CANADIAN NUCLEAR SOCIETY

Bulletin

DE LA SOCIÉTÉ NUCLÉAIRE CANADIENNE

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Editorials

Russian roulette

Take a revolver. Place a single cartridge in one chamber. Spin the cylinder. Now point the gun at your temple and pull the trigger. Click. OK, now spin the cylinder again and pull the trigger ... and again ... and again ...

Surely no-one but a raving idiot would do such a thing, one would think. But in effect this is just what London Underground did – with the difference that the revolver was pointed at 31 passengers who died in a fire at King's Cross Underground Station on 18 November 1987.

In the formal Report of the investigation into the fire, Desmond Fennell noted that between 1956 and 1988, 46 escalator fires had been reported in detail. These events prompted no effort either to eliminate the causes of such fires or put in place appropriate training for station staff. Fires were regarded as an "occupational hazard" and were referred to as "smoulderings".

The loaded chamber fell under the firing pin at King's Cross.

On March 6 1987 the cross-channel ferry Herald Of Free Enterprise capsized shortly after leaving Zeebrugge because the bow loading doors had been left open. One hundred and eighty-eight passengers and crew died. In his investigation the Hon Mr Justice Sheen drew attention to the fact that not only had numerous ferry captains alerted the management of Townsend Car Ferries two years earlier to this hazard and proposed a perfectly sensible and economical method of countering it, but also they had drawn attention to the fact that the ships under their command often sailed with an unknown excess of passengers, in unknown stability conditions and were required to maintain full speed under all conditions (including fog) in the world's most congested sea lanes. Company management cited "policy" and "working practice". As Mr Justice Sheen pointed out, "the shore management took very little notice of what they were told by their Masters".

Townsend Car Ferries had a loaded revolver, but it wasn't pointed at senior management.

The phenomenon is not restricted to England.

In January 1986 the space shuttle Challenger was destroyed when the external fuel tank exploded. The explosion was initiated by a leak of high temperature gas past the aft field joint of one of the solid rocket motors. In an Appendix to the Report of the Presidential Commission, the late R P Feynman drew attention to the fact that the field joint seals had been recognised as being defective, yet flights continued. He also drew attention to the fact that NASA management exhibited an extraordinary (if not wilful) lack of understanding of the shuttle's reliability, their estimates being three orders of magnitude higher than those of the engineers who had actually designed and built it.

The loaded revolver NASA had was aimed at the Shuttle crew, and the whole US space programme.

The May 20 edition of *Pravda* published some notes prepared by Valeri Legasov before his death. Discussing the Chernobyl reactor accident, Legasov commented unfavourably on the lack of individual responsibility for safety in the whole Russian nuclear programme and condemned the "negligent and untidy way" in which work at nuclear power stations was accomplished. He argued that "correct fulfillment of all the technological procedures had to be fought for" because the disregard by station management of the designer's viewpoint was "total". And he concluded by quoting a nuclear station director as saying "What are you worried about? A nuclear reactor is only a samovar".

In this case when the loaded chamber in the revolver was fired the bullet hit two members of Chernobyl's operating crew, twenty-nine firefighters, the surrounding population and a large and hitherto very successful nuclear power programme.

Do we play Russian roulette in Canada? Perhaps it's time to find out.

Cleared for Take-off?

In the nuclear industry the notion that the owner/operator of an installation should be responsible for its safety is an accepted rule. Not everyone would agree that its observance meets fully the spirit of the notion but at least it is not openly contested nor seriously flouted.

Other industries, for example the chemical and aviation industries, likewise work to this sort of standard. Indeed, in its relatively short history, comparable in many ways to the history and development of the nuclear industry, the airlines and aeroplane manufacturers have done a remarkable job in making aircraft safe. Unfortunately this can not be said of all the players in the aviation business.

If the situation at Pearson International Airport in Toronto is any indication, the owner and operator of Canada's airports (i.e. the federal government) believes that the business of ensuring safe operations at its installations is either somebody else's problem or not a problem at all. At a time when traffic volume in terms of both numbers of passengers and

planes was increasing, the complement of people responsible for the safe entry and exit of these machines (i.e. the air traffic controllers) was being reduced. Well publicised near-misses prompted nothing more than bland parliamentary assurances that things were well in hand. It ultimately required a blunt report from the Canadian Aviation Safety Board, stating that something had to be done right away, to bring some response. The response, an announcement that the numbers of controllers would be increased and be up to complement by 1992, was effectively an admission that things were in a less than optimal state. In short, the federal government was not shouldering the full burden for air safety at airports. Since nobody else can assume this responsibility, it was therefore in default.

Having a safety board point out what it feels are oversights in safety coverage is one thing. Having it placed in a situation where it needs to remind someone of their fundamental safety responsibilities is quite another. The significance of such a situation is surely obvious. By its nature air travel is such that a lapse in safety at airports invites a large accident rather than a small one. Waiting for large accidents in order to learn about safety is not a good plan. Such accidents are inevitably tragic, emotionally charged affairs in the wake of which no help for the victims is possible. In addition the hard lessons arising from them may be too hard: they may lead to over-corrections or to a skewing of the appreciation of hazards and their sources.

Tax payers, air travellers and safety professionals (and some of the readers of this will fall into all three categories) have an interest in safety at airports. Seeing junior ministers running inelegantly for cover or trying hurriedly to paper over what appear to be gaping cracks in the air safety story is scarcely an assurance that somebody is taking those interests seriously to heart.

Sleeping Venom

The IAEA report on the Goiania incident (noted elsewhere in this issue) makes chilling reading. A private radiotherapy institute moved to new premises and left behind a caesium-137 teletherapy machine. Using "simple tools" two local residents successfully removed the machine's source assembly, took it home and subsequently opened the source capsule which contained 1375 Curies of caesium-137 in the form of caesium chloride. Contamination was widespread. Of a total of 249 people suffering internal or external contamination four died, including a six year old girl. Others suffered radiation burns of varying severity.

Such reaction as there has been by the nuclear community to the Goiania incident seems inappropriately muted. Suppose there had been a reactor accident (any kind of reactor) resulting in four prompt public fatalities (not operating staff or emergency crews)?

This is not the first time isotopes have gone astray, although it is the most serious incident so far. The IAEA report draws attention to incidents in Mexico (1962 and 1983), Algeria (1978) and Morocco (1983). It may feel comforting to note that of course such things couldn't happen here. It may even be true. But the fact remains that the use of a wide spectrum of radioisotopes in a growing range of industrial and medical applications is increasing worldwide and that familiarity (or total ignorance) may encourage a cavalier attitude to the potential hazards.

Perhaps this is the time for the international nuclear community to apply its mind to the question of isotope safety. Surely this is one area in which international agreement, cooperation and regulation could be most readily achieved. As pioneers in the production and application of radioisotopes Canadians perhaps should be taking the initiative here.

The Goiania tragedy did not result from some arcane technical failure or some unprecedented natural cataclysm. It was eminently preventable. We should all work to prevent a repetition.

From the Gallery

The agenda for '89

A glance at the political agenda suggests that 1989 will not be an uneventful year for the nuclear business in Canada, particularly for the nuclear utility business. Here is a rundown on the things that will be happening in Ottawa and at Queen's Park that are likely to have implications for all those involved in making electricity from uranium. This list is by no means complete, and in some cases the timing may change; but the outlook at this writing is as follows.

JANUARY–FEBRUARY

The period between now and the end of February will be a busy one, with the following events scheduled or likely to take place:

Provincial

– Tabling of the report of the Select Committee on Energy

– Tabling of the report of the Nuclear Cost Review panel

– Possible tabling of responses by Ontario Hydro and the provincial and federal governments, to the Ontario Nuclear Safety Review

The Ontario Legislature will rise for its winter break in February. The date hadn't been established at the time of writing.

Management Board Chairman Murray Elston's Round Table on the Economy and the Environment is scheduled to hold its first meeting in February, and likely will issue a report later in the year.

Federal

A federal cabinet shuffle, with possible elevation of the Environment portfolio to a more influential role, and either a new Minister, or confirmation of Secretary of State Lucien Bouchard in that role should take place in early February.

On February 20, a three-day conference of international lawyers and policy makers will begin in Ottawa to draft a framework for a "Law of the Atmosphere," which the federal government would like to see put in effect internationally by 1992. This will be a step towards establishing limits on greenhouse gases, and possibly a levy on coal use. External Affairs will have the lead role in this conference.

MARCH–APRIL

Federal

Officially, the new House of Commons is scheduled to start March 6. Unofficially, the government is considering extending its winter break another three weeks, until just after Easter. Whenever it starts, it will do so with a Speech from the Throne that is almost certain to contain some environmental promises and possibly some reference to nuclear energy and review of AECL's spent fuel disposal concept.

Provincial

A new session of the Ontario Legislature will begin sometime in mid-April, also with a Throne Speech. Look for a reaffirmation of the government's commitment to a clean environment. It is likely that the provincial utility, Ontario Hydro will be called upon to assure a reliable supply of electricity in bids by the province and Metro Toronto for the World's Fair at the turn of the century, and the 1996 Summer Olympics. The decision on the World's Fair is to be made about next December, and on the Olympics, by September, 1990.

JULY

Federal

Prime Minister Brian Mulroney will represent Canada at the Economic Summit in Paris, where the environment is likely to be one of the main issues.

AUGUST

Federal/Provincial

On August 31, the Council of Canadian Resource and Environment Ministers will meet in Toronto, hosted by the Ontario government. The results of a year-long Greenhouse Effect strategy study will be unveiled, a possible first step towards a federal-provincial accord on greenhouse gas emissions.

SEPTEMBER

Provincial

The Ontario Government will be at the mid-way point of its mandate, a traditional time for Cabinet shuffles. The 1987 election brought into the government MPPs from many areas of the province previously unrepresented by the Liberal party. This is when we may expect many of those new faces to show up in Cabinet.

NOVEMBER

Federal

Ottawa will host a third international conference on the Greenhouse Effect.

Events that are expected to take place at some point during 1989, but whose timing is uncertain, are as follows:

Federal

– Announcement of a National Conservation Strategy, a co-operative programme between EM&R and Environment Canada

– A report by the Standing Committee on Energy, Mines & Resources on the Energy Options Study, which will give the latter a political dimension

– Possibly an acid rain treaty with the United States.

– The task force seeking a site for low-level radioactive wastes will continue its discussions with interested communities, and perhaps issue a report.

Throughout 1989, preparations will continue for review of AECL's nuclear waste burial concept, and for next year's International Conference on Sustainable Development, which Mr. Mulroney would like to host. A location for this conference hasn't yet been chosen.

Provincial

There will be considerable action provincially during the year on the environmental front. Two developments to look for are:

– An advisory committee on environmental standards was the subject of an MOE discussion paper last summer and likely will be established

– MOE's next step in its plans to amend Regulation 308, which governs emissions other than sulphur dioxide and nitrogen oxide.

Cam Campbell/Richard Furness/Patrick Gutteridge

Speakers' Corner

Speak up or shut up

A former colleague of mine, who is a member of the Canadian Nuclear Society, assures me that the CNS is an alternate voice on nuclear energy. If he is to be believed it's a voice that is not being heard by the news media.

The Canadian Nuclear Society could be a source of information for journalists covering nuclear energy. As a former reporter, I know that one of the frustrations about investigating any story is that there are usually only extremes. Take the nuclear power issue. On one side of the coin we have anti-nuclear groups such as Energy Probe. On the other side are those directly involved in nuclear power – organizations such as Atomic Energy of Canada Ltd and Ontario Hydro and lobby groups such as the Canadian Nuclear Association.

The Canadian Nuclear Society has among its members, professors, scientists, engineers and others involved in all aspects of nuclear science and engineering. Those members would be valuable as a distinct voice on the nuclear issue. Although many CNS members are employed by the nuclear industry, they are not perceived as "The Industry". Those members could add to these discussions without being seen as industry lackeys. Yet the Canadian Nuclear Society seems only cuffs. Is the CANDU system the best? Could Chernoybl happen here? How feasible is the current nuclear fuel waste disposal concept? What are the health effects of tritium? CNS members could add to these discussions without being seen as industry lackeys. Yet the Canadian Nuclear Society seems only accessible to reporters with more than general knowledge of the nuclear debate – if then.

In order for the CNS to have its voice heard it has to make people aware of it. I'm not recommending a full media blitz such as the one being employed by the CNA, complete with a multi-million dollar advertising campaign. A low-key approach is more suited to the CNS. In other words, let the media know you're there and willing to help.

One of the main references for contacts for any reporter is *Sources*, which serves as the reporter's Bible for contact names. *Sources* is distributed to more than 12,000 reporters in Canada each year. For about $500 a year, organizations, such as the Canadian Nuclear Society, can place a listing in *Sources*. The advantage of this is that it allows reporters access to the CNS and its members without the CNS having to seek out reporters. Reporters tend to be sceptical of anyone approaching them, welcoming them as they would a rabid dog. However, once a reporter has stumbled onto a contact, he will continue to go back, and often when he returns he will be leading a pack of others.

Many companies have developed a list of spokespersons to handle enquiries from the media. Ontario Hydro has more than one hundred principal spokespersons who are prepared to answer questions from the media on everything from acid rain to health effects of transmission lines. The CNS should develop a list of spokespersons to handle specific issues, be it the greenhouse effect or the reliability of the CANDU.

. . . those who ignore the media or eschew them . . .

A publicly visible CNS could result in more than simply giving the media another group to turn to. It could pay dividends for the CNS in terms of public awareness, and raise its profile. As a result, the next time the Society makes a submission to a government task force, such as the Select Committee on Energy, it would do so with the general recognition that the CNS is THE nuclear science organization in Canada and a voice to be listened to.

All of this is said with the thought that the Canadian Nuclear Society actually does want its voice heard. If it doesn't, then let it keep doing business the way it always has. However, if it's content with remaining on the sidelines, any CNS criticism of the media and how it treats nuclear issues, should be regarded with the same grain of salt that one views editorials. Reformed editorial writer Robertson Cochrane, now Ontario Hydro's Corporate Communications Manager and a former Financial Editor of The Toronto Star describes editorial writers as "anonymous, furrow-browed, hand-wringing viewers-with-alarm who, with hindsight, have all of the questions and none of the answers". That characterization could also be fairly applied to those who ignore the media or eschew them when they call, only to pop their heads out of foxholes when the story appears with comments like "Why didn't they say . . . ?".

Terry Young

Technical Note

A Review of Quantitative Criteria for Demonstrating Nuclear Power Plant Design Adequacy

Introduction

The level of safety at a nuclear power station is determined by many contributing factors including good design, good construction, good operation and good regulation. It is axiomatic that safety can always be improved, albeit at some cost. The question remains as to how it can be demonstrated that the plant design aspect of safety is adequate, where "design adequacy" means that it is no longer necessary to spend money on additional safety features. Design adequacy is, of course, not to be confused with "public acceptability" which involves wider issues of a technical, sociological and political nature.

The demonstration of adequacy is clearer where quantitative expressions of plant performance can be compared with appropriate standards of acceptability. The use of quantitative targets or limits has long been an integral part of the licensing process in Canada. The advent of risk assessment has provided a method of estimating the overall risks due to accidents posed by the operation of the plant and provides an alternative means of quantifying design adequacy.

The problem then becomes one of setting appropriate standards against which adequacy can be assessed. This article examines some current and earlier attempts to establish numerical safety standards and suggests that there are factors other than public health that should be taken into account when assessing design adequacy.

Event-based safety limits

The determination of design adequacy for the purposes of plant licensing is accomplished quantitatively by comparison of predicted plant performance with deterministic, event-based criteria. In Canada this refers to the single/dual failure limits of the AECB Siting Guide[1] or, more recently, the dose limits contained in the Consultative Document C-6[2].

While this kind of approach does provide an effective basis for system design and assessment of system capability under accident conditions, it cannot by itself be regarded as a demonstration of the overall adequacy of the design for the following reasons:

1. There is no limit to the number of sequences in any dose category and hence there is no integration of risk contributions.
2. Multiple system failures outside the single/dual failure definition are excluded.

Examples can be found where design changes have been required even though all dose limits have been met. Discussion related to the need for such changes takes place in something of a void, in the absence of any criteria to determine whether an adequate level of safety has already been achieved.

Probabilistic safety goals

The advent of modern probabilistic safety analysis (PSA) offers a potential solution to the limitations of the deterministic approach. PSA results can be expressed directly in terms of health risk to the individual or to a population. In principle, integrated plant risk can be compared against objective risk based standards ("Safety Goals") and design change recommendations can be evaluated on the basis of their potential for risk reduction and the predicted level of risk imposed compared to the relevant goal. Safety goals are usually expressed in terms of mean risk, which eliminates some of the bias inherent to conservative deterministic analysis.

Safety goals are usually based on a qualitative principle such as: "Due to the operation of a nearby industrial facility, individual members of the public should not be presented with additional risks to life and health which are significant in comparison to other risks to which they are normally exposed". Two sets of proposed risk-based safety goals currently under discussion in North America will be examined in more detail.

The USNRC approach

In 1986 the USNRC published its proposals for probabilistic safety goals in final form. The prompt fatality goal was defined as 0.1 percent of the background fatal accident risk applied to the average individual within 1 mile of the plant boundary. The latent fatality goal was set at 0.1 percent of the background cancer risk averaged over the population within a 10 mile radius of the site.

Quantitatively they translate to about 4×10^{-7}/yr prompt fatality and 2×10^{-6}/yr latent fatality respectively. They apply to the average member of the population group rather than the most exposed individual and to each reactor on a given site.

A Canadian approach

At Ontario Hydro preliminary safety goals for internal use are under consideration. These goals are based on the qualitative principle stated above, where insignificance is interpreted as a risk less than 1 percent of the average accident fatality risk and cancer risk in Canada. They are intended to represent mean values and apply to the most exposed individual in each case.

Expressed quantitatively, they correspond to a prompt fatality goal of 3×10^{-7}/yr and a latent fatality goal of 1×10^{-5}/yr for the site under scrutiny. For a multi-unit station the goals apply to the site as a whole and would be correspondingly smaller on a per unit basis.

Significance of risk-based safety goals

The purpose of defining safety goals is to establish criteria against which the adequacy of any actual or proposed nuclear plant design may be judged. If such goals do not represent an

"adequate" level of safety then they will be of only limited use in the design process.

It is of interest to note that despite the fact that the U.S. goals are based on a criterion for insignificance of 0.1 percent of the background risk to the affected population as opposed to 1 percent for the Canadian goals, the Canadian approach is, in practice, more restrictive. This is because the ratio of critical/average individual risk is usually greater than a factor of 10. The difference is also enhanced because of the units of the safety goals (site-yr or reactor-yr) and the predominance of multi-reactor sites in Canada.

When the proposed safety goals are applied to the results of reactor risk assessments some revealing conclusions emerge (for example[4]). The most limiting seems to be the prompt fatality goal, due largely to the uncertainties involving fission product release and dispersion under severe accident conditions. Latent fatality goals appear to be significantly less restrictive than prompt fatality goals. For example, to pose an "acceptable" risk to the individual of 1×10^{-5}/yr, the predicted frequency of an accident resulting in a dose of up to 1 Sv (e.g. Chernobyl) could be of the order of 1×10^{-3}/yr.

It is expected that improved methods of analysis and continuing safety research will further reduce the predicted likelihood of prompt fatalities from a large release. If this turns out to be the case, it will be more evident that existing reactor designs already meet current proposals for safety goals by a significant margin.

A safety goal which permits an accident resulting in up to 1 Sv to some individuals with a frequency of 10^{-3}/reactor-yr intuitively would not represent an adequate design target even though the derivation is reasonable and objective. The question arises as to whether there are other considerations that might be more limiting than public health-related goals. Some alternatives are examined below.

Economic criteria

The occurrence of an accident would have serious economic consequences to the utility arising from "on-site" and possibly "off-site" damage. On-site costs resulting from the loss of return on investment have been estimated to be in the range of $1 billion to $10 billion at an Ontario Hydro multi-unit station, depending on the severity of the core damage[4]. To limit the on-site risk to an acceptable level of the order of $1-million/reactor year (where "acceptable" is defined as below 1% of annual generation costs), accident frequency should be predicted to be 10^{-3} – 10^{-4}/reactor year or lower, depending on the severity of damage.

The occurrence of an accident that caused a large offsite release of radioactivity could result in a very significant economic penalty. Costs of such an occurrence have been estimated for Southern Ontario[5] to be in the range 1 – 10 billion dollars using 1981 economic data. If an acceptable level of risk is, for example, taken to be of the order of that represented by current insurance premiums under the Nuclear Liability Act, this would be about $100,000/reactor year. To meet this target the frequency of such an accident would need to be below about 10^{-5}/reactor year.

An on-site economic risk target is always likely to be more limiting than offsite risk because offsite consequences require both severe core damage and containment failure, the order of magnitude of economic consequences being about the same in both cases.

Loss of livelihood

Most efforts to derive public safety limits, targets or goals are based on the presumption that the principal concern of safety design is to protect the life and health of the affected population. Thus most are derived by estimating the likelihood of death arising from radiation exposure and comparing this with background mortality levels.

The presumption that mortality risk is the limiting consideration needs to be questioned, at least as far as the derivation of quantitative design goals are concerned. It is proposed here that an issue of major and potentially more limiting concern may be that of "loss of livelihood". There is some evidence to suggest that, at least in the public's mind, risk of loss of livelihood (for example, as the result of a prolonged evacuation due to ground contamination) may be of equal or greater importance. Indeed, people have been known to accept significant health risks in defence of their way of life.

Concerns with respect to the broader impact of a severe accident have led the USNRC to propose a general guideline that "the overall mean frequency of a large release of radioactive materials to the environment from a reactor accident should be less than one in one million per year of reactor operation". One suggested definition of a "large release" is that sufficient to cause at least one prompt fatality, which may or may not be the limiting criterion on plant design depending on future developments in safety research. Currently it is more limiting than the proposed prompt and latent fatality goals.

However, if the concept of a "large release" as one sufficiently large to result in loss of livelihood were adopted a more rigorous and, it is believed, more realistic criterion would result. If the prompt fatality criterion is used, accidents of the magnitude of Chernobyl could occur at a frequency of up to 10^{-3}/reactor year and still meet safety goals, because there were no offsite prompt fatalities and the latent fatality goal is limiting. If loss of livelihood were used, the predicted frequency of such accidents would have to meet the large release goal for the design to be considered adequate.

Suggesting such a safety goal presents two problems:

– defining what is meant by a large release sufficient to cause loss of livelihood

– establishing an acceptable frequency target.

In qualitative terms, any accident sequence involving severe core damage and containment bypass or loss of the containment function would be a candidate for inclusion in the definition. A decision to evacuate an area on a long-term basis would depend on many situation-specific factors (including health risk considerations), but the avoidance of a mean dose to individuals of the order of 0.25 Sv or greater resulting from the pathways associated with the long term effects of ground contamination (ingestion, groundshine, resuspension) might constitute a practical working definition. This figure is suggested by emergency evacuation criteria.

Clearly there is no meaningful "background" frequency

against which to assess acceptability related to loss of livelihood. One possible approach is to aim for a high degree of assurance that no such event will occur during the lifetime of the current generation of nuclear power plant designs. A simple way of arriving at a target frequency is to use the following equation:

$P = (1 - Np)^Y$ where:

P = Target probability that no accident will occur during life of programme

N = Number of reactors in programme

p = Target mean frequency of a large release per reactor-year

Y = Average lifetime of a reactor

There would not be much merit in applying such a criterion to a single reactor or site. Assuming a 20-reactor programme, a 40 year life and a target probability of 0.99, the frequency goal would be 1.3×10^{-5}/yr.

This argument can be extended to include all commercial power reactors. It does not seem reasonable to establish design adequacy standards based on the size of a domestic nuclear programme, especially where reactors are sited close to international boundaries or where several countries use the same basic design. Whatever level of safety is claimed through predictive analysis, the safety of nuclear power plants will ultimately be demonstrated by performance. Further occurrence of severe accidents will undermine the credibility of the technology, wherever they occur geographically. The potential international impact of severe accidents suggests that there should be some consistency in setting design goals.

Figures 1, 2 and 3 show the results of varying the equation parameters for target probabilities of 0.9, 0.95 and 0.99 respectively for up to 50 years. A frequency goal of the order of 2×10^{-6}/reactor yr would provide a degree of assurance in excess of 0.95 over the range considered. A 400-reactor programme, a 40-year life and a target probability of 0.99 requires a goal of 6×10^{-7}/reactor yr. Thus it appears that a "loss of livelihood" goal in the area of 1×10^{-6}/reactor yr would provide a high degree of assurance that such an accident would not occur in the foreseeable future.

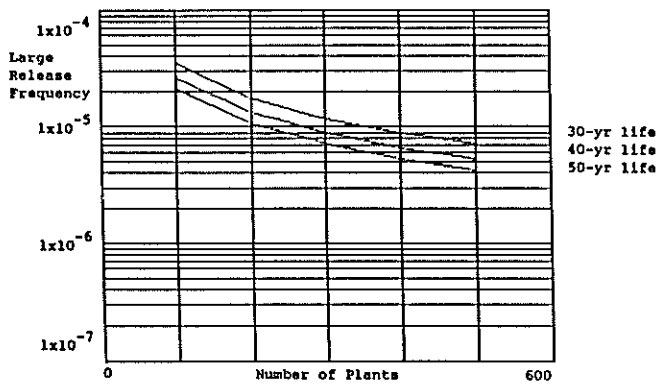

Figure 1 Target Probability 0.9

It is noteworthy that the above result is very similar to the prompt fatality goal under consideration in Ontario Hydro and the USNRC large release proposal, in that they all apply to a large offsite release of radioactivity, with the difference that the consequence of concern is no longer related directly to prompt fatalities. It is also noteworthy that "compliance" can be demonstrated in terms of accident frequency alone.

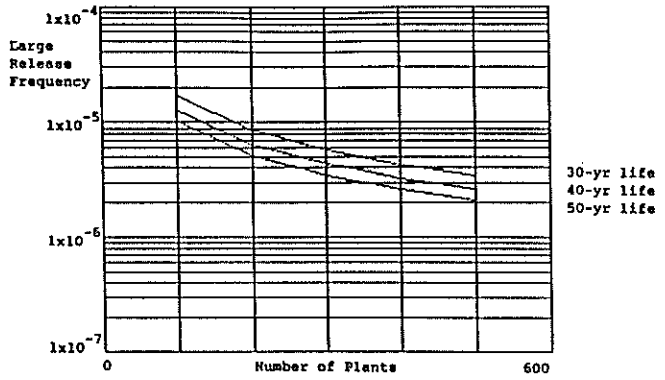

Figure 2 Target Probability 0.95

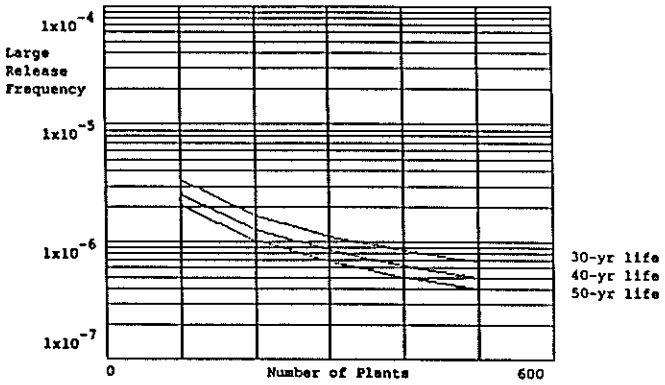

Figure 3 Target Probability 0.99

Conclusions

A number of potential design criteria have been reviewed to attempt to identify those which might determine design adequacy and to suggest some suitable numerical values for use as design goals.

Although safety goals have traditionally been based on comparisons to other societal mortality risks, it is concluded that such considerations may not be sufficient to fully determine design adequacy. Three additional goals are suggested for consideration:

1. The predicted mean frequency of accidents leading to significant damage to fuel in the core should be about 10^{-3}/reactor yr or lower.
2. The predicted mean frequency of accidents leading to severe core damage should be about 10^{-4}/reactor yr or lower.
3. The predicted mean frequency of accident leading to a large offsite release of fission products sufficient to cause loss of livelihood in the local population should be about 10^{-6}/reactor year or lower.

Here "significant" damage implies fuel overheating leading to fission product release but with core structural integrity maintained. "Severe" damage implies loss of core structural integrity leading to the release into containment of a substan-

tial fraction of core inventory. These two criteria are set by on-site economic risk considerations.

"Loss of livelihood" is assumed to be caused by the need for prolonged evacuation (months) to avoid the possible effects of long term dose received through the pathways associated with ground contamination. Adoption of such a goal would require the definition of the cause of loss of livelihood to be expressed quantitatively to achieve consistency and avoid misuse. Avoidance of a mean individual dose in excess of 0.25 Sv is suggested here.

If these goals are met any other rationally-derived goals based on health effects of radiation exposure or economic risk would also be met. Reactor designs which are assessed to meet these goals would not require further design changes to improve safety. Failing to meet the goals would not necessarily imply unacceptability, only that design changes should continue to be considered on a cost-effectiveness basis.

Meeting such goals does not guarantee adequate safety. A good design must be complemented by suitable operating practices. While the results of risk assessment indicate the capability of the design, the manner of operation determines the actual level of safety achieved.

All quantitative targets or goals, whether based on health risk or otherwise, are derived from the same basic objective of establishing a safe and viable nuclear industry. All involve a degree of subjectivity in establishing an acceptable level of risk. This article suggests some design goals which set standards with the objective that, if met, the design could be considered "adequate" and the allocation of significant resources to provide additional safety features would be unnecessary.

Keith Dinnie

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3 *Reactor Risk Reference Document*, NUREG-1150, U.S. Nuclear Regulatory Commission, Draft for Comment, February 1987.

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Background

Background is designed for educators and senior high school students who wish to learn something of the background to nuclear science and engineering.

An Introduction to CANDU Nuclear Fuel

Like any other kind of engine, a nuclear reactor needs fuel to run. Although the product of a nuclear power station is ultimately electricity, the immediate product of a nuclear reactor is heat.

The heat from a reactor is generated in the fuel which is placed within the core in a specific geometrical arrangement. In order to understand something about fuel and its importance, some knowledge of the rest of the core is necessary.

In a CANDU reactor (the only kind we will be considering here) the core consists of a large tank, the calandria, which is penetrated by horizontal tubes (called pressure tubes) in which the fuel resides. Surrounding the pressure tubes, and filling the calandria, is the heavy-water moderator – about which there will be more details later.

Nuclear fuel for a CANDU consists of assemblies (bundles) of 28 or 37 rods (elements) about 50 cm long and about 1 cm diameter. The elements are held together in a fixed geometry in three concentric circles with one central element. Each element contains cylindrical pellets of uranium dioxide. The total weight of a fuel bundle is about 20 kg, with nearly all the weight being contributed by the uranium dioxide. The tubes containing the uranium dioxide pellets are made of zirconium alloy, as are other structural components of the bundle. A large power reactor has 12 or 13 bundles in each pressure tube, and there can be up to 480 pressure tubes per reactor – implying up to 62,400 fuel bundles, or 124,800 kg of fuel – in the reactor at any time.

A nuclear reactor relies on the maintenance of a chain reaction. The individual occurrences constituting the chain are the fissioning of individual atoms of uranium 235. This isotope accounts for slightly more than 0.7 percent of the total isotope mixture in natural uranium, as it is refined from fresh ore. The remainder is a heavier isotope, uranium 238. The adjective "natural" is used to make the distinction from "enriched" uranium in which the naturally occurring concentration of uranium 235 is increased. This latter is used in most other reactor types, including commercial reactors (such as RBMK, AGR and LWR, where enrichment levels range from 2 to 4 percent U-235) and submarine reactors (where the U-235 concentration is very much higher).

It is the fissioning or the uranium 235 which produces most of a reactor's heat.

The agent that brings about the fissioning of uranium 235 atoms is the neutron. The rate of heat production by a reactor is proportional to the number of fissions occurring per second. Since the neutrons themselves are produced by the fissioning uranium atoms, one retains control over the rate of fission, i.e. the power level at which the reactor operates, by controlling the neutron population in the core. If there are too few neutrons, the number of fissions per second may decrease steadily until the reaction stops altogether. If there are too many neutrons present, the rate of fissioning will increase and the power level will rise.

The number of neutrons is not the only factor influencing the fission rate. The chance of a neutron causing a fission in a uranium 235 atom is also related to the speed at which the neutron is travelling. Neutrons released by an atom which has just undergone fission have extremely high energies and are travelling extremely rapidly. To make them most likely to cause fission events they have to be slowed down to a tiny fraction of their original velocity (approximately 2 km/s). This is about the average speed of neutrons which are in thermal equilibrium (hence the term "thermal" reactors) with their surroundings at temperatures near those we are familiar with, i.e. about 100 C or less. Slowing down neutrons (or moderating their speed) is the job of the moderator. An ideal moderator accomplishes this over as short a distance as possible while at the same time absorbing as few neutrons as possible. While heavy water, used in CANDU reactors, does not slow neutrons down over quite as short a distance as ordinary water it absorbs very few neutrons, hence is very close to an ideal moderator.

This is a very simplified picture of what takes place in a reactor. In practice, one has to take account of many other factors, such as the fact that neutrons are not all released at the same time when a fission event occurs, a fact which has considerable significance for reactor design. Another factor is the variation in the neutron population across the core. The calandria is roughly a cylinder turned on its side and those fuel bundles located in pressure tubes near the edges and the ends of the calandria have less fuel (and a less intense source of neutrons) in one direction than in the opposite direction. As a result, the neutron population and the local rate of power production varies across the core. Means are provided to try to level out or "flatten" this power profile across the core to make the best use of all the fuel in the core. Similarly, the control systems not only have to control the total power level in the core but also must be designed to keep local power levels in different sections of the core within predetermined limits.

A full description of the core and what takes place in it would be excessively complex and is unnecessary. A general picture is good enough for present purposes. It is adequate to think of the core as basically consisting of a large number of fuel bundles contained in pressure tubes, with each pressure tube being held a fixed distance from its nearest neighbours, a moderator surrounding the fuel, and systems to control the power level and remove the heat produced.

With this necessary background, we can now look at an individual fuel bundle in some detail.

The term "fuel" here is used to mean the complete assembly of the uranium dioxide fuel pellets, the zirconium alloy tubes containing them, and the structural elements which give the bundle its fixed shape and maintain the separation between individual elements. The fuel actually has two main purposes: (1) to produce the maximum feasible amount of heat per kg of uranium dioxide and transfer this heat to the reactor coolant efficiently, and (2) to prevent the fission products, which result from the fission events occurring within the fuel pellets, from migrating into the reactor coolant. To evolve a fuel design which can accomplish these tasks a large number of factors has to be taken into account.

The fuel's environment: Conditions in a reactor core are very hostile. Each fuel bundle is exposed to an intense neutron bombardment (up to 10^{13} neutrons per square centimetre of fuel surface area per second). Fuel bundles have to be able to withstand this neutron bombardment for the duration of their stay in the core, which may be up to two and a half years. The coolant outside the bundles is heavy water pressurised to 10 MPa (about 100 atmospheres, or 1500 psi) and has a temperature between about 250 and 310 C depending on whether the bundles are at the cool end or the hot end of the pressure tube. The flow of coolant through each pressure tube is large (approximately 25 kg/s). Flows of this magnitude can exert considerable forces on the bundles, which they must be able to resist. This flow rate is necessary to remove the heat produced by the fuel in the channel without causing the coolant to boil, and to increase the rate at which heat is transferred from the outside surfaces of the bundle to the coolant (the same effect that produces the "wind chill factor").

Inside the fuel: Another set of factors to be taken into account in the design of fuel relates to the processes occurring inside the fuel elements. Here conditions are no less hostile. Since uranium dioxide is a ceramic material and does not have a high thermal conductivity, the temperatures vary within the fuel pellets, reaching a maximum near the centre. The actual peak temperature and temperature distribution within the fuel depends on the power level the fuel bundle is operating at, the dimensions of the individual elements, the arrangement and spacing of the elements relative to each other, the coolant temperature and the efficiency with which heat can be passed to the coolant. As we saw earlier, the power level seen by a fuel bundle depends on where in the core the bundle happens to be located. In those fuel bundles producing the most heat, each of the outermost ring of fuel elements will be generating up to about 60 or so kilowatts (of heat) per metre of length, or about 30 kilowatts per element, since they are each about one half metre long. In such elements the temperatures within the uranium dioxide could reach about 1800 C at the centre of the fuel pellets.

Each time a fission event occurs, an atom of uranium (or other fissionable element) is destroyed. This destruction does not always occur in exactly the same way. As a result, the fragments of the uranium atoms which appear after fission,

the fission products (most of which are radioactive), consist of a range of new lighter elements centred around atomic weights about half that of the original uranium. The destruction of uranium atoms and the production of atoms of new elements has implications for fuel design. For example:

– the stoichiometry (balance of uranium to oxygen atoms) of the fuel is altered as fission proceeds. This can affect the physical and chemical behaviour of the uranium dioxide pellets

– some of the fission products are inert gases and the fuel element design should be such that these gases can be retained within the fuel sheaths

– other of the fission products are chemically reactive and provision has to be made to ensure that the presence of these elements does not degrade the internal surfaces of the fuel sheaths excessively.

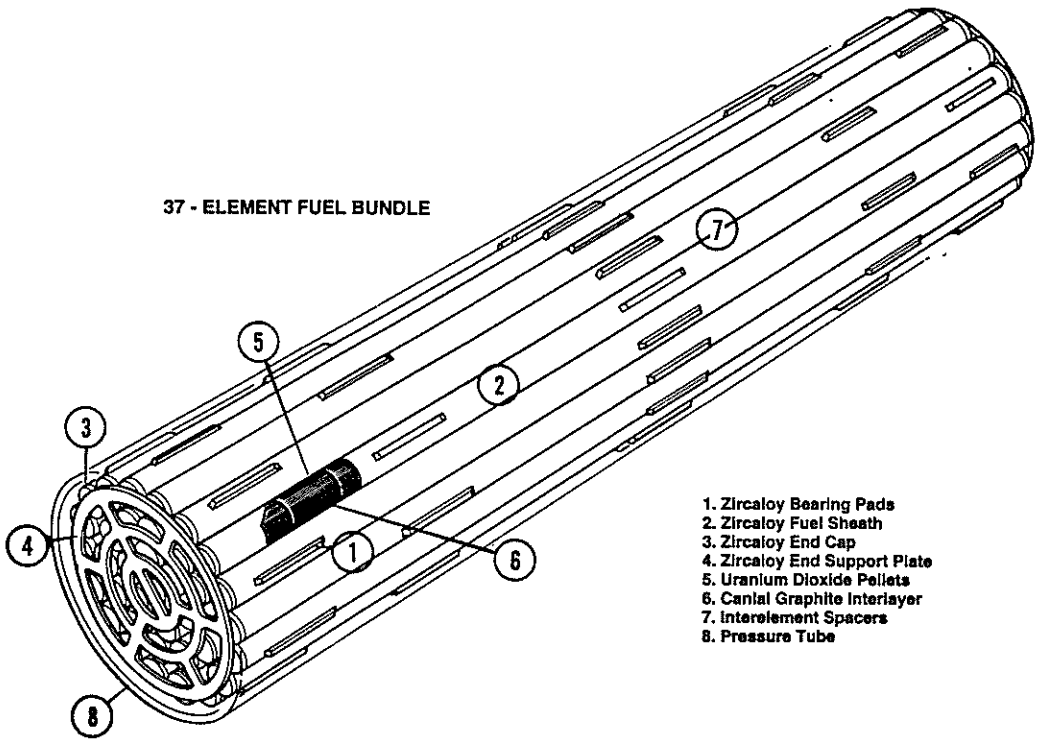
As the fuel spends more time in the reactor, more uranium is consumed by fission and more fission products appear in the fuel matrix. (Isotopes with atomic weights greater than uranium-235 or -238 are also produced by neutron activation. Some of these can undergo fission more readily than others.) The buildup of fission and activation products combined with the depletion of the uranium-235 in the fuel, has the effect of making it more difficult to produce the same amount of heat for a constant neutron flux. Therefore as burnup (consumption of U-235) proceeds the rate of fissioning (and, therefore, the fuel's capability to produce heat is reduced. This means that a fuel bundle has a maximum practical lifetime in the core, at the end of which it has to be replaced with a fresh bundle. Since all fuel bundles do not "burn up" at the same rate, they are not all replaced at equal time intervals. There is an optimum pattern for fuel bundle replacement and this is reflected in the refuelling strategy for a particular reactor.

At the time it is replaced the uranium in a fuel bundle has had its content of the 235 isotope reduced from 0.7 percent to typically less than 0.2 percent. It has also produced about 170 megawatt-hours of heat per kg of uranium contained in it, or over 3000 megawatt-hours for the bundle as a whole. (You can get some appreciation of how much heat this is by comparing it with the heat produced by a portable electric heater, which typically produces one kilowatt-hour of heat per hour.)

After being subject to such harsh conditions one would expect the fuel to have undergone considerable change, and at the very detailed level the changes are indeed considerable, but in outward appearance a fuel bundle as it comes out of the reactor looks very much the same as when it went in. The main difference, of course, is that on emerging from the core fuel bundles are intensely radioactive because of the inventory of fission products now contained in them. This radioactivity also produces considerable residual heat in the fuel and on their removal from the core the bundles have to be cooled by placing them in a water-filled storage pool. The level of radioactivity and the heat produced in used fuel bundles decreases as the short lived fission products decay. The water which cools the bundles also provides shielding from the radiation emitted by the now used, (or spent, or irradiated), fuel bundles.

The full story of nuclear fuel, how it is designed, how it is manufactured and how it works would fill many volumes. The complexities are much greater than are indicated here and only a few of the factors involved have been mentioned. The fact that nuclear fuel is now manufactured and used in what are highly precise but basically standard industrial operations, represents a substantial scientific and engineering achievement.

Keith Weaver



– Ontario Hydro

The affair of the two cultural corridors

Thirty years ago C P Snow delivered the Rede Lecture on the "Two Cultures" which, with some additions, he subsequently published[1] and which dealt with what Snow perceived as an unbridged gap between the "science culture" and the "arts" or "literary culture". The lecture aroused a certain amount of controversy at the time (to put it mildly) and led to one of the most unpleasing and vindictive (on both sides) feuds in post-war academic circles. Since that time the shade of C P Snow has been unfailingly invoked in any discussions related to the relationship between science and technology and society, the role of the scientist, science policies (such as they may be), science education (or the lack of it) and so on and so on. The actual thesis Snow advanced is not explained in these invocations but rather fuzzy and undefined terms such as "the two cultures", "scientific illiteracy" and "non-numerate culture" are waved about the place like a rainmaker's bones in an attempt to bring about some kind of intellectual precipitation. It might not be a bad idea, thirty years on, to examine exactly what C P Snow did say: what was his thesis? does it stand up to scrutiny?

First let's summarize very briefly what Snow says in Two Cultures:

1. The intellectual life of all western society is increasingly being split into two polar groups with "Literary intellectuals at one pole – at the other scientists". Each group totally misunderstands the other. Actually Snow does admit that there are in fact more than two groups or "cultures" but decided against refining his argument further because "it would bring more disadvantages than it's worth".

2. Scientists do not feel that "the literature of the traditional culture" is relevant – they have their own culture which "contains a great deal of argument, usually much more rigorous and almost always at a higher conceptual level, than literary persons' arguments".

3. The "literary intellectuals" are more seriously impoverished than their scientific brethren. They pretend that the "natural order" does not exist and that any exploration of it is "of no interest either in its own value or in its consequences", they have no conception of "the intellectual depth, complexity and articulation" of the "scientific edifice of the physical world" and "Even if they want to have it they can't".

4. The "literary intellectuals" focus on the tragedy and isolation ("loneliness") of the individual human condition. Scientists accept the immutable nature of the individual human condition but are optimistic about the mutability of the human social condition and set themselves the task of working to improve it.

5. Literary intellectuals are "natural luddites". Throughout the industrial revolution the "writers" refused to comprehend what was happening, although "plenty of them shuddered away... it is hard to think of a writer of high class who really stretched his imaginative sympathy.... The only writer of world class who seems to have had an understanding of the industrial revolution was Ibsen in his old age".

6. The educational system requires rethinking at the pre-university level to make it less specialized.

Now all of this must have been rollicking good stuff to his audience. Admittedly Snow does tut-tut mildly over the limitations of the scientists' literary diet, but then he goes on to zero in on the "literary intellectuals" – their voice is "restricted and constrained" as they ponder the tragic nature of the individual human condition, their intellectual impoverishment is such that not only are most of them unable to recite the Second Law of Thermodynamics but they couldn't even define such fundamental terms as "mass" and "acceleration". They have absolutely no conception of the scientific edifice of the physical world – and even if they wanted to understand it they couldn't.

Scientists, on the other hand, are members of a sort of supranational fellowship with "common attitudes, common standards and patterns of behaviour, common approaches and assumptions" which cut across "religion, or politics or class". They "have the future in their bones", they actually get up and do something to alleviate the social condition[2] and, (perhaps most importantly to Snow's audience) "young scientists know that with an indifferent degree they'll get a comfortable job, while their contemporaries and counterparts in English and History will be lucky to earn 60 percent as much".

Certainly good strong stuff this, immensely cheering to the neophyte scientists and, as a sort of morale booster for undergraduates who might be worried about career prospects, quite acceptable. However as a formally published document accorded the authority that went with a person in Snow's position it requires more rigorous scrutiny.

An initial and general observation is that while we can infer that in the category of "scientists" Snow includes everyone from the physicist exploring the quantum jungle to the chemist developing a detergent additive to preclude dish-pan hands, it is difficult to infer just who is included among the "literary intellectuals" (or "literary persons"). Who does he mean? Novelists, poets and dramatists? Newspaper columnists with literary pretensions? Professors of English? Those representatives of the "literary culture" he mentions by name include Amis, Austen, Dickens, Eliot, Emerson, Ibsen, Lawrence, Orwell, Shakespeare, Rilke, Ruskin and Thoreau, although the contexts in which he mentions them differ. And at an early point in his discussion he refers to "the recent literary culture" without further elaboration. He does actually quote the final two lines of Eliot's "The Hollow Men" ("This is the way the world ends/Not with a bang but a whimper") noting disapprovingly that it is one of the least likely scientific prophecies ever made, but this is about the farthest he goes in particularizing his characterization of the "literary intellectuals" or identification of "the recent literary culture". While

Eliot was not a scientist he never, in his capacity as a literary critic, made the blunder of formulating a sweeping generalization on the basis of a single observation – and an inaccurate one at that.

The way in which Snow uses the Eliot quotation seems to typify the Snow approach which is that of the benevolent, if unimaginative, bureaucrat: Eliot says the world will end with a whimper rather than a bang; the world has not yet ended either detonatively or otherwise, therefore Eliot is predicting a future event and one which is scientifically unlikely. Presumably Snow would have equally deplored the meteorological inaccuracy in *Twelfth Night* where Feste sings "the rain it raineth every day".

An even bigger blunder Snow makes is his dismissal of the literary treatment of the industrial revolution. "It is hard to think of a writer of high class who really stretched his imaginative sympathy, who could see at once the hideous back streets ... and also the prospects of life that were opening out for the poor". Snow can't have read Dickens. The realization of the liberating and civilizing forces that the industrial revolution generated pervades Dickens' novels – *Our Mutual Friend* and *Dombey and Son* leap to mind. Explicitly, in a concluding Note to *Martin Chuzzlewit*, Dickens records his admiration for such progress in the United States. And it is significant that in *Little Dorrit* one of the key characters (and one of Dickens' most sympathetic) is an engineer. Dickens reserves his condemnation for the abuses of the tool, not the inventors of the tool or the tool itself[3].

To argue as Snow does, that literature's concern with technical development (call it science, engineering or technology) has been to ignore it or reject it with horror and loathing is simply at odds with the facts. Particularly since the time of the Metaphysical Poets, through Emily Dickinson, Wells, Shaw, Kipling and Auden to Tom Stoppard, scientific speculation, scientific discoveries and the impacts of the application (or mis-application) of science have not only provided themes for poets, novelists and dramatists, but also provided a rich source of powerful imagery[4]. Allan Danzig[5] has compiled an extended anthology of poetry and excerpts from plays, essays and novels (a total of forty) dealing with science and technology. They range from the Bible, via Swift, Wordsworth and Dickens to E E Cummings and Stephen Spender. None of the authors mentioned above is obscure, yet Snow either ignores them or hasn't read them. Interestingly, Danzig discusses the treatment of technology in literature and, using railways as his example, notes:

> *for every metaphorical use of the railroad to indicate the senseless mechanization of man's life or the materialism of his spirit there may be found two or three referring to the railroad as a symbol of new, open perspectives, of powerful beauty, or of civilization, law or comfort.*

All this going-on may seem like employing an excessively large steam hammer to crack a very small nut, but in view of the authority accorded Snow (if not claimed by him) as both scientist and literary man it is very important to establish quite clearly that Snow completely fails to support his assertions about the general antipathy or indifference to science he claims to find in literature.

Snow's background is popularly regarded as providing him with unique authority on both the "scientific" and "literary" spheres. He received a doctorate in physics from Cambridge and was made a Fellow of Corpus Christi in 1930. During the next decade he was engaged in scientific work and college administration. During the Second World War Snow served as the Chief of Scientific Personnel at the Ministry of Labour and was subsequently appointed a Civil Service Commissioner. Following the War he achieved critical and commercial success as a writer with the Strangers and Brothers series of novels which concerned themselves with men in their public capacities negotiating the "corridors of power".

The phenomenon of a person with a scientific or technical background achieving success as a writer is not unique to C P Snow. Arthur Conan-Doyle was trained in medicine, Charles Ludwig Dodgson (a.k.a. Lewis Carroll) was a mathematician and Neville Shute Norway was an eminent aeronautical engineer. While the "literary value" (however you define it) of their various works may be debated, those works are still widely read and probably will be for very many years. Yet not one of these three has been accorded the authority of a literary scholar (nor did they ever claim such authority). There are no grounds for according it to C P Snow.

Having said all this we must now observe that Snow has identified a real problem. The term "cultural impoverishment" may not be strong enough to apply to a situation in which very large numbers of people (including "literary intellectuals") remain ignorant of some of the most basic laws and forces of nature and the manner in which these laws and forces of nature (incompletely understood though they may be) influence their daily lives. This ignorance is dangerous in a strictly material sense since society as a whole is required to make enormously important decisions in which scientific and technical considerations play an important, if not dominant, part. And such decisions should not simply be left to the technocrats. An example with which most readers will be only too familiar is that set of decisions relating to energy policy.

The ignorance is also dangerous in a non-material sense. If a large segment of a society lacks even the most rudimentary sense of the way things work in the physical universe and the way in which our understanding of the way things work is evolving, then that segment is isolated from an immense range of intellectual experience. Spiritual and intellectual growth is stunted or distorted. A sense of wonder at and delight in the complexities and mysteries of the universe (using that term to mean everything "out there" and our own concepts of what it is) is part of the stock in trade of the good scientist, the good engineer – and the good writer. And the civilised human being.

So what do we do about it? Snow himself doesn't really suggest anything specific save that the educational system needs "rethinking" in order to decrease the level of early specialization. It is possible that Snow regarded the problem as insoluble since he states quite explicitly that non scientists are incapable of comprehending the nature of science "even if they want to". Certainly the way Snow has defined the problem – a clash between two irreconcilable "cultures" one of which is on

TECHNICAL SUPPLEMENT

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CHEMISTRY RESEARCH FOR THE CANADIAN NUCLEAR FUEL WASTE MANAGEMENT PROGRAM

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Atomic Energy of Canada Limited

CHEMISTRY RESEARCH FOR THE CANADIAN NUCLEAR FUEL WASTE MANAGEMENT PROGRAM

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ABSTRACT

This publication reviews chemical research in support of the Canadian Nuclear Fuel Waste Management Program. The overall objective of this research is to develop the fundamental understanding required to demonstrate the suitability of waste immobilization media and processes, and to develop the chemical information required to predict the long-term behaviour of radionuclides in the geosphere after the waste form and the various engineered barriers containing it have failed. Key studies towards the above objective include experimental and theoretical studies of uranium dioxide oxidation/dissolution; compilation of thermodynamic databases and an experimental program to determine unavailable thermodynamic data; studies of hydrothermal alteration of minerals and radionuclide interactions with such minerals; and a study examining actinide colloid formation, as well as sorption of actinides on groundwater colloids.

INTRODUCTION

This publication reviews chemical research carried out in the Research Chemistry Branch of Atomic Energy of Canada Limited to support the Canadian Nuclear Fuel Waste Management Program (CNFWMP). The overall objective of this research is to develop the fundamental understanding required to demonstrate the suitability of the waste form, and to develop the chemical information required to predict the long-term behaviour of radionuclides in the geosphere after the waste form and the various engineered barriers containing it have failed.

As it is now envisaged in the CNFWMP, used-fuel bundles will be sealed in corrosion-resistant containers (1). The containers will then be placed in a waste vault excavated deep underground in stable plutonic rock. The used fuel containers will be surrounded by a clay-based buffer to minimize groundwater ingress, and the vault, once filled, will be backfilled and permanently sealed.

In the long term, after failure of the containers, release of radionuclides contained in the used fuel would depend on the rate of dissolution of the UO_2 matrix in groundwater. Thus, we are conducting experimental and theoretical studies to determine the UO_2 oxidation/dissolution mechanisms as a function of pH, redox potential, temperature, radiation fields, and groundwater anion concentrations.

Furthermore, the solubility in groundwater of the various radionuclides contained in used fuel, and the transport of radionuclides through the geosphere, depend on chemical speciation. Thus, thermodynamic data are required to determine the important species and their concentrations in groundwaters of various ionic strengths. For this purpose, we are compiling thermodynamic databases for key radionuclides (U, Pu, Np, Cs, Sr, Tc, I) and groundwater ions (Na^+, K^+, Mg^{2+}, Ca^{2+}, Cl^-, SO_4^{2-}), and experimental programs are in place to determine unavailable data and to improve the accuracy of others.

Also, the transport of radionuclides through rock fissures would depend on their interaction (sorption, chemical reaction) with the hydrothermally altered rock surface. Thus, we have in place a research program to study hydrothermal alteration reactions of common minerals and to define the interactions of radionuclides with mineral surfaces.

Finally, in addition to transport of radionuclides as dissolved species, transport could occur either by sorption of radionuclides on existing groundwater colloids or by transport of pure radionuclide colloids. The latter can form, for example, by the precipitation of dissolved radionuclides on entering a lower-solubility regime. Thus, the sorption of uranium (VI) on magnetite and hematite colloids and the formation of uranium colloids, on reduction of dissolved uranium (VI), have been studied in detail as model systems representative of the behaviour of other actinides.

For brevity reasons, only the more recent highlights of work in this area are summarized below. A previous review (2) summarizes earlier work, and, of course, specific publications quoted in this and the previous review contain additional details.

CHEMISTRY OF URANIUM DIOXIDE

Uranium Dioxide Oxidative Dissolution

Electrochemical techniques and X-ray Photoelectron Spectroscopy (XPS) are being used to study the oxidative dissolution of UO_2. Earlier work (3-9) established the mechanism of oxidative dissolution of UO_2, at room temperature, as a function of pH, Eh, and groundwater anions (PO_4^{3-}, SO_4^{2-} and CO_3^{2-}). It has been established in those studies that the redox potential is the most important parameter affecting UO_2 dissolution. Specifically, for reducing conditions ($\leq$ -100 mV vs SCE), UO_2 undergoes very little dissolution, and significant dissolution occurs only when UO_2 is oxidized beyond the $UO_{2.33}$ (U_3O_7) stage. Also, it has been established that the uranyl ion UO_2^{2+} is the active intermediate in the oxidative dissolution of uranium dioxide, and that CO_3^{2-}, and other anions that form strong complexes with UO_2^{2+} enhance UO_2 dissolution. Acidic conditions also accelerate UO_2 dissolution.

Although the disposal vault environment is expected to be reducing, radiolysis of groundwater by radiation emanating from used fuel may modify the redox chemistry of the system. In general, radiolysis of water by alpha, beta or gamma radiation produces various molecular species (O_2, H_2, H_2O_2) and free radical intermediates (OH, H, O_2^-, e^-). It is thus necessary to ascertain the extent to which radiolysis products modify the oxidative dissolution of UO_2, and a program is in place to address this (10-12).

We found that hydrogen has no effect on the oxidative dissolution of UO_2, except perhaps at temperatures $\geq$ 100°C, in which case it appears to suppress oxidative dissolution. Oxygen, at a concentration of 10^{-9} mol·dm^{-3} and pH = 9, has no effect on UO_2 dissolution. However, in air or oxygen saturated solutions ([O_2] ~ 10^{-4} to 10^{-3} mol·dm^{-3}) at pH > 5, UO_2 dissolution proceeds by the formation of a film of $UO_{2.33}$ which is slowly converted to hydrated UO_3 or, in the presence of complexing ions, to UO_2^{2+} complexes (11,13). Hydrogen peroxide (H_2O_2) is about 200 times more effective than O_2 in oxidizing UO_2 in near-neutral (pH ~ 9) conditions (10). Our studies show that UO_2 oxidation in H_2O_2 increases with increasing pH for pH < 6, is unaffected by pH in the range 6 to 10.5, and decreases with increasing pH for pH > 10.5. The oxidation of UO_2 in the pH range 6 to 10, a range relevant to a waste vault in granitic environments, is significant when the H_2O_2 concentration is higher than 10^{-2} mol·dm^{-3} (12).

Electrochemical and XPS studies of UO_2 oxidative dissolution were also carried out in the presence of alpha- and gamma-radiation fields. We found that alpha radiolysis of water using radiation sources of alpha flux comparable to that expected at the fuel surface (~ 200 kBq) at the time of container failure (500 to 1000 years) did not oxidize UO_2 beyond the $UO_{2.33}$ stage. However, alpha fluxes greater than about 200 kBq lead to oxidation beyond the $UO_{2.33}$ stage. To assess the relative importance of radical intermediates generated by radiolysis of groundwater on the UO_2 oxidative dissolution, we developed an electrochemical system that enables studies in the presence of gamma radiation. Radicals such as OH, O_2^- and CO_3^- were generated selectively by irradiating certain solutions as shown in Figure 1. According to corrosion potential measurements, the efficiency of these radicals in oxidizing UO_2 decreases in the order O_2^- > OH > CO_3^-.

Recently, we have begun to address the effect of temperature on UO_2 oxidative dissolution, as the temperature of the vault could be as high as about 100°C, depending on vault depth and used fuel packing density. Studies of the redox potential at 55°C, pH 9.3 and 0.1 mol·dm^{-3} $NaClO_4$ show that relative to room temperature the rate of dissolution appears to be higher (by a factor of about 2), but the value of the redox potential beyond which UO_2 undergoes oxidative dissolution remains the same, i.e., ~ 100 mV vs. SCE.

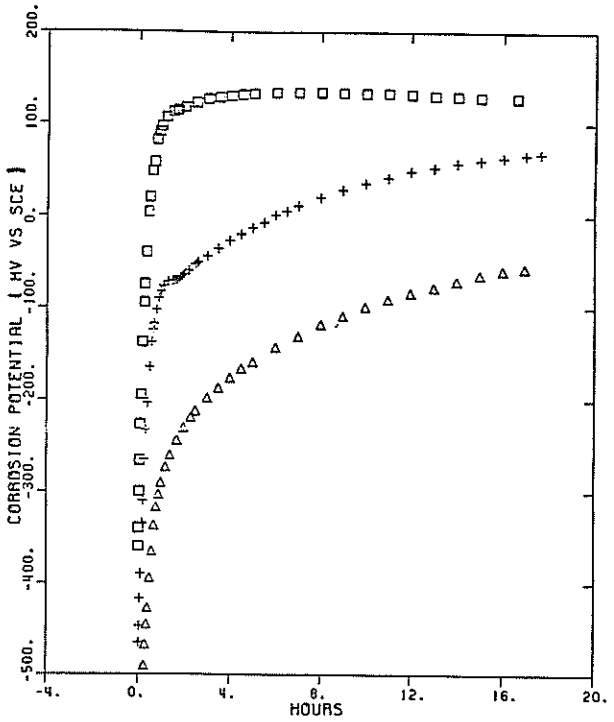

FIGURE 1: CORROSION POTENTIAL OF A UO_2 ELECTRODE IN THREE DIFFERENT SOLUTIONS UNDERGOING RADIOLYSIS: (A) O_2-SATURATED 0.1 MOL·DM^{-3} $NaClO_4$ + 0.01 MOL·DM^{-3} HCOONa, □ ; (b) N_2O-SATURATED 0.1 MOL·DM^{-3} $NaClO_4$, + , AND (C) N_2O-SATURATED 0.1 MOL·DM^{-3} $NaClO_4$ + 0.002 MOL·DM^{-3} Na_2CO_3, △ .

Theoretical Analysis of Used Fuel Dissolution

The safety assessment of used fuel disposal in an underground vault requires information on the rate of release of radionuclides from used fuel to the groundwater. Since more than 90% of the radionuclide inventory in used CANDU™ fuel is contained within the UO_2 grains, the major factor controlling the long-term release of radionuclides from used fuel is the rate of dissolution of the UO_2 matrix.

Used-fuel dissolution rates are often determined using solubility-limited dissolution models (14). In these models, the rate of used-fuel dissolution is limited by the solubility of UO_2, i.e., the dissolution rate decreases as the concentration of uranium in solution approaches C_o, the UO_2 solubility. This is illustrated by the curves in Figure 2. The dissolution rate, which is proportional to $-(\partial c/\partial x)_{x=0}$, decreases as τ increases. At long times, the used-fuel dissolution rate varies linearly wth the UO_2 solubility.

The UO_2 solubility is an important parameter in solubility-limited fuel dissolution models. Thus, using thermodynamic principles, we have derived an explicit mathematical formula to calculate UO_2 solubilities as a function of temperature, pH, oxidation potential and anion concentrations (15). In addition, thermodynamic reaction path calculations have been carried out to model the dissolution of UO_2 (16). The qualitative agreement between these thermodynamic predictions and electrochemical experiments supports the use of thermodynamically derived source terms in the safety assessment of used-fuel disposal.

More recently, we have begun to examine the impact of various phenomena, such as precipitation, on the rate of used fuel dissolution. The solubility-limited dissolution models that have been used to calculate used-fuel dissolution rates implicitly assume that the solubility of UO_2 is spatially invariant (14). However, the solubility of UO_2 could vary from location to location due to, for example, alpha-radiation-

induced redox potential gradients, and precipitation of a uranium-containing solid could occur in the vault environment. After precipitation (at $x = \ell$), the concentration profile of dissolved uranium is given by the dashed line in Figure 2. (In this example, the solubility of UO_2 is equal to C_o for $0 \leq x < \ell$ and equal to 0 for $x \geq \ell$). This concentration profile remains constant as long as the solubility gradient, which caused the precipitation, does not change. Thus, after precipitation, $-(\partial c/\partial x)_{x=0}$ is a constant, whereas without precipitation $-(\partial c/\partial x)_{x=0}$ decreases with time. Therefore, precipitation enhances the rate of fuel dissolution. This effect is particularly important at long times (17).

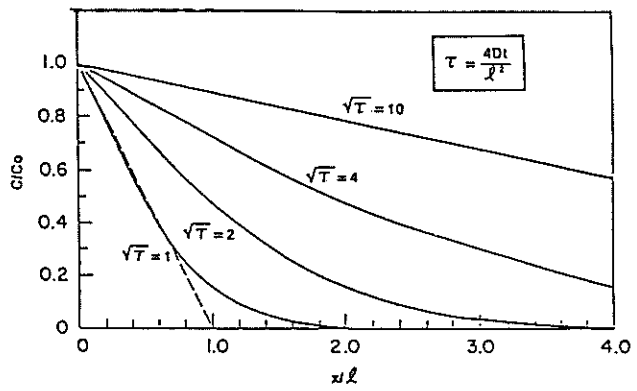

FIGURE 2: CONCENTRATION PROFILES OF DISSOLVED URANIUM AS A FUNCTION OF THE DISTANCE FROM THE USED-FUEL/BUFFER INTERFACE. FULL CURVES REPRESENT NON-PRECIPITATION PROFILES AT VARIOUS TIMES τ. THE DASHED LINE REPRESENTS THE CONCENTRATION PROFILE FOLLOWING PRECIPITATION OF A SPARINGLY SOLUBLE URANIUM-CONTAINING SOLID, AT A DISTANCE ℓ FROM THE FUEL/BUFFER INTERFACE

It should be pointed out that precipitation is not the only phenomenon that can increase the rate of fuel dissolution determined using solubility-limited dissolution models (18). In fact, any phenomenon that decreases the concentration of uranium in solution, e.g., adsorption or chemical reaction, would enhance the rate of fuel dissolution. The importance of all these phenomena in the vault environment must still be ascertained. For example, the magnitude and duration of any gradient in the UO_2 solubility must be determined before a realistic estimate of the effect of precipitation on used-fuel dissolution can be made using simple models.

THERMODYNAMIC DATA FOR KEY RADIONUCLIDES

Chemical Thermodynamic Databases and Calculated Solubilities of Actinides

A thermodynamic framework allows the results of a moderate number of relatively simple experiments to be used to estimate the solubility of UO_2 in groundwaters with widely different compositions and values of pH, temperature and electrochemical potential. The solubility can then be expressed as a function containing a limited number of parameters. Also, the transport behaviour of other actinides in the vicinity of a nuclear fuel waste vault or in the biosphere is dependent on the nature of the equilibrium chemical species. With good thermodynamic data, the important solids and solution species can be identified, and the behaviour of many of the actinides can be modelled.

A critical assessment of chemical thermodynamic data for solids and aqueous species of uranium, neptunium and plutonium is continuing as part of the NEA/OECD Thermochemical Data Base project (19). For those elements most important to the CNFWMP, this project will provide internationally accepted, internally consistent chemical thermodynamic databases that are compatible with the CODATA key values (20). A new interim database for uranium has also been prepared (21) to update and supplement earlier databases (22,23) until the NEA/OECD database is available.

For UO_2 to be a satisfactory waste form, it must be shown to be stable under reducing conditions for a range of groundwater compositions. Calculations have been done to show the effects of different ionic media (using activity coefficients and literature equilibrium constant data) on the solubility of uranium dioxide in model groundwaters (21). Three specific model groundwaters have been considered. Granite groundwater (GGW), which has a low ionic strength ($I < 0.002$ mol·kg^{-1}), Standard Canadian Shield Saline Solution (SCSSS), which is essentially a $Na^+/Ca^{2+}/Cl^-$ solution ($I \simeq 1.4$ mol·kg^{-1}) and SCSB/2, which is a high-chloride-concentration medium ($I \simeq 3.6$ mol·kg^{-1}) in which again the predominant cations are Na^+ and Ca^{2+}. The total carbonate concentration in GGW (1.0×10^{-3} mol·dm^{-3}) is higher than in SCSSS (1.6×10^{-4} mol·dm^{-3}) and SCSB/2 (1.0×10^{-4} mol·dm^{-3}). In the latter two groundwaters the carbonate content is essentially limited by the solubility of $CaCO_3$.

Our calculations show that, in the absence of uranate formation, uranium solubilities in these three model groundwaters are similar for strongly reducing conditions under which UO_2 is the stable solid. For mildly reducing conditions ($E = 0.50 - 0.0592pH$ V) under which U_4O_9 is stable (Figure 3a), the solubility also varies only slightly between the different model groundwaters (less than an order of magnitude within the pH range 6 to 11). This is coincidental. The stable solution species resulting from the dissolution of U_4O_9 (or U_3O_7) are primarily U(VI) species. The lower carbonate concentrations in SCSSS and SCSB/2 compensate for the increased stability of highly charged ionic U(VI) species, e.g., $UO_2(CO_3)_3^{4-}$, in the more saline groundwaters. As shown in Figure 3b, if GGW and SCSSS had the same lower total carbonate concentration (10^{-4} mol·dm^{-3}) as the SCSB/2, the calculated solubility of uranium in the more saline model groundwaters would be significantly higher (by as much as two to three orders of magnitude) than in the GGW.

Actinide Solution Chemistry

Work in this area is presently limited to the study of neptunium(V) chemistry. A knowledge of the aqueous solution chemistry of neptunium(V) is important in that it provides a model for the chemistry of uranium(V) and plutonium(V). Uranium and plutonium in the "(V)" oxidation state disproportionate to the (IV) and (VI) oxidation states much more readily than neptunium(V). Therefore, the "(V)" oxidation state for uranium or plutonium is much less accessible experimentally than it is for neptunium. Also, the predominant oxidation state of ^{237}Np (from nuclear fuel wastes) in solution in surface waters and mildly oxidizing groundwaters would be neptunium(V) (23).

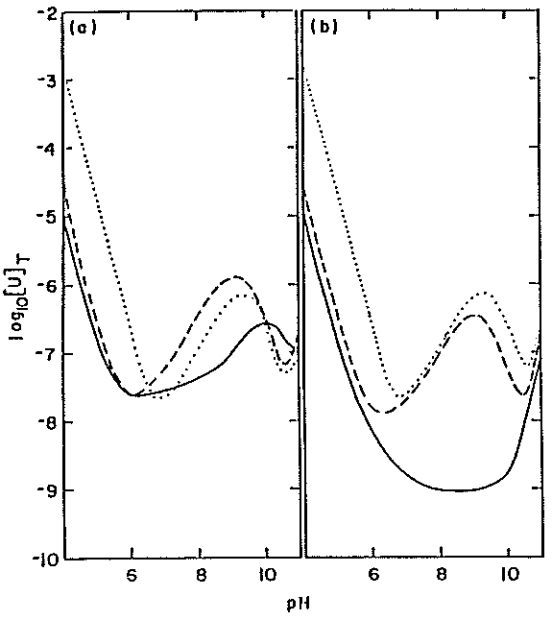

FIGURE 3: ACTIVITY EFFECTS ON URANIUM SOLUBILITY FOR MILDLY REDUCING CONDITIONS (E=0.5-0.592pH V, 25°C): ___ GGW; ----- SCSSS; ····· SCSB/2. (a) CORRECTED FOR ACTIVITY EFFECTS; (B) AS (A) EXCEPT THE MODEL GROUNDWATERS HAVE BEEN CHANGED SO THE TOTAL CARBONATE CONCENTRATION IN EACH IS 10^{-4} MOL·DM^{-3}.

Dioxoneptunium(V) forms a series of anionic carbonate complexes that enhance neptunium solubility in neutral and moderately basic aqueous solutions (24-27). Calculations suggest that the stability field of the carbonate complexes may increase significantly at higher temperatures (23); however, there are essentially no data available for temperatures above 25°C. In order to determine how the formation constants of dioxoneptunium(V) carbonate complexes change with temperature, we have measured the equilibrium concentrations of ^{237}Np in aqueous carbonate solutions (I=1.0, $NaClO_4$) over hydrated $NaNpO_2CO_3$ and $Na_3NpO_2(CO_3)_2$ at 30, 50 and 75°C.

At 30°C over $NaNpO_2CO_3$, a minimum solubility (~10^{-6} mol·dm^{-3}) occurs in a plot of neptunium concentration versus free carbonate concentration at a free carbonate ion concentration of ~10^{-3} mol·dm^{-3}. This is similar to results at 25°C (24). However, at higher temperatures the solubility minimum is less pronounced, and appears to be shifted to higher carbonate concentrations. It appears that above 25°C some conversion of hydrated $NaNpO_2CO_3$ to hydrated $Na_3NpO_2(CO_3)_2$ (and other carbonate-rich solids) occurs even at total carbonate concentrations considerably less than 0.1 mol·dm^{-3} ([Na^+]=1.0 mol·dm^{-3}). This conversion is sluggish even at 75°C, but seems to occur more readily as the temperature is raised. Preliminary results indicate the formation constant for $NpO_2CO_3^-$ increases slightly with increasing temperature.

Technetium Chemistry

Technetium-99 is produced in nuclear reactors with a fission yield of 6%. It is a long-lived beta emitter with a half-life of 2.1 x 10^5 years. Although its specific activity is low and its beta radiation weak, technetium-99 is considered a long-term hazard because of its long half-life and the large quantities involved. Moreover, the oxidized form of the element in water, TcO_4^-, does not interact strongly with geologic materials.

There are few chemical thermodynamic data for technetium(IV) species, although studies have indicated that technetium(IV) could be the stable form of the element in reducing groundwaters (28-30). Thus, the solubility of technetium(IV) oxides is being measured to develop a chemical thermodynamic database for technetium(IV) in order to model technetium behaviour in reducing groundwaters.

We have measured the solubility of amorphous technetium dioxide obtained in situ by titration of an acid technetium(IV) solution with sodium hydroxide. We have also measured the solubility of crystalline technetium dioxide obtained by the thermal decomposition of ammonium pertechnetate. Figure 4 shows the results for amorphous TcO_2 as a function of pH. The solubility curve is typical of that of most transition metal oxides. The solubility is minimum in the pH range from 6 to 9. Figure 5 shows similar results for crystalline TcO_2. Reliable data could not be obtained in acidic solutions due to the formation of a more insoluble compound with the acids used. Both forms of the oxide exhibit a similar behaviour as a function of pH, i.e., the solubility goes through a minimum of about 10^{-8} mol·dm^{-3} at near-neutral pH. More accurate data for the crystalline material would be required to assess reliably which of the two oxides is the thermodynamically stable form of technetium(IV).

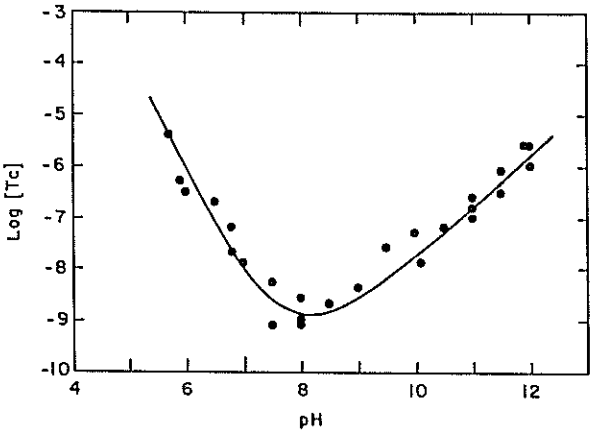

FIGURE 4: SOLUBILITY OF FRESHLY PRECIPITATED AMORPHOUS TECHNETIUM DIOXIDE AS A FUNCTION OF pH AT 25°C.

From our studies, the solubility of freshly precipitated amorphous and crystalline technetium dioxide appears to be of the order of 10^{-8} mol·dm^{-3} near neutral pH at 25°C. The oxidative solubility of amorphous technetium dioxide can be estimated by combining these results with available thermodynamic data. The standard potential for the cell reaction

$$TcO_4^- + 3/2H_2 + H^+ = TcO_2 \cdot 2H_2O$$

is -0.743 V, using the data given by Rard (31). Using this value, the activity of TcO_4^- over solid $TcO_2 \cdot 2H_2O$ near neutral pH has been calculated as a function of the redox potential. The results are shown in Figure 6. From Figure 6, oxidative dissolution will be the

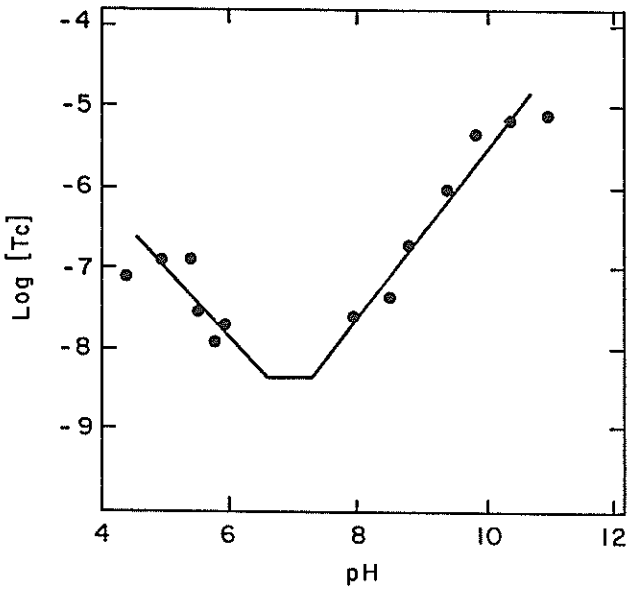

FIGURE 5: SOLUBILITY OF CRYSTALLINE TECHNETIUM DIOXIDE AS A FUNCTION OF pH AT 25°C.

dominant mechanism at pH 7 if the redox potential is above 0.45 V vs SHE at 25°C. Dissolved technetium(IV) species will predominate over TcO_4^- only at lower potentials. (It should be noted that these calculations assume that the amorphous oxide contains two water molecules. The results would differ if a different stoichiometry is used.)

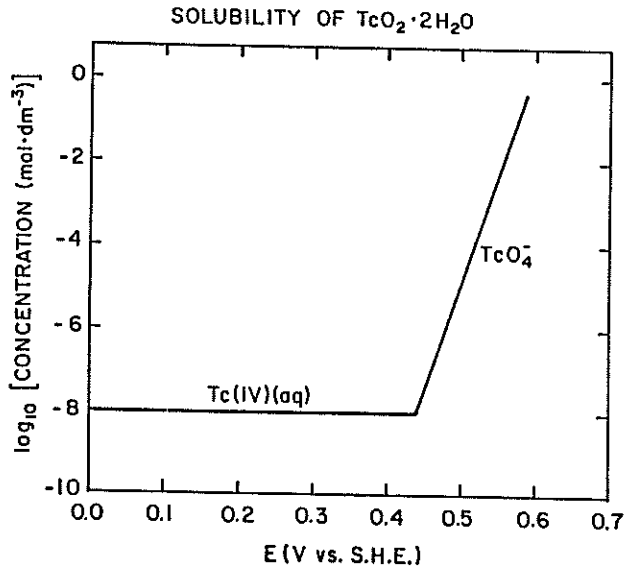

FIGURE 6: CALCULATED SOLUBILITY OF AMORPHOUS TECHNETIUM DIOXIDE ($TcO_2 \cdot 2H_2O$) AS A FUNCTION OF THE REDOX POTENTIAL AT pH 7 AND 25°C.

Heat Capacity Data

The primary objective of this program is to develop methods for obtaining key thermodynamic data (e.g., Gibbs energy, activity coefficient, enthalpy, etc.) for important fission products, actinides and groundwater ions at waste vault temperatures (~ 100°C). Such information is required to model the equilibrium behaviour of key radionuclides (I, Cs, Sr, Tc, U, Np) in groundwaters under vault conditions.

Towards this objective we have measured the heat capacity and density of aqueous radionuclide solutions as a function of temperature using a state-of-the-art flow microcalorimeter. An appropriate model was then applied to the measured data to develop equations for interpolating and extrapolating data. The temperature, pressure and composition dependence of the thermodynamic properties was represented by equations which use theoretical principles to combine the short-range (virial-type) and the long-range (electrostatic or Debye-Huckel type) interactions for modelling aqueous radionuclide solutions. The experimental and theoretical work has been completed for three fission products (Cs, I, Sr) and important groundwater ions (Na^+, K^+ Mg^{2+}, Ca^{2+}, Cl^-, and SO_4^{2-}). Comprehensive equations have been developed for calculating a number of thermodynamic properties (Gibbs energy, enthalpy, osmotic and activity coefficients, etc.) as a function of both the temperature and the pressure. This work is described in detail in recent journal articles (32-35). Currently, we are commissioning a new facility to obtain similar thermodynamic properties for radioactive solutions of technetium and neptunium.

WASTE-ROCK-WATER INTERACTIONS

The sorption of radionuclides on mineral surfaces in rock fractures, and perhaps their incorporation into mineral alteration products, provide mechanisms to retard migration of the radionuclides through rock fractures. Applied research programs are in place to measure sorption coefficients of representative radionuclides on a variety of mineral surfaces, and to characterize mineral alteration sequences on granite fracture surfaces. The following underlying research is being performed in conjunction with these applied programs.

In addition to empirical measurements of sorption behaviour, it is desirable to understand the mechanism of bonding between a sorbed radionuclide and a mineral substrate, and hence gain greater confidence in the prediction of radionuclide migration.

Determination of the structure of species sorbed on a mineral surface is a major challenge. Most surface analytical techniques provide information on elemental composition, and in some cases oxidation state, but little or no bonding information. Conversely, spectroscopic and diffraction methods that do provide bonding information are relatively insensitive to processes localized on surfaces. Fourier-transform infrared spectroscopy has been used with some success to glean information on bonding at catalyst surfaces and some soil minerals (36-38). We are presently evaluating its use to determine the nature of sorption interactions of interest. It shows greatest promise for simple polyatomic sorbates, such as oxyanions, with well-characterized infrared spectra that are sensitive to the strength and symmetry of the surface interaction. For monatomic sorbates, such as Cs^+, Sr^{2+}, or I^-, which have no innate infrared spectrum, information

might be obtained indirectly, from surface hydroxyl vibration features (see, for example, Figure 7B) in the substrate spectrum.

Iron oxide minerals comprise a small fraction of granite, but they are important in maintaining the desired reducing conditions, and also are capable of sorbing both cationic and anionic radionuclides. The spectroscopic studies are therefore focusing on iron oxides and related minerals. Magnetite has been shown (39) to immobilize dissolved technetium by reducing soluble pertechnetate (TcO_4^-) to an insoluble Tc(IV) species, which binds to the magnetite surface (Figure 7A). Ferric oxide minerals (e.g., hematite and goethite) are non-reducing and do not interact with pertechnetate, although they can sorb more strongly coordinating anions such as selenite.

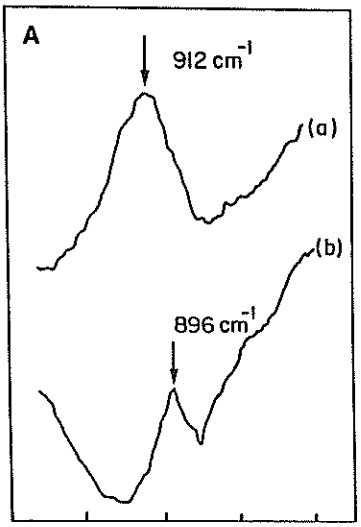

FIGURE 7A: INFRARED SPECTRA OF (UPPER) NH_4TcO_4 MIXED WITH HEMATITE, Fe_2O_3; (LOWER) MAGNETITE, Fe_3O_4, AFTER REACTION WITH NH_4TcO_4. LOWER FREQUENCY OF THE Tc-O STRETCHING VIBRATION INDICATES REDUCTION OF TECHNETIUM, PROBABLY TO A Tc(IV) OXIDE (FROM REF. (39)).

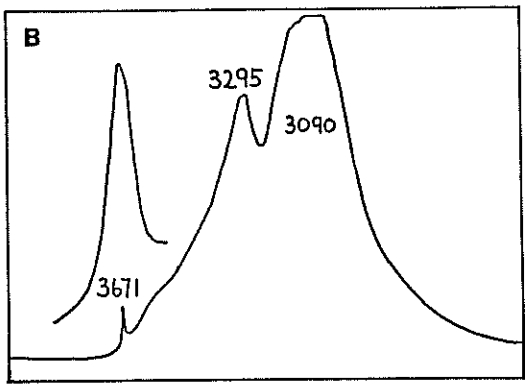

FIGURE 7B: INFRARED SPECTRA OF BOEHMITE, γ-AlOOH. MAJOR PEAKS AT 3295 AND 3090 CM^{-1} ARE DUE TO BULK HYDROXYLS. THE SHARP ABSORPTION PEAK AT 3671 CM^{-1} (ALSO SHOWN ENLARGED) AND THE BROAD, WEAK FEATURE AROUND 3560 CM^{-1} ARISE FROM SURFACE O-H VIBRATIONS.

Iodine-129 is one of the most problematic radionuclides, since the iodide anion is very soluble, and does not interact strongly with any common minerals. Consequently, current models indicate that it will be the principal source of radiation dose arising from a high-level waste disposal system. Recent experiments indicate that iodide may in fact be sorbed weakly by some iron-containing minerals. We are investigating this in more detail to determine whether this interaction may significantly retard iodine migration in the geosphere. This work will draw from our previous experience in the evaluation of candidate waste forms for iodine-129 (40).

Work on waste forms for iodine-129 and carbon-14 required an understanding of alteration processes involving hydrolysis and the displacement of I^- or CO_3^{2-} by other anions present in groundwaters (40,41). There are close parallels between these reactions and silicate mineral alteration reactions, which are largely a combination of hydrolysis and cation displacement. We are therefore using the methodology developed for waste-form reactions to help understand mineral alteration processes.

Cesium aluminosilicates, including the mineral pollucite (ideal formula $CsAlSi_2O_6$), are among the few insoluble compounds of cesium. They are known to be formed by reaction of cesium-containing solutions with a variety of aluminosilicate precursors, and have been proposed as host phases for radioactive cesium. We have examined their formation and alteration under hydrothermal conditions, and thereby estimated their thermodynamic stability limits (42). Results demonstrate that pollucite is unlikely to be formed in a waste repository, unless solutions are both alkaline and contain high concentrations of cesium. Again, the methods used are generally applicable to mineral alteration processes, although the experiments are time consuming.

In another study, we are characterizing mineral powder surfaces representative of the nuclear fuel-waste vault environments. This study is a prerequisite for interpreting mineral dissolution and for formulating predictive models for the adsorption of radionuclides onto mineral surfaces. For this work, we established a state-of-the-art sorption microcalorimeter system to measure surface areas and heats of adsorption.

Earlier, we developed a relatively convenient method for measuring surface areas of pure oxide powders, which was applied successfully to selected minerals (kaolinite, palygorskite, and feldspars). The principle, operating procedures and advantages of our calorimetric technique are described in detail in a recent publication (43). We have further developed this technique to characterize fracture-filling minerals with particular emphasis on the untreated minerals with surface areas less the 1 $m^2 \cdot g^{-1}$. Initially, we established a calibration curve using extensive saturation adsorption experiments on five alpha-alumina powders covering a wide range of surface areas (0.1 to 81 $m^2 \cdot g^{-1}$). We have also measured surface areas for quartz, albite, chlorite and kaolinite covering a range from 0.11 to 10.2 $m^2 \cdot g^{-1}$. Our results (0.11, 0.18, 1.2 and 10.2 $m^2 \cdot g^{-1}$) are in good agreement with the known BET values (0.15, 0.15, 0.8 and 9.5 $m^2 \cdot g^{-1}$), respectively. We are now extending our measurements to several fracture-filling minerals (basalt, calcite, chlorite, gabbro, goethite, granite, gypsum, kaolinite, hematite, illite, muscovite and piemontite).

COLLOID CHEMISTRY

In a nuclear waste vault located in granitic rock, colloidal transport of actinides such as uranium could take place in two ways. Actinides could be adsorbed onto groundwater colloids and be transported in that manner. Alternatively, if actinide dissolution and reprecipitation occurred, stable actinide colloids could form. Therefore, to determine the possible role of colloids as transporters of activity from a nuclear waste vault, it is important to understand the mechanism of colloid formation and behaviour in environments that are as similar as possible to those of an underground disposal vault. Thus, the research done in this program has focussed on the adsorption of uranium onto iron oxide colloidal particles and on the formation of uranium colloids by reduction of an aqueous uranium(VI) solution.

Early in the program, we studied the adsorption of uranium(VI) onto hematite particles (44-46). The effects of pH changes, and the effects of bicarbonate ions and humic acid were studied. These studies lead us to conclude that the adsorbing species in the absence of bicarbonate was likely a hydrated cation such as $(UO_2)_3(OH)_5^+$, whereas, in the presence of bicarbonate, a hydrated carbonate anion, possibly, $(UO_2)_2CO_3(OH)_3^-$, was the main adsorbing species. The effects of humic acid were complex, but it could both increase adsorption or decrease it, depending on conditions.

More recently, adsorption of uranium(VI) species onto colloidal magnetite particles was studied both in the presence and in the absence of bicarbonate. With bicarbonate present, adsorption was studied in the pH range of 7 to 9. The initial uranium uptake decreased as the pH increased, and an anionic hydroxy carbonate species is likely involved. At the highest pH and at uranium(VI) concentrations above 70 $\mu mol \cdot dm^{-3}$, a precipitate formed on the surface of the magnetite. This precipitate increased the apparent adsorption enormously, but, of course, this is not true adsorption. The precipitate consisted of very thin plates and contained a great deal of uranium. It did not form in control experiments where the magnetite was not present. A few studies were carried out of adsorption of uranium(VI) onto the same colloid, but in the presence of 500 $\mu mol \cdot dm^{-3}$ sodium chloride and in the pH range of 3 to 6. A small initial adsorption was noted at lower pH values, but this increased considerably when the pH reached 5.7. These adsorption results are roughly similar to those observed for adsorption of uranium(VI) onto a hematite colloid when adsorption is compared on a unit surface area basis. The largest adsorption corresponds to 2 $mg \cdot m^{-2}$, so the amount of actinide that could be transported by this mechanism is likely small.

An analysis of the Fe^{+2}/Fe^{+3} ratio in the surface of the magnetite sol was carried out using photoelectron spectroscopy. The Fe (3p) band was deconvoluted into Fe^{+2} and Fe^{+3} components according to the procedure of McIntyre and Zetaruk (47). The ratio was 0.08, suggesting that the surface does contain Fe^{+2}, but perhaps not in the full stoichiometric ratio.

The second phase of this work involved studies of uranium colloid formation by reducing aqueous uranium(VI) ions with sodium sulfide. Early work showed that uranium colloids were formed above 60°C (48), and that the colloids were either a mixed valency (uranium(IV) + uranium(VI)) oxide or a complex uranium(IV) hydrated oxide. More recently the reduction has been studied at temperatures as low as 10°C (49). At these temperatures the reduction is slow, yielding a dispersion of black particles. In some cases, a mixture of black and purple particles is formed. These particles were characterized by X-ray diffraction, X-ray photoelectron spectroscopy, scanning electron microscopy, Fourier transform infrared spectroscopy, photon correlation spectroscopy and microelectrophoresis. The black particles were found to be a mixed-valency uranium oxide, and the uranium oxide particles that formed at 10°C had a higher oxygen to uranium ratio on the surface than those formed at 25°C. There was some evidence that the purple particles were a reduced form of uranium. At higher pH or lower uranium concentration, a complex uranium(VI) hydrous oxide can also form.

We have also studied the effects of bicarbonate, humic acid and sodium chloride on the reduction of uranium(VI) to uranium(IV) by aqueous sulfide at 10° and 25°C (50). Bicarbonate tends to stabilize uranium(VI) towards reduction, but sodium chloride has little effect. Humid acid enhances the reduction. In most cases, either a reduced form of uranium or a mixed uranium oxide is formed. Characterization of the reaction products by X-ray diffraction, X-ray photoelectron spectroscopy, Fourier transform infrared spectroscopy and photon correlation spectroscopy has been carried out.

These studies have shown that uranium colloids could possibly form near a waste vault if certain, perhaps restrictive, conditions are achieved. The movement of these colloids would contribute to the mobility of uranium. Other actinides have not been investigated in this program but they could potentially behave somewhat similarly.

CONCLUSIONS

The above work highlights elements of an extensive program of in-depth chemistry research conducted by Atomic Energy of Canada Limited in support of the Canadian Nuclear Fuel Waste Management Program.

Electrochemical and spectroscopic studies, and theoretical thermodynamic calculations are being used to delineate the chemical conditions over which the fuel matrix remains integral and dissolves the least in groundwater. Work to date has shown that chemical conditions provided by environments such as those encountered deep in granitic rock formations, in the Canadian Shield, favour long-term fuel matrix stability with respect to dissolution.

A large component of chemistry research is also dedicated to assessing thermodynamic data, and measuring unavailable data, in order to determine radionuclide solubilities and to define chemical forms required to assess the transport of the radionuclide through the geosphere. This component of research shows that, with the exception of iodine, most radionuclides would not be transported easily through the geosphere due to low solubility in groundwater and/or strong interactions (sorption, chemical reactions) with the mineral surfaces.

Also, a limited number of studies have been conducted to define the conditions under which sorption of uranium on groundwater colloids and true uranium colloid formation can occur. Such colloids could form under certain restrictive conditions near the waste vault, but they are not expected to be an important carrier of radionuclides through the geosphere.

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the retreat – leaves no solution but the elimination of the retreating culture. Then, *voilà*, one "culture" only!

Perhaps the first question to ask is if the division of human intellectual activity into Snow's two categories reflects actual, fundamental differences in the nature of the activities. It will be argued here that, taking the widest view of these activities, it does not. Two years before Snow delivered the Rede lecture, William Beck (Professor of Medicine at Harvard) wrote:

> *We must recognize for what it is man's predilection for dividing things into tidy categories, irrespective of whether clarity is gained or lost thereby. Learning, thus, is scientific or humanistic .... We will come to realize that these boundaries have been established by us for our own reasons. They are man-made, and despite their long tradition, despite the problems of university organizers, book classifiers and curriculum planners, despite the tribal instincts of professional men, fields of learning are ultimately surrounded only by illusory boundaries – like the "rooms" in a hall of mirrors. It is when the illusion is penetrated that progress takes place. To the cell or the atom, it matters little whether its pursuer is a bio-chemist, philosopher or diplomat. Likewise science cannot be regarded as a thing apart, to be studied, admired or ignored. It is a vital part of our culture, our culture is part of it, and its continued separateness from what is fondly called "the humanities" is a preposterous practical joke on all thinking men*[6].

The last two centuries have seen what can be fairly described as a major scientific revolution. If one takes physics as an example, then "cataclysm" might be a more apt word. Was this "revolution" confined to what C P Snow would call "the science culture"? Looking at developments in literature (particularly poetry) and literary criticism over the same period one sees some interesting parallels.

Starting in the nineteenth century, poetry began increasingly to explore the conjectural nature of the universe – in both theme and imagery. The concept that the act of observation changes what's observed saw expression, initially by Emily Dickinson. In the twentieth century Eliot exploited the concept in his critical essays (particularly in his discussion of the Metaphysical poets) and in discussion of his own poetry (the meaning of his poems must "lie halfway between the poet and the reader"). By the post-World War II period it was becoming an accepted axiom among literary critics that the Heisenberg Uncertainty Principle appplied, in all its implications, as well to the world of poetry as it did to that of physics.

Literary criticism itself underwent a revolution. At about the end of the nineteenth century academic literary criticism – that is, studied discourse on works of literature – had begun to evolve from the vague invocation of absolute (but ill-defined) principles of what literature should be, to a more specific examination of specific texts. For a while criticism had two major aspects which are often informally defined by a contemporary *Punch* cartoon caption:

> *O cuckoo shall I call thee bird, or but a wand'ring voice?*
>
> *State the alternative preferred with reasons for your choice.*

Coincident with the abandonment by science of the absolute we see the start of critical focussing on items of literature *per se*. The literary equivalent of the luminiferous aether was discarded. This process started with rigorous Shakespearian textual scholarship (interestingly enough led by German academics) and, over the next three or four decades, evolved into the highly disciplined technique of practical criticism in which profitless (if mellifluous) speculation on the transcendental was replaced by the exercise of examining the words of the works themselves. An important feature of this method of analysis is in the fundamental requirements it makes of the practitioner – the ability to approach a problem with a good all-round critical awareness, to carry out a rigorous systematic analysis and to reach conclusions that are well supported by the evidence. These abilities seem to be not altogether dissimilar to those of the scientist.

An interesting (and surely not coincidental) parallelism between science and literature may be seen when the following two passages are compared:

> *People like us, who believe in physics, know that the distinction between past, present and future is only a stubbornly persistent illusion*

> *Time present and time past*
> *Are both perhaps present in time future,*
> *And time future contained in time past.*
> *If all time is eternally present*
> *All time is unredeemable.*
> *What might have been is an abstraction*
> *Remaining a perpetual possibility*

The first is from a letter by Albert Einstein written in March 1955 some four weeks before his death[7]. The second is from T S Eliot's "Burnt Norton" (1935), the first of the Four Quartets[8].

Snow founded his discourse on the assumption that something called "science" and something else called "literary culture" live in separate boxes, that the contents of the "science" box are accessible only to card-carrying scientists (see above, "even if they want to, they can't") and that science aims at bettering the material lot of human kind while the literary types gaze moodily into the existential void and wait for death. That initial assumption does not seem justified and *The Two Cultures*, at best, makes the scientists feel good, the "literary intellectuals" annoyed and establishes an unreal and unnecessary class structure in the intellectual/academic environment.

On the other hand Beck gives us a rather more plausible, useful and optimistic starting point. That all – physicists, painters, chemists, dramatists, biologists, novelists, mathematicians and poets (to name a small but representative selection) – are labouring in the same vineyard. The universe is a marvellously puzzling, ambiguous, paradoxical, frightening and exciting sort of place. Everyone's trying, if not to make sense out of it, at least to illuminate it – however flickering that illumination may be. The thing called "science" (not to mention the thing called "engineering") has, over the last two centuries, evolved some formidable tools that can help in that. Those tools

belong to and are usable by everyone – not just the inhabitants of one of Snow's cultural boxes.

David Mosey

Notes

1 C P Snow, *The Two Cultures and the Scientific Revolution*, Cambridge University Press, 1959.

2 The motivation cited by Snow, essentially improvement in material welfare, is certainly not one to be sneered at. It seems to be most directly that of engineering – one of the simplest and most noble descriptions of any profession is one of the Oxford English Dictionary's definitions for "engineer": one who designs and constructs "works of public utility". Science generally could also be said to have as its ultimate aim the betterment of humankind's welfare. And such a worthy aim undoubtedly impels many people towards careers in science or engineering. But is what drives them when they're actually "doing" science or engineering? It is plausible to suggest that while doing the work (rather than considering it in an abstract and generalistic way) attention and creative drive are focussed on the actual project in hand – the project itself becomes the motivation and the results can be quite wonderful. This may be one of the closer relationships between art, particularly poetry, and engineering.

3 It's somewhat ironic when reviewing the progress of the industrial revolution in Britain to note that the people who actually drove that revolution through were not the scientists, but the engineers – many of them self educated – and even more ironic to observe that they did so in spite of the scientists. The most notable example of this is the case of the railways where the received wisdom was that such contraptions clearly defied the laws of science as well as the laws of God. Snow's assertions about the lack of appreciation of the nature and significance of the industrial revolution exhibited by the "literary culture" should be applied to the 19th century scientific establishment. Snow doesn't really talk about engineers, indeed he seldom uses the words "engineer" or "engineering" and certainly not in the context of the "science culture". Perhaps he took them for granted – a not uncommon oversight.

4 The Metaphysicals made particular use of Newton's physics (especially in the areas of gravitation and optics). Dickinson's poetry is so strongly marked by the use of scientific and technical concepts and images that it is difficult to suggest individual references, however her much-misinterpreted poem "I like to see it lap the miles" could be cited as a representative comment on technology, "Safe in their alabaster chambers" an exploration of the concept of an expanding universe and "Before I got my eye put out" as the employment of a scientifically accurate comparison of monocular and binocular vision for an extended metaphor. The writings of H G Wells are well enough known to all. Shaw's exploration of scientific themes might be best exemplified by *The Doctor's Dilemma*. Kipling, a writer who has been quite incorrectly labelled as a leading celebrant of British Imperialism (and hence received until recently little serious critical attention), is remarkable in his celebration of engineers and engineering (especially marine engineering) – perhaps the best example is *The Devil and the Deep Sea*. Auden, unarguably a major literary figure of the twentieth century, originally wanted to become a mining engineer and always maintained a more than ordinary interest in geology (see "In Praise of Limestone"). Tom Stoppard's latest play, *Hapgood*, is a remarkable use of the quantum theory as an extended metaphor for counter-espionage activities involving double (and perhaps triple) agents. Or it may be the other way round.

5 Allan Danzig (Ed), *The Theme of the Machine*, William C Brown Company, Iowa, 1969

6 William S Beck, *Modern Science and the Nature of Life*, Harcourt, Brace, 1957.

7 This letter is quoted in Freeman Dyson's *Disturbing the Universe*, Harper and Row, New York, 1979

8 T S Eliot, *Collected Poems, 1909 – 1962*, Faber and Faber, London, 1963.

Book Reviews

Pallid Praise

Mind, Heart, and Vision: Professional Engineering in Canada, 1887 to 1987, Norman R. Ball, National Museum of Science and Technology/National Museums of Canada, Ottawa, 1987, ISBN 0-660-12000-3.

In the introduction to this book the author laments that "Canada's engineering heroes and their accomplishments remain largely unsung". He goes on to note that "Canadians are well-known for their reluctance to celebrate or even recognize excellence in their own country" and remarks with disapproval that "most Canadian historical studies have tended to ignore engineering". This book then has as its purpose to provide "an introduction to engineering excellence and the essential role engineering has played in Canadian history".

The occasion for producing the book was the centenary, in 1987, of the founding of the first Canadian professional engineering organization, the Canadian Society of Civil Engineers. From its coffee table format, the book is clearly intended for the general reader and is arranged (sensibly enough, on the face of it) to span the hundred years linearly in seven chapters. The numerous photos (there are from one to four pictures on most of the book's 167 pages) depict all the main themes in the book – railways, canals, bridges, roads, and in the later sections, transportation, aviation, telecommunications, and buildings. With such a vast amount of material to be covered, few topics get more than a few pages, including photographs. As an example, the complete story of the CANDU reactor over its 40 year history rates only about 300 words and no photos.

There is certainly something to be gained from this book, even if it is only the vaguest idea of the size of the job undertaken by the early engineers, the conditions they had to endure and the imagination and initiative they brought to the task. However, more might have been expected and the book is disappointing and perplexing in some ways.

Part of the problem lies with the unimaginative linear recounting of events in time series. While the railways, canal building and the two wars provide natural themes around which different sorts of engineers and their work will naturally cluster, the text is too compressed to allow any but the grand-

est themes to be developed. Also, the treatment of the leading engineers is very brief; an individual pops out of the text, but there is only time for a few words about him or her before the narrative hurries onwards. It may be that the book was intended to be restricted to recounting the achievements of engineers resident in Canada, but it is perplexing that the role of Robert Stephenson, designer of the Victoria Bridge over the St Lawrence at Montreal, receives no mention, particularly when the bridge itself is identified as "one of the outstanding landmarks of nineteenth century engineering in Canada". There is also a peculiar shortage of information on engineers from Quebec.

A greater difficulty is the oddly flat and uninspiring character of the writing. Perhaps space, or a perceived need to produce a factual and somewhat prim text (the author is Head of Research at the National Museum of Science and Technology) served to throttle an occasional burst of adrenalin. Somewhat greater license would have enlivened the rather remarkable story of telecommunications in Canada, or the country's strange prominence in aviation right from the earliest days. The author's weak tut-tutting over the way the Arrow was cancelled is certainly no tribute to those who designed, built and flew it. (All the drawings, design notes, flight records, official photographs, and all the planes were, for some unrevealed and possibly dark reason, completely destroyed. There is little physical evidence remaining that the plane ever existed.)

This history of professional engineering will be as unsatisfactory to engineers as it is likely to be uninspiring for the general reader. The Mind and Vision of Canadian engineering may have been chronicled and recited briefly, but the Heart is still missing. The heroes and their achievements still remain to be *sung*.

Keith Weaver

Form and Content

Geometry and the Visual Arts, Dan Pedoe, Dover, ISBN:0-486-24458-X

To those of us of middle age or beyond, "geometry" may conjure up memories of the relationship between angle AOC (at the centre of a circle) and ABC (at the circumference), the particularities of the rhombus and the teeth-edging CREEEK-GROINK noise of the maths master's board compasses. For the younger set, unfortunately, it may conjure up nothing at all. Geometry now seems to be widely regarded as an area of endeavour properly within the ambit of the mildly eccentric or antiquarian sort of chap who might otherwise spend time collecting rare moths, writing Greek verse or composing music for the sackbut.

Dan Pedoe's book should change all that. As he notes in his Preface, not only does geometry have enormous historical interest and aesthetic appeal, but is a practical and powerful tool for artist, architect, logician, mathematician and engineer, and a source of fascination to anyone. Pedoe, Cambridge educated and now Professor of Mathematics at the University of Minnesota, has written a book which will delight, inform and stimulate any reader.

Modestly describing the work as "a diversion into the by ways of history" Pedoe begins by showing us the enormous importance of geometry to Vitruvius, Albrecht Dürer and Leonardo da Vinci and illustrates their own contributions to the subject.

In the first chapter we are introduced to those aspects of geometry to be found in Vitruvius' *Ten Books on Architecture*. Vitruvius argued that an architect must not only be skilful with his pencil and instructed in geometry but also should be conversant with history, have followed the philosophers with attention, understand music, have some knowledge of medicine be interested in the opinions of jurists and aquainted with astronomy and the theory of the heavens. Undoubtedly Vitruvius felt that "other duties as required" went without saying. But as Pedoe points out, the rationale for requiring such a catholic array of qualifications was eminently reasonable – for example, an architect required to design a theatre must be able to produce an acoustically optimum design and must therefore understand something about music. Musical expertise was also required when working on military projects – not for writing victory marches, but for ensuring equal tension in the cables of ballistae and catapults. Pedoe's book is stuffed with fascinating little nuggets like these, not only entertaining and enlightening in themselves but serving to illuminate and enliven his major theme.

Vitruvius' *Ten Books* included detailed observations on the proportions of the human figure, the utility of the 3, 4, 5 triangle in constructing staircases, planning the street layout of a city, the incorporation of optical illusions in architecture and the design of an odometer for chariots. All of this, Pedoe points out, demonstrates that in Roman hands geometry was an essential and powerful tool. Just how powerful, he invites you to find out by completing the exercises at the end of the chapter. Using just compasses and straight-edge you may carry out the simple task of constructing hexagons and duodecagons, then move on to the regular pentagon (think a bit about that one), a number of specified angles and selected spirals. You are also invited, by inscribing a square within a square, to deduce Pythagoras' famous theorem about the relationship between the sides of right angled triangles.

In his second chapter, Pedoe hops about a millenium and a half on from Vitruvius (early Christian period) to the fifteenth century Albrecht Dürer (1471-1528). He makes no apology for doing so, for Dürer was not only a fine "natural geometer", and the figure most often cited as the German incarnation of the Renaissance, but the author of two major treatises: *Underweysung der Messung mit dem Zirckel und Richtscheyt* (on descriptive geometry) and *Vier Buecher von Menschlicher Proportion* (on human proportions). The former, Pedoe points out, is important in two respects. It is the first literary document in which a strictly representational problem receives a strictly scientific treatment. It also emphasizes that perspective, to which Dürer devoted considerable research, was not simply a technical discipline subsidiary to painting or architecture, but an important branch of mathematics capable of development. Indeed, Dürer can be fairly credited with laying the foundations of that development which culminated in projective geometry and inventing some of the first technical aids to accurate perspective representation.

A fairly short chapter discusses form in architecture and the various theories which have been fashionable from time to time. Many strands of aesthetic principle developed in earlier chapters – particularly those of Dürer and da Vinci – are drawn together and projected forward to their more recent application, for example Le Corbusier's "Modulor". What is particularly interesting here is Pedoe's's illustration of the manner in which geometry has been consistently used to derive or document and formalize these principles.

Two chapters are devoted to Euclid who is introduced through his *Optics* and *Elements of Geometry* – the latter work being that which for a while shared with the Bible the honour of being the world's best seller. Pedoe explains that while *Optics* is the lesser work it has particular significance in that it introduces the first concepts of proof in geometry, this concept subsequently being fully exploited in the *Elements*. Pedoe's examination of the *Elements* alone is worth the price of the book, since it is in this chapter that he not only deals exhaustively with the concept of proof but also opens up a startling trapdoor to the world of Gauss, Bolyai, Lobachevsky and Poincaré – non-Euclidean geometry – "one of the great leaps forward of the human mind". This trapdoor was designed by Euclid himself in the form of Postulate 5 which is unique in that it is independent of the other Euclidean postulates and cannot be deduced from them. As Pedoe points out, Euclid left us with the key to the non-Euclidean universe and hence can justifiably be recognised as the first non-Euclidean geometer!

Pedoe notes that the concept of non-Euclidean geometry was (and is) not appealing to all, citing not only a post-war Oxford philosopher who always became incensed when any young gentleman was rash enough to mention the possibility of non-Euclidean geometries, but also the elder Bolyai who wrote to his son in 1820 to caution him about obsessive interest in Postulate 5, arguing "you should detest it as much as lewd intercourse".

The final three chapters build on the previous six. Pedoe introduces Cartesian and projective geometry and shows how some of the great theories of projective geometry can be used in perspective drawing. Some of those most beautiful and subtle curves, from conic sections to equiangular spirals, "which geometers should certainly not keep to themselves" are explained, methods of construction illustrated and mathematical embroidery is introduced. And then Pedoe concludes by examining space, offering "adventures in two, three and four dimensions".

One of Pedoe's strengths in this book is the effortless way he can hop back and forth from Poincaré to Euclid via Dürer and half a dozen other classical geometers, without for one moment losing or confusing the reader, while illustrating the evolution of particular geometrical concepts. Another strength is his use of just the right anecdote at just the right time to fix an idea, or give it some three dimensional background. Whether he's explaining the physical contortions necessary to ascertain Holbein's point of view in *The Ambassadors* (Pedoe was nearly chucked out of Britain's National Gallery by attendants suspicious of his twisting and turning) or recounting how many oxen Pythagoras sacrificed to celebrate his discovery of THE theorem, Pedoe never fails to entertain, educate and leave you hungry for more. In fact the whole style of the book is that of a series of tutorials with an erudite and witty professor who, in the middle of being witty and erudite (and making you feel that you're a pretty bright sort of chap too) will shoot in the odd sudden and disconcerting question, such as "what do you mean by proof?".

If Pedoe's lectures are one tenth as good as his writing, then he's a formidable teacher. Indeed *Geometry and the Visual Arts* would be a valuable text for teachers at any level (from fifth-grade to undergraduate) and in almost any subject area – as Pedoe hiumself notes, "experience with a wide variety of audiences, in many different countries, has shown that the topics discussed here interest the majority of literate people". He's right. It will be a dull reader indeed who will not be infected by Pedoe's affection and enthusiasm for his subject.

The publisher's blurb on the dustcover puts it this way: "For artists, mathematicians, architects, students, teachers and all those who delight in the beauty of geometric forms, *Geometry and the Visual Arts* is an indispensable addition to the bookshelf and a lasting delight to the mind and the eye". That about says it.

David Mosey

Statistics With Significantly Fewer Tears

Practical Statistics, S.S. Cohen, Published by Edward Arnold, London, 1988, ISBN 0-7131-3648-0.

Mood and Graybill, Feller, Bowker and Lieberman, are all recognizable as snatches from a distant dream, to those of us with fairly long incisors. Of course for some it could be a nightmare, depending on how close to the final exams their "change" occurred. (The "change" is that annual redirection in an engineering student's search for truth, from the beer bottle and the other sex to the course books.)

Having discovered, some months after graduation, that statistics actually does have some use in making sense of the chaos of experimental and test data, the now gainfully employed engineer usually has little taste for ploughing again through pages of theorems and endless stratospheric explanations. Fortunately our engineer now has *Practical Statistics* to turn to.

This book contains no theorems. In their place are numerous examples of different sorts of statistical problems. There are exercises at the end of each chapter, and these are mercifully free of exhortations to display one's algebraic virtuosity. The text covers the basics (terminology and types of distributions), the problems of one sample, two samples, many samples, experimental design, sampling and sample surveys, quality control and a final chapter on computing aspects. But the two real strengths of the book are the clarity of its writing and the many well-explained examples. There is also a sensibly arranged bibliography and an index that includes references to the examples that appear throughout the book.

Purists and their disdain notwithstanding, this sort of Guide for the Statistically Perplexed is a welcome addition to the book shelf.

Keith Weaver

Publications Noted

The Radiological Accident in Goiania, IAEA, Vienna, 1988, STI/PUB/815, ISBN 92-0-129088-8

Serious radioactive contamination resulted from the disassembly by local residents of an abandoned radiotherapy machine containing caesium-137. The source capsule was opened and particles of caesium chloride were widely distributed resulting in the internal and/or external contamination of 249 people. Four deaths resulted. This report stems from an investigation of the incident by an international panel of experts and includes a detailed chronology of the event and the immediate and near-term responses including medical treatment, environmental assessments, decontamination and waste disposal. Concise and clearly written, this Report should be required reading for safety professionals and contingency planners. It's chilling reading for anyone.

The lessons of Chernobyl are important for all, Valeri Legasov, Novosti Press Agency Publishing House, 2304000000. Translated by Valeri Epstein.

This booklet is one of a series entitled "Expert Opinion" put out by Novosti Press Agency for readers "who are eager to obtain reliable and exhaustive first-hand information on the USSR's accelerated social and economic development" and appears in a question and answer format. As those who read his posthumously published article in *Pravda* last May will know, the late Academician Legasov wrote with clarity, eloquence and conviction that show through the filters of translation. The Novosti booklet is aimed at "the general public", yet avoids being patronising, obscurationist, misleading or irrelevant. Legasov deals with the issues in a forthright manner, and doesn't mince words. An impressive insight into the Soviet approach to public information the booklet is commended particularly to those on the public affairs side of the nuclear business. But anyone would find it interesting.

A Korean connection

Whether it be "reactor trip", "business trip" or "pleasure trip", one always seems to have to report on it. A "reactor trip" demands a significant event report to the regulator, a business trip demands a justification report to the boss to recover expenses and a pleasure trip usually requires a slide presentation to friends and neighbours. This report is about the business aspects of my recent sojourn in South Korea. As far as the pleasure aspects of the trip are concerned, they're my own business. However I would enthusiastically recommend the trip to anyone – it was a wonderful experience.

How did I get so lucky? In late 1987 I was fortunate enough to have a couple of papers accepted for the Third International Topical Meeting on Reactor Thermal Hydraulics and Operations which was to be held in Seoul. Hosted by Korea's Advanced Institute of Science and Technology, this major event was organized principally by the Korean Nuclear Society in conjunction with the American Nuclear Society. CNS cosponsored the meeting. An indication of the size and significance of the conference is given by the fact that it drew 263 papers from 12 countries including 34 papers from Canada. The week-long conference was extremely well run with a fine range of technical papers, an exhibition and technical tours.

South Korea has a major committment to nuclear energy. Indeed, 52 percent of its electricity was nuclear generated in 1987. By the end of last year the estimated nuclear contribution was 56 percent, supplied by 6600 Mwe of installed nuclear capacity. Three more reactors will be in service by 1996. All are LWR with the exception of the single Wolsung CANDU. Not only is the Korean construction programme one that would be the envy of many, but so is their operational record, with combined average capacity factors for all their nuclear units knocking on the door of 80 percent.

I was fortunate enough to have the opportunity to meet many officials involved in South Korea's nuclear energy development and from my conversations with them it is clear that nuclear energy has a bright future in South Korea.

While it was not unexpected that the conference tended to be dominated by LWR technology, it's still surprising (and depressing) to find so many PWR and BWR affiliates who don't know (or don't want to know) the attributes of the CANDU, such as its high neutron efficiency and on power fuelling, etc. Howver CANDU performance and capabilities were certainly well described at the conference and were backed up by a site tour of the Wolsung CANDU station site following the formal programme.

On my arrival in Seoul I was met by Patrick Tighe of the Seoul office of Atomic Energy of Canada Limited (AECL). The Korean CANDU at Wolsung is performing extremely well and both Patrick and Manager Bob Keating are doing a marvellous job as AECL technical advisors to the operating unit, as well as keeping the CANDU in the forefront of the options for any future reactor business in South Korea. The AECL office staff were a great help during my stay, helping to organize meetings with South Korean officials. They have also offered assistance in future communication with the Korean Nuclear Society.

The Korean Nuclear Society, like our own organization, is a Society for individuals who have an interest, professional or otherwise, in nuclear technology. Our objectives are therefore very similar. We had, for some time, been talking with the Korean Nuclear Society on a cooperation agreement between our two organizations and I was hopeful that this could be signed during the proceedings.

This hope was realized following my meeting with the President of the Korean Nuclear Society, Dr. Pilsoon (also President of the Korea Advanced Energy Research Institute). We signed the agreement for cooperation between our two organizations and then drank a toast to the next CANDU in South Korea.

The agreement is similar to the one we have with the Chinese Nuclear Society, namely to:

– promote the establishment of contacts with members of the other Society for the purpose of exchanging information and experience

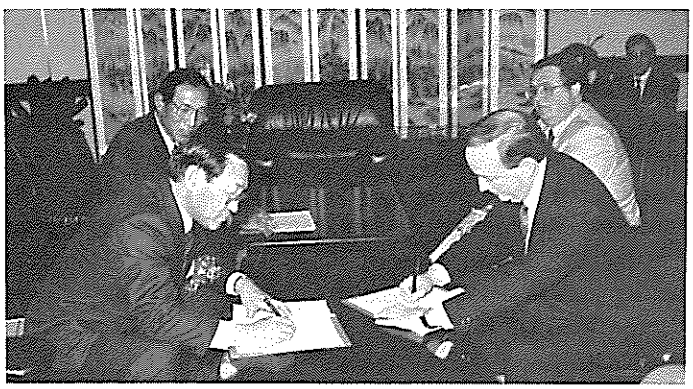
– assist in facilitating exchange visits for the purpose of cooperation and information on aspects of nuclear science and technology

– encourage the interchange of technical information, journals and periodicals which are jointly identified by the executive officers of each Society

– inform the other in advance of sponsored conferences and meetings of international significance, and also to charge no basic registration fee for three official representatives who have preregistered.

The Korean Nuclear Society gave us a fine conference that in itself was ample justification for the trip. But as well it provided an opportunity for initiating what is certain to be a most fruitful relationship between our two organizations for the furtherance of the peaceful uses of nuclear energy.

Ken Talbot



CNS President Ken Talbot and KNS President Dr. Pilsoon-Han sign cooperation agreement.

CNS Branch News

Ottawa Branch

AMPS Submarine Nuclear Power Plant Development

Recent progress on prototype demonstrations of principal technologies of the recently advanced AMPS nuclear power plant was reported on October 20, 1988 at the second seminar of the season organized by the Ottawa Branch of the CNS.

The AMPS nuclear plant, intended to provide small-scale nuclear power primarily in the submarine environment, is under development by ECS Power Systems of Ottawa. Not surprisingly, the usual turn-out to the seminar series was augmented by a uniformed cadre from the Department of National Defence.

Ron Gray, Supervisor of Reactor Development and Testing at ECS, presented a photographic record of the construction and assembly of the Company's multi-million dollar thermalhydraulics experiment, designed to verify the special thermalhydraulic concepts which had to be incorporated in the design to meet the stringent submarine requirements relating to size, weight and safety. The experiment allows the investigation of both special effects and system behaviour of all important thermalhydraulic phenomena of the AMPS concept under a variety of operating and accident conditions. Studies include flow, temperature, and critical heat flux profiles of the AMPS core, as well as the uneventful defaulting of the system to passive cooling on strictly hydrodynamic (non-mechanical) principles, regardless of the physical orientation of the submarine containing the reactor plant. By reporting extensive experimental data, the speaker supported his claims that, although the series of tests was not yet completed, the results to date confirmed performance to be as good or better than those called for in the design.

Nino Oliva, Vice-President of Engineering at ECS Power Systems, was also on hand to give a run-down on the background of the ECS Group of Companies and the overall objectives of the AMPS development. The Group, which includes German and Milne Inc (marine engineering and naval architects), TIAC Systems Inc (computer and control systems), and Infintum Sciences Ltd (special computer analyses), as well as ECS Power Systems Inc (nuclear plant design, development and application) constitutes a team of engineering, scientific and technical professionals working on various aspects of the AMPS development and, in addition, providing services and products in the nuclear, marine, and computer fields in general.

ECS, originally established in 1973, began to take on its present organizational form in early 1985 to respond effectively to a contract to supply an autonomous marine power source (AMPS) for an oceanographic exploration submarine. In addition to continuing its civilian focus, ECS is actively pursuing the adaptation of the AMPS, as a generic reactor type, to the modern diesel electric naval submarine and thus create the nuclear hybrid submarine. This approach endows the conventional submarine with the atmosphere-independence of the full-scale nuclear submarines planned for acquisition by the Canadian Navy.

Market studies show that many of the world's navies are keenly interested in acquiring the hybrid submarine which combines the sprint capability and stealth of the conventional submarine with the submerged endurance of a nuclear submarine. Moreover a number of the world's submarine manufacturers, recognizing this market potential, are working closely with ECS on the evolution of the fully integrated nuclear hybrid concept.

The thermal hydraulic experiments are being conducted according the ECS design, specification, and direction by Stern Laboratories in Hamilton. The experiment serves as a full-scale demonstration of the AMPS thermalhydraulics in the civilian (100 kWe) application and, at the same time, serves as a scaled prototype study of the thermalhydraulic design applicable to the larger hybrid submarine designs. Such designs call for propulsion and auxiliary outputs of up to 1000 kWe. A prototype 140 kWe low-temperature Rankine cycle engine, also designed by ECS and configured to fit in the restricted space of a very small submarine, is currently being assembled at the Stern Laboratories. Actual testing of this component will begin in early 1989.

The presentation prompted from the audience numerous expressions of interest in the technical and organizational aspects of the AMPS programme.

Toronto Branch

"Excellence in Science" Awards

The Canadian Nuclear Society is committed to the contined strengthening of the scientific/engineering industrial and academic base in Canada. To this end the Toronto Branch co-sponsors a number of technical information presentations and university symposia each year.

Rather than provide the speakers at our meetings with honoraria, we have instituted the Canadian Nuclear Society Scientific Excellence Awards. These $50 prizes are donated on a one-time basis to Canadian high schools chosen by the speakers. The chosen school, in turn, presents the Award to a deserving graduating student selected by the school. We do not specify that the recipients should should be those with the highest science marks, but rather should have demonstrated a

strong aptitude and ability in any scientific discipline, with a performance worthy of recognition.

The winners for 1987-8 were:

Peter Unrau, Mackenzie High School (Deep River, Ontario)

Phil Reiss, Joseph Wolinsky Collegiate (Winnipeg, Manitoba)

Stan Polak, Mimico High School (Etobicoke, Ontario)

Robert Wickham, Woburn Collegiate Institute (Scarborough, Ontario)

Guy Lemieux, Marc Garneau Collegiate Institute (Scarborough, Ontario)

Sowmil Mehta, Pinawa Secondary School (Pinawa, Manitoba)

On behalf of the Canadian Nuclear Society, the Toronto Branch would like to congratulate these winners on their achievements and wish them well in their future work.

Shayne Smith

Myths and the Media

What many people in the nuclear industry accept as "reality" about public perceptions of nuclear energy turns out to be a myth. That was the central message in Rita Dionne-Marsolais' talk at the Toronto Branch meeting on October 25. As Vice-President of Information for the Canadian Nuclear Association, Ms Dionne-Marsolais was reporting some of the findings of a survey carried out as part of the CNA's Public Information Programme. While most people in the nuclear industry may have the impression that the public is preoccupied with the environmental impact of nuclear energy, survey results suggest that this is not in fact the case. Indeed only two percent of the sample polled identified any aspect of civilian nuclear energy as the most important environmental or economic issue facing Canada today. In contrast 43 percent identified acid rain as the top issue.

As was demonstrated by an extended and lively discussion period, public perception of nuclear energy is a topic about which few CNS members lack opinions.

Eva Marczak

Letters

Nuclear energy not credited

Sir:

I enjoy the new format of the Bulletin. But as a nuclear physicist who worked way back in 1970 on the Pioneer 10 and 11 spacecraft I was very disappointed that your editorial "Testing the Bathwater" (Bulletin November/December 1988) didn't mention the most important aspect of the success of the two spacecraft. Namely that they, like all deep space probes, are powered by radioisotope thermoelectric generators (RTG) fuelled with Pu-238. We in the nuclear community should take pride in all nuclear accomplishments, including nuclear medicine and such outstanding achievements as the deep space probes. Later this year the nuclear powered Voyageur spacecraft will pass by Neptune. Those beautiful pictures of the surface of Mars, Saturn and the satellites of Jupiter all came back to us because of nuclear energy.

It is ironic that plutonium is thought to be "deadly". Equally ironic were some early objections to spaceflight on the grounds that radio transmitters would require far more power than could be provided on a launchable space vehicle. The original power of the Pioneer transmitters was all of 8 watts – about the same as a Christmas tree light bulb. Just shows what smart engineers can do. Incidentally, Pu-238 is primarily an alpha emitter so external radiation levels around the RTG are very low indeed, despite the long half-life and the large number of Curies involved to produce the heat needed.

On another topic, you might keep your ears open for the big fuss likely to break out quite soon about Health and Welfare Canada vastly underestimating the radon levels in Canadian homes despite the fact that available data indicates that their sample measurements (grab samples made in daytime during the summer in 14,000 homes) are completely inadequate for evaluating the radon levels for the country. H & W are saying that 0.1 percent of Canadian homes (about 8000) would exceed 20 picocuries per litre of air. A more realistic number would be 2-4 percent (160,000 to 320,000 homes). Stay tuned ... could become as big an issue as UFFI ...

Most cordially,

Stan Friedman
Fredericton

We are properly chastened and thank Dr Friedman for drawing attention to this vital feature of the space probes. The only thing that worries us now is the thought of hundreds of earth-bound nuclear power plant managers grinding their teeth in envy as they contemplate a reliability record their plants are unlikely to match ...

Symposium ... seminar ... or booze-up?

Sir:

The heavy involvement of the Canadian Nuclear Society in "Symposia" and "Seminars" has prompted me to try to determine the differences between these two classes of occasion.

I looked them up in Webster's Encyclopaedic Dictionary and this is what I found:

symposium – a feast where there is drinking; a convivial meeting; a discussion by writers in a periodical

seminar – a group of students studying under a professor, doing original research, and studying and then discussing the results.

Now I know why the CNS sponsors symposia (eg Uranium and Electricity) and the IAEA sponsors seminars (eg Research Reactors).

Jim Weller
Toronto

Jim Weller's perceptive comment on seminars and symposia is well taken. He could, however, have pressed the point all the way home.

The etymology of these two words indicates that they are both very venerable. "Seminar" comes to us through the European (especially the German) monastic tradition, and thence, somewhat inexplicably as will be seen, through the German universities. The word itself derives from the Latin **seminarium**, *which is generally thought to have been the plot of ground used to germinate seeds and produce seedlings for planting out. The root word in Latin is connected to a large family of English cognates, which include seminary, seminal and a host of other terms. Most of these words (there are one or two glaring exceptions) are associated with nurturing, husbanding, raising, growing, etc.*

The reference made above to German universities relates to the extraordinary tenacity which the word "seminar" has demonstrated. In passing from the mediaeval monastic Christian tradition to the modern day, the word must have been assimilated by pagan Teutonic groups and been transmitted thus to the modern Germanic language group. All the innate ambiguity which the word shows through its cognates in English, most of them reducible to a confusion, a blending, or even a conjunction of feminine and masculine characteristics, cannot be explained merely on the basis of the lack of gender in English. Even in German, which has clear gender definition, the complementary but rather inexplicable combination of gender-related meanings which the word has taken on are still strongly in evidence. This can be seen most clearly through the origin of Brahms' well-known Academic Festival Overture, the melodies of which are derived from nineteenth century drinking songs that were a very prominent feature of German university life at the time. These universities were at the same time the seat of traditions which accepted and indeed spread over the world the notion and the practice of seminars. It can only be concluded, therefore, that the ability of this word to survive must derive from its appeal to both the feminine and the masculine principles of the human race.

If we turn now to the word "symposium", it is clearly the Latin word "symposium" taken directly into English (and other European languages) but is derived from the Greek term for "fellow-drinker". The meaning of the term in Greek as well as English texts was intended to indicate a party or gathering where there was drinking as well as conversation and intellectual entertainment. This is seen clearly upon reading Plato's "Symposium". However, and this is the crucial point, this dialogue by Plato also indicates that such a meeting included other activities which delicacy prevents one from describing too graphically. Suffice it to say that serving wenches were not a feature of such parties organised by the ancient Greeks. Young boys filled the role of serving wenches, which seems through modern eyes to be very unfair both to the wenches and to the participants. Nevertheless, it is perhaps not stretching a point to infer that a similar confusion or conjunction of gender indications is also present in the word "symposium". The relative rigidity of the definitions associated with "symposium" must be contrasted with the fluidity of meanings carried by "seminar". Why do two words with such different inherent characteristics survive and why is it that they come down to us with such stripped down present day meanings? There is today almost no confusion and very little ambiguity in the meanings of either word. Their meanings are almost clinical compared to those of their venerable forebears, and yet the words themselves are just as tenacious as ever.

The answer is perhaps not so difficult to find as it may seem. Flying in the face of all current linguistic thinking, it would seem that these two words actually do incorporate characteristics of the events which they designate. People recognize these characteristics subconsciously and respond to them strongly. The increasing numbers of women attending scientific meetings is only a reflection of rapidly changing social and work conventions and indicates that women respond to the resonance in these words just as strongly as men do.

Expressed more bluntly, seminars and symposia offer not only booze but hold out the promise of a fair bit of grubby passion as well.

Conferences and Meetings

International Conference on Simulation Methods

Papers are solicited for presentation at the Third International Conference on Simulation Methods in Nuclear Engineering. The conference, sponsored by the Canadian Nuclear Society and co-sponsored by the American Nuclear Society, will be held **18–20 April 1990** at Montreal, Quebec.

Papers and their summaries should contain descriptions of simulation methods, including a numerical approach, empiricisms used, verification, validation and results from practical applications. Extended summaries (750–1200 words in length) should be submitted by 15 October 1989 to: Dr W I Midvidy, Ontario Hydro H11 A09, 700 University Avenue, Toronto, Ontario M5G 1X6, (416) 592-5543.

Second International Conference on CANDU Fuel

Sponsored by the Canadian Nuclear Society and co-sponsored by the American Nuclear Society the Second International Conference on CANDU Fuel will be held **1–5 October 1989** at Chalk River, Ontario.

Papers, for oral or poster presentation are invited on all aspects of CANDU fuel technology, including production, manufacture, testing, analysis, operating experience, fuel management, PIE techniques and storage. Submissions of generic interest from other water reactor systems are also invited. Summaries of no more than 500 words in length should be submitted by 31 March 1989 to: Dr I J Hastings, Chalk River Nuclear Laboratories, Chalk River, Ontario K0J 1J0, (613) 584-3311.

International Symposium on Fission Product Transport

The International Centre for Heat and Mass Transfer, in cooperation with the International Atomic Energy Agency, is sponsoring an International Symposium on fission product transport processes in reactor accidents to be held in Dubrovnik, Yugoslavia on **22–26 May 1989**. The objective of the symposium is to provide a critical review and evaluation of international developments in understanding the roles of heat and mass transfer in the behaviour of fission products under reactor accident conditions. Lectures and papers will be by invitation. Participants are invited to take an active part in the discussions of the presented papers. Papers will be pre-printed and available to attendees on their arrival at the meeting. The proceedings will be published.

For more information contact: Prof J T Rogers, Carleton University, Ottawa, Ontario K1S 5B6, (613) 564-7153.

MIT Summer Seminars

In its 1989 summer series of professional seminars the Massachusetts Institute of Technology is offering the following courses of potential interest to CNS members:

June 12–16: Modern Nodal Methods for Analyzing Light Water Reactors, Prof A F Henry (Programme 22.80s)

July 10–14: Nuclear Power Reactor Safety: Part One – Thermal Power Reactors (Programme 22.95s) Prof N C Rasmussen

July 17–21: Nuclear Power Reactor Safety: Part Two – General Safety Issues (Programme 22.96s) Prof N C Rasmussen

For further information, contact F J McGarry, MIT Summer Session Office, Cambridge, MA 02139, (617) 253-2101.

15th Annual Symposium on Waste Management '89

Sponsored by ANS/ASME , to be held **Feb. 26-Mar. 2, 1989,** in Tucson, Arizona.

International Conference on Availability Improvements in Nuclear Power Plants

Sponsored by the Spanish Nuclear Society / CNS / IAEA / ENS, to be held **April 10-14, 1989** in Madrid, Spain. For information contact: **K. Talbot, Ontario Hydro,** (416) 823-9040.

Fifteenth Annual Simulation Symposium

Sponsored by CNS (NSED), to be held **May 1-2, 1989** in Mississauga, Ontario. Contact: **B. Rouben, AECL,** (416) 823-9040 or **J. Marczak,** (416) 592-7622.

CNA/CNS Annual Meeting

To be held **June 4-7, 1989** in Ottawa. Contact: **P. Fehrenbach, AECL/CRNL,** (613) 584-3311; **T. Jamieson,** (613) 236-3920.

5th International Conference on Emerging Nuclear Energy Systems

Sponsored by ANS/ENS/CNS, to be held **July, 1989** in Karlsruhe, Germany. Contact: **A. A. Harms, McMaster University,** (416) 525-9140.

World Energy Conference: Energy for Tomorrow

To be held **Sept. 18-23, 1989** in Montreal. Contact: **TPC,** (514) 878-3124.

IAEA Seminar on Research Reactors

Sponsored by the IAEA, to be held **Sept., 1989** in Chalk River, Ont. Contact: **P. Simpson, AECL/CRNL.**

International Symposium on Quality in Nuclear Power Plant Operation

An international symposium in cooperation with the IAEA, to be held **Sept. 10-14, 1989** in Toronto, Ontario. Contact: **D.J. Bartle, CANATOM Inc.,** (416) 366-9421.

Specialist Meeting on "Leak-Before-Break"

Sponsored by CNS/OECD/NEA, to be held **Oct. 25-27, 1989** in Toronto. Contact: **L. Simpson, AECL/WNRE,** (204) 753-2311.

4th International Topical Meeting on Nuclear Reactor Thermal Hydraulics

Sponsored by KFK/ENS/ANS, to be held **Oct. 10-13, 1989** in Karlsruhe, Federal Republic of Germany. Contact: **J.H. Kim, EPRI,** (415) 855-2000.

International Waste Management Conference

Sponsored by ASME/ANS/CNS, to be held **Oct. 23-28, 1989** in Kyoto, Japan. Contact: **R. Kohout, Ontario Hydro,** (416) 592-5384.

Sleeping Dogs

They were shocked and disappointed, but I was adamant. I would have nothing to do with it.

It all started innocuously. The Premier announced a Cabinet shuffle. Nothing extreme; a fairly normal and unremarkable event. The problem was that the new Minister of Energy wanted to Understand Things, wanted to see Reports on Nuclear Matters written in Clear Plain English. Can you imagine?

Although the Minister had spoken what he thought were words of support and motherhood, urging the nuclear industry to be more open, more responsive, to explain things in terms the people could understand, etc., little did he know what he had wrought. Somewhere within the great bosom of the industry there was an unwonted fluttering. Faint cerebral rustlings caused the mighty head to nod; new life quivered in the remaining functional synapses. Several of them even fired tentatively.

The behemoth stirred.

When the dust and the executives had settled once again a blinding light was seen to be directed from the empyrean upon a new committee. The Committee for Nuclear English had been struck and the Public was about to be Informed.

Assessing the faults of existing documents was set as the first priority. Two floors in the CNS Tower were cleared and soon boxes of safety reports, standing committee papers, submissions to energy boards and all nature of other material was seen flowing into the Examination Chambers, and the machinery of Nuclear Judgement began to grind. Up to this point I had steered clear, but it was only a matter of time until the call came.

"Bauer here."

"Ahem-hhhemmmm, Hhhrruuummphphp. Aaaarrgghhh. Ah, yes, Mr. Bauer?"

(Why do people do this? Not only into the telephone, but most noticeably at symphony concerts. Are they paid to attend and then disrupt the proceeding at the end of the first movement by these massive bronchial excavations?)

"Yes", I said, knowing what was in store.

"Ah, yes. I, ah, am calling from the CNE".

"CNE? Well, my price for stuffed giant pandas is the same as last year", I prodded maliciously.

"Wha-aa-aa, hhhaaaaarroouuughhh, horkkk, aaaaarrghhh."

I blanched, fearing I had caused the tape to rewind. I had.

"Is this Mr. George Bauer?" he began again, shouting to be heard above a sustained overlay of heckling from his own adenoids.

I said yes and together we began rolling the heavy stone back up the hill again.

"I phoned to advise you", he managed at length, "that you've been appointed to prepare a style book for Nuclear English".

"Why? What's wrong with *Strunk and White*?"

"Eh? What? What's his name?" he chirped, following a mild catarrhal after-shock.

We fenced some more, but at length I said I would have no part of it. He grew annoyed and agitated and was difficult to understand, since judging by the background rumbling we seemed to be near some frightening pulmonary epicentre. Would Mr. Bauer be prepared to direct a course in technical sindock? If the caller meant synedoche, then no, Mr. Bauer was not interested. Onomatopoeia in single and dual failures? No. How about advanced use of simile in FORTRAN? No. Analogy as a licensing tool? No. Click.

The whole grim undertaking left my mind for the next few days but returned with a thud when I received a thick envelope from an industry worthy. Would I be good enough, the covering note asked, to review these assignments "produced by some of our most promising word-smiths"? Two minutes was more than enough. After telephoning Worthing and asking him to meet me

. . . another working day had begun for Lutitia Distlefink, nuclear chemist . . .

in The Bohr's Head, I stormed out of the flat. Feeling that I just had to make some noise, I passed on the Lagonda, kicked the Brough into life, and blasted down Bay Street.

On entering the pub, my mood wasn't improved by Worthing's smug expression. I slapped the envelope onto the table in front of him. "Read that!".

He pulled out the first sheet and looked at it with exaggerated care. "Abstract", he read in a loud voice, "Chapter 13. Accidents Beyond the Design Basis". He cleared his throat, checked a smile, and continued. "Ominous pools of arterial red spattered the sky as the dawn light spilled over the jagged remains of the Pickering vacuum building . . .".

He set it aside with ponderous deliberation and pulled out the next sheet. Scanning down the page until he found what he wanted, he read: ". . . long black tresses cascaded across her off-the-shoulder lab coat; with her fingertips she swirled the surface of the spent fuel bay languidly as she read the opening pages of the quarterly Station Water Chemistry Report. Another working day had begun for Lutitia Distlefink, nuclear chemist".

Something was wrong. Worthing would not normally be so serene in the face of a linguistic Paschendaele like this. "What are you up to? Have you already seen this?" I said slowly.

"Me?" he said, recoiling in mock offence. "My dear Bauer, this is not my doing, and I don't like it one bit. Neither will the Minister, I expect, when he receives the copy of these which I took the liberty of sending to him."

The Minister didn't like it. Yes, he said when we were called to an audience with him that afternoon, he did want us to re-instate the previous perfectly acceptable state of affairs. Yes, he realized that it could not be done for nothing. Yes, he finally said with some difficulty after we mentioned a modest fee, that amount was within his signing authority.

George Bauer

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