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Editorial

A Lesson From Chernobyl

With the conclusion of the IAEA post-accident review meetings in Vienna it is clear that the Soviet Union has more than lived up to its commitment to provide the world's nuclear energy community with a full account of the Chernobyl Unit 4 reactor accident. It is also clear that this tragic event was, like major reactor accidents since NRX in 1952, primarily the result of human intervention rather than the failure of engineered systems or components.

There have been, and presumably will continue to be, comments by the proponents of a variety of reactor systems to the effect that if Chernobyl-4 had been fitted with a fast shutdown system . . . if the Chernobyl design did not have a positive void coefficient . . . if the reactor had not been graphite moderated . . . and so on. As the old saying has it, "If 'ifs' and 'ands' were pots and pans there'd be no need for tinkers."

Such arguments miss a rather important point about the Chernobyl accident – that it was the result of a series of explicit, active violations of laid down operating procedures. The reactor was operated in a forbidden regime. Required shutdown depth was not maintained. Safety systems were blocked. Supposed design "deficiencies" are simply not the issue – indeed any reactor design could be said to have "deficiencies" if you look at things in the right way. With its plethora of instrumentation, blind flying aids, inertial navigation systems and stall-warning alarms a modern airliner can still be a very unsafe machine if its aircrew proceed to turn off most of their nav-aids and jumper some of the safety interlocks.

It is rather ironic that at a time when there is reportedly widespread disenchantment with technology throughout our society, response to an accident such as Chernobyl (or Bhopal) is too often expressed in terms of hardware fixes. Such fixes may indeed be desirable but they are not the complete answer. In automotive safety a vital (perhaps the principal) component is "the nut behind the wheel."

Our response to the Chernobyl accident must include serious consideration and evaluation of the human systems upon which, ultimately, public safety must rely. Suggestions have been made that operators who violate established procedures and jeopardize public safety should be subject to penalties under law. This does not seem to be an ideal solution from the point of view of either human motivation or natural justice. If law is to be invoked perhaps a better approach might be to establish legal protection for nuclear plant operators who disobey instructions which, if followed, would place the reactor in a hazardous condition. Impinging as it would on the relationship between employer and employee, such legislation would not be easy to draft or interpret, and might well be viewed with some concern by those utilities operating nuclear power plants. But in Canada at any rate, the fact that reactor operators must be licenced by the regulatory authority is explicit recognition of the fact that a reactor operator's responsibilities are wider than the traditional responsibility of employee to employer. Legislation which would establish a reactor operator's responsibility to maintain safe procedures in spite of directions to the contrary from a superior (however improbable a situation this might be) would provide formal assurance that public safety will not be compromised by "corner cutting" in attempts to maintain a production record or meet a schedule.

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Perspective

Ethics and Energy

The following article is based on a talk given by Tom Dowell (Energy Exchange, Toronto) to managers from Ontario Hydro's Design and Development Division earlier this year.

Ethics is something of a growth industry, and we should expect this. Energy, like the economy, is subject to exponential growth. Similarly, I would like to suggest that ethical questions, concerns and criteria are an exponent of technology development. I think this has always been so. Ethics has, until recently, been anthropocentric – centred upon the effect of human actions upon human beings. This will probably not always be so.

For thousands of years, ethical concerns have been with the effects *here* and *now* of human actions on human kind. This is changing, and it is changing due to exponential development of science and technology. We now have unprecedented possibilities for the effects of our actions to be felt around the world and for time scales greater than the whole of human history.

When Aristotle wrote his *Ethics*, more than

2000 years ago, he was concerned with the effects of human actions on the citizens of Athens. He was concerned with the *there* and the *then*. And most of our ethics has, similarly, been concerned with *here* and *now*.

Aristotle defined ethics in terms of happiness, or well-being, resulting from right action. For him, happiness was the highest good of human beings, and the first principle of ethics. I think we hear too much ethical discussion of good and bad, right and wrong, duty and obligation, divorced from its aim and object of human happiness.

Much more recently than Aristotle, the 18th century English philosopher Jeremy Bentham defined ethics as the production of the greatest possible happiness. This became the founding principle of the utilitarian ethics of the 19th century which sought the greatest good for the greatest number - not supreme good for everybody. As engineers we know that nothing is perfect, and that too much advantage in one area of our engineering efforts results in the disadvantage of other areas. Managers know that too much advantage in one section of a department, leads to disadvantage in another and hence, should practice the ethical principle that Aristotle described as acting in moderation - seeking the balance which will provide the greatest good for the greatest number.

A fundamental problem is that in any diverse group of people, there are conflicting visions of the good.

Earlier this year I was asked to classify and summarize submissions to the provincial consultation program on "Meeting Future Energy Needs." One section of the resulting report has been entitled "Values." It is our differing values which lead to different visions of the good. Some submissions to the consultation program stated the values underlying the considerations they thought important. The values included fairness or justice, stability, self-sufficiency and openness. The Municipal Electric Association said,

> "The consistent dominant attitude of the utilities has been centred on the concepts of fairness and sharing. They continue to be the centerpiece of the collective voice of the utilities."

But different groups had different understandings of what fairness required.

The Association of Major Power Consumers in Ontario was concerned with fairness. It said that the association "works towards establishing fair and reasonable electricity rates for the corporations it represents."

The United Church of Canada was particularly concerned with fairness to poor, residential customers and said that "industry and commerce enjoy effective rates which are lower still than *rich* residential customers. This is surely unjust." The United Church said that in response to the increased electricity rates to industry which their understanding of fairness required, companies only had to increase prices. But others disagreed.

The Ontario Mining Association pointed out that one of its members "is the largest individual user of electrical power in Ontario" and that,

> "much of Ontario mineral production is exported with prices being set on world markets that are totally unresponsive to the Canadian domestic scene. As a result, mining companies are unable to control prices and must control costs."

The Ontario Chamber of Commerce was concerned with fair pricing and said,

> "The business community requires assurance that future electricity pricing will also be fair. Proposals have been put forward by some groups that would, in the name of "conservation," severely penalize large and / or new users of electricity. The threat of any such discriminatory pricing policy must be dismissed out of hand. This pricing approach would not promote energy conservation but would accelerate the depletion of fossil fuels and stunt economic growth in the province."

It is easy to see from this that different groups can agree on a general principle such as fairness, yet fail to agree on what it requires in any specific situation.

The implementation of any ethical principle, such as fairness, requires careful balancing of advantage and disadvantage - and I know of no real-life situation where you can have one without the other. It is for this reason that I am uneasy with the application of any single criterion, for even overarching principles can compete with each other.

Even when there is agreement on principles and priorities, decisions can be difficult and agonizing. The submission of the Conference of the United Mennonite Churches of Ontario was particularly sensitive to this difficulty. Their brief discussed social harmony, health, the environment, jobs and costs. They described their underlying beliefs and listed their priorities. These were:

- *Social harmony:* decisions should be such that they foster people living in harmony and peace.
- *Health:* meeting energy needs should contribute to the health needs of all persons.
- *Environment:* any disruption in the environment should be only to the extent it allows ecological systems to function well.
- *Jobs:* if a greater supply of energy creates more jobs, it should do so only if it meets the above criteria first.
- *Cost:* once the above priorities have been taken into consideration, only then is cost relevant. Cheaper energy which violates this will be more expensive in the long run.

A list of principles or priorities, even if agreed upon, does not necessarily make decisions easy. The Mennonite churches said that "their beliefs and priorities do not make it easy to make decisions . . . It will be agonizing and difficult to decide if a particular course of action contributes to these ends, but the process of considering them and the desire to make a right decision will contribute to a better world for all of us."

These quotations illustrate that it is not always easy to know what is required to ensure the greatest good of the greatest number. But what of minorities who sometimes pay more than their fair share towards the good of the majority?

In their submission to the provincial consultation program on "Future Energy Needs" the Foodland Hydro Committee asked questions about the social costs that rural communities bear for the benefit of others. They said:

> "If the rural community seems less willing to accept the debris of the industrial society of which it is a part it may be a reaction to the logic which says 'put the undesirable things where they will affect the least number of people.' This means that the rural community gets the waste dumps, the risky generators, the heavy water plants, the transformer sites, the transmission lines."

It is utilitarian ethics which says put the undesirable things where they will affect the least number of people. What answer would *you* provide to minorities who are disadvantaged for the good of the majority?

Utilitarian ethics, the greatest good of the greatest number, is frequently criticized on the grounds that it ignores minority interests. I think that a greater weighting to minority interests has to be added to utilitarian ethics.

Earlier I referred to ethical concerns that were constrained by the limitation of the effects of human actions to the here and now; situations where the consequences were

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Editor / *Rédacteur*
David Mosey (416) 592-8333

Associate Editors / *Rédacteurs associés*
Hugues Bonin (613) 545-7613
Keith Weaver (416) 592-2456

Production Editor / *Rédacteur, production*
David McArthur (416) 977-6152

severely limited to the locale and time of the action.

The dramatic rise in the consequences of technology since the start of the industrial revolution has changed the locus of the effects of human action. It is a change of rate rather than a change in kind.

The domestication of the camel and the horse, the invention of spur and harness, paddle and sail, all expanded the locus of human action in trade, travel, emigration or conquest. Greatly accelerated advances in technology have greatly increased the locus of the good or bad consequences of human action. The benefits and disbenefits of the application of science and technology go round the world as never before. We can spread the products of our technology around the globe to those who want them, and the waste by-products to those who do not want them. The emissions of industrial wastes from smoke-stacks or effluent pipes know no provincial or national boundaries. Information, rumour, speculation, or propaganda can be beamed around the world at the speed of light.

Our concerns are no longer restricted to the locale of the originating human action. Nor are they restricted to the human time span of the action. As an alternative to dispersing industrial wastes we can concentrate them in densities previously unknown. The treated and concentrated wastes from the production of paint or synthetic rubber tires can take a thousand years to leach from engineered landfills to monitoring wells. The nuclear industry has responsibilities for the storage of dangerous wastes for time-scales greater than the whole of human history. The locus of the consequences of human action is no longer limited to the here and now.

It is for this reason that some have great concern with the consequences of unrestrained technology. It has brought to many, not to all, benefits undreamed of by previous generations. But we do not know what the ultimate consequence of it will be to human beings or to the rest of nature.

This has produced various reactions. There are prophets of doom who are anti-technology. There are others who selectively apply to nuclear technology criteria which could well be applied to all technology. There are yet others, more cautious, who recognize that modern technology constitutes a different scale of human action. Since it affects the whole of nature on this globe for unprecedented time scales they struggle to develop an appropriate ethic which takes this into account. It will be an exceedingly difficult task and I think we may rightly suspect those who provide easy, glib answers. And I include engineers and technologists, with ethicists, reformers, or Utopians; we are all capable of providing glib answers.

The search for an ethic which is appropriate for the present, the near future, and the distant future, requires great openness on the part of all of us. We may disagree with what a social reformer is telling us, but do we listen, so that we understand not only what the reformer is telling us, but why, and what the underlying concern or interest really is? It's not easy. Usually we are preparing our rebuttal before the other person has finished speaking.

We need this greater degree of openness with ourselves and towards others, particularly with regard to far-distant things we do not, and cannot, know with certainty.

We not only need ethical principles for the unprecedented locus and legacy of the consequences of technology, but we need a new process for negotiating agreement on them and, still more difficult, what they will mean in practice. As the Mennonites reminded us, it will be difficult and agonizing to decide if a particular course of action contributes to the good of all, not only here in Ontario over the next 30 years, but around the world in the time-scales now being highlighted by, but by no means restricted to, nuclear technology.

I've raised a *few* questions, and I'm acutely aware that I have provided *no* answers. I've shared my thoughts with you and I have to leave you to provide your own answers or, better still, to develop and participate in processes that will facilitate agreement on answers.

Some of you have responsibilities for forecasting and meeting energy needs here in Ontario for the next thirty years. Some of you are working with the international community in developing energy options, such as fusion, which may be of great importance in the next and succeeding centuries. Others have responsibilities for the consequences of actions taken in the past half-century which will endure for millenia to come.

Tom Dowell

FYI

Uranium Notes — August

(R.T. Whillans)

• Cluff Mining will reportedly spend some $2.6 million to modify its mill at Cluff Lake in northern Saskatchewan and, early in 1987, begin to reprocess its accumulated radioactive wastes to recover gold and uranium.

The radioactive mill residues, containing radium and economic concentrations of gold and uranium, resulted from the processing of high-grade uranium ore during Phase I of the operation. These residues were placed in concrete vaults as an interim measure pending the selection of a final treatment solution.

The plan, approved by the federal Atomic Energy Control Board and Saskatchewan's Department of the Environment, is designed to enhance worker safety and reduce environmental impact, but reportedly could result in a $1 million profit for the company.

Cluff Mining is owned 80 per cent by Amok Ltd. and 20 per cent by Saskatchewan Mining Development Corporation.

• As a result of a lawsuit by the Uranium Producers of America, the United States District Court of Colorado ordered the U.S. Department of Energy (DOE), on June 20, 1986, to restrict the amount of foreign-source uranium enriched in DOE facilities for use by U.S. domestic utilities. The court ruling would limit to 25 per cent the amount of foreign uranium DOE could enrich for domestic use for the remainder of 1986, and thereafter place a ban on the enrichment of all foreign uranium for domestic use, until such time as the viability of the domestic uranium industry is assured. As a result, many non-U.S. producers faced major disruptions of their uranium supply agreements with U.S. customers.

However, on July 21, the Tenth Circuit Court of Appeals in Albuquerque, New Mexico, issued a stay of injunction against the June 20 order and has agreed to hear the case on September 11, 1986. Until the appellate court issues a decision, which could take several months, there will be no change in DOE's operating policy or in the amount of foreign-source uranium enriched for domestic use.

Darlington Goes Ahead, With Safety Review (Ministry of Energy)

The Ontario Cabinet has accepted two major recommendations of the Select Committee on Energy – dealing with the completion of the $11-billion Darlington Nuclear Generating Station, and an independent review of the safety of Ontario's nuclear reactors.

Energy Minister Vincent G. Kerrio announced in August that the Cabinet agreed with the Select Committee's recommendation that "because of Darlington's low incremental cost and the uncertainties associated with other short-term options, all units of Darlington should proceed on schedule."

More than $7-billion has already been committed to the facility, which is slated to come fully on line in 1992.

In making the announcement, Mr. Kerrio noted that the Select Committee's other proposals for change relating to Ontario Hydro are very much in line with the government's direction, which emphasizes energy conservation, efficient use of energy and diversification of the province's energy supply. He also commended the committee for its work over the past year.

Commenting on the nuclear safety review, the minister pointed out that two previous reviews in Ontario – one in 1978 by the Royal Commission on Electric Power Planning, and another in 1980 by a previous Select Committee on Ontario Hydro Affairs – found the CANDU system used in Ontario to be acceptably safe.

"We have great confidence in the CANDU reactors used by Ontario Hydro. The system has proven itself to be safe, reliable and efficient," he said.

At the same time, the minister noted that Ontario will never become complacent. "I believe we should always be looking for ways to make an excellent system even better."

In its report the Select Committee recommended that "The Minister of Energy should appoint an independent panel of internationally-recognized experts to review, on a priority basis, the safety of the design, operating procedures and emergency plans associated with Ontario Hydro's CANDU nuclear generating plants. This panel should prepare a report to the Minister which should also be made available to the Members of the Legislature." The government has accepted this recommendation of the committee.

"I have discussed the possibility of a review with the federal minister, Mr. Masse, who has offered the full co-operation of the federal agencies concerned with nuclear safety," Mr. Kerrio added.

The members of the review panel and its terms of reference will be announced this fall.

Mr. Kerrio noted that the government would be responding soon to the other recommendations of the Select Committee. The issues dealt with include promotion of electricity conservation, electricity planning, rate regulation, and the overall relationship between the provincial government and Ontario Hydro.

Bruce-2 Restarts (AECB)

Unit 2 at Bruce Nuclear Generating Station A has been restarted, after the Atomic Energy Control Board announced that approval has been granted for the resumption of operation at normal power levels of the reactor. The unit was shut down in March for replacement of a failed pressure tube and recovery of fuel.

Permission was granted following a thorough review of the results of examinations of the failed tube, and inspections of the reactor vessel and a number of pressure tubes having a similar fabrication history to the failed one. Ontario Hydro has also undertaken to conduct an intensified inspection program on pressure tubes, not only in unit 2, but also in the other three reactors of the Bruce A station. While accepting the general terms of the undertaking, the AECB has ordered that further inspections of tubes in unit 2 be completed on an earlier schedule than that proposed by Ontario Hydro.

C-E Wins Korea Contract (Staff)

Combustion-Engineering Inc. of Connecticut has won a contract to supply two pressurized light-water reactors to Korea Electric Power Corp. of South Korea. C-E won out over 13 bidders, including Atomic Energy of Canada Ltd. to supply South Korea's 10th and 11th reactors. Sargent and Lundy will provide design engineering and project management services while General Electric Co. will supply turbines.

Iodine Pills to be Distributed to Nuclear Plant Areas in Ontario (Staff)

Ontario policy recently approved by the cabinet now allows municipalities around the Pickering, Bruce and Darlington nuclear power plants to pre-distribute potassium iodide (KI) pills to residents and workers in the areas. The pre-distribution would be performed where post-emergency distribution to people within three kilometres of the plant, and within four hours, wasn't feasible. The pills would block the uptake of radioactive iodine to the thyroid gland in the event of a major radiation release, however, some people, particularly children, may be allergic to iodine and should not use it.

OECD Nuclear Generation Increases (OECD NEA)

Nuclear electricity production in the OECD countries grew at a rate of 19.2 per cent in 1985, the largest rate of increase since 1977, according to an annual survey just completed by the Nuclear Energy Agency.

All but one of the 13 OECD countries with nuclear programs increased their nuclear electricity generation in 1985. Five countries reported a more than 20 per cent increase, i.e., Belgium, the Federal Republic of Germany, Japan, Spain and Switzerland.

Electricity generation during the twelve month period rose by 3.1 per cent, from 5382 terrawatt hours (TWh) to 5550 TWh. The share of total OECD electricity generation met by nuclear power increased from 18 per cent to 21 per cent. Nuclear is now the second largest contributor to electricity generation in OECD after coal (42%) and is ahead of major renewable sources - hydro plus geothermal - (20%) and of oil and gas combined (17%). The nuclear contribution was over 50 per cent of the total electricity generation in two OECD countries, France (65%) and Belgium (60%).

Total installed nuclear capacity in the OECD area reached 207 gigawatts (GWe) at the end of 1985, an increase of 15 per cent.

CAN-DECON Cleared By Latest Tests (Nucleonics Week)

London Nuclear Services Inc. has lifted self-imposed restrictions placed on the use of CAN-DECON one year ago because new test results show that the decontamination solution does not contribute to intergranular stress corrosion cracking (IGSCC). The tests were performed by London Nuclear, the Electric Power Research Institute (EPRI), Atomic Energy of Canada Ltd., the Ontario Research Foundation and General Electric and presented at the last meeting of the BWR Owners Group.

"For a time, utilities were somewhat reluctant to use the process, even though they had used it before . . . CAN-DECON has always been safe (and) we can show that even under extreme conditions the solution will not produce (IGSCC)," said Eric LeSurf, President of London Nuclear.

Laboratory tests in 1984 suggested otherwise.

LeSurf said that the company and EPRI did not initially realize that the ferric ions produced when CAN-DECON is flushed through an irradiated system react with chemicals in the solution to form a crack inhibitor. "That's why in practice we don't see any (IGSCC) because any irradiated system will produce the ferric ions," he said, adding that the 1984 tests did not add ferric ions. London Nuclear will monitor ferric ion levels in all future decontamination projects and, if necessary, add more to the solution to ensure crack inhibition.

New Democrats Launch Post-Chernobyl Nuclear Inquiry (NDP)

The federal New Democratic Party launched a public inquiry into the question of nuclear energy in Canada in July. Called "What Ordinary Canadians Think of Nuclear Energy," the inquiry will be co-chaired by environment critic Bill Blaikie and energy critic Ian Waddell. Other New Democrats, both federal and provincial, will also participate in the inquiry.

"The disaster at the Chernobyl nuclear reactor has focussed public attention on the serious risks involved in the nuclear option and has prompted many Canadians to take a more critical look at nuclear energy," said Blaikie.

The inquiry will be the first of its kind at the national level. It will investigate, among other things, reactor safety, the cost of nuclear power, uranium mining, the disposal of wastes, international sales, nuclear proliferation and alternatives to nuclear power.

De-Voe Holbein Launch Decontamination Process (Nuclear Engineering International)

A new system to extract radioactive metals from waste water and effluents has been launched by DeVoe-Holbein of Canada.

The "Vitrokele" system was discovered by Dr. Irving DeVoe and Dr. Bruce Holbein after studies of natural metal-carrying molecules in cells. It consists of synthetic immobilized chelating compounds.

Vitrokele compositions have been field tested for cobalt-60 uptake at a U.S. nuclear plant in conjunction with Chem Nuclear. They were superior to commercially available ion exchangers, according to DeVoe-Holbein.

Through a contract with West Valley Nuclear of the United States, DeVoe-Holbein developed compositions to capture cesium-137, strontium-90, and trace amounts of plutonium from reprocessing liquors.

Another composition was shown to be capable of removing strontium-90 from spent, stored ion exchangers that have undergone degradation due to high radiation fields.

DeVoe-Holbein compositions are also under evaluation by British Nuclear Fuels.

THE CHEMISTRY OF IODINE

J. Paquette and W.C.H. Kupferschmidt

Research Chemistry Branch
Atomic Energy of Canada Limited
Whiteshell Nuclear Research Establishment
Pinawa, Manitoba, Canada R0E 1L0

INTRODUCTION

Radioactive material could be released to the environment following a severe nuclear reactor accident in which fuel failure occurs. Of all the fission products that can escape from irradiated nuclear fuel, iodine has been considered in the past as being the most important one. This is due not only to a combination of inventory and half-life, but also to the biological activity of iodine and to its potential volatility which could make it difficult to contain. As a result, reactor licensing, safety systems design and operation, as well as emergency planning regulations, are often based on conservative assumptions regarding the amount and chemical form of radioactive iodine that could be freed in a serious reactor accident. One of these assumptions is that a large fraction of the iodine released from defected nuclear fuel would become airborne in the containment building and be readily available for release to the environment.

In March 1979, unit 2 at Three Mile Island, a 900 MW(e) pressurized water reactor, suffered a partially mitigated loss-of-coolant accident, which eventually led to severe core damage. Extensive fission-product release occurred, and about 40% of the radioiodine present in the reactor core was dispersed in the containment and auxiliary buildings. One of the most important features of the accident was the very low concentration of iodine found subsequently in the atmosphere of the containment building. This suggested that the assumptions concerning the chemical behaviour of iodine following a nuclear accident could have been overly conservative. An extensive effort to obtain a better understanding of the behaviour of iodine following severe reactor accidents was initiated by many countries, including Canada. The important question was whether or not the behaviour of iodine at Three Mile Island—2 was typical of reactor accident situations or was due to some local peculiarities. The answers could have an important impact on the regulatory and safety requirements for water-cooled nuclear reactors.

We summarize below the research on iodine chemistry performed at the Whiteshell Nuclear Research Establishment (WNRE) of Atomic Energy of Canada Limited (AECL) over the last few years. Most of this research was performed as part of a cooperative development program (COG-CANDEV) between AECL and the electrical utilities. The approach has been to try to understand in detail the chemistry of iodine in the primary heat transport system and in the containment building of the CANDU reactor, to formulate realistic codes to predict the concentration and speciation of iodine as a function of time, and thereby to estimate the radiological consequences of various postulated reactor accidents. Research into various aspects of iodine release from nuclear fuel at high temperatures is performed at the Chalk River Nuclear Laboratories of AECL and will not be described here.

IODINE CHEMISTRY IN THE PRIMARY HEAT TRANSPORT SYSTEM

The transport of iodine into and outside the containment building following fuel failures depends on the speciation of iodine in the primary heat transport system. This in turn can be influenced by the chemistry of iodine in UO_2 fuel.

Iodine isotopes in fuel are formed mostly by the beta decay of tellurium isotopes, except for ^{135}I, which is also formed directly by fission. The iodine so produced is initially trapped within the UO_2 lattice as an impurity atom or ion. Due to thermal motion, iodine ions or atoms will migrate and accumulate in voids, at grain boundaries and in the region between the external fuel surface and the internal cladding surface. There, iodine atoms or ions are free to interact with other fission products. This amount of iodine is collectively known as the gap inventory. The current understanding is that iodine that has escaped the UO_2 lattice combines with the fission product cesium to form CsI. This is based on calculations [1] and on experimental evidence [2–4]. Should failure of the cladding occur, the gap inventory of iodine will be immediately released, very likely as cesium iodide. In a severe accident, the increasing temperature of the fuel will cause additional release of iodine, cesium and other fission products from the UO_2 crystal lattice. Due to the high temperature, these will be released as atoms and the rate of release will be controlled by diffusion.

Thermodynamics

The speciation of iodine in the primary heat transport system following its release from fuel can be calculated using the principles of chemical thermodynamics. The equilibrium speciation in the system Cs-I-O-H has been calculated at WNRE using available thermodynamic data [5]. These calculations indicate that, in a high temperature steam-hydrogen atmosphere CsI is the dominant stable species at lower temperatures, whereas at higher temperatures CsI is less stable and HI becomes more important. The relative stability of CsI and the temperature at which the changeover to HI occurs depend on a number of factors including the total pressure, the iodine concentration, the Cs/I ratio, and the H/O ratio. This is illustrated in Figure 1. The factors that favour the stability of CsI are a high iodine concentration and high Cs/I and H/O ratios. Since the Cs/I ratio is about 10 in fuel, and both cesium and iodine are released at similar rate from overheated UO_2, CsI formation would be favoured in most accident conditions. The exception would be an accident in which large amounts of oxygen would be present in the primary system. This is an unlikely situation since zirconium cladding reacts with steam at high temperature to produce hydrogen.

Kinetics

Although the formation of CsI in the reactor coolant system is thermodynamically favoured, it is not assured unless it is also kinetically allowed. This is true in a steam environment, because most of the cesium atoms released from fuel could initially be scavenged by steam according to the reaction

(1) $$Cs + H_2O \rightarrow CsOH + H$$

Subsequent reactions of CsOH with iodine atoms to form CsI would have to be fast to ensure CsI formation. Also, radiation effects in the gas phase could upset the equilibrium.

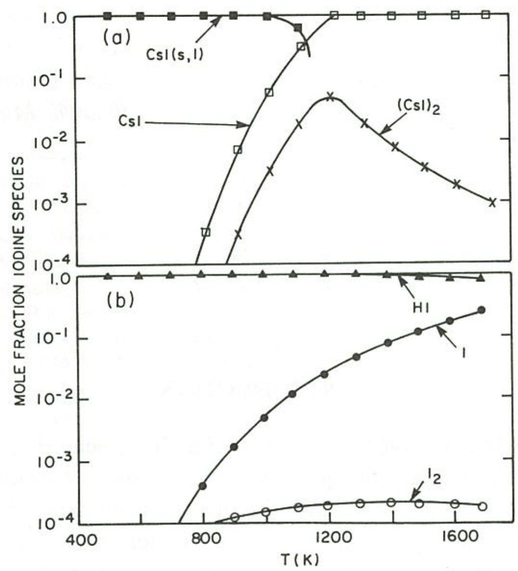

Figure 1:
Iodine species distribution at equilibrium as a function of temperature for a system at 1.2 MPa containing 4 moles of steam, 10^{-2} mole of iodine and:
a) 0.1 mole of cesium or
b) 2.5 moles of hydrogen
All species are gaseous except CsI which is either solid or liquid.

To evaluate if equilibrium can be achieved rapidly under these conditions, we have calculated the speciation of iodine in the primary heat transport system as a function of time using a chemical kinetic model [6]. The model was based on elementary reactions involving the major gas-phase reactions and radicals in the Cs-I-O-H system. In all cases, for temperatures above 1000°K, the system reached equilibrium in less than 0.1 second. The worst chemical scenario for an accident is a situation where all the cesium is released and reacts with steam to form CsOH before any iodine release occurs. Figure 2 shows that even under these conditions, the system reaches equilibrium in less than 0.01 second. Radiation was found to have only a minor effect on the system.

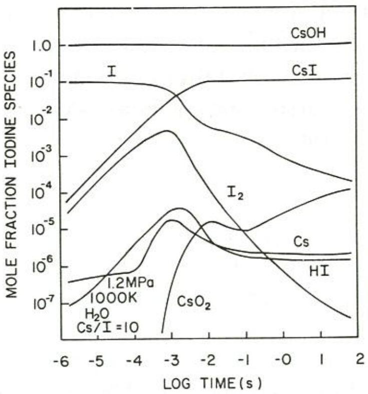

Figure 2:
Concentrations of iodine and cesium species as a function of time after releasing CsOH and I (CsOH / I = 10) into a steam atmosphere at 1.2 MPa and 1000° K.

The general conclusion from these calculations is that thermodynamic calculations are an accurate tool for predicting gas-phase iodine speciation in the primary heat transport system under accident conditions if the temperature is above about 1000°K.

In addition to steam, hydrogen and oxygen, the fission products leaving irradiated fuel can be exposed to various components of the heat transport system such as zirconium and steel surfaces. Although it is unlikely that interaction with these materials would lead to decomposition of CsI and formation of I_2, experiments are being conducted at WNRE to examine the fate of CsI vapour in contact with steel at about 900°K and in the presence of a strong radiation field [7].

IODINE CHEMISTRY IN THE CONTAINMENT BUILDING

Most severe accidents are expected to result in the release of large quantities of water (or heavy water) to the containment building. Both cesium iodide and hydrogen iodide are very soluble in water where they instantly dissociate to yield the iodide ion, I^-. Thus the near- and long-term contributions to the iodine source term will depend on the behaviour of iodine in aqueous systems. To address this, we have performed thermodynamic calculations on the speciation of iodine in aqueous environments and have studied the kinetics of some key iodine reactions. We have also examined various reaction paths that could lead to the formation of volatile organic iodides and have investigated the effect of evaporating small drops and of radiation on the volatility of iodine.

Thermodynamics

A thermodynamic database containing the most reliable available values for the Gibbs energies of formation in the iodine/water system has been compiled and used to determine the equilibrium speciation of iodine in the aqueous and gaseous phases of a containment building [8]. Experiments have also been carried out to improve the accuracy of some of the key thermodynamic data, especially for the higher temperatures. As an example, heat capacity data have been measured as a function of temperature for aqueous solutions of various iodide and iodate salts. This has allowed the calculation of highly accurate values for the Gibbs energy of formation of the iodide and iodate ions in the temperature range 298° to 573°K [9]. Also, an upper limit of 10^4 was obtained for the $HOI_{(aq)}/HOI_{(g)}$ partition coefficient using mass spectrometry to analyze the gas phase [10].

The thermodynamic analysis shows that, at equilibrium and at the low total iodine concentrations typical of reactor accident situations ($<10^{-5}$ mol.dm^{-3}), the predominant iodine species in solution are the iodide (I^-) and the iodate (IO_3^-) ions, both of which are nonvolatile. Only for very acidic oxidizing conditions would potentially volatile species (I_2, HOI) be important. Thus, the natural tendency of the system favours low iodine volatility under chemical conditions typical of reactor accidents.

Kinetics

Although thermodynamic calculations can provide a detailed picture of the iodine/water chemical system at equilibrium, such calculations provide no information on the concentration of the various species prior to equilibrium; the time-dependent behaviour of the system depends on the kinetics of the individual chemical reactions.

As discussed in the previous section, iodine is expected to be released to the containment building as CsI which will dissociate into its constituting ions on contacting water. The iodide ion in itself is nonvolatile and nonreactive. It has to be oxidized in order for any reaction leading to potentially volatile species to occur. The various reaction pathways available to iodine in solution are summarized in Figure 3. It is only the I^- that is oxidized to more reactive and volatile species that can contribute to iodine volatility.

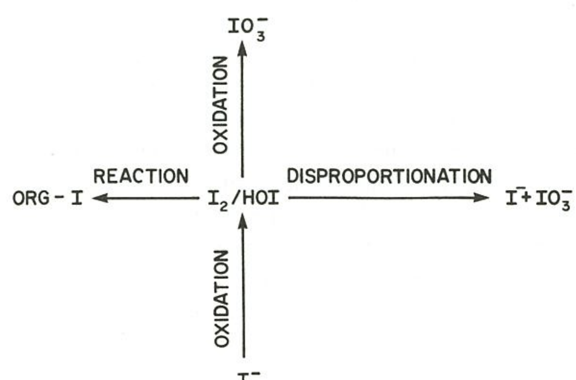

Figure 3:
The various reaction channels available to iodine in solution if it is initially present as the iodide ion.

Dissolved atmospheric oxygen is likely to be the major oxidizing agent in the containment building water. One of the most important reaction sequences in that context is the direct oxidation of the iodide ion by dissolved oxygen,

(2) $$2I^- + 2H^+ + \frac{1}{2}O_2 \rightarrow I_2 + H_2O,$$

followed by the hydrolysis equilibrium

(3) $$I_2 + H_2O \longleftrightarrow HOI + I^- + H^+.$$

Reaction (3) is established rapidly and I_2, HOI and I^- are always at equilibrium. The kinetics of reaction (2) have been examined in the past [11] and again more recently [12]. The reaction is very slow near neutral pH even at 300°C.

In a loss-of-coolant type of accident, water containing fission products could be released to the containment building as a fine mist or a fog comprised of small-diameter droplets. To ascertain that iodide would not be rapidly oxidized when these droplets evaporate and to verify that no unexpected chemical reaction would occur on evaporation, experiments involving the rapid evaporation of a mist made with cesium and potassium iodide solutions were performed [13]. The gas phase was analyzed in situ using a mass spectrometer. No unexpected oxidation occurred; only a very small amount of I_2 was found in the gas phase.

After some I^- has been oxidized to I_2 and HOI, there will be competition between disproportionation to nonvolatile species and formation of volatile inorganic iodides, as indicated on Figure 3. The concentration and nature of iodine species in solution as a function of time will depend on the relative rates of the reactions shown in Figure 3.

A kinetically important reaction is the disproportionation of iodine:

(4) $$3I_2 + 3H_2O \rightarrow 5I^- + IO_3^- + 6H^+.$$

This reaction is important since it involves the conversion of a volatile and reactive species into nonvolatile, nonreactive species. The kinetics of reaction (4) had not previously been investigated systematically. For these reasons we have studied the disproportionation in detail [14—17]. We have identified unambiguously the reaction intermediates using electrochemical techniques, uv-visible spectrophotometry and Raman spectroscopy. These studies have revealed that the reaction is in fact a reaction of the +1 oxidation-state species HOI:

(5) $$3HOI \rightarrow 2I^- + IO_3^- + 3H^+.$$

It is second order in HOI and involves the +3 oxidation-state species HIO_2 as an intermediate. The reaction is slow near neutral pH and for low concentrations, which means that HOI could accumulate in solution and be available for reaction with organic impurities.

Organic Iodides

One of the most perplexing aspects of the behaviour of iodine following reactor accidents, or in large scale tests simulating accidents, is the formation of volatile organic iodides. Various mechanisms have been proposed to explain the formation of these compounds. Mechanisms involving radiation effects, gas-phase reactions and surface-catalyzed reactions have been considered. We have recently reviewed this topic in detail [18].

Since most of the iodine is expected to be in solution following a reactor accident, it is worth examining the possible mechanisms for organic iodide formation in water containing iodine species and organic impurities. Iodination of these impurities can proceed rapidly and could be a major source of airborne organic iodides. For instance, we have observed a variety of volatile organic iodides emanating from samples of reactor sump water containing I^- when the latter was oxidized to HOI [13].

To shed some light on the mechanism of such reactions, we have studied the iodination of phenol using a flow system and uv-visible spectrophotometry [19]. We have demonstrated that the reactive species in the formation of iodophenol is HOI and not I_2. The reaction between HOI and phenol is very rapid and is controlled solely by diffusion.

Organic iodides are thermodynamically unstable in water. They are decomposed by reaction with water and hydroxyl ions (hydrolysis), and by interaction with light (photolysis). It is as important to know the rate of destruction of organic iodides as it is to know their rate of formation. For these reasons we have initiated an experimental program to study the rates of hydrolysis and photolysis for these compounds.

Radiation Effects

High radiation fields can be present in a containment building following a severe nuclear reactor accident. Radiation-induced reactions can have an important impact on the interconversion of aqueous iodine species and must be considered for a complete description of the system.

The radiolysis of iodine solutions has been studied extensively over the last twenty years, and the radiation-induced interconversion between I^- and I_2 is relatively well understood [20]. Recently, good progress has been made toward understanding the radiation chemistry of iodine in higher oxidation states [21]. Following a reactor accident in which fuel failures occur, it is likely that the containment building water would contain substantial amounts of various dissolved ions, organic contaminants, particulate matter and debris. The role of these extraneous materials in influencing the radiation chemistry of iodine is not well known. A comprehensive experimental program has been initiated at WNRE to examine the effects of various impurities on the radiation-induced volatility of iodine. As an example, it was found that colloidal iron oxides have very little effect on the radiolytic oxidation of I^- to I_2, whereas hydrazine can be quite effective in suppressing the radiolytic oxidation by rapidly reducing back to I^- any radiolytically-produced I_2.

Trace amounts of organic material dissolved in the containment water will also be affected by radiation. This could potentially lead to the formation of organic iodides according to the general reaction scheme

(6) $$RH + \text{radical} \longrightarrow \cdot R + \text{H-radical}$$

(7) $$\cdot R + \text{I-compound} \longrightarrow RI + \cdot\text{compound} .$$

For instance, we have observed the formation of methyl iodide in irradiated solutions containing I^- and methane (CH_4) as the starting material. Even more methyl iodide was obtained by irradiating solutions containing iodate (IO_3^-) and methane. This shows clearly that radiation-induced reactions between organic impurities and iodine species can be a major source of volatile organic iodides and deserve careful study.

Once formed, either by chemical or radiation-induced reactions, organic iodides will be subjected to radiolysis, in addition to hydrolysis and photolysis. Again it is important to understand how organic iodides are destroyed by radiation in order to model their behaviour accurately.

Gas Phase Abatement

Reactor containment buildings contain engineered systems to remove radioiodine from their atmosphere, should it be required. The performance of these systems under reactor accident situations is of prime importance. The most common of these systems is a charcoal bed which removes iodinated compounds by adsorption onto activated charcoal impregnated with chemicals. The performance of these charcoals under chemical conditions typical of reactor accidents has been studied in detail at WNRE [22]. The effects of steam, hydrogen, radiation and of potential poisons on the removal efficiency of various charcoals for methyl iodide have been investigated. A modified gas chromatography theory has been used successfully to model the sorption and desorption of organic iodides. The theory can be used to predict the performance of a charcoal bed of a given depth.

Although charcoal beds are highly effective at removing radioiodines from the gas phase, they present some disadvantages. They can potentially be a source of organic iodides and they can be rendered ineffective through poisoning by various gaseous chemicals. For these reasons, research on advanced abatement techniques for radioiodine has been underway at WNRE for a number of years. Two promising techniques appear to be corona scrubbing and photochemical abatement. The corona scrubbing technique is based on reacting iodinated compounds in a corona discharge to form solid iodine oxides [23]. The photochemical abatement technique consists of decomposing iodinated compounds by reaction with light and ozone, resulting also in production of solid iodine oxides [24]. These techniques have been or are being tested at the pilot-level scale.

It is also important to ascertain if there is any gas phase reaction that could affect the behaviour of iodine. Interactions between various iodine species is unlikely in the gas phase. Direct formation of organic iodides in the gas phase by either chemical or radiation-induced reactions is also unlikely; radiation-induced reactions are more effective in the liquid state. Some reactions could occur at surfaces and this merits investigation. Direct radiolytic destruction of iodinated compounds in the gas phase is expected to be less effective than in solution. However indirect radiation effects can be important.

In most postulated nuclear reactor accidents, the containment building air would be subjected to high radiation doses, due mostly to the presence of radioactive noble gases. Irradiation of air can produce a substantial amount of ozone which is known to react rapidly with I_2 in the gas phase to form iodine oxides that, in contact with water, decompose to IO_3^- [25,26]. Thus, low concentrations of ozone generated by the radiolysis of oxygen in post-accident atmospheres could serve as a built-in chemical sink to attenuate the airborne radioiodine concentrations [27]. Clearly this deserves further study.

Modelling

One of the aims of the iodine research program is to develop a realistic model that would predict the concentration and speciation of iodine as a function of time and thereby help to estimate the radiological consequences of various postulated reactor accidents. A preliminary kinetic model of aqueous iodine chemistry and partitioning into the gas phase has been assembled [28].

The model is a detailed mechanistic one based on chemical kinetics. It includes the aqueous inorganic chemistry of iodine, the chemistry of hydrazine, the radiation chemistry of water and of iodine, as well as a mass transfer section. By far the most complex part is the section dealing with radiation chemistry. The model has been used to calculate the partition coefficient of iodine as a function of several important parameters, including the presence of a radiation field. These calculations have confirmed that, according to our current understanding, most of the iodine present in the gas phase following a severe reactor accident would be existing as organic iodides. These would originate from chemical reactions with organic impurities as well as from radiation-induced reactions. The calculations also indicate that hydrazine could be quite effective in suppressing iodine volatility.

The model is being updated to include the latest experimental results and to take uncertainties into account. Many of the rate constants available bear a large uncertainty often due to the inability to fully take into account possible catalytic effects. Also, there is only limited information on the nature of organic impurities likely to be present in the containment water during an accident. A sensitivity analysis will be performed to ascertain the effects of these uncertainties and to simplify the model by eliminating reactions to which the system is not sensitive. The model will be validated by comparison with experimental results from bench-scale experiments and with results from experiments in a semi-scale test facility, the Radioiodine Test Facility.

THE RADIOIODINE TEST FACILITY

The ultimate goal of the iodine volatility model, and of our study of the chemistry of iodine, is to predict the airborne radioiodine concentration in an actual reactor accident. Of course, validation of the model is difficult owing to the very rare occurrence of such an event. As a result, it was decided to construct a new semi-scale research installation at WNRE, the Radioiodine Test Facility (RTF). This facility will enable iodine partitioning and speciation to be measured under conditions simulating, as closely as possible, various postulated reactor accidents. In this way, we hope to verify our existing iodine volatility model and, if necessary, to refine it to account for new results obtained from the RTF experimental program.

Description of the RTF

The basic design of the RTF is shown in Figure 4. The facility consists of a series of gas and liquid recirculation loops and three vessels: a 1000-dm^3 Chemical Spray Solution Vessel which is used to clean the facility between tests, a 100-dm^3 Mixing Vessel and a 400-dm^3 Main Vessel. The test solution will be initially prepared in the Mixing Vessel by the addition of appropriate quantities of water and other reagents needed to achieve the desired water chemistry conditions (pH, redox potential, etc.). The solution will then be heated to the required temperature ($\leq$ 80° C) and the desired form of iodine will be added. Iodine-131 will also be added at the tracer level to facilitate the monitoring of iodine distribution between the aqueous and gaseous phases. The test solution will then be delivered to the Main Vessel, initiating the experiment.

The Main Vessel has been designed to simulate a reactor containment building as much as possible. Because the vessel is lead-shielded, radiation dose rates of up to 10 $kGy \cdot h^{-1}$ can be used in the RTF, thereby simulating the radiation fields expected in a containment building shortly after a severe accident. Since radiation effects are thought to be one of the dominant factors affecting iodine volatility, this is a very important feature of the facility. In addition, containment temperatures can be simulated since temperatures of up to (80°C) can be maintained in the RTF. Provisions have also been made for studying surface effects by using replaceable inner liners made of different materials. As previously noted, iodine distribution and speciation can be affected by reactions at surfaces.

Each of the RTF gas and liquid loops serves a special purpose. The Aqueous Recirculation Loop enables the effects of mixing and turbulence in the aqueous phase to be ascertained. Since the aqueous phase can be optionally returned to the Main Vessel via a spray header, the effectiveness of sprays for airborne iodine removal can be tested as well. The Aqueous Sampling Loop allows for collection of samples for remote analysis and, more importantly, incorporates pH, redox potential and dissolved oxygen sensors in addition to a rapid-scanning fiber-optic ultraviolet-visible spectrophotometer. This on-line instrumentation facilitates detection of any changes in water chemistry conditions during the course of each test.

The Gas Recirculation Loop, in addition to providing variable mixing of the air in the Main Vessel, serves to maintain safe levels of H_2, which is produced by water radiolysis. This is done using an on-line hydrogen detector and a hydrogen recombiner. This loop also possesses a cooler to determine the effect of changes in the gas phase temperature. The Gas Ventilation Loop enables iodine re-evolution rates to be measured. In some studies, the gas phase will be passed through an on-line charcoal filter which will remove all of the airborne iodine. The rate at which iodine is subsequently released from the aqueous phase to the gas phase will then be determined.

The Gas Sampling Line is used to measure the concentration of airborne iodine in the Main Vessel. Gas samples drawn from the Main Vessel can be passed through an automated air sampler which traps the airborne iodine by deposition onto charcoal-containing cartridges. The trapped iodine-131 is then measured using a γ-counting system. Also incorporated onto this loop is a gas chromatograph which will help to determine the speciation of the volatile iodines.

In addition to the instruments already described, the

RTF is equipped with liquid and gas flow meters, numerous temperature sensors and pressure and level monitoring devices. A Programmable Logic Controller is used to regulate the pumps and valves while a real-time data acquisition system is used for collection of data from the many sensors installed onto this facility.

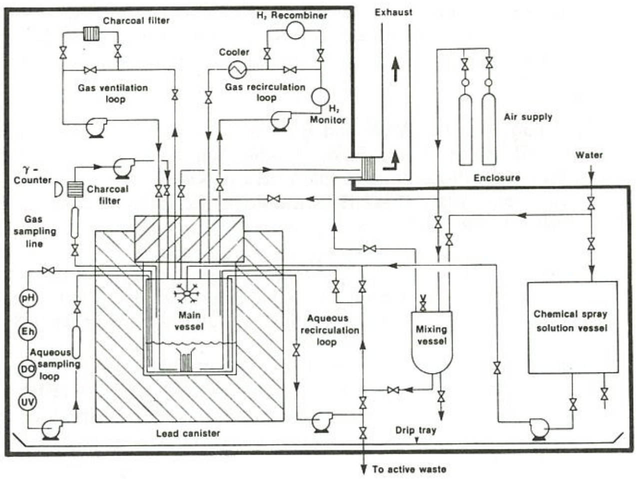

Figure 4:
A schematic diagram of the Radioiodine Test Facility.

RTF Experimental Program

As has been already noted, numerous factors can dramatically affect iodine volatility in a containment building after an accident. Many of these are chemistry-related including parameters such as pH, redox potential and dissolved oxygen concentration, temperature, the concentration and chemical form of the iodine, inorganic and organic impurities in the aqueous phase, and, of course, the radiation dose. These factors have been studied extensively in bench-scale experiments. There are, in addition, other less-studied variables that could potentially influence the volatility of iodine. These include variables such as surface-to-volume ratio, venting rates, gas and liquid recirculation rates, the nature of the liner materials (concrete or various steels) and their surface coating (uncoated or painted), and the use of sprays. The RTF has been designed such that these and other chemistry- and engineering-related variables can be simultaneously studied in a series of semi-scale integrated tests. These tests are part of a four-year experimental program which is scheduled to commence in April 1987.

The initial tests to be undertaken in the RTF will be conducted in the absence of a radiation source. In this way, that portion of the iodine volatility model not pertaining to radiation chemistry can be tested. This will also provide an opportunity to ascertain the effect of many of the engineering variables. These are not presently incorporated into our model. This investigation may result in the need to refine the model to include some or all of these additional variables.

Subsequent tests will utilize a radiation source, thereby providing data to test the entire iodine volatility model. Two sets of cobalt-60 sources will be employed, providing 0.1 and 10 $kGy \cdot h^{-1}$ dose rates. It will also be possible to determine whether, as we believe, the radiation-induced aqueous phase reactions affecting iodine volatility are more important than the corresponding reactions in the gaseous phase. This is possible since the irradiation sources can be placed in either phase.

The studies outlined above will be conducted in zinc primer coated steel vessels since a large fraction of the exposed surface in a CANDU™ reactor containment is of this type. Subsequent studies will test the effect on iodine volatility of other surfaces, such as unpainted steel and steel with other coatings, and painted and unpainted concrete. This will provide valuable data that can be used to refine our existing model to account for reactions at different surfaces that may produce volatile iodine species.

In addition to providing early integral data that can be immediately used in radiological evaluations, the RTF experimental program will undoubtedly produce some unexpected results that will identify parameters requiring further investigation at the bench-scale or fundamental level. Nevertheless, it is anticipated that at the conclusion of the Radioiodine Test Facility experimental program, the behaviour of iodine in containment will be better understood as a result of these semi-scale integrated tests.

CONCLUSION

There has been considerable progress over the last few years in our understanding of the many factors determining the behaviour of iodine in reactor accidents. This has been possible because of a concerted effort in Canada and other countries to investigate in detail the chemistry of iodine. Our current understanding is that the iodine gap inventory in fuel is in the form of CsI. Upon cladding rupture, this CsI will immediately be released to the primary heat transport system where, under most accident conditions, it is the thermodynamically and kinetically stable form of iodine.

In most severe accidents, large amounts of water would also be released, making the behaviour of iodine in water very important. Thermodynamic considerations have shown that, in the containment building, equilibrium would favour low volatility. Kinetic studies have indicated that the behaviour of the system is controlled by kinetic factors, if the iodide ion is the initial chemical form of iodine. The oxidation of the iodide ion by dissolved oxygen and by radiation is then the rate-determining step in the formation of volatile iodine species.

This work, which includes studies into both the inorganic and organic chemistry of iodine, hydrazine chemistry and radiation chemistry, has resulted in the development of a detailed kinetic model that predicts the partition coefficient of iodine as a function of time. Interestingly, this model predicts that most of the iodine present in the gas phase will be present as organic iodides, in agreement with findings at the Three Mile Island-2 reactor.

A new research installation, the Radioiodine Test Facility, is presently under construction at WNRE. Semi-scale integrated tests will be undertaken in this facility which will be used to simulate, as closely as possible, a reactor containment under various accident conditions. The data obtained during the planned four-year experimental program will be used to refine the current iodine volatility model.

ACKNOWLEDGEMENT

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CNS News

CNS Annual Conference — Session Reports

The following are the available reports by CNS session chairmen on papers presented at the CNS Annual Conference, June 1986. Proceedings are due to be published this Fall.

Fuel and Fuel Channel Materials

Six papers were presented in session A, four dealing principally with fuel, and two principally with pressure tubes. All papers were well attended, with audience size ranging from 45 to 20 persons, and with a total of 25 questions being asked. The fuel papers ranged from a description of the fuel performance data base required to support the use of slightly enriched uranium (SEU) fuel in CANDU reactors, through a description of a new stress analysis code for fuel assemblies, the metallographic examination of a fuel bundle subjected to the temperatures associated with postulated severe accidents, to the tomographic examination of experimental fuel subjected to severe accident conditions. The two papers on pressure tube technology dealt with measured elongation rates in CANDU pressure tubes, and the development of failure maps to assess pressure tube integrity during postulated accident scenarios.

Glen MacGillivray's presentation on the performance data base required for SEU fuel use showed that there is in existence a significant data base to support satisfactory behaviour to burnups over twice that from natural fuel, but that a large scale demonstration would be required. Glen works in the Fuel Materials Branch of AECL at Chalk River.

Mac Tyall's presentation on the newly-developed "FEAST" code for finite element stress analysis in fuel elements, described an efficient code for calculating stresses, strains and displacements in fuel elements, and presented the results of a number of sample applications. The code is sufficiently general that it can be used in other applications as well. Mac works in the Fuel Engineering Branch at AECL-CANDU Operations in Mississauga.

Cliff Poidevin made a very informative presentation on pressure tube elongation rates based on data from measurements made on pressure tubes in the Pickering and Bruce reactors. As the data show differences in elongation rates for different reactors, and for different locations in a given reactor, the results are reported in elongation per unit fluence to allow comparability. A general conclusion is that temperature has greater impact on the rate of growth than does flux level. Cliff is a Supervising Design Engineer in Reactor Development at Ontario Hydro.

Prabhu Kundurpi's presentation on the development of failure maps for assessing the integrity of pressure tubes during postulated accident scenarios identified internal pressure, the extent of the hot region and the rate of temperature rise as the major factors influencing pressure tube deformation. The results of a series of sensitivity studies were shown. Dr. Kundurpi works in the Nuclear Studies and Safety Department of Ontario Hydro.

Dr. R. Choubey presented a paper on the metallographic examination of CANDU fuel bundles that had been heated to 1,900°C by an oxygen torch in a steam atmosphere to simulate severe accident conditions in a CANDU fuel channel. Numerous macrographs were presented showing the extent of mechanical slumping, melting and interaction between the UO_2 and Zircaloy, and concluded that Zr/UO_2 interaction would be minimized at slow heat-up rates due to cladding oxidation. Dr. Choubey works in the High Temperature Chemistry branch of AECL at Whiteshell.

Lawrence Lupton's presentation on the conceptual design of a tomography facility for irradiated fuels identified the need for a non-destructive, post-irradiation facility to investigate the distortion and distribution of previously molten materials in experimental fuel assemblies subjected to severe accident conditions. He illustrated the ability of gamma ray tomography to do this through a series of proof-of-principle scans through distorted fuel bundles. Lawrence Lupton works in the Radiation Engineering Branch of AECL at Chalk River.

Alan Lane

Fusion Sessions

The fusion sessions generated significant interest, with attendance varying from a minimum of about 20 to a maximum of about 45. Of most interest were the more general papers such as "Update on the Tokamak de Varennes" and "Critical Safety Issues." Of less interest were the more theoretical and physics papers such as "The Potential in Canada for Fusion by Polarized Nuclei." One may conclude that such papers are more suitable for meetings of the particular discipline than for the more general audience of the CNA / CNS annual meeting.

The quality of all papers and presentations was, in general, very good. Question periods were lively and interesting.

It is clear that fusion is now an established field in Canada, and topical presentations should be continued at future annual meetings of the CNS.

Alan Meikle

Thermalhydraulics I

The session opened with presentation of a pair of papers concerned with steam-line break transients in U-tube steam generators. Experimental data were obtained from a mockup rig attached to the RD-14 loop at WNRE; analysis models and calculations were done at Ontario Hydro. The most significant results showed that, for large breaks, the inventory depletes very rapidly (of the order of 20 seconds after the break). This result was not extrapolated to the equivalent time in a full-scale steam generator. The analytical model was, however, reasonably successful in prediction of the experimental blowdown behaviour, thereby giving some measure of model verification. Additional large-scale measurements may be useful.

The third paper concerned detailed prediction of the behaviour of fuel bundles in a CANDU channel under externally defined steam-cooling conditions. The work was done at Ontario Hydro. The paper concluded that pressure tube failure caused by early fuel element slumping, before pressure tube contact with the calandria tube, is precluded under these conditions. Some questions remain concerning the imposed channel inventory and cooling conditions. A related paper, from Carleton University, indicated that a significant improvement in pressure tube cooling under these conditions could be obtained by circulating helium gas through the annulus space. The main benefit was found to be due to improved heat transfer through the gas to the moderator rather than to direct heat removal by the gas stream. Another paper covering this general area was to be presented, but the author was unable to attend the meeting. The paper will be published in the Proceedings.

The final paper of the session presented a detailed analysis of a recent significant event in KNU-3, in which a large amount of primary coolant was discharged from the system through open valves in the pressure and inventory control system. Reasonable agreement between measured and calculated data was obtained using the new WNRE blowdown analysis code CATHENA.

Overall, the session gave the impression of slow and steady progress in the area of transient thermal-hydraulic modelling, but also gave clear indication that experimental verification of most aspects of predictions will remain an essential part of this field for many years to come.

D.A. Meneley

Thermalhydraulics II

The session papers were not safety related and presented results on the following topics: CHF enhancement, drypatch spreading, onset of subcooled boiling, void fraction, flooding in inclined pipes and simulation of jet dissipation in the MAPLE reactor chimney. The results presented were interesting and significant. There were some questions from the floor. On the results of a paper on "Onset of Subcooled Nucleate Boiling...", the author was asked whether he had studied the sensitivity of the correlation for the onset of significant void to local effects. The answer was "no." On the results of the paper "Prediction of Void Fraction...", the author explained that the presence of fuel bundles would not have any significant effect on the predicted void fraction. In discussion of the paper "Air-Water Flooding in an Elbow...", the author noted

that he was not aware of any pipe angle beyond which no significant change in the flooding limit occurred nor had he studied the effect of the horizontal pipe length on the hydraulic jump.
Parviz Gubhami

PRV

Chernobyl Estimates

PRV is exercised here by CNS Bulletin Production Editor David McArthur. Views expressed are entirely his own.

It has become a challenge to track estimates of the radiation released from the Chernobyl reactor accident, not to mention estimates of the radiation dose to the population and future cancer cases resulting from this. The range of estimates is indicative of the controversy over the health effects of low-level radiation as well as the variation in applying the mathematics of radiation exposure to the same data.

These estimates have been issued by various experts ever since the accident on April 26, 1986.

With the Chernobyl review meeting sponsored by the International Atomic Energy Agency August 25-29, there has been a start at developing an international consensus on these estimates. However, the studies on Chernobyl which will give internationally accepted figures, such as we now have by UNSCEAR, ICRP, WHO and others on past radiation-exposed populations and which form the basis of world radiation standards, will take years to produce.

In the meantime the estimates of the radiation release seems to be settled for now: almost 100 million curies. But the population dose hasn't been settled satisfactorily yet. Soviet estimates have differed from estimates by Western experts. Some estimates only examined effects on the Western USSR and not the surrounding population, or the world. Others only examined external doses, and not internal doses. Different experts used different cancer risk factors. There has been a wealth of variability. But the Vienna meeting suggested that cancer fatalities may be about 2,000 (based on actual body scans), much lower than some projections. jections.

While even the most pessimistic projections would raise cancer mortality due to the accident by 1%, this figure is highly significant, and will also be viewed as highly significant, if not horrendous, by the average person. It is the average person who ultimately gives nuclear technology its support. One recent, popular book on Chernobyl by Pan and Heinemann is entitled "The Worst Accident in the World." I don't believe that dismissing the 1% figure as insignificant, when compared to the vast majority of cancers, is an appropriate response to the accident by the nuclear industry. The possible absolute number of cancer cases due to the Chernobyl accident is staggering and the average person pays attention to absolute numbers. Many comparisons are being made between Chernobyl and the atomic bombings of Hiroshima and Nagasaki.

Two significant, related trends I see are: worldwide, regulation of pollution seems to be tending to absolute (and tighter) discharge limits, rather than dilutive, or probabilistic limits. In the nuclear industry, Sellafield in the UK is experiencing this. The ultimate limit may become zero emissions, or the least emissions achievable using the best available technology. New energy technologies (such as fluidized-bed combustion) with which nuclear power will be compared do have reduced emissions.

Dismissing pollution releases due to dilution or through comparison with background levels is not a luxury that any industry group may enjoy for much longer. Another trend which the accident may hasten is the uniting of the disparate national nuclear industries into a single community, one with more uniformity, standardization and solidarity.

The impact of Chernobyl has the potential of being as significant to the nuclear industry as the Hindenburg accident was to the airship industry, and one way to deal with this is to face the seriousness of the accident.
D. McArthur

CNS Division Update

Call for Nominations to NSED Executive

The Nuclear Science and Engineering Division will hold an election for three positions on the NSED executive. The term of office for these positions is two years (1987/88).

Nominations are hereby solicited. Each nomination must be made by at least one CNS member. The candidate must be a CNS member and indicate a willingness to serve, in writing to the returning officer, E. Young, at the following address.

Evan Young, c/o Point Lepreau Generating Station, P.O. Box 10, Lepreau, N.B. E0G 2H0.

CNS Branch Programs

Toronto Branch Financial Statement – August 31/86

The Toronto Branch of the CNS receives funding for its branch activities from the national office. With these funds the branch has sponsored six general meetings over the past year (Sept. 1/85 - Aug. 31/86). The statements below provide a summary of the Toronto Branch's financial position outlining where members' fees are being spent in support of local activities.

A. BALANCE SHEET		
CURRENT ASSETS:		
Bank Balance	$2,096.28	
Petty Cash	67.33	
TOTAL ASSETS:	$2,163.61	
B. INCOME STATEMENT		
REVENUE:		
Funds forwarded from National Office	$3,000.00	
Bank interest (less service charge)	56.62	$3,056.62
EXPENSES:		
Mailings and photocopying	$ 730.68	
Newspaper Advertising	756.44	
Coffee and Donuts	368.19	
Donation to McMaster Nuclear Conference	300.00	
Miscellaneous (nametags, stamps, etc.)	32.67	2,187.98
NET INCOME:		$ 868.64

John V. Marczak
Vice-Chairman/Treasurer

Conferences & Meetings

International Symposium on Nuclear Material Safeguards

Sponsored by International Atomic Energy Agency, to be held **Nov. 10-14, 1986** in Vienna, Austria. For information contact: **IAEA, Conference Service Section, P.O. Box 100, A-1400 Vienna, Austria.**

Annual Conference of the American Nuclear Society and Atomic Industrial Forum

To be held **Nov. 16-21, 1986** in Washington, DC. For information contact: **Meetings Dept., ANS, 555 North Kensington Ave., La Grange Park, IL 60525.**

Annual Reliability and Maintainability Symposium

Sponsored by ASME, IEEE et al., to be held **Jan. 27-29, 1987** in Philadelphia, Pennsylvania. For information contact: **Gen Pettee, Lockheed Missiles and Space Co., P.O. Box 1269, Cocoa Beach, FL 32931.**

United Nations Conference for the Promotion of International Co-operation in the Peaceful Uses of Nuclear Energy

To be held **March 23-April 10, 1987** in Geneva, Switzerland. For information contact: **Executive Secretary, UN Conference for the Promotion of International Co-operation in the Peaceful Uses of Nuclear Energy, Vienna International Centre, P.O. Box 500, A-1400 Vienna, Austria.**

International Topical Meeting on Remote Systems and Robotics in Hostile Environments
Sponsored by ANS, cosponsored by CNS et al., to be held **March 29-April 2, 1987** in Pasco, Washington. For information contact: **James D. Berger, P.O. Box 928, Richland, Washington 99352.**

International Conference on Methods and Applications of Radioanalytical Chemistry
Sponsored by ANS, CNS et al., to be held **April 5-10, 1987** in Kona, Hawaii. For information contact: **Dr. R.C. Ragaini, Lawrence Livermore National Laboratory, P.O. Box 808, Mail Stop L-128, Livermore, CA 94550.**

ANS Topical Meeting on Anticipated and Abnormal Transients in Nuclear Power Plants
Sponsored by ANS, cosponsored by EPRI, to be held **April 12-15, 1987** in Atlanta, Georgia. For information contact: **R.A. Karam, Neely Nuclear Research Centre, Georgia Institute of Technology, Atlanta, Georgia 30332-0425.**

CNA Seminar on Integrated Information Management
Sponsored by CNA, cosponsored by CNS, to be held **April 22, 1987** in Toronto, Ontario. For information contact: **J.A. Williamson, Ontario CAD/CAM Centre, 400 Collier-MacMillan Drive, Cambridge, Ontario, N1R 7H7.**

Canadian Engineering Centennial Convention
Sponsored by CNS, CSME, et al., to be held **May 18-22, 1987** in Montreal. For information contact: **Engineering Centennial Board Inc., Suite 410, 276 Saint-Jacques St., Montreal, Quebec, H2Y 1N3.**

14th International Reliability, Availability and Maintainability Conference
Sponsored by IEEE, cosponsored by CNS et al., to be held **May 26-29, 1987** in Toronto. For information contact: **M.S. Grover, Ontario Hydro, H14-G4, 700 University Ave., Toronto, Ontario, M5G 1X6, (416) 592-7728.**

27th Annual International Conference of the CNA and 8th Annual Conference of the CNS
To be held **June 14-17, 1987** in Saint John, New Brunswick. For information contact CNS office.

International Meeting on Nuclear Power Plant Operation — Call for Papers
Sponsored by the American Nuclear Society Reactor Operations Division, Nuclear Reactor Safety Division, and Chicago Section, in cooperation with the European Nuclear Society, the Canadian Nuclear Society, and the Atomic Energy Society of Japan, to be held **Aug. 30 — Sept. 3, 1987** in Chicago, Illinois. Papers are sought in all subject areas dealing with nuclear power plant operations, including the following: plant reliability improvement programs; emergency planning, including public/media relations; optimization programs for technical specifications; learning from other industries (invited); training issues and programs; modifications-implications in safety and configuration control; improvements in predictive and preventive maintenance; performance monitoring; outage planning and execution; plant operator issues and viewpoints; fuel performance experience; radiological protection; plant practices in radioactive waste management; self-assessment programs for plant operations; recent unusual operational events and prevention of recurrence; in-plant human performance improvements; plant chemistry and decontamination; regulatory impact on plant operations/integrated living schedule; results from the industry's self-regulation programs (INPO/NUMARC); operating and maintaining for plant life extension; computer applications for plant operations; robotics applications for plant operations. The deadline for submission of abstracts is **January 23, 1987.** The abstracts should not exceed 1000 words (where one figure is counted as 250 words), and should be sent to: **Norman Wandke, Chairman, Technical Program Committee, International Meeting on Nuclear Power Plant Operation, c/o Commonwealth Edison Company, P.O. Box 767, Chicago, IL 60690.** Authors will be notified of the results of the Paper Review by **April 3, 1987.** The abstracts of the papers which are accepted for presentation will be published in the Transactions of the meeting. It is expected that some papers will be selected for a poster session. There will be a page charge to authors (currently $175) for publishing the abstracts in the Transactions. Canadian contact: Ken Talbot, (416) 839-1151.

International Topical Meeting on Probabilistic Safety Assessment and Risk Management
Sponsored by SNS, ENS, ANS, CNS et al., to be held **Aug. 31-Sept. 4, 1987** in Zurich, Switzerland. For information contact: **PSA '87, c/o ENS, P.O. Box 2613, CH-3001, Berne, Switzerland.**

1987 International Waste Management Conference
Sponsored by ASME and IAEA, cosponsored by ANS, CNS et al., to be held **Nov. 30-Dec. 5, 1987** in Kowloon, Hong Kong. For information contact: **L.C. Oyen, Sargent & Lundy, 55 E. Monroe St., Chicago, Illinois 60603**, (312) 269-6750.

Third Topical Meeting on Tritium Technology in Fission, Fusion and Isotopic Applications
Sponsored by Canadian Nuclear Society, 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.**

The Unfashionable Side

Dear Sirs,
Re: Proposed Co-operative R&D and Marketing Program

The following letter is an open invitation to parties in the nuclear industry to join forces with my organization and pursue challenging and exciting commercial opportunities.

I am involved in the design and manufacture of acoustic organs. Since the connection between our industries may not be immediately obvious, let me explain myself.

Over the past three years I have become increasingly absorbed in the design of the CANDU reactor, the nature of your R&D programs and the scope of your commercial marketing sorties. As a first observation, I would say that their excellence decreases rapidly in the order stated.

My interest in the CANDU design should be obvious. A CANDU reactor and an organ have much in common and I have come to the firm conclusion over the past ten months that a common brain-storming session would be very fruitful. For my part, I can offer a wealth of experience which your industry cannot even begin to match.

My industry has been designing and building organs in all parts of the world for over 900 years. At a conservative estimate, pipe organs have accumulated a total of 855,000 unit years of experience. Since even a modest sized pipe organ makes the entire Darlington station look like a piker, and large organs can have upwards of 10,000 pipes, it should be clear that the number of pipe-years of experience is truly enormous. Compared with the short record for CANDU reactors, there is a clear potential for fruitful collaboration.

My industry also has vast experience with a wide range of materials, including tin, lead, copper, brass, reed and other woods, as well as a range of newer materials — high density plastics, fibre reinforced composites and a full range of mild and stainless steels.

This brings me to my second main point: the area of R&D. Canada has some excellent programs for materials behaviour, pressure and stress testing and determination of material properties under high fluences. Unfortunately, much of this effort suffers from two problems: (1) it is unnecessary in the areas where it is being carried out; (2) it misses several key areas. I will illustrate each of these points with examples.

In illustration of point (1) the effort devoted to demonstrating pressure tube integrity is largely wasted. My industry has had the vast experience noted above with pipes of all size ratios, all materials and various operating conditions and WE

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HAVE NEVER HAD A TUBE FAILURE! There has not been ONE tube failure in roughly 38 million pipe years of experience. I have done some limited data analysis of the information, selecting data for tubes closest to CANDU pressure tubes and have convinced myself that there is sufficient data to predict pressure tube behaviour under all conceivable conditions of interest to a confidence of 99.9% WITHOUT PERFORMING A SINGLE MATERIALS TEST!

Point (2) can be illustrated easily by referring to some recent papers on reactor noise. The significant thing about all the papers on this subject that I have been able to obtain is that they miss the point completely. In the first place, it should be evident to the dimmest practitioner that pipes are the ideal sound production device. This has been recognized by the rudest peasants in the most backward countries for millenia. Why then does such an elementary observation evade nuclear engineers? You have spent years and millions of dollars trying to determine whether reactors will make noise, surely a supreme waste of resource. Instead of this pointless effort it would be much sounder to accept the obvious and find ways of living with it.

There is a second feature of this point that is far more important, however. You appear to have totally overlooked the possibility that the noise necessarily produced by your pressure tubes has a downside. Clearly, it will not lead to pressure tube failure, but it could result in degraded performance. You have ignored this aspect, I submit, because not one of you has a degree in music. If this were not the case, it would have been recognized instantly that the multiplicity of harmonics inherent in the CANDU system can affect the properties of your pressure tube materials and that these factors should be accounted for during design by adjusting the equations used to predict creep, sag and embrittlement due to neutron bombardment. None of these issues has been considered and you are exceptionally vulnerable in this area. Luckily, through a stroke of good fortune, the existing CANDU pressure tube design is close to the optimum that would be indicated using properly modified equations.

This is the main thrust of my suggestions for collaboration on the technical side and basically applies the organ builder's experience to reactor design.

The second half of my proposal turns the tables and suggests that reactor designers should adjust their product to fit the organ builder's market. Some thought will demonstrate, I believe, that there is a market potential here that is significant but which you have ignored up to now. What I am suggesting is indeed the combination of music-making and energy-making machines.

Let me now put some solid suggestions before you:

A. My first suggestion is that you drop all further work on demonstrating pressure tube integrity on the grounds that this is a fully solved problem. What is needed now is a controlled test to show that pressure tubes can meet any anticipated demands over any length of service life. This can be done by developing a CSA acceptance standard for pressure tubes. I would propose an acoustic test for "Acceptable Nuclear Standard" that would submit candidate tubes to:

- The final movement of Saint-Saens' third symphony.
- The 1812 Overture transcribed for organ,
- Selections from Cavalliera Rusticana.

My proposal for a standard suggests an overlay of these pieces with specified times and scoring for maximum harmonic exposure.

A further test to meet "Highest Nuclear Standard" is also included. This test is recommended for reactors that will need to follow load or in whose channels boiling at the channel ends is allowed. This test is essentially a field trial by either Keith Jarrett or Peter Planyavsky.

Pressure tubes meeting the standard acceptance test could be classed as "Pandu" while those meeting the higher test could be designated as "Calliope."

B. My second suggestion is that you join with me in developing a new range of CANDU systems suitable for an ecclesiastical market. Some concrete examples will make my meaning clear.

A range of power organs is required. Some of these might be:

The LOFTLIGHTER: — this would be a device for production of sound and light in a smallish church.

The PACHELBtu: — this is a combined space heating and sound production instrument for use in large churches and cathedrals.

The NAVE-BUSTER: — this is a high power option combining the production of heat, light and sound for large cathedrals along with district heating for a town of up to 10,000.

I believe that these proposals have great merit and would be of mutual benefit to our industries. If any of your member companies is interested by what I have expressed in very abbreviated form, I would be pleased to meet them either singly or as a group. I look forward to a most interesting association.

Yours truly,

Dr. N. Wetblatt
President
Litzruwer Organ Works
Tubingen, Ontario
N0S T0P
(George Bauer)