vienna under IAEA auspices from 18-19 October 1987; more than 30 delegates from the European Community, Japan, USA and USSR attended.

The four parties – who have worked together as partners through IAEA-sponsored fusion research since the late 1970s – agreed at the meeting that the objective of their co-operation is to develop by the end of 1990 a conceptual design of an international thermonuclear experimental reactor (known by the acronym ITER).

ITER – which will be carried out under IAEA auspices – is the next step required in the long-term development of the tokamak approach to controlled thermonuclear fusion for electricity generation, a goal whose achievement is still several decades away. It includes determination of the technical parameters of the experiment and the estimation of costs and time needed to actually build the fusion machine. At the October meeting, parties agreed to propose the Institute of Plasma Physics in Garching, Federal Republic of Germany, near Munich, as the technical site at which to initiate the joint design work.

IAEA's Marine Scientists Tracking Chernobyl Fallout

Under joint projects with French and Italian institutes, scientists at the IAEA's International Laboratory of Marine Radioactivity (ILMR) in Monaco are continuing studies in the Mediterranean Sea on the downward movement of radionuclides attributed to fallout from the Chernobyl accident in 1986. Based on evidence obtained so far, scientists have concluded that biological particles in the Sea carried the fallout radionuclides from surface waters to depths below 100 metres much more rapidly than had been hitherto imagined. Current studies are centred on the search for "Chernobyl tracers" in biological particles from deeper Mediterranean waters and in bottom sediments. The information will be extremely useful in waste disposal matters for establishing the rates at which radionuclides and other contaminants introduced into surface waters are transported through the world's oceans.

International Co-operation and nuclear power development

Addressing the US industry's Nuclear Energy Forum in Los Angeles, California, in November 1987, IAEA Deputy Director General for Nuclear Power and Safety, Prof. Leonard Konstantinov, underlined the important role of international co-operation in improving safe and reliable operations of nuclear power plants. "International co-operation . . . can and does favourably affect the economics of nuclear power and contributes substantially to enhance its safety," he said. "One can learn from the experience which has been acquired at considerable cost by others, and expensive mistakes can be avoided." He noted that countries have used the IAEA as an effective channel of co-operation for more than three decades in all areas of the nuclear fuel cycle, as well as in the field of safeguards to ensure the peaceful uses of nuclear technology. In reviewing nuclear power programmes around the world, he said that, with some exceptions, governmental support for nuclear power development remains strong, primarily for economic and environmental reasons.

FAO/IAEA Symposium on Changing Perspectives in Agro-Chemicals

An international symposium focusing on important implications of the use of agricultural chemicals and their behaviour in the environment was jointly convened by the IAEA and Food and Agriculture Organization (FAO) from 24-27 November in Neuherberg, Federal Republic of Germany. More than 80 scientists from 25 countries participated. The symposium was held in conjunction with a meeting of the Society of Ecotoxicology and Environmental Safety, and joint sessions were held on topics of soil-pesticide relationships and the safety of chemicals.

Interested in Contributing to the *CNS Bulletin*?

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- **J. Nathwani, Editor,** *CNS Bulletin*, c/o Ontario Hydro, 700 University Avenue, Toronto, Ontario, M5G 1X6.
- The *CNS Bulletin*, c/o the CNS office.
- Your branch or division representative.

Book Reviews

Great Experiments in Physics Morris H. Shamos (Ed.), Dover Publications, New York, 1987. ISBN 0-486-25346-5.

"Viewed in retrospect, the most significant ideas in physics stand out in simple elegance against a background shadowed by confusion, clouded at times by bigotry, yet always illumined by man's search for truth. Because so many of our key conceptual schemes seem almost 'self-evident' in the light of experience, we frequently lose sight of the fact that there is a history to physics". Thus Morris Shamos introduces his collection of first-hand accounts of the major milestones in physics from Galileo's *Discourse* on accelerated motion to Compton's work on X-ray scattering.

This book was originally published in 1959 with the twofold purpose of providing liberal arts undergraduates with an introduction to the development of physical principles, and to supplement some of the more conventional undergraduate physics courses. The book is more than this. It's a feast for anyone – physicist or non-physicist – who has the least bit of intellectual curiosity. Shamos has selected 24 accounts, including those of Newton (on the Laws of Motion), Boyle (pressure-volume ratios in a gas) and Coulomb (laws of electric and magnetic force) and concluding with a galaxy of stars from the last 100 years of physics, including Becquerel, Roentgen, Thompson and the immortal Rutherford.

Experiments are presented in their original form or in translation, though spellings have been modernised. Wherever possible the original illustrations have been used. Each experiment is preceded by an introductory essay which includes biographical information on the individual concerned and some indication of the political and cultural atmosphere of the period. Each experiment is thoroughly (but unobtrusively) annotated and followed by a comprehensive list of supplementary material.

One point that strikes one repeatedly is the lucidity and elegance with which all these people presented their work. All these truly epoch-making experiments are intellectually accessible to any literate person, regardless of their academic specialization. They are at once enthralling and entertaining. For example, Galileo presents his findings on motion in the form of a three-way dialogue between "Salvati" (who is supposed to be reading from the manuscript of an unidentified scholar), "Sagredo", another scholar skilled in mechanics and "Simplicio", who is the antagonist or "devil's advocate" supporting the Aristotlean view – and supporting it in a manner reflecting his name.

Naturally such an arrangement gives the author the opportunity to pay off a few old scores and it is possible to infer from some of the less intelligent comments put into the mouth of "Simplicio" that Galileo certainly

TECHNICAL SUPPLEMENT

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THE CONSEQUENCES OF FAILURE TO SHUTDOWN FOLLOWING A LOSS OF COOLANT ACCIDENT IN A PICKERING NGS A UNIT

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THE CONSEQUENCES OF FAILURE TO SHUTDOWN FOLLOWING A LARGE LOSS OF COOLANT ACCIDENT IN A PICKERING NGS A UNIT

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ABSTRACT

The accident at Unit 4 of the Chernobyl nuclear plant has focussed the attention of the international nuclear community on severe core damage accidents caused by reactivity excursions. In response to a request from the Ontario Nuclear Safety Review, Ontario Hydro has conducted an analysis of the consequences associated with total failure to shut down following a large loss-of-coolant accident. There has been considerable advancement in our understanding of the phenomena involved in such an accident and these advances, both experimental and analytical, have been factored into this analysis.

The accident considered is the one which adds the most positive reactivity to the core - a guillotine failure of the largest reactor inlet header. Discharge of the heat transport system coolant from the affected part of the reactor core occurs within about 1 second. The void which it creates within the reactor core results in less neutron absorption and a rapid increase in the reactor power.

In the course of the super-prompt critical power excursion, disruption of high-powered fuel elements occurs by ejection of molten UO_2 from the centre of these elements. The first channel failures occur approximately 3.7 seconds after the pipe break. Approximately 30 percent of the fuel channels fail by this mechanism during the power excursion phase of the accident.

Peak pressures in the boiler room are expected to reach 160 kPa (absolute). At this pressure minor cracking of concrete may occur in the region of the closure plug at the top of the dome. In the worst case, even if all 390 fuel channels were to fail during the power excursion, the peak pressure in the boiler room would be limited to 180 kPa (absolute). Some cracking of concrete and some yielding of reinforcement around the dome closure plug may occur in this case, but structural integrity of the containment envelope is maintained.

There are a number of features of the CANDU design that facilitate rapid termination of a power excursion. Firstly, the behaviour of CANDU fuel during a power excursion is significantly different from that observed in stylized reactivity initiated accident (RIA) tests performed on Light Water Reactor (LWR) fuel.

Secondly, no mechanism was identified whereby simultaneous failure of all fuel channels could occur. Specifically, failures of the first channels in Pickering NGS A initiate a rapid termination of the fissioning process by rapid displacement of moderator fluid. In Chernobyl, it is believed that failure of the first channels initiated a simultaneous ("coherent") failure of all channels. This, furthermore, exacerbated the magnitude of the energy deposition in the fuel by causing a rapid escalation of the power excursion due to coherent voiding of all fuel channels in the core.

Thirdly, the major source of energy transfer to containment structures in both Pickering NGS A and Chernobyl is the heat transport coolant which flashes to steam. Relative to the inventory of a Chernobyl reactor, the energy available from the Pickering heat transport system coolant blowdown is an order of magnitude lower.

Because structural integrity of the containment envelope is maintained, despite the severe damage sustained within the calandria vessel, the off-site radiological consequences of this accident are not expected to be significantly different from other severe dual failure accidents analyzed as part of the licensing process.

1.0 INTRODUCTION

The four units of Pickering NGS A are the first multi-unit CANDU-PHW reactors constructed and operated by Ontario Hydro. These reactors possess a number of distinct design differences relative to Ontario Hydro's later multi-unit stations at Bruce NGS A, Bruce NGS B, Pickering NGS B and Darlington NGS A. Following the accident at unit 4 of the Chernobyl Nuclear Power Station in the Ukraine, USSR on April 26, 1986 the issue of a single shutdown system at Pickering NGS A has been raised in an Atomic Energy Control Board (AECB) review of the implications of the Chernobyl accident and by the Ontario Nuclear Safety Review (ONSR). In June 1987 the ONSR requested that Ontario Hydro assess the consequences of an extreme accident at Pickering NGS A involving total failure of the shutdown system to operate.

In addition to the analysis performed by Ontario Hydro, the Reactor Analysis and Safety Division of Argonne National Laboratory was contracted to perform an independent analysis of aspects of the postulated accident. The results of their independent analysis are presented in a separate report.

The accident scenario considered in this analysis[2], namely a large rupture in a heat transport system pipe accompanied by total failure of the shutdown system to operate, is distinctly different from the Chernobyl accident. There was no major component failure acting as an initiator in the Chernobyl accident and the shutdown system did operate. Unfortunately, that shutdown system was unable to insert negative reactivity at a high enough rate to terminate the power excursion.

LARGE BREAK LOCA AND FAILURE TO SHUTDOWN

Definition of the Limiting Accident

A large break loss of coolant accident imposes the greatest demand for large, rapid negative reactivity insertion from the shutdown system. This is a consequence of the high rate of positive reactivity insertion associated with rapid coolant voiding in the fuel channels. Furthermore, the more rapidly positive reactivity is inserted without compensating negative reactivity from the shutdown system, the earlier is the time at which the reactor can become prompt critical. Prompt criticality is achieved when the excess positive reactivity equals the fraction of neutrons in the total neutron population that are produced from the delayed decay of fission products - the "delayed neutron" fraction, β.

Weighted average coolant void fraction transients in the fuel channels of one loop of the Pickering NGS A heat transport system experiencing a large break loss of coolant accident are shown in Figure 1. The magnitude of the pipe rupture is expressed as a percentage of twice the cross-sectional area of the reactor inlet header. It is apparent from these voiding transients, and the fact that the coolant void positive reactivity is directly proportional to the flux - square weighted average void fraction, that a 100% RIH break occurring from full power operation leads to the most rapid insertion of positive reactivity. Therefore, this magnitude of pipe rupture occurring at full power has been adopted as the initiating event in the analysis of a power excursion with failure to shut down.

PHASES OF THE ACCIDENT

A reactivity initiated power excursion accident may be divided into three phases. These phases are defined, in part, by the initiating accident and, in part, by the post-accident state of the plant and the related potential for fission product release from the plant.

(1) The <u>Prompt Phase</u>, which lasts for approximately 20 seconds, consists of fast energetic events associated with the power excursion, the resultant reactor shutdown by core disruption and the subsequent blowdown of the heat transport system. (Core disruption is a term used to denote a process whereby uncontrolled thermal or mechanical energy transfers occur within the reactor that cause damage to the reactor core to the extent that the fission chain reaction is terminated).

(2) The <u>Short Term</u>, post-excursion phase, in which transient mass and energy transfers occur at slower rates from the damaged reactor to the containment volume and internal structures. During this period the stored heat remaining in the reactor core, chemical heat from exothermic oxidation of Zirconium alloys, and decay heat generated in the irradiated UO_2 fuel is removed by ongoing discharge of heat transport coolant. This is supplemented by emergency coolant injection which initiates approximately at the end of the prompt phase. This phase may last for several hours to tens of hours.

(3) The <u>Long Term</u> phase is a continuation of the Short Term phase from the point at which a long term heat sink has been established and any uncontrolled fission product release from the damaged unit is essentially terminated.

VOID FRACTION VERSUS TIME
(Reactor trip credited, Broken Loop)

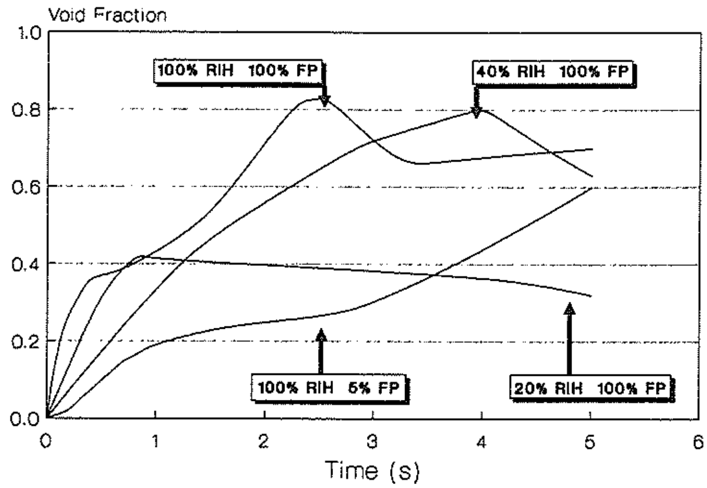


FIGURE 1

LOSS OF SHUTDOWN
ANALYSIS COMPONENTS

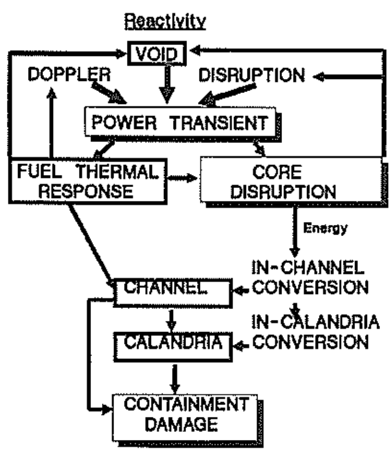


FIGURE 2

LOSS OF SHUTDOWN
PARAMETRIC ANALYSIS

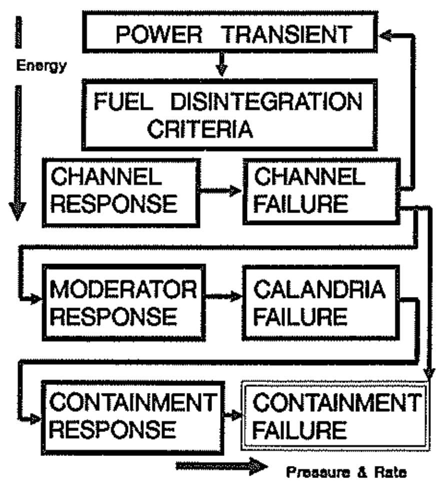


FIGURE 3

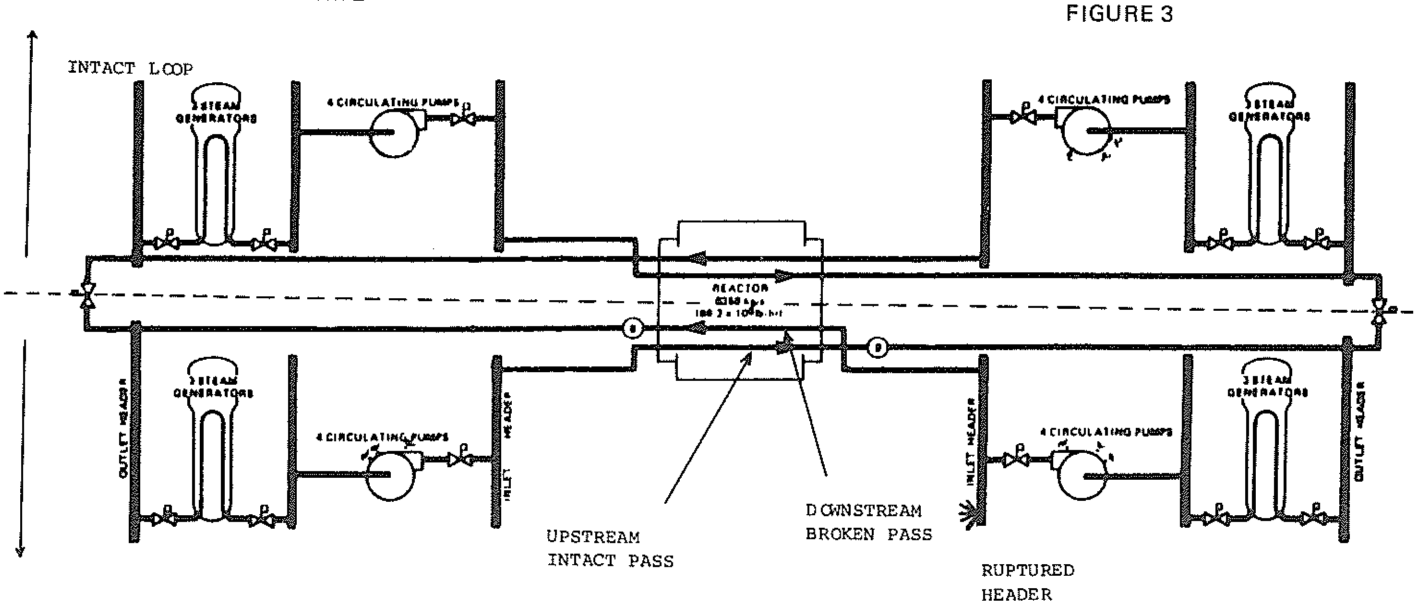


FIGURE 4
Schematic of Pickering NGS A
Heat Transport System

The magnitude of damage to the reactor, and equipment and structures within containment during the prompt phase of the accident is the primary factor characterizing the consequences of the accident. It is this factor that determines the nature of both the short and long term phases, with respect to duration of the phases, stabilization of the state of the accident unit and the magnitude of fission product releases. Consequently, characterization of the prompt phase of the accident has been the primary focus of the analysis effort.

Analyses of various aspects of the power excursion and the potential to fail fuel, fuel channels, calandria and containment (the successive barriers to radio-activity release from the plant) have been performed independently by Ontario Hydro and by Argonne National Laboratory. An outline of the scope of the analyses is depicted in Figures 2 and 3. The first stage involved a number of separate parametric analyses performed to establish the transient physical phenomena, relevant to the CANDU design, that can influence the progression of the accident. In the second stage, the results of the parametric analyses were employed to establish and evaluate an integrated accident scenario. Failure criteria were derived from the parametric analyses, and the more probable modes, magnitude and timing of fuel channel failures were established on a core wide basis for the prompt phase of the accident. This enabled computation of the termination of the power excursion by core disruption, and the assessment of consequential calandria vessel damage and the resultant challenge to containment integrity.

The results from the integrated analysis provide estimates of the likely sequence of events during the accident, the damage sustained within the plant and the consequences with respect to public safety. The most probable case, referred to as the base case, is summarized in Table 1. Additional detailed discussion of the sequence of events is also presented in this paper.

It became apparent in the course of the analysis that there are inherent features of the CANDU design which facilitate rapid termination of an overpower excursion - the most important of which is that a limited number of fuel channels failing in the calandria cause rapid displacement of moderator fluid and reactor shutdown. It was also recognized at the outset of this analysis that some residual uncertainty in characterizing the sequence of events would exist. In view of this, the consequences of the most probable (base case) scenario have been placed in perspective by evaluating two additional scenarios. The first scenario is based upon an earlier time to failure for the first channels, relative to the best estimate of the time for early failures. The second case represents an upper bound of the possible range of prompt core damage. Note that, by definition, these alternative scenarios are considered to be more improbable than the base case.

The important conclusion to be drawn from Table 1 is that, despite extensive damage to fuel channels and the calandria vessel, the structural integrity of the containment envelope is maintained. Even in the upper bound scenario, in which the majority of fuel channels are postulated to fail within a short time interval, the containment envelope suffers only minor damage in the form of cracking and incipient yielding of the reinforcement, limited to a small region around the closure plug at the top of the reactor building dome. This finding has significant and positive implications with respect to risk to the public from radiological hazards associated with this severe core damage accident.

THE SEQUENCE OF EVENTS DURING THE ACCIDENT

The most probable sequence of events during the accident is described here and a summary of the sequence of events for the three scenario analyzed is presented in Table 2.

THE POWER EXCURSION

Following the guillotine rupture of a reactor inlet header there is rapid coolant flow reversal in the fuel channels of the flow pass in the affected heat transport system loop downstream of the broken header (refer to Figures 4 and 5). The upstream flow pass initially has slightly accelerated coolant flow induced by the rapidly depressurizing reactor inlet header. The other loop of the heat transport system, hereafter referred to as the intact loop, is initially affected only slightly by the rupture - there is a minor depressurization to the saturation pressure of the coolant in the reactor outlet headers.

The primary effect of the initial depressurization of the coolant in the broken loop is the rapid development of steam in the channels of this loop (referred to as coolant voiding). The resultant reduction in coolant density in the fuel channels leads to positive reactivity insertion, making the reactor delayed super-critical and leading to a rapidly developing overpower.

The term "delayed super-critical" refers to a state of a nuclear reactor in which there is a limited excess positive reactivity that

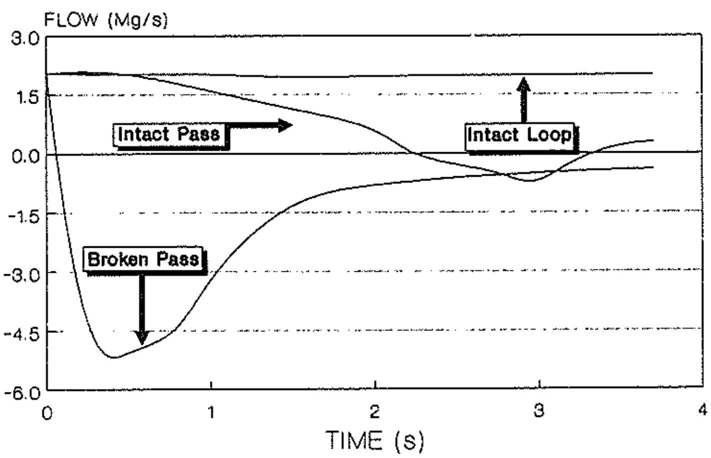
TABLE 1
Summary of Key Findings from Analysis
of a Loss of Coolant Accident with Failure to Shutdown

	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
Number of Channels Failed During Power Excursion (Percentage of Core)	115 (30%)	45 (11%)	195 (50%)
Number of Channels Failed at End of Prompt Phase (Percentage 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)

TABLE 2
Summary of Sequence of Events During
the Prompt Phase of the Accident

EVENT DESCRIPTION	TIME (SECONDS) 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 to 1.0	0.9 to 1.0	0.9 to 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 to 3.45	3.3 to 3.45	3.3 to 3.45
- First Channels Fail into 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 Depressurized Below 1 MPa	~12	~20	~12
- Intact Loop Depressurized Below 1 MPa	>20	>>20	>20

TOTAL PASS FLOWS AT CHANNEL INLETS
PRIOR TO CHANNEL FAILURES



TRANSIENT PRESSURES
INTACT & BROKEN LOOPS

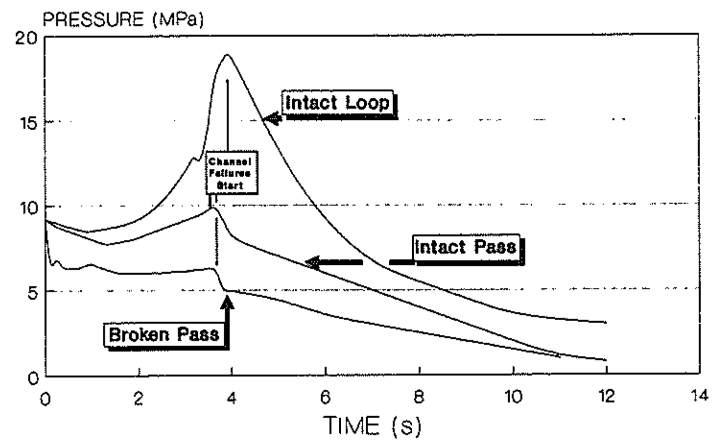


FIGURE 5

results in an increasing rate of fissioning. The rate of increase is controlled essentially by an excess of delay neutrons (produced from the decay of fission products), in the total neutron population of both prompt and delayed neutrons. Because the increase in the neutron population is governed by the delayed neutrons, the rate of increase is slow relative to the lifetime of prompt neutrons. When the excess reactivity equals the fraction of neutrons that are produced as delayed neutrons, then the fission chain reaction can be sustained by the prompt neutrons alone. This condition is termed "prompt critical". If the reactivity is in excess of the fraction of delayed neutrons then the reactor becomes "super-prompt critical".

Normally, the shutdown system is activated within approximately 0.3 to 0.5 s following the rupture and rapidly terminates the power excursion, limiting the maximum power to less than 3 times full power at 1.5 s following the failure. However, since total failure of the shutdown system is postulated here, the power being generated in the fuel will continue to rapidly escalate. This leads to an increase in the heat transferred to the coolant which increases the rate at which coolant boils in the channels of the broken loop and, in turn, increases the amount of positive reactivity inserted.

One fully voided heat transport loop will insert at most 8.5 mk of positive reactivity at equilibrium fuel burnup. The increase in fuel temperature during an overpower transient initiated from full power will, with some delay, insert about 2 mk of negative reactivity (the so-called doppler reactivity feedback effect). This is not sufficient to prevent the reactor from becoming super-prompt critical. In addition, because the positive reactivity insertion is in one half of the core, a large side-to-side distortion of the neutron flux distribution develops. Within 3 seconds, the amplitude of the side-to-side first azimuthal flux mode that governs the distortion is 40 percent. This results in the fuel in the broken loop generating, on average, 40 percent more power than the fuel in the intact loop.

At about 2 seconds after the large break occurs, super-prompt criticality is achieved and an extremely rapid escalation of the power excursion occurs, as shown in Figure 6. This leads to a commensurately rapid escalation of fuel temperatures. The increased rate of heat transfer to the coolant during the period from 2 to 3 seconds has two effects. Firstly, in the <u>intact pass</u> of the <u>broken loop</u> (refer to Figure 4) the coolant flow rate from the inlet header rapidly decreases due to rapid vapour generation. Between 2.5 to 2.8 seconds the inlet flow is halted by the increase in pressure inside the fuel channels (see Figure 5) due to rapid boiling and superheating of steam. Secondly, the coolant in the fuel channels of the <u>intact loop</u> begins to rapidly pressurize, due to liquid coolant density changes associated with the increase in coolant temperature . Because there is limited relief capacity through the heat transport interconnect lines and relief valves, the entire intact loop experiences a pressurization. Furthermore, since very little coolant has been lost from this loop in the first 3 seconds, the loop remains essentially liquid filled with the hot, saturated coolant at the exit of the fuel channels governing the loop pressure.

The rapid fuel overheating in the broken loop leads to fuel element failures in some channels at around 3.3 seconds, which initiates disruption of the reactor core and leads to termination of the overpower excursion.

FUEL HEATUP DURING THE POWER EXCURSION

The fission energy deposition in the UO_2 fuel pellets during the power excursion is well in excess of the energy removal by heat transfer from the fuel sheath to the coolant. Consequently, the fuel heatup rate is close to adiabatic, with the exception of the periphery region.

The relationship between the initial fuel element power and the energy deposition required for onset of fuel melting, is summarized in Figure 7. A representative range of times to onset of fuel melting in the outer fuel elements of bundles located at the axial centre of the core is shown in Figure 8. The times shown in this figure are for the outer elements of fuel bundles in channels along the cross-section X-X at the centre of the core. This figure illustrates the strong influence of the side-to-side flux tilt on the fuel energy deposition.

In the intact loop the onset of dryout is significantly delayed because of the suppression of coolant boiling that accompanies loop pressurization. Critical heat flux is exceeded at approximately 3 seconds in the highest powered channels and subcooled film boiling heat transfer is established. At this time the average power transferred to the coolant is approximately 2.2 times full power and the pressure in the intact loop is 12 MPa and rapidly rising. Energy deposition in the intact loop fuel is lower than in the broken loop, due to the lower flux in this region associated with the transient side-to-side neutron flux tilt. This, in conjunction with the somewhat higher heat removal from the fuel during the power excursion leads to lower transient fuel

FUEL POWER TRANSIENTS
BASE CASE

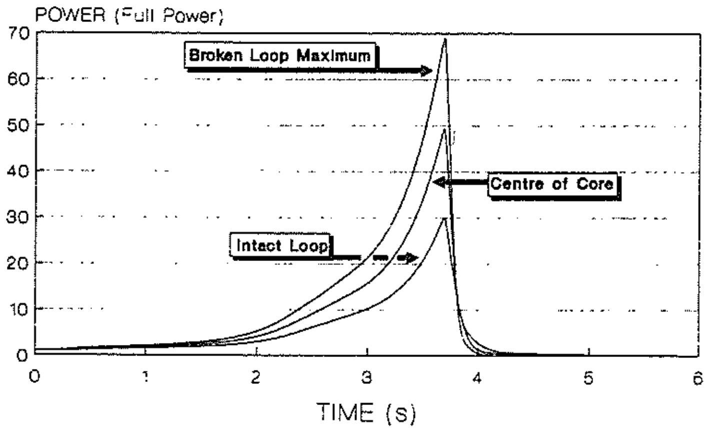


FIGURE 6

TIME TO ONSET OF FUEL MELTING
IN OUTER ELEMENTS

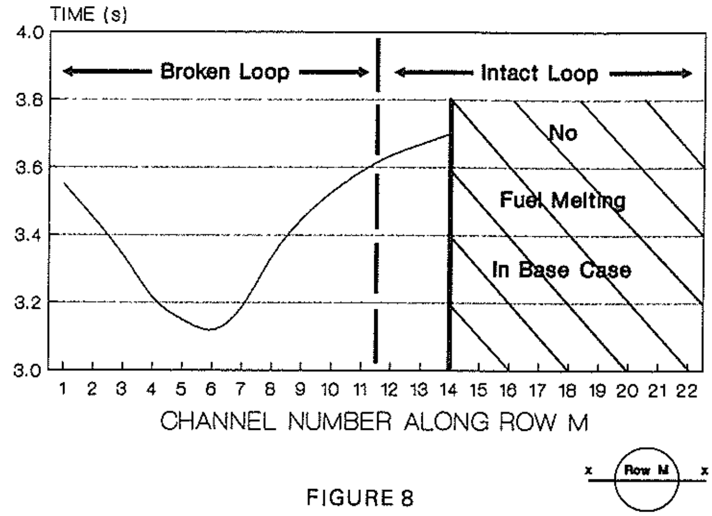


FIGURE 8

NET ENERGY DEPOSITION REQUIRED FOR FUEL MELTING VERSUS INITIAL ELEMENT POWER

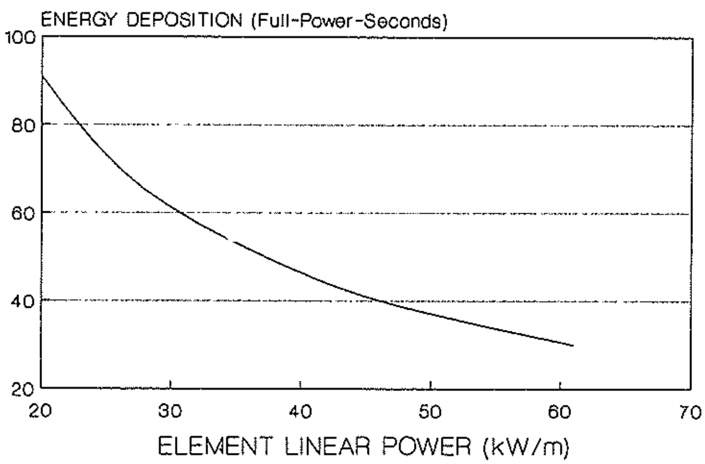


FIGURE 7

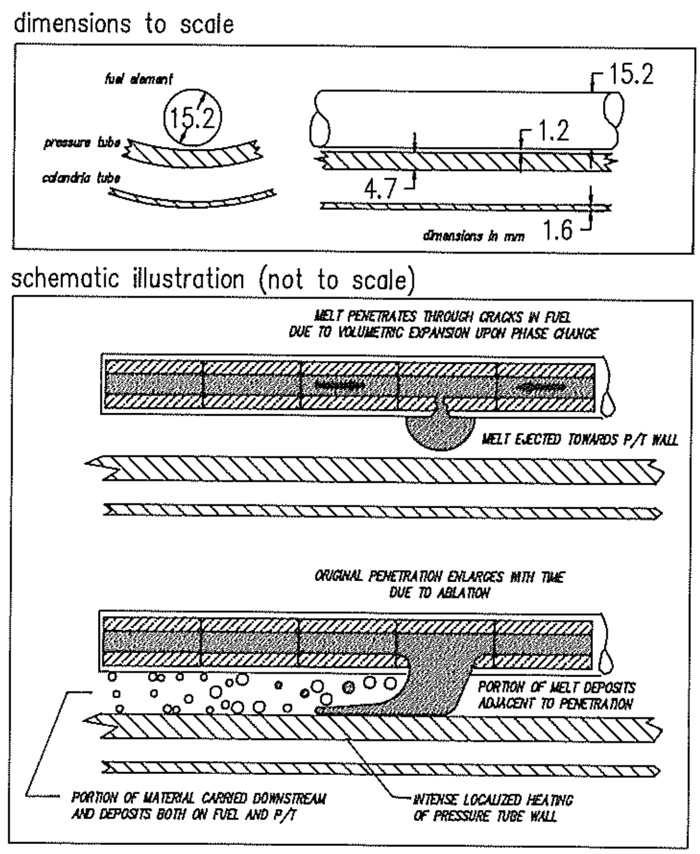


FIGURE 9
Fuel Injection Process

temperatures and later times at which significant fuel melting can occur in this loop, as indicated in Figure 8. This delay is of importance in the dynamics of the subsequent core disruption.

FUEL CHANNEL FAILURES DURING THE POWER EXCURSION

The fuel elements experiencing the most rapid energy deposition are the outer elements of fuel bundles at the centre of the high powered fuel channels that experience the largest side-to-side tilting.

Between 3.1 and 3.45 seconds a significant percentage of the UO_2 in these pellets has undergone a phase change and become molten. During this change in phase, from solid to liquid, there is a large and rapid volumetric expansion. This instantaneous expansion, together with the heating and expansion of gaseous and volatile fission products contained in the melt, results in rapid progressive relocation of molten fuel from the centre of the pellet to the outside, where it contacts the fuel sheath. The Zircaloy fuel sheath rapidly melts at points of contact between molten UO_2 and Zircaloy. Note that prior to the molten fuel contact, the fuel sheath temperatures were already rising rapidly in the broken loop channels, as a consequence of earlier sheath dryout.

By 3.45 seconds, or earlier, the fuel sheaths of the highest powered elements will have failed by through-wall melting, and molten fuel ejection will have occurred from the outer elements into the fuel channel. The internal pressure within fuel elements prior to sheath failure does not significantly exceed the external coolant pressure due to the pressure relief provided by the increase in the internal volume that accompanies strain of the hot Zircaloy fuel sheath. Consequently, the molten UO_2 ejection process is characterized by a "squirting" stream of molten material, rather than a finely fragmented energetic dispersal. Because of the relatively slow increase in fission generation rate during the super-prompt critical excursion, as compared to very rapid power bursts over millisecond time scales that characterize reactivity initiated accident (RIA) fuel behaviour tests performed on Light Water Reactor fuel, the fuel relocation mechanism in CANDU fuel is relatively benign and non-energetic.

In the channels downstream of the ruptured header, the reverse coolant flows in the high powered channels have decreased due to rapid vapour generation in the channel. Nonetheless, relatively high steam linear velocities between 10 and 20 m/s can occur in some channels. Therefore, some of the ejected fuel - primarily that from the top outer elements - may be swept downstream by the drag force exerted by the steam flow, relocating on downstream regions of the pressure tube and fuel elements, and heating up the pressure tube in the process. Once contact is made with the colder pressure tube wall, the UO_2 will tend to adhere as a result of rapid freezing at the interface between the Zr-2.5% Nb pressure tube and molten UO_2. The channels in the upstream, intact flow pass of the broken loop have essentially stagnant superheated steam at this point in time, due to their rapid internal pressurization by coolant vaporization. In these channels, and in some of the narrow clearance subchannels of the downstream pass discussed above, the ejected molten fuel will contact the pressure tube wall directly adjacent to the failed sheath location. These molten UO_2 relocation patterns are depicted graphically in Figure 9.

Following contact of molten UO_2 and the pressure tube wall, rapid local heatup of the pressure tube will occur as heat is transferred from the UO_2 to the pressure tube across the contact interface. Not only does the molten UO_2 have high stored heat, but the volumetric fission heat generation rate in the relocated fuel increases significantly, due to the fact that the thermal neutron flux is higher by a factor of between 1.8 and 2.0 at the pressure tube wall than it is within the UO_2 pellets of the outer elements.

The rapid local heatup of the pressure tube wall results in a rapid reduction in the strength of the tube as the thermal front propogates from the interface into the pressure tube wall. Furthermore, as the thermal front propogates, the stress in the remaining lower temperature, outer fibres of the pressure tube rapidly increases. Once the yield stress of the Zr-2.5% Nb pressure tube is exceeded, rapid unstable plastic strain leads to failure of the pressure tube by fishmouth ruptures of length, typically, in excess of 2 m. This is, with high probability, the mechanism leading to failure of fuel channels during the power excursion.

Other channel failure mechanisms including end-fitting failures in the pressurized, intact loop and overpressurization failures due to fuel-coolant interactions have been considered. The pressures in the intact loop at the time of molten fuel/pressure tube failure are less than 20 MPa. The end-fittings and closure plugs have been proof-tested to 34 MPa, therefore this failure mechanism is unlikely.

Detailed analysis of pressure tube/calandria tube thermal-mechanical response following molten UO_2 contact with the pressure tube was performed. This analysis indicates that fuel channels will fail by pressure tube/calandria tube rupture within 300 ms, or less, after molten UO_2 is relocated onto the pressure tube wall. This time delay between molten UO_2 contact and fuel channel failure is primarily a function of pressure, the relocated UO_2 temperature and the power generation in the molten fuel. The higher the pressure in the channel and the higher the molten UO_2 temperature are prior to failure, the shorter is the time delay to failure. This general trend is depicted graphically in Figure 10.

The timing of onset of molten fuel relocation from the outer elements to the pressure tube wall can be related directly to the progression of the radial melt front from the centre of the pellet toward the outer surface. Molten fuel relocation can be correlated to the radially-averaged fuel enthalpy exceeding 300-310 cal/g UO_2, depending upon the burnup of the element. (Note that an enthalpy rise of 335 cal/g is required to fully melt solid UO_2 starting from an initial temperature of 25^oC). A fuel enthalpy threshold, at which molten fuel relocation occurs, serves as a useful criterion for triggering molten fuel/pressure tube interaction in full-core integrated analysis. In this analysis channels experiencing molten UO_2 relocation, and the time at which this occurs, can readily be identified. Furthermore, based on the fuel channel failure analysis and analysis of the moderator/calandria response following channel failures in the core, the timing of lead channel failures and resultant rate of negative reactivity insertion due to moderator displacement is established. This is then employed in calculating the reactor dynamics leading to termination of the power excursion by core disruption.

The first channels to fail are the high powered channels in the upstream, higher pressure pass of the broken loop. In the base case, molten fuel relocation is initiated by 3.4 seconds in a number of channels of the broken loop. These lead channels are clustered at the horizontal centreline of the core and offset to the peak of the side-to-side first azimuthal flux mode. The full-core integrated analysis established that within the short time interval from 3.4 to 3.5 seconds, a total of 10 channels in this cluster, 5 in each pass of the broken loop, have experienced molten UO_2 relocation onto the pressure tube wall. By 3.7 s the first channel failures occur in the intact pass of the broken loop. Note that the channels in the broken pass of the broken loop will fail slightly later in time, as shown in Figure 10.

The calculated timing and number of failed channels occurring during the power excursion is shown in Figure 11 for the broken and intact loops of the heat transport system for the base case. The termination of the power excursion by the negative reactivity insertion associated with rapid moderator displacement is governed by the failure of the first few channels - the five lead channels in the broken loop that are predicted to fail in rapid succession. A number of channels fail in the intact loop due to molten fuel relocation. In the base case, 20 channels are predicted to fail due to this mechanism, starting at 3.9 seconds.

The termination of the power excursion is not sensitive to the timing of the subsequent failure of channels in either the intact or broken loops. This is a consequence of the fact that the reactor shutdown is governed by the rapid moderator displacement induced by the first few channels that fail in the broken loop. Therefore, any uncertainty in the total number of channels that fail during the power excursion has little impact upon the neutronic transient. The primary impact of this uncertainty is upon the mass and energy discharge rates into the calandria from failed channels following the termination of the fission chain reaction.

CORE DISRUPTION AND TERMINATION OF THE OVERPOWER EXCURSION

The progression of channel failures, starting with the first channel failures at 3.7 s is depicted pictorially in Figure 12. These diagrams show the expanding region of channel failures that occur within the period from 3.7 to 5 s. The first channels to fail produce a rapidly growing, highly voided steam bubble in the moderator surrounding the failed channels. The combination of flashing, hot coolant discharged into calandria and rapid heat transfer from fuel fragments carried out of the channel by the discharging coolant, produces a sharp pressure rise in the calandria. Within 100 ms following failure of the lead channels, the pressure in the calandria is sufficiently high to fail the calandria vessel at the weld between the annular plate and the main shell.

The rapid moderator displacement illustrated in Figure 12 is a result of the following:

(a) displacement of liquid moderator into the free cover gas volumes in the calandria relief ducts and reactivity guide tube extensions,

(b) collapse of calandria tubes onto pressure tubes (50 percent of the available volume in the annular space between pressure tubes and calandria tubes is accounted for in the base case analysis),

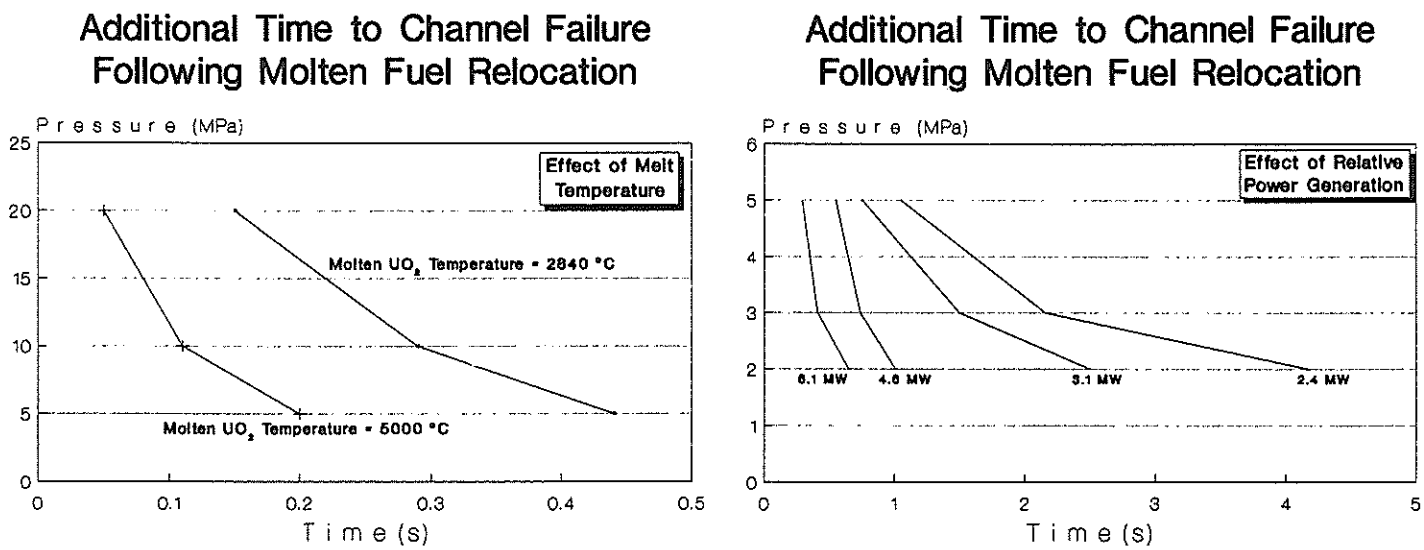


FIGURE 10

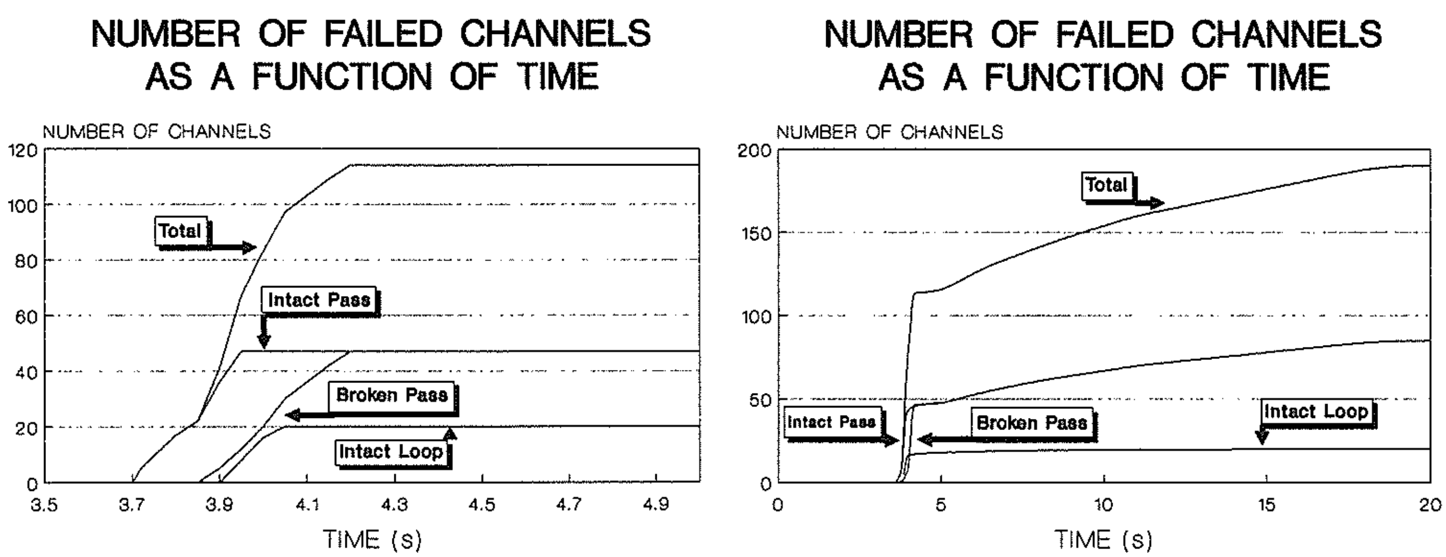


FIGURE 11

(c) establishment of high rates of moderator discharge through the dump ports -- in essence the channel failures induce a moderator dump that is an order of magnitude more rapid than the normal dump,

(d) establishment of high rates of moderator fluid discharge through the calandria relief ducts following failure of the rupture disks, and

(e) the large moderator displacement through the area created by vessel failure at the annular plate weld.

The more energetic the discharge from failed channels into the moderator, the more rapidly moderator displacement occurs, and consequently, the more rapidly the excursion is terminated. This is an important observation since termination of an overpower transient is governed by the rapidity of moderator fluid displacement. This is an extremely efficient process when discharge area is available from the dump ports, further area is created by vessel rupture, and an internal driving pressure exists due to coolant discharge into the vessel.

CONTAINMENT RESPONSE FOLLOWING CORE DISRUPTION

As discussed previously, failure of the calandria vessel occurs shortly (approximately 100 ms) after the lead channels fail. Vessel failure occurs at the weld between the annular plate and the main shell of the calandria.

The steam component of the fluid discharge rapidly pressurizes this vault. Hatches at the top of the vault, located on either side of reactivity mechanisms deck are blown off at a differential pressure of approximately 100 kPa(d) (14 psi), resulting in steam discharge into the boiler room. Prior to this a smaller blow-out panel separating the calandria vault and boiler room will have lifted. The steam discharge into the boiler room through these openings relieves the overpressure in the calandria vault, thereby limiting the potential for structural damage in the vault.

The containment pressure transient has, in all three cases, been evaluated based upon a conservative, stylized representation of channel failures and resultant steam discharge from the calandria vessel.

Because of the concern with the potential damage to containment during this type of accident, the failures of channels during the prompt phase of the accident are treated as if they all occur during the power excursion stage. The resultant pressures in the containment compartments are shown in Figure 13 and 14. Based upon the analysis of containment structural response and the assessment of containment failure thresholds, the potential damage to containment and internal structures is as summarized in Table 1. Because of the large volume in containment and the rapid equalization of pressure within internal compartments, the structural damage in the base case is minor, being limited to the immediate vicinity of the calandria. The containment envelope will not fail since the maximum containment pressure attained is 160 kPa(a) in the base case. This is slightly in excess of the design pressure of 142 kPa(a). Some minor cracking of the plug structure at the top of dome may occur. These cracks would reseal once the boiler room pressure decreases.

Even in the worst case scenario in which all channels are assumed to rupture rapidly, the peak containment pressure is 180 kPa(a). At this overpressure only minor cracking of concrete and incipient yield of reinforcement occurs in the plug structure at the top of the dome of the reactor building. With the structural integrity of the containment envelope maintained intact, this limited cracking is relatively inconsequential with regard to activity released from the accident unit. Furthermore, the conservative timing of channel failures employed in the assessment yields a significant overestimation of the early steam discharge rates into containment.

RADIOLOGICAL CONSEQUENCES OF THE ACCIDENT

Radiological consequences of any reactor accident are governed by a number of parameters. The amount and the composition of radioactive materials released from the plant as a function of time (called the source term) is the major parameter, but other variables can be of equal importance in determining the public doses.

Fission Product Release

The source terms change with time according to the three phases of the accident.

The prompt release involves rapid heating of fuel to very high temperatures, melting of high power fuel elements and widespread fuel sheath failures by strain and mechanical damage upon channel failures, all in the span of 20 seconds. Estimates of the early core damage indicate that by the end of the prompt stage, between 0.5 to 2.5 percent of fuel (in the core) will have been dispersed from fuel elements as molten droplets which subsequently quench into fine fuel particles. Furthermore, up to 10 to 20 percent of the fuel could be fragmented into coarser particles and

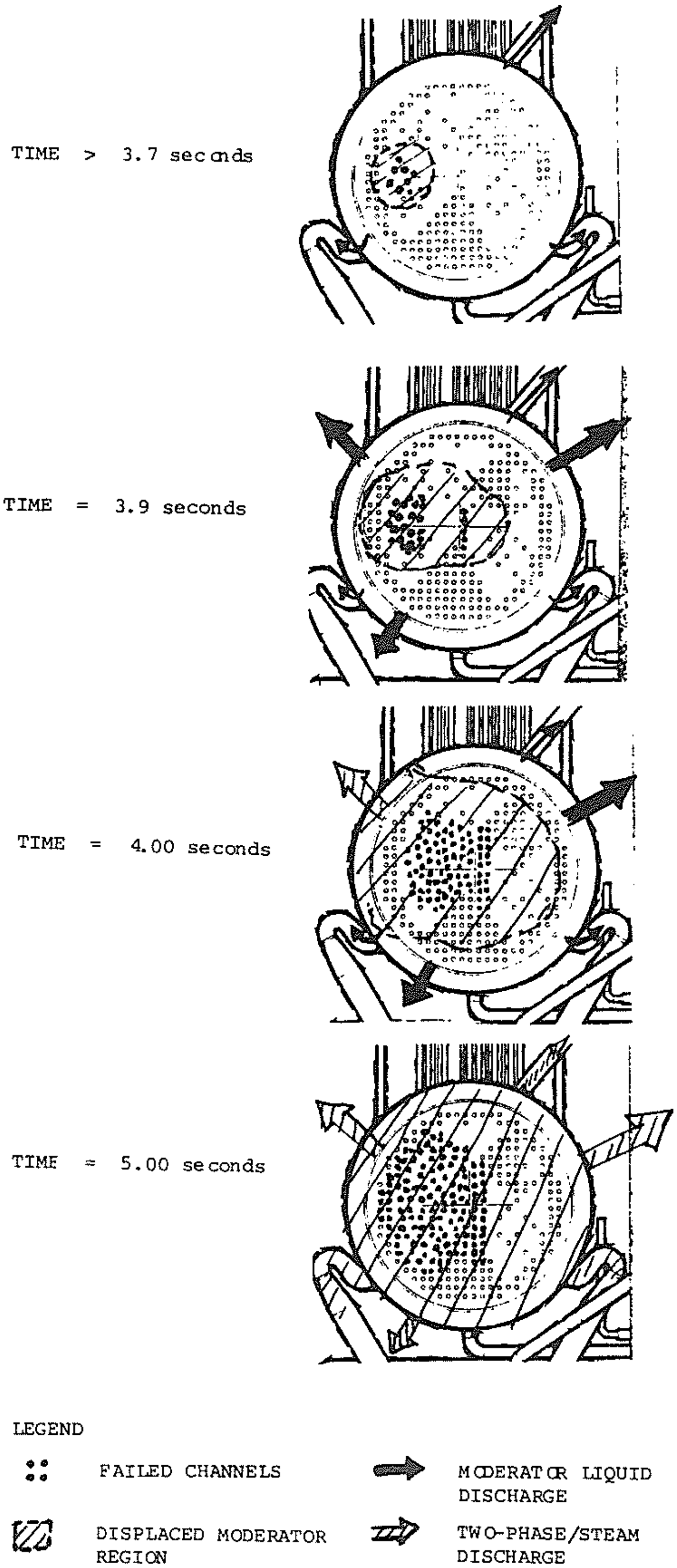


FIGURE 12
Progression of Channel Failures and Moderator Displacement Following First Channel Failure at 3.7 s

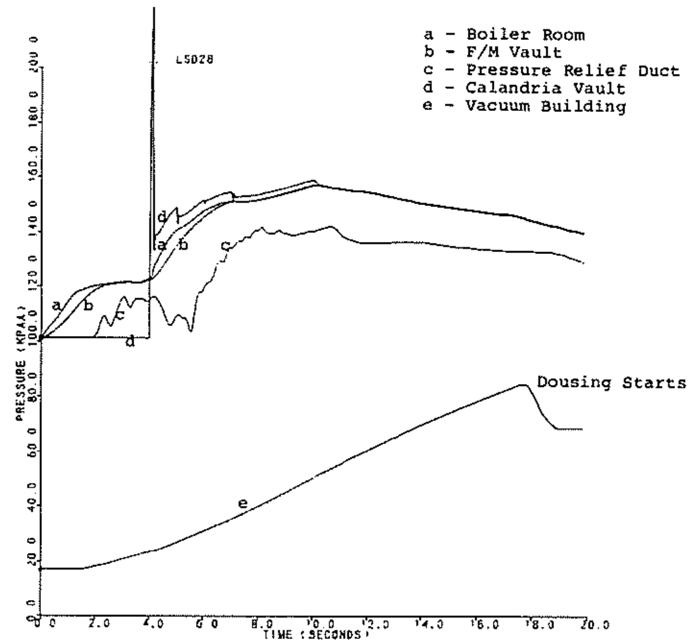


FIGURE 13
Pressure Response in Containment Following a Large LOCA with Failure to Shut Down (Early Termination Case)

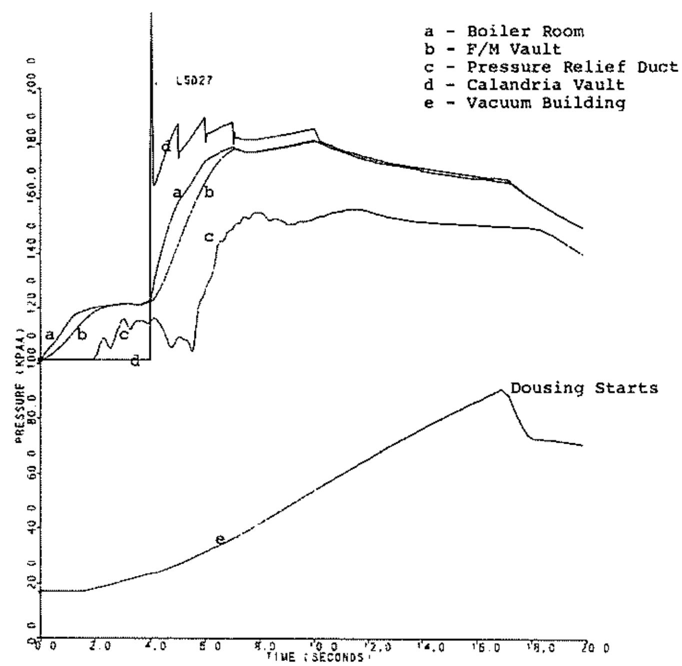


FIGURE 14
Pressure Response in Containment Following a Large LOCA with Failure to Shut Down (Worst Case)

displaced from the fuel channels and calandria vessel by the blowdown of coolant.

The above fuel conditions are quite severe from the standpoint of mechanical fuel damage, but they are not conducive to a large release of volatilized fission products from the fuel matrix. The prompt release involves mainly the fission products already present within the open and closed cavities of the fuel (i.e., the free and grain-boundary inventories). The anticipated range of prompt release from the fuel for these conditions is illustrated in Figure 15. The base case estimate approximately equals the free inventory of fission products in the core.

Intact containment will limit the prompt leakage of released fission products to much less than 1 percent assumed for the low end of the source term in Figure 15. Cracking of the containment dome which is anticipated at the upper end of the potential plant damage range, and the resultant limited duration venting of the adjacent containment volume, would increase the leakage of truly volatile species (homogeneously mixed in the containment atmosphere) by a small percentage amount.

The subsequent fuel conditions involve rapid cooling of the vast majority of the fuel to low temperatures. This cooling preclude any further rapid release of fission products from the fuel matrix. The only release during the cooling process would be from the residuals of the free and grain boundary inventories not released during the prompt phase. This fuel would respond in a manner similar to the conventional loss-of-coolant accident coincident with a loss of emergency cooling. The residual hot fuel would produce a relatively slow release of noble gases and certain fission product vapours from the fuel, the magnitude of which would be proportional to the amount of hot fuel. Up to 30 percent of the hot debris inventory could be released within a few hours, based upon the results from conventional accident scenarios. The late termination case may would not experience this mode of release since all channels are failed and cooled by ECI water.

Fuel fragments ejected and dispersed from the calandria vessel would remain adequately cooled throughout the short term period, whether or not immersed in water. At worst, some of this fuel could experience a low temperature (250 to 600°C) air oxidation once air returns to the vaults in the long term, resulting in slow generation of U_3O_8 fines.

Estimated magnitudes of release from the fuel subsequent to the prompt phase are illustrated in Figure 16. Compared to the prompt releases in Figure 15, the composition of release is altered somewhat, with the less volatile species having much smaller release fractions than noble gases. This is fully consistent with observed release patterns or rapid fuel cooling. It is this rapid cooling of the vast majority of the fuel that limits the subsequent release to a few percent of total inventory, rather then several tens of percent that would be released if the cooling were to be unavailable.

The containment envelope returns to a sub-atmospheric pressure shortly after the transient prompt pressurization, so there would be no release into the environment at the beginning of the short term stage. However, the internal pressure would return to atmospheric as the vacuum reserve becomes depleted by air in-leakage. Operator initiated filtered venting will then commence, resulting in release of noble gases at a rate of 0.1 percent of the containment inventory per hour. Corresponding magnitudes of release from the plant are illustrated in Figure 16.

In the long term, the release from fuel will cease and the only release from the plant would consist of residual noble gases from the containment atmosphere and minute fractions of other species desorbing from the filters. Note that the term "no release" used in these figures does not imply absolute zero, but is used to denote a very low rate of release consistent with the high efficiency of the EFADS filters.

OFF-SITE CONSEQUENCES

The total magnitude of release from the fuel is actually of the same order of magnitude as that estimated for severe loss-of-coolant accidents coincident with a loss of emergency cooling in conservative licensing analyses. The containment retention characteristics are also similar at least following the early containment pressure transient. The public doses in the conventional accident scenarios are typically a small fraction of the relevant regulatory dose limits. The limit cracking of concrete in containment dome in the accident considered here would slightly increase the magnitude of the prompt noble gas release relative to the conventional accidents and reduce the time to the onset of controlled venting. These changes in the source term characteristics would tend to increase the public dose, but an increase beyond the regulatory limits is not likely.

CONCLUSIONS

Analysis of a failure to shutdown following a large loss-of-coolant accident at Pickering NGS A has established the following as the most probable consequences of such an accident.

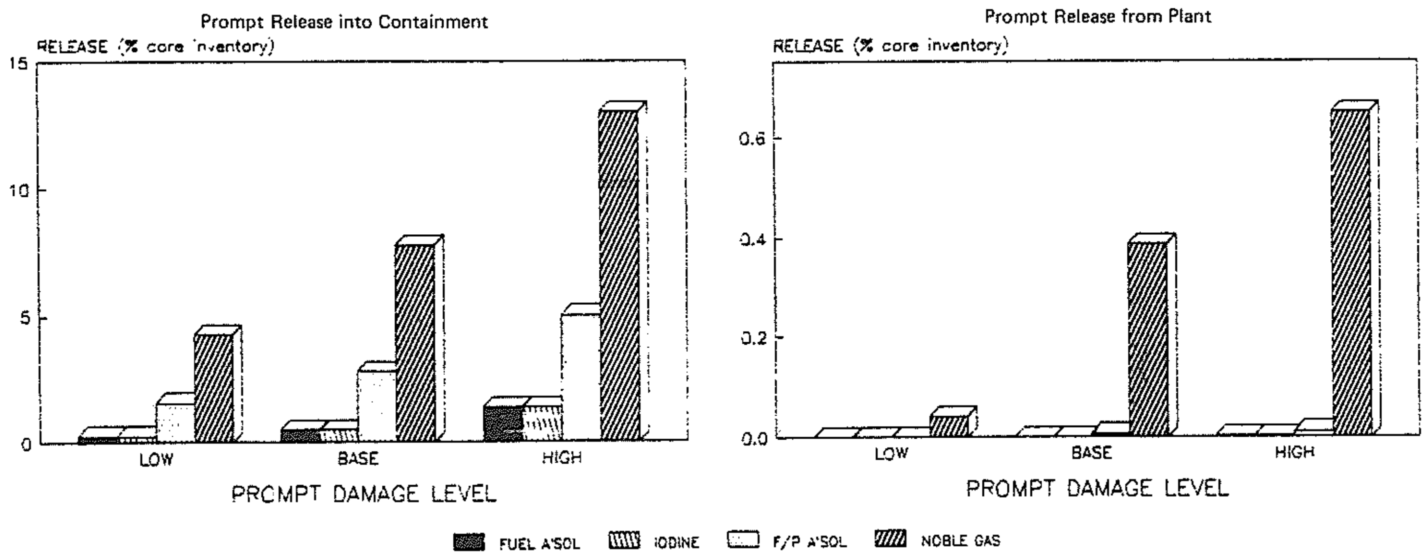


FIGURE 15

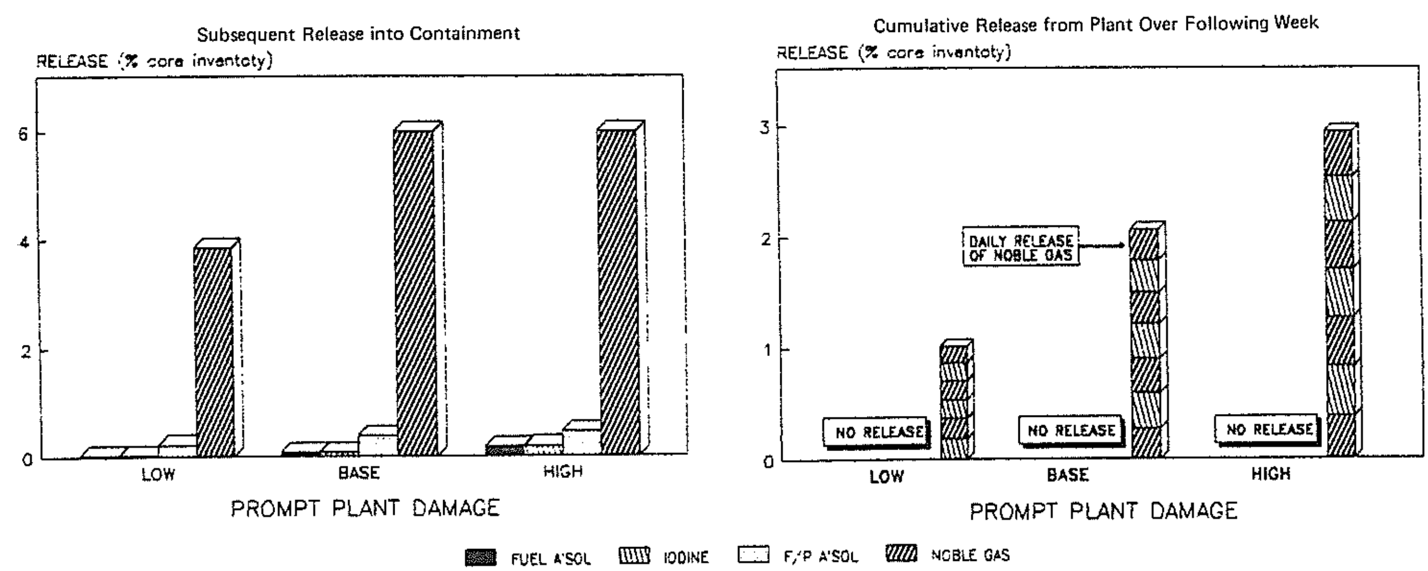


FIGURE 16

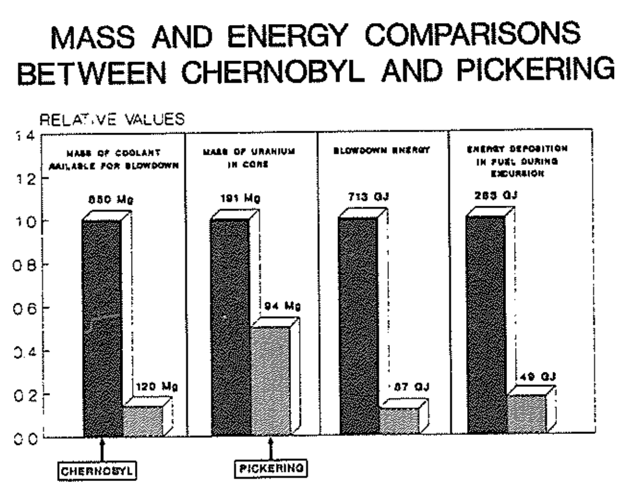


FIGURE 17

1. Rapid termination of the power excursion will occur at 3.75 seconds following the initiating failure, when the first fuel channels fail into the calandria.

2. The mode of failure of fuel channels is rapid local strain failure of pressure tube and calandria tubes due to molten fuel relocation onto the pressure tube. Later failures of some channels due to overheating and deformation will occur following the power excursion.

3. Up to 50 percent of the fuel channels could fail during the prompt phase of the accident.

4. Calandria vessel failure will occur at the weld between the annular plate and main shell due to overpressurization associated with multiple channel failures.

5. The structural integrity of the containment envelope is maintained following this event. At worst, there will be some limited cracking and incipient yielding of reinforcement in the region of the dome closure plug at the top of the reactor building dome.

6. The source term (fission product release from the damaged unit) associated with this accident is not substantially different than that associated with the type of extreme dual failures that are analyzed as part of the licensing process for the station.

Inevitably, the reader of the above conclusions will ask "Why does a power excursion in Pickering produce consequences that are so different from those associated with the Chernobyl accident?". The answer to which became increasingly apparent during the analysis, lies in the following:

(a) 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. In the Pickering reactors there is no mechanism to induce this "autocatalytic" process.

(b) The major energy discharge from a damaged reactor in this type of accident is associated with blowdown 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.

(c) The large volume of the Pickering containment, coupled with a design that is based upon minimizing pressure differentials between internal compartments, limits the damage potential associated with the energy release during the accident.

The first two factors are illustrated graphically in Figure 17.

REFERENCES

1. AECB, "The Accident of Chernobyl and Its Implications for the Safety of CANDU Reactors", AECB Report INfo-0234(E), Atomic Energy Control Board, Ottawa, May 1987.

2. Ontario Hydro Report to the Ontario Nuclear Safety Review, "Analysis of the Consequences of Failure to Shutdown Following a Large Loss of Coolant Accident in a Pickering NGS A Unit", Nuclear Studies and Safety Department, October 1987.

ACKNOWLEDGEMENTS

Many people from the Nuclear Studies and Safety and Civil Design Departments of Ontario Hydro made contributions to the study summarized here. Listed in alphabetical order they are:

Nuclear Studies and Safety

O. Akalin, J.C. Amrouni, R. Arora, C. Blahnik, R.A. Brown, J.W. Blyth, K. Fung, P. Kundurpi, V. Langman, J. Lau, K. Locke, A.P. Muzumdar.

Civil Design

A. Danay, P. Ko, J. Tang.

availed himself of this opportunity. It is quite probable that his former professors at the University of Pisa (who had been unimpressed by his outspoken attacks on the widely held Aristotlean views) would have not found the *Discourse* pleasant or relaxing reading. Those who find themselves faced with the prospect of preparing lengthy technical reports might find it sometimes diverting to consider how Galileo's approach might be applied today.

By the time we reach the late Seventeenth Century and beyond, however, scientific literature has become more formal (though eminently readable). The accounts by such as Newton, Coulomb and Cavendish are much closer to the idealized model of scientific discourse, though the elegance and clarity of the presentations are of a level to which it is doubtful any modern scientific journal could aspire. By way of example, a short passage from Newton's *Principia:*

"We are to admit no more causes of natural things than such as are both true and sufficient to explain their appearances. To this purpose the philosophers say that Nature does nothing in vain, and more is in vain when less will serve; for nature is pleased with simplicity, and affects not the pomp of superfluous causes".

As we progress through the Eighteenth Century a particularly interesting feature is the precise and comprehensive description of experimental apparatus and method. Anyone (given time, a reasonable amount of manual dexterity and access to simple tools) could repeat most of these experiments in a basement workshop. This, of course, is a principal objective of reporting scientific experiments – to enable someone else to repeat the experiment.

For this reviewer perhaps the highlight of Shamos' book is the Rutherford work on "Induced Transmutation" with its discussion of "An Anomalous Effect in Nitrogen". If this isn't **the** experiment in the history of the nuclear business it is difficult to say what is. Though those readers who take issue with this assertion will find much useful ammunition in the Shamos book, since Einstein, Bohr, Planck and Chadwick are also represented.

There is not one page in this book which fails to absorb, stimulate and divert. It belongs in every civilised person's library.

David Mosey

Clouds in a Glass of Beer. Simple Experiments in Atmospheric Physics, Craig F. Bohren, John Wiley and Sons, Wiley Science Editions, New York, 1987.

"I've looked at clouds from both sides now . . ."

If, like me, you are partial to good beer and interested in aerosol science, this book would seem to be just the ticket. In fact, no matter what attracted you to the book you would be likely to be somewhat taken aback.

Although the title is catchy, the sub-title is something of a cold shower. Atmospheric physics is a subject which seems to have all the appeal of a broken light bulb. It conjures up pictures of some poor sod measuring millimetres of rainfall in the pouring rain, or of a Cray mindlessly crunching out wind speeds in hundred metre cubes of frightfully boring air six miles south of Wingham. It has almost no connection with the nuclear industry and, in the final analysis, seems to be one of those forgotten outer circles of Hell where Ph.D.s in meteorology labour, Sisyphus-like, solving again and again the same old solved problem.

Nobody could come away from this book with any such view. Although there is not an equation in its 185 pages, the author explains with ease and disarming simplicity such diverse phenomena as light scattering, blue moons, cloud formation, the thickness of ice on lakes, the greenhouse effect, blackbody radiation, surface tension, the colour of wet sand and a few other things of that sort. The book could be read and understood by almost anybody, and I would venture that there are few people who could not learn something from it.

The real accomplishment of the book is its deft splicing of very simple experiments and observations of the most humble sort with quite detailed explanations of the phenomena and effects driving the things seen. The experiments involve such expensive equipment as bath tubs, mirrors, cameras, electric heating elements, milk, and slide projectors. The effects include skylight, wettable surfaces, the thermal conductivity of water, and refraction, reflection, scattering and extinction of light. Of course, if you are completely clear on the distinction between surface tension and surface energy and which should be considered real, if Stefan's relation of ice increasing in thickness as the square root of time (and why this can't be demonstrated in a freezer) makes you yawn with the contempt born of familiarity, if you have on the tip of your tongue a satisfactory explanation as to why milk is white and not blue, then you need read no further.

The chapters that were most intriguing to me were those on the greenhouse effect and the green flash. Perhaps you have seen the green flash at sunrise or sunset and wondered what it was. If you haven't, there is a way to simulate it using a slide projector, a shallow tray of water, a mirror and a few drops of milk. What you do is aim the slide projector into the tray of water in which you have placed the mirror as well as a few – but why spoil the fun. Bohren explains it so much better than I can.

I spent a couple of very enjoyable hours with this book and there is every reason to expect that I will be dipping into it again. It deserves a place along with those other examples of the clear and simple explanation: Gamow's "One, Two, Three . . . Infinity", Hoffman's "The Strange Story of the Quantum", Gardner's "Logic Machines and Diagrams", Moroney's "Facts from Figures", and Fenn's "Engines, Energy and Entropy".

It's all too easy to forget, while looking up the fifth decimal place of Boltzmann's constant, or interpreting (??) the results of some obtuse computer code, that the world really is a most interesting place where lots of odd and fascinating things happen, if only one looks. "Clouds in a Glass of Beer" is a very pleasant reminder of that.

Keith Weaver

Better a Shield than a Sword – Perspectives on Defense and Technology, Edward Teller, published by The Free Press, 1987. ISBN 0-02-932461-0

Few people are indifferent to Edward Teller. One of the most eminent and articulate scientists of this century, he has cultivated his role as a sort of *enfant terrible* scandalising the middle-class liberal consciousness with his outspoken (and highly articulate) support for such things as weapons development and civilian nuclear energy.

This book is a collection of essays, lectures and speeches ranging in date of original publication/delivery from 1946 to 1985 and organized under 5 topic headings: "The Strategic Defence Initiative", "Atoms and Individuals", "The Unstable Peace", "Progress and Paradox" and "Science and Responsibility". As may be discerned from some of these topic headings (and as indicated by the book's subtitle), Teller is reiterating some of his perennial political concerns in the area of defence strategy, and doing so with his customary forthrightness and vigour. Fortunately there is much more to the book than this, particularly in the fifth section.

In his treatment of the issues of nuclear weapons development and testing, test ban and weapons reduction treaties and the strategic defence initiative (SDI) Teller is presenting a viewpoint – his – and he does it with eloquence and conviction. But it's important to remember that it is only an individual viewpoint, and the fact that the presenter may be an eminent physicist should not automatically endow that viewpoint with any particular authority. The fact that Isaac Newton was particularly interested in alchemy should neither change our estimate of the legitimacy of alchemy as a science nor our estimate of Newton as a scientist.

Nuclear Weapons – Defence and Deterrent

Teller's approach to the whole question of nuclear arms and the nuclear arms race is informed by the assumption that the United States would not want to drop atomic bombs on other people unless other people threatened to drop atomic bombs on the United States so there is no rationale for anybody else to have atomic bombs unless they're going to use them for aggressive purposes. Apart from the fact that this glosses over such inconvenient considerations as assistance to allies or the use of battlefield nuclear weapons against conventional forces, it is an assumption that can easily be transferred to any country, including the Soviet Union.

Distrust is one of the most enduring and stable of international currencies and what could be legitimately described as well-founded distrust on all sides has ensured that the development and enhancement of weapons (nuclear or otherwise) has continued in a healthy and enthusiastic fashion. Regardless of the practicability of the SDI programme, institution of a successful defence against incoming missiles would simply be a way-station on the progress towards countering that defence.

Teller is quite right when he argues that incoming missiles may be stopped, but he doesn't suggest what proportion might get through. And while he argues (in "Widespread Aftereffects of a Large-Scale Nuclear War"), convincingly enough, that food storage programmes could help offset harvest failures resulting from temporary climatic changes following a major nuclear exchange he does not suggest either how many people might be around to eat the food, or what transportation systems might still be functioning to deliver it.

In a sense, Teller's genius (and that's the right word) for simplification is part of his greatness as a physicist, but it's part of his undoing in argument. Teller's ultra-keen mind seems to lose some of its edge when he has to deal with the complexities – the sheer "messiness" of human activities. He can't (or won't) see anything but black and white, do or don't, for or against. It is odd (and a little disappointing) that a man who can clearly appreciate what he calls "the ambiguous and paradoxical nature of that which we accept as reality" does not seem to so clearly appreciate these same qualities in humankind.

There is the danger that, in reaction to the woolly-thinking, fractured syntax and mindless slogan chanting that characterize some segments (one hopes small segments) of the "anti-nuclear weapons" activist groups, one may be captivated by the wit and liveliness of Teller's exposition. But this is reacting to one simplistic view by adopting another. The issue is too complicated and too important for that.

Nuclear Reactor Safety

The Chernobyl reactor accident is covered in an essay which illustrates the best and worst features of Teller's approach. His description of fission, the delayed neutron phenomenon, positive reactivity effects and prompt criticality are superbly lucid. His description of the actual reactor accident is simple and clear. But his discussion of the general nuclear safety implications of the accident are disturbingly simplistic, and in some instances, plain wrong. For example, to suggest that there are no reactors in the West in which a void in the cooling system can produce "prompt criticality" ignores the existence of the CANDU-PHW – and to further suggest that such a reactor is "dangerous" implies either that other positive reactivity effects are not dangerous or don't exist in other western reactor designs (untrue).

A major point about Teller's treatment of reactor safety is that he seems to totally ignore the non-design contributors to accidents – and the one thing that the history of major (and minor) reactor accidents since 1952 should teach us is that design is only one element in the nuclear safety picture and, over the long term, is probably not the dominant one.

People and Physics

However, there is more to this book than well-written simplistic polemic. It is in the sections "Atoms and Individuals" and "Science and Responsibility" where perhaps we come closest to the real Teller – a humane, cultivated and articulate scientist who is anxious to explain and share his passionate love affair with physics to anyone who'll listen. And a generous-spirited friend and colleague – his Dedication to Leo Szilard and his accounts of contemporaries such as Oppenheimer and Lawrence are fascinating and, at times, moving.

The "Atoms and Individuals" section is of particular fascination. It is studded with little anecdotes about such epochal figures in the nuclear business as Bohr, Szilard, and Wigner – one is especially delightful. Told to illustrate Wigner's humanity, it describes Wigner and a friend relaxing at the Gottingen Municipal swimming pool. The friend, observing some ants crawling over Wigner's leg, asked if they were biting. "Yes" said Wigner. "Then why," queried the friend, "don't you kill them?". "Because I don't know which one did it," responded Wigner. As well this section contains a detailed account of Teller's role in the so-called "Oppenheimer affair", correcting some inaccuracies in the BBC Television programme "In the Matter of Robert Oppenheimer", particularly with reference to the character and motivations of Lewis Strauss.

At its best, this book is fascinating, exciting and illuminating – at its worst it's still highly readable and provocative. After reading it one's greatest regret is that of not having had the opportunity to attend Teller's lectures at the University of California some twenty years ago.

David Mosey

CNS Branch News

Central Lake Ontario Branch

On February 24, 1988, a meeting of the CNS Council was hosted by the Central Lake Ontario Branch at Darlington NGS. Immediately following the Council Meeting a special Branch Meeting was held. The Branch Meeting was opened with a welcoming from Council by Dr. Irwin Itzkovitch and was followed with a presentation on "The Slowpoke Reactor – Its Use in Space Heating" by Dr. Gerald Lynch, Chalk River Nuclear Laboratories. About 30 branch members listened to Dr. Lynch as he described the attributes of a Slowpoke heating system and its potential benefits. Of particular interest is the fact that a Slowpoke hot water heating system can be very cost competitive even when compared to the process steam used for space heating in a CANDU nuclear generating station!

Thanks to the CNS Council and Dr. Lynch for a very interesting Branch Meeting.

Dan Meraw

New Brunswick Branch

The Past Chairman of the CNS New Brunswick Branch, Mr. J.F. Lafortune, a Ph.D. student at the University of New Brunswick, has been awarded one of the three North American Life Scholarships for the 1987/88 academic year.

Mr. Lafortune obtained a M.Sc. degree in Nuclear Engineering from Ecole Polytechnique in 1985. His current research is in the development of small nuclear power units.

David O'Connor, a CNS Student member and the winner of the Best Undergraduate Paper Award of the CNA/CNS Student Conference of 1985, has been awarded a Graduate Scholarship Award of the Nuclear Plasma Sciences Society of the IEEE. David, working under the direction of Professor E. Hussein at the University of New Brunswick, has also made contributions in the development of a gadolinium concentration monitor for SDS 2.

Ottawa Branch

Seminar Programme: 'The CNA Public Information Program'

Ian Wilson, CNA Vice-President, gave a talk to the Ottawa Branch on February 11 concerning the CNA Public Information Programme.

As we are all well aware, the uranium and nuclear industries have, over the past twenty years, seen their public support eroded as a result of activist propaganda, economic re-adjustments and accidents. Recently it has become clear that, without a significant increase in public support, the future of nuclear power in Canada is in jeopardy.

The CNA is undertaking a major public information programme to improve the public's image of nuclear energy.

Ian outlined this programme and reported on the experience gained as a result of the first few months of operation. The strategy behind the formulation of the television and print ads was discussed, and some of the reasons for the differing advertising thrusts in Quebec versus Ontario, for example, were reviewed.

Various members of the audience who had previous experience with similar campaigns on a more local level offered some insights into the process. A few interesting suggestions, such as the use of local newspapers to gain provincial and even national attention, were also offered.

Terry Jamieson

Conferences & Meetings

14th Annual Simulation Symposium
Sponsored by Canadian Nuclear Society, to be held **April 24-27, 1988** in Pinawa, Manitoba. For information contact: **V.S. Krishnan, Whiteshell Nuclear Research Establishment, Pinawa, Manitoba, R0E 1L0,** (204) 753-2311.

International Topical Meeting of the Safety of Next Generation Power Reactors
Sponsored by ANS; cosponsored by U.S. DOE, CNS et al., to be held **May 1-5, 1988** in Seattle, Washington. For information contact: **Robert Ferguson, Ferguson & Associates, 7601 W. Clearwater, Suite 450, Box 16, Kennewick, Wash. 99336,** (509) 783-1446.

Third Topical Meeting on Tritium Technology in Fission, Fusion and Isotopic Applications
Sponsored by CNS, cosponsored by American Nuclear Society, to be held **May 1-6, 1988** in Toronto, Ontario. For information contact: **C.D. Burnham, CFFTP, 2700 Lakeshore Rd. W., Mississauga, Ontario, L5J 1K3,** (416) 823-6364.

4th Workshop on Analytical Chemistry Related to Canada's Nuclear Industry
Sponsored by AECL, Ontario Hydro and others, to be held **May 15-18, 1988** in Kimberly, Ontario. For information contact: **K.R. Betty, Eldorado Resources Ltd., 360 Albert St., Suite 700, Ottawa, Ontario, K1R 7X7,** (613) 238-5222.

International Symposium on the Feedback of Operational Safety Experience in Nuclear Power Plants.
Sponsored by the IAEA and OECD/NEA, to be held in Paris, France, **May 16-20, 1988.** For information contact: **IAEA.**

4th International Conference on Human Factors in Power Plants.
Sponsored by the IEEE and ANS, to be held in Monterrey, California, **June 5-8, 1988**. For information contact: **D.L. Sherman, EG&G,** (208) 526-9578.

28th Annual International Conference of the CNA and 9th Annual Conference of the CNS
To be held **June 12-15, 1988** in Winnipeg, Manitoba. For information contact CNS office, (416) 977-7620.

15th International Conference on Reliability, Availability and Maintainability
Sponsored by Bonneville Power Administration, to be held **June 14-17, 1988** in Portland, Oregon. For information contact: **R. Vanderznden,** (503) 230-5143.

14th International Symposium on the Effects of Radiation on Materials.
Sponsored by ASTM, to be held in Andover, Mass., **June 27-29, 1988.** For information contact: **C.H. Woo, AECL/WNRE,** (204) 753-2311.

Nuclear Power Plant Life Extension
Sponsored by ANS, to be held in Snowbird, Utah, **July 31-August 3, 1988.** For information contact: **H. Zeile, EG&G,** (209) 526-1603.

Spectrum '88: International Topical Meeting on Nuclear and Hazardous Waste Management
Sponsored by ANS, cosponsored by U.S. DOE, Canadian Nuclear Society and others, to be held **September 11-15, 1988** in Pasco, Washington. For information contact: **Eva Rosinger, Whiteshell Nuclear Research Establishment, Pinawa, Manitoba, R0E 1L0,** (204) 753-2311.

Short Course in Reactor Safety
Sponsored by CNS/NSE, to be held in Toronto, Ontario, **September 19-20, 1988.** For information contact: **W. Midvidy, Ontario Hydro,** (416) 592-5543.

International Conference on Thermal Reactor Safety
Sponsored by ENS/ANS/CNS, to be held **October 2-7, 1988** in Avignon, France. For information contact: **H. Tamm, AECL/WNRE,** (204) 753-2311.

Tritium Safe Handling Course
Sponsored by CFFTP, to be held in Toronto and Chalk River, **April 25-29, 1988** and **October 3-7, 1988.** For information contact: **R. Matsugu,** (416) 823-0102.

Call for Papers
The **Canadian Nuclear Society** is sponsoring a conference on **The Performance of Polymers in Nuclear and Related Environments,** to be held in Toronto, Ontario, Canada, on **February 20-21, 1989.** Topics will include:

- design and materials selection (electrical insulation, seals, hoses, coatings, lubricants, NDE, waste encapsulation).
- equipment qualification (standards, design basis events, end of life criteria, maintaining quality).
- operating experience and plant life extension (station feedback, surveillance, prediction methods, life criteria revisions).

Abstracts to be submitted by **June 30, 1988** to:

Mr. E.G. Price
AECL
CANDU Operations
Sheridan Park
Telex 06-982372
Telephone 416-823-9040
Fax 416-823-6120

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Bruce	Karel Mika	(519) 368-7031
Golden Horseshoe	Bill Garland	(416) 525-9140

The Unfashionable Side

Seven Types of Corporate Culture

I had spent a breezy afternoon road-testing the Bentley and so had worked up a considerable thirst by the time I pulled up into my usual blast pen outside the faculty club.

The bar was deserted, save for George Bauer deep in conversation with a chap wearing a pin stripe suit and an expression of concern. Bauer turned and waved for me to join them at their table by the fireplace. I dropped my helmet and sidcot onto a spare chair and sat down with a sigh of satisfaction.

"Worthing, I'd like you to meet Norbert Tidmarsh from the Atomic Energy Confusion Board" said Bauer, indicating the corporately clad person, "he has a problem for which you may be able to suggest a solution". Bauer turned to his guest, "Professor Worthing and I have worked together on a number of cases and I can assure you that his methods, while sometimes a little unconventional, invariably achieve results". Tidmarsh turned his somewhat hamsterish features in my direction, mumbled something that sounded like "G'day", and sipped at his pallid looking fizzy drink. "Glad to meet you" I beamed at him, "and how can I assist the old atom factory inspectorate?" I waved vaguely at the bar to indicate a requirement for beer.

Brown, the lugubrious caledonian bartender, delivered our supplies and I raised my glass. "Cheers" I said, then, remembering the linguistic sensibilities of the Ottawa set, added "bonne chance et toutes cettes sortes des choses". Bauer broke in to the rapidly congealing silence: "perhaps if you would run over the main points for Worthing, Tidmarsh . . .". The visitor shook himself slightly, then reached for an expensive-looking attaché case – all bright leather and little brass bits. He pulled out a thick file-folder and handed it over.

"This submission to the Ontario Nuclear Safety Review concerns the regulatory authority". I nodded and continued sketching faces in the capital O's on the papers in the file. "Our particular concern relates to Section 2.4". He looked up expectantly, and I observed a few sentences on one page which had been painted over with some lurid dayglow material.

"Ah yes, Mr. er . . Toadswamp . . . I have the reference here," I read the marked words aloud, "'A number of ambiguities in the corporate culture of the AECB have been identified' – Identified as what?" I asked casually. Bauer coughed delicately and interjected "I believe what the writer means is 'found' " he said. The civil servant nodded agreement. "Aha!" I said with an air of dawning enlightenment "and you want me to do the identifying – right? Well, I think I can get that sorted out without too much difficulty – and I must say I'm glad the AECB has finally woken up to the importance of rigorous critical analysis". The visitor looked blank. I raised an enquiring eyebrow at Bauer.

"Actually, Worthing, old chap," Bauer said in a rather over-precise tone "they want the ambiguities got rid of. Extirpated. Unequivocally removed. Rendered unambiguous. And what is more, Worthing," (Bauer's voice if anything became more precise) "they have a large budget earmarked for this task. A very large budget indeed". I began to get the message. "Naturally Mr. . . . er . . . Tolpuddle, I believe I can help you out. Though of course this would be an extensive project. Am I to understand that you wish me to deal with all seven types of ambiguity?" The atomic referee nodded. He seemed to have calmed down a bit. "Very well," I said, "I shall leave for Ottawa at once. Please make arrangements for me to review the relevant documentation at your headquarters." I picked up my gear and headed off leaving Bauer perhaps unfairly lumbered with both bill and visitor.

It took me just a few minutes to pick up the copy of Empson I would need and pack a couple of bottles of brandy and the gasogene into the Bentley's stowage compartment, then I was on my way. I made it to Ottawa in good time and without undue incident. It was about 20:30 as I nosed the Bentley through the city centre, and those sidewalks which had not been rolled up for the night were sprinkled with joggers and people walking in and out of craft boutiques.

I turned onto Slater Street and parked outside the imposing facade of the nuclear regulators. Luckily Todpond – or whatever his name was – had made the necessary arrangements and the security people ushered me up to the Directorate Offices. The Big Z and his understrappers had all left for the night, and I had the place to myself. The documents I wished to examine had been piled on a desk – about two dozen thick loose-leaf binders – and a microcomputer stood beside them ready for action.

It didn't take me very long to confirm my suspicions. A quick sampling of the documents, a few glances at Empson and the job was more or less done. I made a few notes (by hand since for some reason the micro went on the blink), left a written message stapled to the desk top requesting a meeting for 9:30 the next morning and then phoned Bauer, asking him to meet me at the Bohr's Head Tavern when I got back to Aphasia.

The meeting went much as I'd expected. There were a few snarky remarks about spilled brandy in the disk drives and empty bottles in the wastebasket, but once they'd got that off their chests everything went smoothly. And though I was well aware of the strength of my arguments, I was still pleasantly surprised by the alacrity with which they agreed to my proposals and signed the appropriate documentation. I was on the road by lunchtime and it was about three hours later when I strode into the Bohr's Head. Bauer was waiting for me with an expectant look and two full pint glasses.

"Well, how did it go?" he asked. I downed sufficient ECI to preclude immediate failure before I responded "very well, old boy. It's all sorted out". A shadow flitted across Bauer's face – "all sorted out?" he queried.

–"Yes, no more problems" I said with finality. Bauer's index finger began to tap the table, a demonstration of emotional disturbance equivalent to a lesser person's sweeping the glasses off the table and tap dancing on the remains. When he spoke Bauer's voice had the tension of a bomb disposal officer examining an ageing 500 pounder which has just started ticking. "Do you mean to tell me that is all?" he said. I nodded. "Worthing, why do you do these things?" Bauer said in a voice trembling with emotion, "I would have thought that after the radioactive lavatories debacle you would have at least had the . . ."

Bauer broke off as I waved two folders of papers in front of his face. He took them, and began reading. "But . . . but . . ." It was delicious to hear Bauer at least temporarily at a loss for words. He read further and an expression of mixed incredulity and delight spread over his face. "But Worthing", he exclaimed "these contracts run for a year! How did you do it?".

I leaned back expansively. "The first part was easy" I explained, "to whit the question of culture. Everybody knows that the only culture in Ottawa is yoghurt. As I explained to the AECB, jogging and spritzers do not form the basis for a culture, however primitive." Bauer nodded his head and absentmindedly poured his beer into a nearby potted plant. "Having established no culture in Ottawa, ergo no culture at the AECB, half their problem was solved" I continued. "It was then merely necessary to establish to them the importance of ambiguity" I flourished the second document and then, to be on the safe side, transferred Bauer's remaining beer to my side of the table. "Once caught on the idea of seven types of ambiguity, the lads were concerned enough to enquire about the seven pillars of wisdom".

Bauer leapt to his feet "you mean?" he said in a strangled whisper. "Yes, Bauer" I said, "we are retained to carry out field investigations. Our flights are booked, and we leave for Alexandria at just that time when the meteorological conditions in Canada become insupportable."

At sublime moments such as this one's perception can play tricks, but there was no doubt about Bauer waving to the waiter for more supplies, then saying to me in a low voice, "Worthing, magnificent! The beer's on me." He paused a moment, coughed discreetly, then added "or rather, on the AECB".

Ernest Worthing