CANADIAN NUCLEAR SOCIETY

Bulletin

DE LA SOCIÉTÉ NUCLÉAIRE CANADIENNE

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IN THIS ISSUE:

Contents

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Editorials

Testing the Bathwater

In March 1972 the unmanned spacecraft Pioneer 10 was launched. It has now become the most distant spacecraft ever to have left Earth, and is presently over 45 astronomical units (more than 4000 million miles) away. Radio signals from it now take 6 h to reach us.

Against the glitzy background of an aggressive manned space programme, the launch of Pioneer 10 would have attracted little public attention had the spacecraft not been designed to eventually leave the solar system and travel indefinitely. Since the possibility existed that the spacecraft might encounter some intelligent being, Pioneer 10 carried a plaque, painstakingly designed to be intelligible to any life form, indicating the point of origin of the vehicle and some idea of the nature of the creatures who had launched it.

To some of the more serious-minded scientific correspondents this appeared a little fanciful and prompted a certain amount of harrumphing at the time. Pioneer, it was argued, seemed to be more some sort of Dan Dare publicity stunt than a serious scientific enterprise. And the New Scientist made a rather snarky comment about what any intelligent race would think of a spacecraft whose electronics would be knocked out of action in very short order by cosmic radiation.

Pioneer is still working and is confidently anticipated to continue doing so for at least another decade. The spacecraft has successfully passed through the most dangerous part of its voyage – the asteroid belt – and this December will be at the centre of an experiment to detect gravity waves whose existence was predicted by Einstein but which have not yet been observed. As well Pioneer will be part of attempts to verify the existence of "Planet X", a possible tenth planet in the solar system.

So Pioneer 10 may well be instrumental in humankind's gaining a significant insight into the nature of the universe. That's not bad for a sixteen-year-old. And surely, for scientist and non scientist alike, there's the excitement in the notion of this vehicle leaving our system to begin its indefinite and unguided tour of the universe. Perhaps it will bump into something. Perhaps it won't. The important thing is that it's out there – the first human finger to test the cosmic bathwater and a testament to what is best in human optimism and curiosity. It's one of the nicer Christmas presents this year.

Lots of Oil

Last year Canada exported slightly more than 12,000 tonnes of uranium – about 85% of our annual production. Perhaps the most remarkable thing about this statistic is that few people seem to care about it. Would they view it any differently if it were expressed as follows: last year Canada exported the equivalent of about one billion barrels of oil, and sold it for a billion dollars, about a dollar a barrel? Misleading, you protest? Possibly.

Cast your minds back to the sixties. When Richard Nixon was President in the U.S., one of his least popular actions (least popular among Canadians, that is) was to slap a quota on imports of oil from Canada. Public opinion here was outraged. How dare he do anything so dastardly! A few years later, along came the "oil crisis". Consumers in Atlantic Canada received a nasty jolt when their electricity bills began competing with their mortgages for top spot. There were doom and gloom reports swirling everywhere, but it took a while for the Canadian public to tune in. The reason for this delay was that many people thought there was plenty of oil around.

"No need to worry too much. There's plenty of oil out West."

"How much?"

"Oh, lots."

"Yes, but how much?"

"Probably enough for a few thousand years."

For a time, a good number of people actually believed things like this, partly because they had not been discouraged from doing so. But when official questions began to be asked, it turned out that there really was far less oil "out West" than most people, including a goodly few in the Government, believed. This ultimately spelled trouble for the oil companies, who were blamed, rightly or not, for the information gap.

Although uranium is different in many ways, and although there are plans in place to make sure that "enough" is held back for domestic "needs", there is no doubt that the demand for energy in Canada is increasing sharply, and there is also no doubt that the amount of uranium left is decreasing, dwindling, being depleted, since it is available in finite quantity. The first of these messages is welcome under bull market conditions but the second is not. It would be nice to believe that we could just go on mining and exporting increasing quantities of uranium, but alas....

Industry and exports are both very good things. They supply life to business, jobs to people and dividends to investors. But while taking advantage of this positive side of things, it's as well to remember that the capacity of people to discount the future seems to be unlimited.

Why don't we get together ...

Conferences are important. They are one of the principal means by which people can meet and exchange information on the latest developments in their various areas of endeavour. Not just during the formal sessions but in the course of the social get-togethers, when you have the chance to find out the real story behind those carefully sanitized and excruciatingly qualified disquisitions.

There are lots of conferences, as a glance at the quite limited list in this Organ will demonstrate.

Without wishing to sound snarky about the whole thing, however, we might ask whether all these conferences are quite as cost-effective as one might wish. Major conferences can cost several hundred dollars for registration alone. If the conference is in some distant city, then transportation and accommodation charges can triple this figure, effectively limiting attendance to those whose employers will pay the shot.

This often means that attendance at a conference, with all the trimmings, becomes in part a "goodie" to be dished out to the deserving. As well the conference is a place to "show the flag" in a general sense, which may account for the significant proportion of senior corporate types to be found at these affairs – particularly when they are held at places such as San Francisco or Vienna.

We do not wish to question the importance of large conferences held in pleasant locales using expensive hotels, but rather to suggest that their major importance may be in areas other than that of traditional scholarly exchange. Perhaps it is time we began to apply our minds to the more extensive use of less elaborate (and more affordable) arrangements for getting together, to supplement (not replace) existing arrangements.

If we make the assumption that the opportunity for information exchange and general interaction between specialists in one particular field, or group of related fields, is important then we should be devoting some effort to increase not only the number of such opportunities but also to making them as accessible as possible.

From the Gallery

Those who watched the great leaders' debate back before the election saw sparks fly over a question of interest to those following the energy question: does the much-misunderstood Free Trade Agreement (FTA) mean that utilities have to sell electricity at the same price to the Americans as in Canada?

Mr Turner argued that the FTA constricts Canada's right to charge higher export prices. Mr Mulroney argued the opposite. Both are right ... as far as they go.

Confused?

The agreement says that neither government can "impose a higher price for exports of ... energy ... than the price charged ... when consumed domestically, by such means as licences, fees, taxation, and minimum price requirements ... " (Article 904, subparagraph b). According to Gillian Lapointe of the Department of External Affairs, this "means that prices will be set by the market. The agreement binds only governments – meaning that governments cannot set higher export rates, but private firms can".

Ms Lapointe went on to emphasize that the aim is to make trade in energy and other commodities operate on "strictly commercial" lines, bringing market forces to bear. So although government won't be able to set higher export prices (point to Mr Turner) commercial enterprises can sell for whatever price they can obtain. One example of this is Hydro-Quebec's recent deal with New England to sell at three times the price charged to Quebeckers (point to Mr Mulroney).

Similarly, the FTA reaffirms the General Agreement on Tariffs and Trade (GATT) rule that minimum energy export prices can't be set by either government. Where the implications of FTA get interesting is in the treatment of crown corporations like Ontario Hydro, and in the Ontario Government's reaction: its planned amendment to Hydro's Power Corporation Act, intended to assert provincial rights.

Although the FTA doesn't change any province's ability to set domestic rates, an attempt by Ontario to regulate Hydro's export prices higher than domestic ones could be subject to legal challenge from Ottawa. Under the Canadian Constitution, Ottawa is in charge of international trade, but the provinces are in charge of electricity production and distribution.

Article 103 of the FTA specifies that "The Parties to this Agreement shall ensure that all necessary measures are taken in order to give effect to its provisions, including their observance, except as otherwise provided in this Agreement, by state, provincial and local governments." That's why Ottawa is concerned by Queen's Park's challenge.

What the agreement doesn't say is more important than what it does, says Mike Spence, of Ontario Hydro's Electricity Exports Department, "It doesn't say we're forced to sell to the US", he points out. Other commentators note that so far as electricity is concerned, it improves access to US markets because it constrains US protectionists who would ban Canadian electricity imports.

The FTA doesn't alter a province's ability to set domestic rates, which are invariably lower than freely negotiated export prices.

The final irony is that the energy aspects of the deal weren't apparently written with electricity in mind, and were arrived at near the end of the negotiations. External Affairs says that whatever the agreement says, or doesn't say, domestic prices will tend to equal export prices in an unregulated, market-based environment.

Cam Campbell

Technical Note

Proton decay

It has been known for some time that the protons and neutrons making up the atoms and molecules that constitute the matter we are familiar with are not the fundamental particles of our universe.

Quark theory has given us a group of smaller particles that make up the proton and who knows what these may be made up of. The question now is not whether the proton is made of some constituent parts, but does the proton decay into these constituent parts spontaneously? The unification theory SU(5) not only predicts proton decay but it also gives an expected lifetime to lead experimenters. Newer and more complicated unification theories also predict proton decay but are less able to give a quantification of the lifetime. These theories have spawned numerous experiments searching for the finite proton, experiments which are very different from conventional particle physics experiments.

Things began at least as far back as the 1860s when Maxwell developed a unification of the laws of electricity and magnetism. This was the ground work for the unification theories that exist today. In the 1930s Weyl, Stuckelberg and Wigner tried to explain the apparent stability of the proton with a new conservation law – baryon conservation. The proton couldn't decay because it was the lightest baryon, however this didn't explain the stability, it just gave it a name. Also baryon conservation wasn't a general law of physics since the universe is not neutral with respect to baryon number.

In 1973 Salam and Pati proposed that the proton would decay, from their theory to unify the different forms of matter and fundamental forces of nature. Their theory, and others that followed, not only allowed the possibility of proton decay but definitely predicted it. As a result theoretical interest grew and experiments became necessary.

Glashow, Salam and Weinberg developed a theory which encompassed the weak and electromagnetic forces (known as the electroweak theory) thereby expanding on the work of Maxwell. This presented the weak and electromagnetic forces as visible manifestations of unseen underlying forces. The next step was to include the strong nuclear force, the force between quarks which holds protons and neutrons together by the exchange of gluons. Could the electromagnetic, weak and strong forces all be different manifestations of one basic interaction?

Salam and Pati were the first with a workable unification of the forces. This theory, minimal SU(5), is made up mathematically of 5×5 matrices, composed of 3×3 matrices for the gluon interaction and 2×2 matrices for the lepton pairs. These matrices connect the various particle groups and in particular connect the quarks to the leptons through a very heavy field quantum known as the X particle. This leads to the idea of the unstable proton.

The down quark of a proton can (by the theory) change into a positron by the emission of an X particle. The two up quarks combine to form a neutral pion after one of the up quarks absorbs the X particle to become an antiquark. The pion then decays into two gamma rays which produce electron-positron pairs, while the positron from the down quark moves off in the other direction.

This predicted X particle is very massive, about 10^{15} GeV, which is roughly the energy of the grand unification of the three fundamental forces. These energies existed only in the first 10^{35} seconds after the big bang. It is believed as the universe expanded and cooled symmetries were broken, field quanta became massive and the basic forces separated.

The probability of proton decay is dominated by the mass of the X particle, which exists as an intermediate state in proton decay.This massive particle's existence would seem to violate energy conservation coming from a proton with mass less than 1 GeV. The X particle is so short lived though that it cannot be detected, even in principle, (Heisenberg Uncertainty) and the conservation is not broken. None the less the great mass of this intermediate state greatly reduces the probability of proton decay and early theories placed the lifetime of a proton at about 10^{30} years.

So now we have a particle which exists for 10^{30} years in a universe that's only roughly 10^{10} years old. Obviously rather than watching one proton for 10^{30} years, one watches 10^{30} protons for one year. The SU(5) predictions had a number of effects on the physics community. First of all the prediction for proton lifetime was not beyond the limit of possible measurement. Also it provided a preferred decay mode, and as a result much interest was generated and finally there was a goal and direction for experiments into proton lifetime.

The most crude method of measurement simply recognizes proton decay as a form of radiation contributing to the background radiation at the earth's surface. One can measure the background radiation with a Geiger counter and subtract the contributions from known sources. Then one assumes whatever is left is due to proton decay, giving a crude lower limit of 10^{17} years.

In 1954, Cowan, Goldhaber and Reines found a lower limit of 10^{22} years using a 300 litre tank 30 metres underground which had originally been planned for a different experiment. Other experiments, based on radio-chemical analysis of geologic samples raised the lifetime to 10^{26} years.

In the later era of the search for a finite proton lifetime, physicists have adopted two main designs of detector, both of which have been taken underground. Both detectors rely on the motion of charged particles through some medium, but cosmic radiation in the form of charged particles produced by high energy protons from space striking the atmosphere can create a great deal of interference in such detectors. The earth is used to shield out much of this radiation to make the analysis of the detectors' output at least possible.

The first of the detectors are known as iron plate detectors. In this configuration a decaying proton in one plate sends charged particles through its neighbouring plates. In travelling from one plate to another the particles pass through gas-filled tubes in the gaps between the plates. The gas is ionized and the ionization releases electrons and ions which are detected electronically. This provides information on the position of segments of a particle track through the gap, but the back to back nature of the proton decay must be inferred from other phenomena.

The other main type of detector is the water detector. Many of the particles from proton decay travel faster than the velocity of light in water. While doing so they emit light at an angle to their path known as Cerenkov radiation. Light sensitive phototubes on the sides of the tank convert the light pulses to electric signals. Indeed these phototubes must be sensitive since the Cerenkov light from a single charged particle at 5 metres is about as bright as the light of an ordinary flashbulb as seen at the distance of the moon. The relative time the Cerenkov light hits each tube, the size of the signal and the pattern of tubes hit provide information about the tracks of particles through the water. The major advantage of the water detectors is cost. The water is not the major cost, rather the photomultipliers are, and they are usually used on the surfaces of the volume of water. Ultimately, however the size of the detector is limited by the absorption of light in water, a limit which has not been reached yet.

In 1974 Reines worked with a 20 ton detector 2 miles underground in South Africa and arrived at a lower limit of 10^{30} years. After 1978 the Italians built a 150 tonne iron plate detector in the road tunnel through Mont Blanc. Also the Frejus tunnel houses a 900 tonne iron plate detector. The Americans have a 30 tonne concrete detector in the Soudan Mine and were planning a 1000 tonne iron plate detector with the English for 1987. Also, in Pennsylvania there is a 300 tonne water detector in the Homestake gold mine. Harvard, Purdue and Wisconsin have collaborated in a 1000 tonne water detector at Salt Lake City, and the Japanese have a 3000 tonne water detector in the Kamioka iron mine.

But perhaps the most important proton decay detector to date is the Irvine-Michigan-Brookhaven (IMB) 9000 tonne water detector at the Morton-Thiokol salt mine. This detector houses 7 million litres of water, has 2048 phototubes, and has a total active water mass of 3300 tons. Technically, an event is recorded every time 12 or more phototubes fire within 50 nanoseconds of each other. Even at 600 metres below the surface the detector is triggered by penetrating muons about 2.7 times per second.

Obviously there are a lot of extraneous events, which are not proton decays, but which can trigger the detector. These must be blocked out or identified and discounted from the data, or both. Neutrino events, for example, cannot be prevented and must therefore be distinguished from the proton decay events. This is most easily done by analysis of the angular distribution of the products (the neutrino with momentum as opposed to the proton at rest). This requires that the detectors measure the total energy of the event and position and direction of products. The onus is on the analysis of the data to determine which events are interacting neutrinos or charged muons which have made it from the surface and which are contained events (events occurring wholly within the active volume). However the distinction between the patterns of detectors firing, and therefore the distinction between events, is not clearcut.

To determine proton decays from other events, the characteristic topology of the decaying proton is modelled. This would be a positron going in one direction and a neutral pion with equal momentum going in the opposite direction. Unfortunately in the real world things aren't quite that easy. The proton can have some momentum which smears out the 180 degree orientation of the products.

Finally a small subset of contained events satisfy the geometric criterion and then further analysis considers each of these as a possible candidate for each possible mode of proton decay. The number of candidates for each mode (or lack thereof) determines the lower limit on proton lifetime for that mode.

At a conference in the spring of 1984 some results from the world's larger detectors were compared: the IMB had 8 candidate events, the Wisconsin-Harvard-Purdue had 1, and the University of Tokyo had 2. This gives some indication of the difficulties involved in this kind of analysis and the rarity of the events with which we are concerned. In 204 days of operation, the IMB detector discovered 169 contained events. But none were positron-neutral pion events. This places a lower limit of 1.7×10^{32} years on the life of the proton. The other possible modes and their candidate events aren't so clear cut. At any rate, the minimal SU(5) model predicted 10^{28} to 2.5×10^{31} years, so obviously other theories which predict a longer lifetime are closer to the mark.

There are definitely candidate events but the evidence is not airtight. Experiments so far have been finding events characteristic of the less spectacular decay modes. Also perhaps the most important part of finding proton decay is not finding the extraneous events. For this more information about the background due to neutrinos is needed and here we must turn back to the particle accelerators of the more conventional particle physics experiments. Another problem confronting experimenters is that they cannot proceed indefinitely. If the lifetime of the proton is much longer than 10^{33} years the irreducible background of neutrino events would obscure the proton decay modes no matter how large the detector was.

One of the most recent proposals to solve some of these problems has been put forward by Salam and some American colleagues. Their proposal involves building a detector based on the same principles as those presently in operation, but doing it on the Moon. The arguments involved are apparently quite good but obviously the logistics will require some careful thought. They propose a tunnel 300 metres by 15 metres wide by 7 metres high dug into the side of a crater 100 metres below the lunar surface. In the tunnel would be 25 to 50 modules each containing 400 tonnes of lunar rock. But the detection apparatus would have to come from the earth, and this is where the problems start.

On another front, new theories of supersymmetry (unified gauge theory) predict that proton decay modes involving K mesons may be detectable by present experiments.

Do protons decay? The question is still not definitely answered but it is known that they do not decay as quickly as minimal SU(5) originally predicted. So the search continues in new sites and in old sites, with constantly updated equipment. It is interesting that when the idea was first proposed and the predictions of proton lifetime were not very high (relatively) most particle physicists believed the answer to be NO. Now the estimates have increased by many orders of magnitude and most physicists believe the answer is YES.

Peter D. Lowe

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Speakers' Corner

Caveat calculator

In a recent issue of an always interesting and valuable industry news sheet, CANDU Update, the last item began with the following quote:

Never in history has society been confronted with a power so full of potential danger and at the same time so full of promise for the future of man and for the peace of the world. . . . The discovery with which we are dealing involves forces of a nature too dangerous to fit into any of our usual concepts.

In quoting this the editor of CANDU Update rightly refrained from appending any quick editorial witticisms. The editorial comment immediately following the quoted sentences is

Nuclear energy? Not at all. Gasoline.

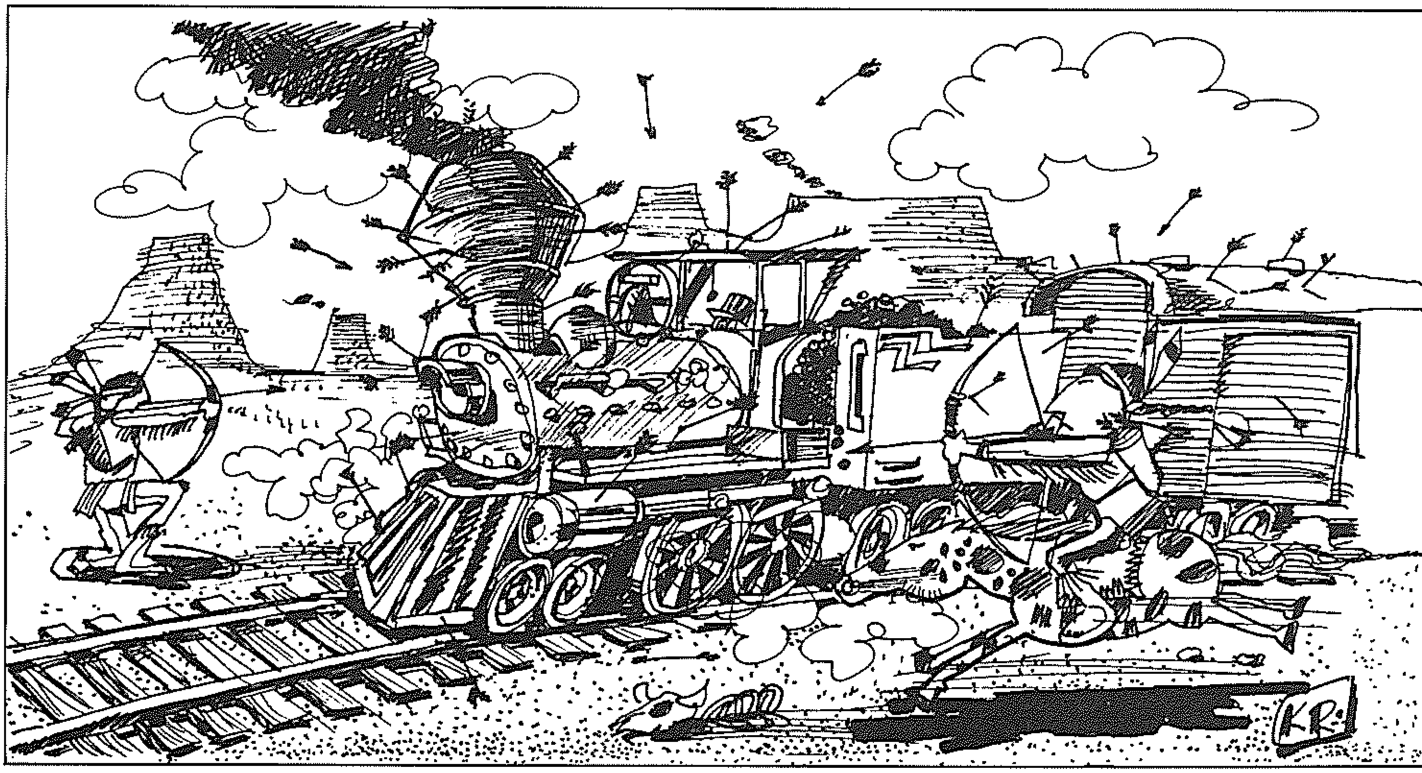
The tendency for many people, including those in the nuclear industry, to assume that the subject of such a quotation should be nuclear energy, speaks volumes. It is worth speculating on why this should be so.

In their time, iron, coal, railway trains, electricity, motor cars, radio waves and aeroplanes have been the Great Bogeymen. Iron was at one time considered unnatural and a threat to the continuation of the species; coal and the power it made available gave rise to "dark Satanic mills" and was once greatly feared because of its evil vapours; in the last century there were confident predictions that the human form could not survive travelling at speeds of 40 and 50 miles per hour, and that consequently anyone foolhardy enough to board a railway train courted a particularly loathsome end; motor cars were perceived to be so dangerous that for a time they had to be preceeded by a flagman on foot. And so it goes. Today the Bogeymen are still with us but have changed costume again: nuclear energy, genetic engineering, PCBs, are some of the Dark Deities that have been unwisely let loose from the Underworld and which now roam among us.

It is tempting to interpret these diverse cases according to the same format, i.e. as demonstrating an apparent progression of people's reactions to such novelties, from initial interest, to apprehension, to overwhelming fear and loathing, to annoyance and irritation, and finally to unconcern. This view encourages an approach to the next horror in the series based on inductive thinking: such things have been perceived in the past as threats which subsequently turned out to be hollow. It also encourages the sort of rhetoric that has been deliberately allowed to creep into the present discussion. Thus the perceived threat of nuclear energy is sometimes compared with other things in the past which have mistakenly been considered threats and the inevitable inference is then drawn either explicitly or implicitly.

The history of technology is a rich and fascinating field, and has yielded many valuable insights, but we are still very far from a proof of the proposition "History repeats itself". Furthermore, that portion of the field which considers the reactions of people to a new technology, how they adapt to it and how their initial perceptions of its risks and benefits compare with later perceptions or with the empirical estimates which ultimately become available, is largely unfurrowed by serious scholarship. So any bald statements that "X is feared but should be considered safe because Y was once feared but is now considered safe", are either leaps of faith or wishful thinking and in strict terms are worth approximately a pinch of the proverbial. The interesting question, however, is why and how do people overcome, abandon, outgrow, or whatever it is that they do, their fear of something? Why, for example, do people now have essentially no fear of the dangers of cars? Why would most people look at one dumbly if asked how they manage to avoid the dangers of using gasoline?

Of especial interest here is the relative importance of three factors in our perception (by this is meant the perception by people in general) of the nature of a potential threat. These factors are the apparently different sorts of "understanding" which are derived (i) through detailed analysis, (ii) through collected empirical data, and (iii) through "common judgement". The first is capable, in principle, of giving a balanced picture of all undesirable events, from the highly likely to the highly unlikely. Such an exercise would require a great effort and even then the result may be hopelessly inaccurate due to data limitations and errors which might creep into the many small judgements required during the course of the analysis. The second can provide excellent quality information on very likely events, but will lead to less likely events being increasingly discounted, simply because they become too unlikely to be observed. The third is a very dark horse but may well be the most important factor of the three in practice.



. . . anyone foolhardy enough to board a railway train courted a particularly loathsome end

With new technologies, item (ii) is not available to be consulted, and where (i) is available it may be incomprehensible to all but a few. What, then, is the operative mechanism that allays fear? Is (iii) just a fuzzy version of (ii) and does (i) even count at all?

Do people become more assured just because they live with a developing technology and, through experience, find that the risk as revealed in accidents is not as horrific as they once feared? Is it because they wait for the worst to happen and either it doesn't, or it turns out to be a wet squib? Is it something else unrelated to these, for example, just learning to live with a fear and learning to recognize its independent and daemon-like quality after long acquaintance? Would an exhaustive study of history help answer these questions? Has a technology ever been rejected only on the basis that its "actual" risk turned out to be too high? Will the reasoned conclusion that a probability is low enough ever be a match for the fear that a consequence may be too high? Is there any real evidence that "society" is capable of "understanding" or "appreciating the significance of" (in a "rational" sense) a probability of, say, 0.001/year?

What is the origin of hypotheticality and how does it fit into all this? Is it really any more than a systematic and quantified version of the urge, arising out of primal fear, to avoid something? Is it actually anything new or just a refinement of "good judgement"? (Is postulating accidents and then examining their outcome only an attempt to ferret out the unknown in a technology, rather than wait until it rounds the corner suddenly and flattens you?) Do the results of an analysis of hypothetical events provide sufficient of whatever it takes to short-circuit general public fears of something, or is it necessary actually to go to bed with the beast as well and get to know it viscerally?

By now, there will be those out there in Readerland who are grinding their teeth and muttering about "paralysis through analysis". That indeed is quite a common end point, a particularly uninspired one, and one which is generally an unaffordable luxury. The less appetizing alternative (but the only other one available) is to press forward through the gloom and muck, using whatever evidence is available as a guide. The historical record is one source of such evidence, scanty and distorted though it is. So are the conclusions drawn from analysis, incomplete, inaccurate and falsely alarming or comforting though they may be.

It remains to be shown whether, from a societal point of view, "common judgement" and its forms of expression are a reflection of any sort of emperical evidence, just what that underlying evidence is and what distortions, if any, are introduced in the process of turning it into common property.

Keith Weaver

Background

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

What is the Atom?

Early concepts

The original concept of the atom is very old. The Greek philosopher Demokritos (460-357 BC) pondered about the divisibility of matter and concluded that matter consisted of enormous number of indestructible particles called 'atomos' (meaning indivisible). These atomos were thought to exist in different sizes and shapes, be in constant motion and come together to form different substances. This concept of the atom was further elaborated by the Roman poet and philosopher Titus Lucretius (98-55 BC). He wrote in a poem about the hard and solid atoms with no colour, taste or smell, and never annihilated.

For a long period of time these early conceptual propositions of the atom were not challenged. Up to the 17th century people were content with some extension and refinement of the Demokritos atom. By the 18th century chemists were obsessed with careful measurements of weights and volumes before and after chemical reactions, and observed the conservation of the total quantity of reagents. The corpuscular nature of matter was recognized. John Dalton (1766-1844) stated the law of constant proportion - that chemical substances combine in definite simple ratios (e.g. weights of hydrogen and oxygen combined in forming water are always in the same proportion). Furthermore for elements that combine in more than one way (e.g. carbon dioxide and carbon monoxide) the weights of the elements are always simply related. The French chemist Louis Gay-Lussac (1778-1850) stated that the volumes of gases that combine together do so in simple ratios.

Two other observations around this time had profound influence on later developments. The Italian scientist Amodeo Avogadro (1776-1856) stated in his molecular theory of gases that under identical conditions of temperature and pressure, equal volumes of all gases contain the same number of molecules. (The Avogadro Number became a well known constant). Robert Brown (1773-1858), a botanist, observed molecular activities in that small grains move about in a zig-zag manner when suspended in a liquid medium - a phenomenon now known as Brownian motion.

Around the same time, the classical electromagnetic field theory was developed by James Maxwell (1831-1879). Light was recognized as a form of electromagnetic wave travelling at a certain speed. Electromagnetic waves could exist with all wavelengths, both shorter and longer than those of visible light. Spectroscopy was a well developed observational tool and a great amount of accurate spectroscopic data had been accumulated. The quality of light was analyzed by splitting it into its constituent frequencies. Instead of a continuous 'rainbow' of frequencies, scientists found distinct and well-defined lines corresponding to definite frequencies. These atomic spectra were not readily explained.

The Thompson atom

Around the turn of the century the modern conception of the atom started to take form with the identification of the electron (1897) and the discovery of radioactivity (1896). J.J. Thompson (1856-1940) experimented with a pair of metal plates inserted in a low pressure gas medium and connected to an electric potential. He observed a glowing discharge emitted from the negative terminal, a discharge which was demonstrated to be a stream of electrically charged particles that could be deflected by an electric or magnetic field. The ratio of mass to electric charge (m/e) was measured. The particles were named "electrons", a Greek word meaning "amber". (Ancient Greeks noticed that amber rubbed with fur produced static electricity and attracted small light objects). Later Robert Millikan (1868-1953) measured the charge of the electron, which was then recognized as the basic unit of electricity in nature. It was deduced that the mass of an electron was about 9×10^{-31} kg, about 1/2000 of that of the hydrogen atom.

Discovery of radioactivity is credited to Henri Becquerel (1852-1908). He observed that certain heavy atoms such as uranium are unstable, emitting penetrating radiation. Among different types of radiations, he identified the beta ray, consisting of high-speed negatively charged particles. These could penetrate aluminium by a few millimeters and air by a few meters, and were deflected by a magnetic field.

Available evidence led to the deduction that electrons are present as constituents for all atoms and are the direct source of spectral radiations. This meant that some other constituents carrying positive charges must be present in the atoms, since matter is ordinarily electrically neutral. Furthermore, most of the mass of the atom must be associated with the positive charge components since the m/e value for the electron is very small compared to the lightest atom. Thus the atoms were no longer regarded as elementary indivisible particles, but recognized as having a complicated internal structure which could be explored.

J.J. Thompson devised an atomic model that explained many of the known properties of atoms: the positive charged mass of the atom was postulated to have the form of a viscous, elastic sphere with the negative-charged electrons distributed more or less uniformly throughout it. The overall size was of the order of 10^{-10} m. The positions of the electrons were postulated to be fixed but capable of simple harmonic vibrations about their equilibrium positions. The various normal modes of vibrations were formulated to account for the frequencies observed in spectral radiations of the atoms.

The Rutherford atom

The Thompson atomic model was soon drastically revised by Ernest Rutherford (1874-1937). In a classic experiment he allowed a beam of energetic alpha particles from radioactive atoms to pass through thin metal foils. Scattering of the alpha particles was measured by counting the scintillation produced by impacts of the particles on a zinc sulfide screen. Thompson's atomic model predicted that practically all alpha particles should be found within a few degrees of the original path of the beam. However, a large number were observed to have scattered by very large angles, even greater than 90 degrees, suggesting a much stronger force had acted upon them than could be explained by the Thompson atom.

This led Rutherford to postulate in 1911 that the positively charged material must be concentrated at the centre of the atom, which has the shape of a spherical shell of radius 4×10^{-10} m. Alpha particles passing close to the positively charged nucleus would be deflected through large angles. Ignoring the shielding effect of the electrons as a first approximation and assuming a point nucleus, the scattering problem is reduced to that of the trajectory of the alpha particle under an electrical force that is inversely proportional to the square of the distance to the nucleus. Solution of this classical problem predicted that the number of scattered alpha particles (per unit solid angle) is proportional to the thickness of the foil and to the square of the atomic number of the scattering nuclide in the foil and inversely proportional to the square of the kinetic energy of the alpha particles and the fourth power of half of the scattering angle. Careful measurements were performed and the results were in excellent agreement with these predictions. They provided strong evidence for the validity of the planetary model of the atom.

The Bohr atom

The classical Maxwellian electromagnetic theory was soon applied to study how the orbiting electrons would radiate: accelerated charged particles were known to emit electromagnetic radiation and the electrons moving in a curved path are constantly changing direction and therefore accelerating. There appeared to be a serious inconsistency regarding the stability of the planetary atom when an infinite number of orbits for the electrons are possible. When an electron whirls around the nucleus it should emit electromagnetic waves and therefore lose energy. The radius of its orbit should then decrease with a corresponding increase in rotational frequency. This in turn should cause it to radiate energy more vigorously, and the orbit would get smaller and smaller and eventually collapse.

In 1913 Niels Bohr (1885-1962), a Danish physicist, presented his atomic model of hydrogen. His theory embodied the following ideas:

1. A hydrogen atom consists of a positively charged nucleus (a proton) and a single electron in a state of relative circular motion under the action of mutual electrical attraction.
2. The atom may remain for an extended period of time in a stable state (without radiating electromagnetic waves) on condition that this state is one for which the angular momentum of the atom is an integral multiple of $h/(2\pi)$ where h is Planck's constant (see note).
3. Radiation is emitted when an atom jumps from one of the allowed states with energy E1 to another allowed state of energy E2. The frequency of radiation is given by:

$$h = E1 - E2$$

Here the classical electromagnetic theory was replaced by the introduction of Planck's quantum, h. There are only certain circular orbits having specific angular momenta and energies that are allowed. Using this condition it can be deduced that the radius and the energy of the allowed electron orbits are given by:

$$r_n = \frac{n^2 h^2}{4\pi^2 me^2}$$

$$E_n = \frac{2\pi^2 me^4}{h^2 (1 + m/M) n^2}$$

where:

m is the mass of the electron,
M is the mass of the proton,
e is the electric charge of the electron

The smallest orbit with n = 1 has a radius of 5.3×10^{-11} m.

The frequency of the radiation corresponding to the transition from orbit n1 to orbit n2 is given by:

$$\upsilon = c R_H \left(\frac{1}{n_1^2} - \frac{1}{n_2^2} \right)$$

where

$$R_H = \frac{2\pi^2 me^4}{ch^3 (1 + m/M)}$$ is known as Rydberg's constant.

This equation had previously been deduced empirically from spectral line measurements. Bohr's atomic model not only worked from the mathematical viewpoint, but also provided a more rigorous value for R_{-11}.

Later developments

The success of Bohr's theory of the hydrogen atom soon led other scientists to apply his postulates to more complicated atoms. More elaborate quantization rules were worked out. More confirmatory experimental observations were made, such as the quantized energy transfer from beta particle collisions with atoms (Franck Hertz 1914). A self-contained set of laws which embodied both classical mechanics and the quantized conditions emerged and was called quantum mechanics. Mathematical formulations were put forward by Schrödinger (the Broglie-Schrödinger wave equation, 1926) and also independently and from a different perspective by Heisenberg (the Uncertainty Principle, 1927).

By this time, the study of radioactivity had made tremendous progress. The three types of radiations were correctly identified (alpha, beta and gamma), and their 'tracks' observed by using various detecting devices. The transmutation properties associated with alpha and beta decay were recognized. Artificial nuclear disintegrations were observed: bombardment of nitrogen by alpha particles produced positively charged particles (protons) whose range through air was observed to be much longer than the alpha particles (Rutherford, 1919).

With the discovery of subatomic particles, the internal structure of the nucleus became a fascinating subject, especially with regards to the unknown force holding the like charged particles together in the nucleus. The other constituent of the nucleus, the neutron with no electric charge, was discovered by James Chadwick in 1932. This eventually led to the whole new field of nuclear physics.

H. C. Chow

Planck's constant

The first quantum hypothesis appeared as early as 1900. There were difficulties in explaining the spectral distribution of thermal radiation from a black body by classical electromagnetic theory. Planck was able to explain the black body radiation spectrum in terms of emission and absorption of electromagnetic radiation in discrete quanta of energy equal to the frequency of radiation multiplied by a constant h. Einstein used this idea to explain some of the experimental observations on the photoelectric effect (the ejection of electrons by light) in 1905.

H.C.C.

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Eyepiece

Fifty years of fission

In 1938, in the Berlin suburb of Dahlem, two men carrying out an experiment obtained a result they didn't really understand. It was subsequently interpreted by a woman and her nephew in Stockholm, by two other German researchers in Heidelberg and by the original workers themselves. By using the droplet model of the atom recently proposed by Bohr, these various workers had come to the conclusion that in this experiment the nucleus of a uranium atom had been broken into pieces.

Hahn and Strassman's discovery of nuclear fission has been regarded, and justly so, as an event of significance in science. But much hyperbole has also been encouraged to grow up around it. The beginning of a new age was said to have hailed from that moment in Dahlem. The world was reported to have undergone an abrupt change as a result of that one mistily viewed result, derived from scant and difficult to interpret data. What such accounts should say, in fact, is that the discovery of nuclear fission can be identified, in hindsight, as the page 1 marker for a subsequent research and development assault which has scarcely been equalled for brilliance, ingenuity and achievement before or since.

The fact that a huge enterprise has been built up around a body of scientific data the beginnings of which can conveniently be dated to Hahn and Strassman's discovery, really has very little to do with that discovery. It would be less confusing, and lead to a more honest and valuable historical appraisal, if the threads of the nuclear story were separated more diligently.

The story of nuclear fission as it has developed down to our time is actually two stories.

On the one hand there is the supreme (but still incomplete) intellectual monument which is the present day understanding of the atom, its structure and behaviour. On the other there is the account, scarcely less than epic, of the practical genius and the physical effort which had to be mobilized in order to turn one of the microscopic phenomena of the atom to macroscopic use. The two threads overlap and interweave. The design and construction of research and test reactors, the development of new types of alloy, concrete and instruments, and the production and refining of fuel needed an enormous intellectual as well as fabricating input.

But in the beginning there was the challenge of a puzzle to be understood and then the gleam of applying hard won knowledge. The two stories have to advance independently from this point.

Like Newton in his day, we today also stand on the shoulders of giants. To the extent that our view is unobscured and of good range, we have to recognize that this is due to the great stature of our giants. Now, fifty years on from page 1, there is a need to acknowledge the importance of both strands of the cable connecting us with the past. One of these is through the closely packed but venerable series that includes Cockcroft, Fermi, Teller, Oppenheimer, Wigner, Lewis, Cipriani, Keys, Gray and others. The other strand is much longer and more tenuous, but winds its way past an equally or even more venerable group of personages who are often unfairly left out of the reckoning.

Today, we know where the path Hahn and Strassman were following would eventually lead because we are at the end of it.

Where they were on the way from may not seem important, since that is all just history now. However, this sort of approach makes it easy to adopt the rather arrogant view that is mocked and laughed at today, the view that seems so ludicrous in Max Born when he declared, just before the glorious quarter century, that physics would be over in six months. To avoid this pitfall, we have to try to see things through the eyes of an earlier time. As a result of this, if we are lucky, we may manage to have a fleeting impression of just how difficult it must have been for the pioneers to discover what we now almost take for granted: the basis of our present understanding. It's all too easy to assume that knowledge is ours by right, that it leads an independent existence in books and only needs to be looked up.

Just where the history of fission began is difficult to say, but the year 1800, which marked so many other profound changes, seems a good start. It was in the first decade of the nineteenth century that John Dalton and Louis Joseph Gay-Lussac determined that gases combine in fixed ratios, indicating that some sort of underlying structure was involved. In 1811, Amodeo Avogadro made the scarcely credible suggestion that under the same temperature and pressure conditions, equal volumes of different gases contain equal numbers of atoms. This was doubted, at least in part, because the atom was such a speculative entity. In 1858, Stanislao Cannizzaro used Avogadro's principle to demonstrate that molecular weights could be determined, and by this means he established the first crude system of physical chemistry.

The connection between the atomic puzzle and and the mysteries of electricity and magnetism were not appreciated as yet, and the work of Ohm, Oersted, Ampere, Faraday and Hertz proceeded along what seemed to be an independent path. Einstein placed Faraday, Hertz and Maxwell in a group apart because of their work in developing the concept of the continuous field. Maxwell was one of only five people whom Einstein considered to be his true precursors. (The other four were Newton, Lorentz, Planck and Mach.) Maxwell, in Einstein's view, was a revolutionary figure and deserves the lion's share of the encomiums in bringing the field concept to centre stage. This work was largely responsible for reshaping the rigidly mechanical world picture which had existed up to then. In Einstein's words, "This change in the conception of reality is the most profound and the most fruitful that physics has experienced since the time of Newton". It was in the 1860s that Maxwell made a most significant advance in understanding by tying together electric and magnetic fields. Atoms, however, were still a rather arbitrary plaything and their connection with electro-magnetic fields was still rather a long way off.

From the 1830s a third front was being rolled back by Carnot, Joule, William Thomson and others. This involved the study of heat engines and why they so maddeningly offended the understanding that was then current about conservation of energy. A huge step forward was taken, and much of the agenda for the coming decades was set, when Clausius formulated what we now know as the Second Law of Thermodynamics.

In 1860, the first international scientific meeting was held and it drew luminaries from across the scientific world. High on the agenda were atoms. They were becoming somewhat more respectable but even at this point their existence was confidently denied by men whose brilliance could not be doubted. Respectability for atoms received boosts from kinetic theory, and from other quarters. Great advances were made in this and in statistical mechanics by Boltzmann and Gibbs, while Dewar and van der Waals pushed forward on the study of liquids and gases. Even though there were some late (but still very revered) dissenters, more pieces of the jigsaw were falling into place. One such dissenter was Ernst Mach, who died in 1916, and probably disbelieved in atoms to the end. By the end of the third quarter of the nineteenth century, there appeared to be grounds for feeling that a relatively complete understanding (barring some loose ends) of nature would soon be in place. Predictions of the end of physics as a serious field of endeavour began to appear. Max Planck was almost convinced not to enter physics, but rather to follow his second love and become a concert pianist.

The last expectations of any such early conclusion to the great venture were ground out in the final heady decade of the nineteenth century. In that astonishingly productive period, classical physics received a long series of fatal body blows.

In 1895, Wilhelm Roentgen discovered X-rays.

In 1896, Henri Becquerel discovered radioactivity.

In 1897, the experiments of J.J. Thompson demonstrated the existence of the electron.

In 1898, Planck explained the ultraviolet catastrophe, but at the price of having to postulate the existence of "particles" of energy.

During 1898-1907, Rutherford discovered alpha and beta particles and deduced the existence of the nucleus.

In 1905, Einstein published his Special Theory of Relativity, completing a full scale house-cleaning of classical physics, and committing the ailing notion of the aether to a fate that had earlier befallen caloric and phlogiston. As an aside, the eclipse and abandonment of the aether, a notion that had been around in some form or other for over two thousand years, has been puzzling in its abruptness and totality. (Who knows anything about it today, or why it was important in its final stages of development?) Poincaré and Lorentz, who were both men of unquestioned brilliance, never fully adjusted to the demise of the aether. Although the field concept is far superior as a mental tool, its ability to "explain" (as opposed to "rationalize") the hoary old problem of action-at-a-distance is something like the ability of wallpaper to cover nasty cracks.)

By the time we reach Hahn and Strassman, physics was aglow with the works of genius: Chadwick, Moseley, Bohr, Heisenberg, Dirac, Pauli, Schroedinger, de Broglie and others. The brilliance of their contributions sometimes blinds us to the great tracts of knowledge still hidden from them, but which we can now look up in numerous texts. It is from this point of view that any self-congratulatory celebration of "Fifty Years of Fission" is unsatisfactorily narrow. Unsatisfactory, because of its teleological leaning, and the unpleasant whiff of manifest destiny it leaves in the air. Narrow because so few of the great pioneers rate marquee billing, while most are even denied a place in the stalls. To us may fall the material benefits flowing from their work, but theirs were the triumphs.

TECHNICAL SUPPLEMENT

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THE RELATIONSHIP BETWEEN NATURAL URANIUM AND ADVANCED FUEL CYCLES IN CANDU REACTORS

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THE RELATIONSHIP BETWEEN NATURAL URANIUM AND ADVANCED FUEL CYCLES IN CANDU REACTORS

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ABSTRACT

CANDU is the most uranium-economic type of thermal power reactor, and is the only type used in Canada. CANDU reactors consume approximately 15% of Canadian uranium production and support a fuel service industry valued at ~$250 M/a. In addition to their once-through, natural-uranium fuel cycle, CANDU reactors are capable of operating with slightly-enriched uranium (SEU), uranium-plutonium and thorium cycles, more efficiently than other reactors. Only SEU is economically attractive in Canada now, but the other cycles are of interest to countries without indigenous fuel resources. A program is underway to establish the fuel technologies necessary for the use of SEU and the other fuel cycles in CANDU reactors.

BACKGROUND

All currently operating or planned nuclear-electric generating plants in Canada are of the CANDU type, and so the choice of fuel cycle for these plants will determine the use of fuel cycles in the domestic Canadian fuel industry for the foreseeable future, and consequently the impact they will have on the Canadian uranium industry. In Canada there are currently 18 CANDU reactors operating with a capacity of 11.8 GW(e) (1,2). Of these, 16 are operated by Ontario Hydro (capacity 10.5 GW(e)) and the remaining two are operated by Hydro Quebec and the New Brunswick Power Commission. There are four more reactors under construction by Ontario Hydro, that will provide an additional 3.5 GW(e) by 1992 (3), bringing the net generating capacity of CANDU reactors in Canada to 15.3 GW(e) by that date. All current CANDU reactors were designed for, and are still operating with, natural uranium fuel. Canadian requirements are estimated to be approximately 1700 tonnes of uranium in 1988, or approximately 15% of the Canadian production (4). A mature fuel industry has grown to service these reactors, with an annual product value of approximately $250 M per year focused on the supply of the uranium, its processing to UO_2 and manufacture into fuel bundles, plus the generation and application of the fuel technologies necessary for their optimal use, such as irradiation testing, behavioural modelling, fuel management and fuel handling.

There are six CANDU-type reactors currently operating outside of Canada (3 in India, and one each in Argentina, Korea and Pakistan), and eleven are under construction (6 in India and 5 in Romania) (1,2). Perhaps as importantly from the viewpoint of fuel cycles, there are a number of energy-resource-poor countries actively considering CANDU reactors for use with fuel cycles based on the spent fuel from existing light-water reactors (LWR), in order to maximize the energy they can extract from the uranium which must be imported. At least two of these countries (Japan and Korea) import significant quantities of uranium from Canada.

RATIONALE FOR FUEL CYCLES

The reason for using various resource-conserving fuel cycles in any reactor is to reduce the amount of uranium consumed by that reactor for each kW of electricity generated. This ability to reduce the amount of uranium required per unit of electricity produced is seen as an important hedge against potential uranium shortage and escalating price by utilities and planners in countries who must import their uranium. Having been vulnerable to external forces during the 1974 oil crisis, such countries now want technologies which will allow them to be more energy self-sufficient, even if they are more expensive. Even countries such as Canada, with large oil, coal and uranium resources, are not free from the price instability effects of events such as the 1974 oil crisis, since domestic prices are also forced up. It is worth noting that the price of uranium increased by a factor of approximately 5 during the late 1960's and early 1970's due to the pressure of rapid nuclear expansion during that period.

Uranium conserving fuel cycles have been extensively documented for both LWR (5-8), and CANDU reactors (8-15). Their importance to both the health and growth of the nuclear industry can be seen in Figure 1, where the projected uranium requirements (for both high and low growth scenarios) are compared with the projected uranium-production capability from known uranium resources.

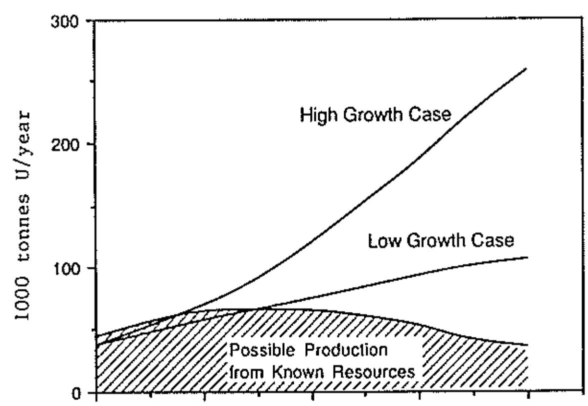

FIGURE 1: PROJECTED REACTOR REQUIREMENTS AND URANIUM PRODUCTION (CURRENT LWR ONCE-THROUGH STRATEGY).

The figure is based on 1986 OECD data for the world outside of centrally-planned economies (18), and uses information received from uranium-producing countries, plus countries with either programs or plans for producing electricity from nuclear reactors. The uranium consumption is based on the use of once-through cycles in LWR's (thus omitting

CANDU's, gas-cooled reactors and fast-breeder reactors), since LWR's represent ~80% of the operating power reactors (1). The uranium production capability is based on currently-known resources in existing, committed, planned and prospective production centers, which includes uranium recoverable at up to $130 US/kg in the "reasonably assured" and "estimated additional" resources categories in the NEA/IAEA resource classification system (18).

The CANDU reactor, because of its neutron-economic design and flexible, on-line fuelling capability, is ideally suited to operate with a wide range of fuel cycles. Not only can it operate on cycles ranging from natural uranium through enriched uranium, recycled plutonium, to various thorium cycles, but can do so with greater efficiency in fuel use than any other type of thermal reactor (i.e. excluding the complex and expensive fast-breeder reactors).

R&D programs to investigate the economics and technical feasibility of using advanced-fuel cycles in CANDU reactors, as well as to develop the key supporting technologies for them, have been pursued over the past 20 years (9,13-17). While the burnup and fuel-conserving advantages of advanced cycles have been clear in these studies, the economics have been uncertain for all cycles except enriched uranium. This is because the extra processing and complex fabrication required for each of the advanced fuels introduces significant extra costs, and these costs have been rising for key steps such as reprocessing. The economics are dependent on the difference between the extra cost for advanced fuels, and the cost for uranium. As the cost of uranium goes up, the advanced cycles become more attractive, and since the market price for uranium has moved both up and down significantly during this period, meaningful projection of when advanced fuel cycles will become economic has been difficult, other than that it will probably require uranium prices several times more expensive than current levels, possibly as high as $500/kg U (10).

However, while the use of advanced fuel cycles beyond enriched uranium does not appear to be economic for the foreseeable future in CANDU reactors in Canada, it is worth noting that uranium-plutonium fuel cycles are being introduced into existing PWR reactors in France on a commercial basis, and the use of such fuels are being actively studied in Japan for use in CANDU reactors. Recently, it has also become clear that the cost of transporting and disposing of spent fuel and other high-level wastes is increasing because of environmental concerns, and has thus become another important factor in the economic attraction of fuel cycles which increase burnup and reduce spent-fuel volume, particularly in highly-populated countries where such disposal is both difficult and expensive.

DESCRIPTION OF FUEL CYCLES

The various fuel cycles applicable to the CANDU reactor are shown in Figures 2-4 plus 6. Figure 2 depicts the once-through, natural-uranium fuel cycle which is the basis for the design of the CANDU reactors, and has been used exclusively in these reactors up until now. The fuel fabrication step shown in Figure 2 includes the conversion of the uranium concentrate (or yellowcake) into nuclear-grade sinterable UO_2 powder, its fabrication into high density UO_2 pellets, the incorporation of these pellets into 50-cm-long Zircaloy-clad fuel elements, and the assembly of the fuel elements into CANDU fuel bundles. These bundles can have either 28 or 37 elements, depending on the reactor into which they are loaded.

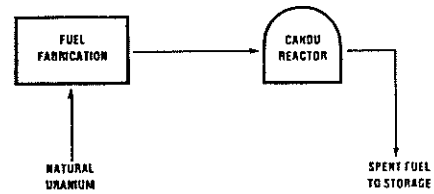

FIGURE 2: ONCE-THROUGH NATURAL-URANIUM FUEL CYCLES.

Figure 3 shows the once-through, enriched-uranium fuel cycle. This is the cycle commonly used in most power reactors other than the CANDU type, and involves an enrichment step prior to fabrication of the fuel assemblies or bundles. In this case the

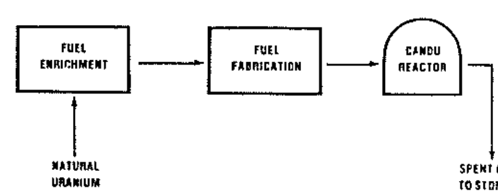

FIGURE 3: ONCE-THROUGH, SLIGHTLY-ENRICHED URANIUM (SEU) FUEL CYCLE.

uranium concentrate is converted into the gaseous compound uranium hexaflouride (or HEX) to enable enrichment in the concentration of the isotope U-235 by means of either the gaseous diffusion or centrifuge process. Following enrichment to the desired level, the HEX is converted to ceramic-grade UO_2 powder for the fabrication process.

Figure 4 shows the major steps in the uranium-plutonium fuel as it would be used in either

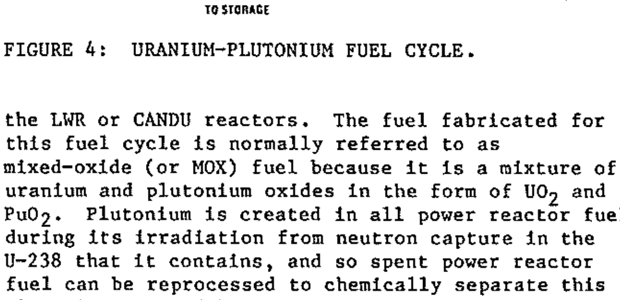

FIGURE 4: URANIUM-PLUTONIUM FUEL CYCLE.

the LWR or CANDU reactors. The fuel fabricated for this fuel cycle is normally referred to as mixed-oxide (or MOX) fuel because it is a mixture of uranium and plutonium oxides in the form of UO_2 and PuO_2. Plutonium is created in all power reactor fuel during its irradiation from neutron capture in the U-238 that it contains, and so spent power reactor fuel can be reprocessed to chemically separate this plutonium. The fabrication of fuel for the uranium-plutonium cycle thus starts with the reprocessing of previously-irradiated spent fuel to separate the plutonium. This Pu can then be blended with either natural or depleted U, either in the form of liquid nitrate solutions, or in the form of oxide powders. If liquid nitrate solutions are blended, homogeneous $(U,Pu)O_2$ can be obtained, whereas when dry powders are blended the degree of homogeneity is dependent on the particle size of the powders involved. The resultant $(U,Pu)O_2$ powder is then fabricated into fuel assemblies as described previously, except that because Pu is a very α-toxic carcinogen, all of the fabrication operations must be undertaken inside sealed, sub-atmospheric glove boxes (similar to the one shown in Figure 5), to the stage where the Pu-containing pellets are sealed within fuel elements. With MOX fuel it is the blending step which establishes the fissile loading or "enrichment" of the resultant fuel.

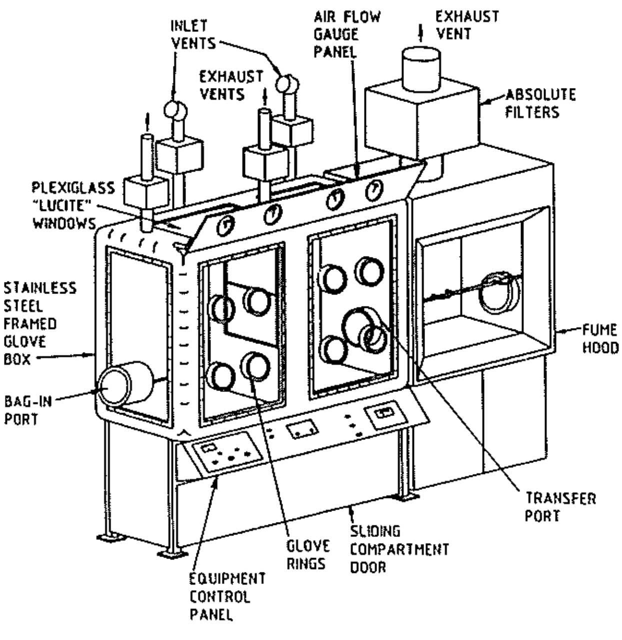

FIGURE 5: GLOVE BOX USED FOR FABRICATION OF ALPHA TOXIC MOX FUEL

The thorium fuel cycle is by far the most complex of the fuel cycles, and its main elements are shown in Figure 6. Unlike uranium, there is no naturally-occuring fissile isotope of thorium, and so all of the necessary fissile material must be added. Plutonium, as separated from spent uranium fuel, is probably the

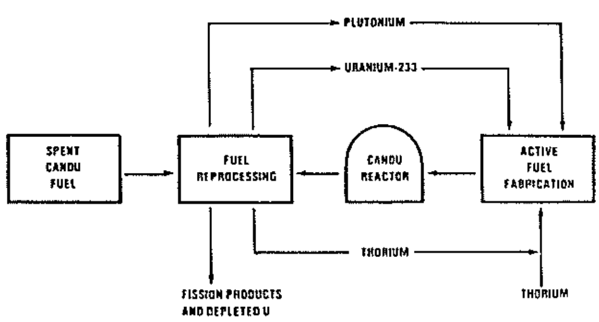

FIGURE 6: THORIUM FUEL CYCLE

fissile material that would be used, although uranium which has been highly enriched in U-235 could also be used. The fabrication of fuel for the thorium cycle thus normally starts with spent fuel which is reprocessed to separate Pu, which is then blended with thorium to fabricate $(Th,Pu)O_2$ fuel as described above. Because of the Pu, this fuel must again be fabricated in a glove-box facility. Following irradiation, the spent fuel will contain U-233 from neutron capture in the Th-232, according to the reaction described in Equation 1.

$$\text{Th-232} + n \longrightarrow \text{Pa-233} \xrightarrow{\beta} \text{U-233} \quad \text{(Equation 1)}$$

The major rationale for this fuel cycle is the U-233 which it produces. U-233 has by far the greatest yield of neutrons of any of the fissile isotopes when undergoing fission by well-thermalized neutrons - as is the case in a CANDU reactor. Although some of this U-233 is fissioned in the original fuel as it is irradiated, there is a considerable quantity of U-233 left in the fuel when it is discharged. Therefore, to optimize the cycle, the U-233 in the spent fuel must be recycled with fresh thorium and some Pu "topping". This requires a special facility for fabricating thorium fuel when it has had the U-233 added to it, because of the high γ fields that are associated with the U-233. These additional special facilities, for reprocessing and fabricating the recycled U-233 containing thorium fuel, tend to make the reprocessing and fabrication portions of this cycle very expensive, and thus make the cycle less economic. However, the cycle does offer the opportunity for near breeding or uranium self-sufficiency.

FUEL CYCLES IN CANDU

As can be seen in Table 1, the uranium savings possible range from 30%, by the addition of slight

TABLE 1: COMPARATIVE URANIUM USE FOR POTENTIAL CANDU FUEL CYCLES (AT EQUILIBRIUM)

	URANIUM SAVINGS (%)
NATURAL URANIUM, ONCE-THROUGH	0
SLIGHTLY-ENRICHED URANIUM (1.2%) ONCE-THROUGH	30
URANIUM-PLUTONIUM, RECYCLE	50-60
URANIUM-THORIUM, RECYCLE WITH PLUTONIUM TOPPING	
- HIGH BURNUP	70-75
- LOW BURNUP	75-100

enrichment to the present once-through cycle, to approaching 100% (self-sufficiency) within a low burnup, plutonium-topped thorium cycle. In Canada, the choice of what cycle is used at what time and under what circumstances, will depend upon a number of factors, such as rate of load growth, rate of uranium export and new discoveries, uranium price, and the cost and availability of the fuel reprocessing and fabrication services, but could be quite different in some other countries. The order in which the cycles are listed in Table 1 corresponds to the degree of technical difficulty involved in implementing these cycles, their probable cost, and thus the probable sequence for introducing them in Canada (17). This is the inverse of the order of resource conservation. The salient features of these cycles in CANDU are outlined from a fuel viewpoint in the following paragraphs.

Natural Uranium

Since this is the standard fuel cycle in CANDU reactors, and is described in most publications on CANDU, it will not be covered here.

Slighty-Enriched Uranium

The use of slightly-enriched uranium (SEU), with enrichments ranging from 0.9 to ~1.5 wt% U-235 in total U, is the first fuel cycle that will be employed in CANDU reactors, and probably the only one in Canadian CANDU's within a 20-year planning horizon. This is because it is clearly economic at current price levels, and offers the incentive to become more so as enrichment price levels fall due to an industry over capacity, and the introduction of new, potentially lower-cost enrichment technologies such as the laser based AVLIS (Atomic Vapour Laser Isotope Separation) process (15,19,20).

For example, recent estimates of the potential savings that could be achieved through the use of SEU fuel in existing CANDU reactors range from about $5 M/a per reactor of approximately 750 MWe size, using 1.2 wt% U-235, to a present worth of about $800 M from all Ontario Hydro nuclear stations over the next 30 years using 0.9% SEU (21). These cost savings come from both the fuel-supply cost and the "back end" storage, transportation and disposal cost. It is worth noting that the "back end" component of the cost saving is due to the reduction in the volume of the spent fuel by a factor of two-three, and that if the cost of disposal rises above current estimates (particularly in countries with high population densities where the identification of areas for nuclear-waste disposal is a difficult political problem) then the advantage of SEU use is increased even further.

There is currently an excess capacity in the uranium-enrichment industry, resulting from the sharp decrease in the anticipated growth rate in the nuclear power business, principally in the USA. This excess capacity will be increased with the introduction of the new lower cost enrichment technologies - currently the improvements to the gas centrifuge, and in the future the introduction of the AVLIS or other laser-based technologies. The American AVLIS process is expected to be in commercial operation during the 1990's. As a result of the present and future over-capacity, the price of enrichment (or more correctly, separative work units) is currently depressed, and is expected to stay depressed, or possibly fall lower, between now and the end of the century. This situation provides a competitive benefit to those reactors that use enriched uranium, and it is desirable to have CANDU reactors similarly benefit from such low prices.

The SEU cycle will also establish most of the key reactor operating technologies, in-core fuel management and fuel design and behaviour-prediction technologies that will be necessary for the introduction of any other fuel cycles into CANDU which involve larger fissile loadings, and significantly higher fuel-burnups than in the current natural-uranium-fuelled reactors.

The use of SEU fuel, with the extra fuel reactivity and burnup that are available from its use, provides an extra degree of flexibility in the design of new CANDU reactors, by allowing the very strict neutron economy in CANDU reactors to be traded off against other economic benefits such as lower capital cost, or extended pressure-tube life. One particularly attractive economic benefit is the use of more than one enrichment level to flatten the power profile across the core of the reactor, thus allowing up to 19% more power to be generated from the same size of reactor core, without increasing maximum channel powers or fuel ratings, thus lowering the specific capital cost of a reactor using this feature (22).

In order to demonstrate that the fuel defect rate, at the higher fuel-burnups available with SEU and with the changes in fuel-power level likely to be associated with both fuel management and load following, is maintained at less than the 0.1% reference level for natural CANDU fuel, significant irradiation testing will be required. The objective of such testing will be to establish an appropriate fuel-behaviour data base at the higher burnups during both steady operation and with a range of power ramps, plus a large-scale demonstration of operation within a power reactor. This testing program could be done using the current 37-element bundle common to most recent CANDU reactors. However, increasing the burnup by a factor of three, plus a significant degree of power manoeuvring associated with load following and fuel management, would probably increase the defect rate of the fuel, and extensive testing would be required to confirm the fuel's performance. Another option is to reduce the fuel rating by increasing the number of pins in the bundle, which would remove the fuel's performance further from the area of uncertain performance and reduce the amount of radiation testing required. This latter concept has given rise to the CANFLEX 43-element bundle, which is described elsewhere, along with its development program (15,20).

A variation on SEU which is economically attractive, and could find its way into CANDU reactors once SEU technology has become firmly established, is a group of cycles that would be based on utilizing the spent fuel from light-water reactors. The spent fuel from these reactors contains significant fissile material in the form of both U-235 and plutonium. Significant quantities of this fuel are being reprocessed now for various strategic and political reasons, and the recovered U-235 from this fuel has an enrichment range of 0.7 - .95%, which makes this recovered enriched uranium (REU) a potentially cheaper alternative to SEU in CANDU reactors where strategic considerations are favourable. However, it is the technical problems associated with the other uranium isotopes, plus the traces of fission products which contaminate the REU, which cause most concern regarding the feasibility of its use.

To put this into perspective, the uranium isotopic composition in REU is compared with normal, natural and enriched uranium in Table 2 (8,11). Analysis has shown that the radiological problem with the enhanced concentration of U-232 is small and will not have a significant impact on fabrication or handling. Although the effects of the enhanced concentrations of U-236 are significant in LWR reactors, necessitating the use of additional U-235, the softer spectrum in CANDU reactors reduces this effect by a factor of approximately seven.

TABLE 2: TYPICAL URANIUM COMPOSITIONS

ISOTOPE	% COMPOSITIONS		
	NATURAL	ENRICHED	REU
U-232	0	0	1.1×10^{-7}
U-234	0.0055	0.03	0.02
U-235	0.72	3.25	0.91
U-236	0	0	0.42
U-238	99.275	96.72	98.65

Uranium-Plutonium

Once the SEU fuel cycle has been established in CANDU reactors, along with all of the operating technologies for higher fuel-burnups and the fuel-management technologies for higher fissile loadings, the next logical step in resource conservation involves the reprocessing of spent fuel, and the recycling of the recovered plutonium back in the form of a uranium-plutonium (MOX) fuel. The fuel contribution to the unit energy cost when MOX fuels are used is currently higher than the cost with natural uranium, and significantly higher than with SEU because the cost of plutonium is higher than that of U-235 in the form of SEU, and the fabrication cost of fuel containing Pu is significantly higher than that for natural U or SEU. Therefore, MOX cycles are unlikely to be economic in Canada until the price of uranium increases to well above $300 CDN/kg U. Given the fact that there are neither reprocessing facilities, nor a program to develop them in Canada, it is most likely that the first use of the U-Pu cycle in CANDU reactors would be outside of Canada, using plutonium from a source other than CANDU fuel. Because of the neutron efficiency of CANDU reactors the residual fissile plutonium in discharged CANDU fuel is about 2.8 g/kg, or a factor of two and one half less than that in the discharged fuel from PWR reactors operating on a normal non-extended-burnup cycle. Since the cost of reprocessing is dependent on the mass of fuel that must be reprocessed, the cost of Pu from spent LWR fuel is clearly much less. Although the fissile Pu contained in spent SEU fuel would be about 25% higher than in natural fuel, the extended-burnup cycles being introduced into LWR's will also increase the content of the Pu in their discharged fuel, so that PWR plutonium will always be cheaper.

The lower cost of LWR Pu gives rise to various tandem cycles with LWR's where CANDU reactors can burn reprocessed LWR fuel down to very low levels of residual fissile material, thus not requiring multiple reprocessing. This feature is attractive to countries that already have LWR reactors and a reprocessing capability, such as Japan.

Thorium

Thorium fuel cycles are uniquely advantageous for CANDU reactors, which offer the potential for near breeding of fissile material, or self-sufficiency in uranium. However, their technical difficulty and high cost mean that it is unlikely that such cycles would be introduced before plutonium recycle. In fact, a plutonium fuel capability is required for the startup fissile inventory for thorium cycles unless more valuable U-235 were used. Even though Canada has large quantities of thorium sitting in tailings ponds from the production of uranium from ores in the Elliot Lake area, it is unlikely that the use of thorium cycles could become economic in Canada until well into the next century. Although these cycles do not have any significant near-term effect on the present natural-uranium fuel industry, their long-term impact on the viability of the CANDU reactor concept is of particular importance, because of the drastic reduction in uranium requirements which they allow.

CONCLUSION

Although natural uranium is currently used in all CANDU reactors, slight enrichment has already become significantly more economic, and will establish the operating technologies necessary for the use of other cycles which are expected to become economic early in the next century. For the CANDU reactor concept to survive in both Canada and abroad, it must remain competitive through the use of advanced fuel cycles where and when they are economically attractive. This ability is already a requirement for the use of CANDU in many countries that depend upon imported uranium. The ultimate incentive is that if nuclear fission is to remain a major energy source through the next century, it can only do so with the efficient recycle of fissile material in advanced fuel cycles and breeding.

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The stories of greatest interest lie mouldering.

Such as the picture of Rutherford, hands on hips, surveying the meagre few pounds' worth of equipment available to him at the Cavendish, and delivering himself of the exhortation to his colleagues: "We haven't much money so we will have to think".

Or the accounts of Lise Meitner and Otto Frisch grasping what the Hahn and Strassman results were showing by means of pictures drawn in the snow while they rested during a skiing outing.

Or the story of Fermi next to the pile under Stag Field, watching a few paltry instruments, scribbling hurriedly on the back of his slide rule, relaxing, smiling and then announcing

"I think it's going to be alright."

Keith Weaver

Book Reviews

Poincaré and Prigogine

Order Out of Chaos, Ilya Prigogine and Isabelle Stengers, Bantam, New York, 1984, ISBN 0-553-34082-4.

Chaos: Making a New Science, James Gleick, Viking, New York, 1987, ISBN 0-670-81178-5.

Mathematics and the Unexpected, Ivar Ekeland, University of Chicago Press, Chicago, 1988, ISBN 0-226-19989-4.

The fact that safety work, particularly in the nuclear industry, has (mis)appropriated the label "determinism" to describe one of its approaches to safety studies is not without a certain irony. The confident determinism of Laplace and the eighteenth century has long since been consigned to File 13 but in many ways it was a case of "The King is dead! Long Live the King!" Other variants of the dogma grip the scientific mind just as firmly.

One of the people during the past hundred years who was least likely to be held in the determinist thrall was Henri Poincaré, "the most penetrating critic of quantitative methods, and the great proponent of qualitative ones". In Poincaré's mature work in celestial mechanics, published nearly a hundred years ago, he questioned the belief that quantitative models can be used to predict the future. Of course, celestial mechanics is far removed from everyday processes. Or is it? Poincaré's methods are every bit as applicable to other areas as they were to celestial mechanics, and it is for this reason that he is regarded by some as the first practitioner in an area that now labours under the unfortunate (but trendy and fundable) name of "chaos dynamics".

The three books listed above present very different views into what is meant and what is implied by work on "chaos". Ilya Prigogine was awarded the Nobel Prize for chemistry in 1977 for his work on non-equilibrium thermodynamics. In particular, he has pioneered the study of those systems which he calls "dissipative structures", and which include novelties such as the Belousov-Zhabotinsky oscillating reactions, probably the Great Red Spot on Jupiter, weather systems and life processes. James Gleick is a journalist and editor with the New York Times. Ivar Ekeland is a French mathematician. The three books are as diverse as are their authors. All of them are interesting.

The book by Prigogine and Stengers is a huge striding work that sweeps across the Western tradition of human thought but always picking out, as it goes, a theme which could be inadequately summarized as our awakening to the central importance of subtlety and complexity. The book is in fact a vast paean to human knowledge and intellectual endeavour. (Italo Calvino prefers the inferior aphorism "a passionate meditation on Man and Universe".)

Yes, but what's it like, one might ask.

VERY many threads are brought together in this book, and it would be the rare person (which category certainly does NOT include the present reviewer) who would be comfortable with all of them. *Order Out Of Chaos* is less obscure than Prigogine's earlier book *From Being to Becoming*, but is much broader. Be prepared to grasp (or at least step around) such nettles as Leibnitzian monadology and don't be surprised to encounter Gibbs, Popper, Einstein, Boltzmann and Giordano Bruno all on the same page. For those who don't like grand themes and sweeping vistas, this is definitely a book to avoid.

Any discussion of "chaos" would be expected to include Prigogine and it is therefore puzzling that Gleick's book manages to avoid even mentioning his name. As one would expect of a book written by a journalist, the prose is such that one can hum through its 317 pages in a few hours. It is half novel and half documentary, but then the topic does seem to lend itself to this approach very nicely. The book begins with the Butterfly Effect. In 1961, as Gleick relates the tale, a meteorologist named Edward Lorenz noticed that if data sets, which differed only by extremely small variations, were entered into a computer model of the weather (primitive by today's standards) they resulted, after some hours of simulation, in totally different weather predictions. Even the presence of a perturbation as small as the flapping of a butterfly's wings on one side of the world (fairly daring hyperbole by anyone's standards, but one that results in a memorable image) could be credited with the difference between clear skies or a hurricane on the other side.

The book then changes scene (it really does seem like the bibliographical equivalent of a television documentary) to take in the work of Mitchell Feigenbaum (then at Los Alamos, now at

Rockefeller University) and the fascinating and ongoing series of experiments at the University of Chicago being done by Albert Libchaber's group. (Further results from this work are still being reported in such popular journals as *Physics Today.*) Benoit Mandelbrot makes a predictable appearance and the book draws to a rousing conclusion in the final chapter, entitled "Chaos and Beyond". This is a very readable and clearly-written book, but if your scientific sensibilities bridle at chapter subheadings such as "The Monsters of Fractal Geometry", "Quakes in the Schizosphere", and "The Trash Cans of Science", then you should give *Chaos: Making a New Science* a miss.

Ivar Ekeland is a professor of mathematics at the University of Paris-Dauphine, and the original French version of the book (*Le Calcul, l'Imprévu*) was awarded the Jean Rostand prize in France given for popularizations of science. For those with a constitutional distrust of translators, Ekeland did his own (excellent) translation.

With two appendices and index this book is only 146 pages, but is written with great subtlety and finesse. Beginning with the rise of the Copernican system and Kepler's laws, and thereby putting us on the deterministic course in celestial mechanics, the book advances quickly to enunciate its main themes: the roles of Poincaré and René Thom (catastrophe theory) in throwing sand into these heavenly gears. The stage for this book is essentially topology, and the Bernoulli shift (the "baker's transformation") and "Arnold's cat" both make appearances. Of the three books, Ekeland's essay illustrates most clearly, I think, the innate complexity and subtlety present in physics, partly through reproducing, in connection with the discussion on Poincaré's work, Hénon's patterns of perturbed trajectories.

The final chapter, "Back to the Beginning", admits implicitly that a higher arbiter is needed in sorting out the significance of what has been discovered. A dogged pursuit of dynamical systems, as they are now constructed and understood under the deterministic paradigm, leads to a confused interpretation of time. Appropriately the author turns to *The Iliad* and *The Odyssey.* Any attempt to summarize this chapter would only diminish it.

A verdict is eventually given on catastrophe theory: it may be a hopeless endeavour but it does salvage "a few pieces of floating debris from the shipwreck of geometry". Poincaré does an encore in Appendix 1, entitled "Prelude and Fugue on a Theme by Poincaré". There may be those who don't care much for reflective works of this sort. Such people should read this book anyway; it's short and the pain will be brief but it may lead to a pleasurable addiction.

Keith Weaver

Crossing the Minefield

A Journalist's Guide to Nuclear Power, Ontario Hydro, 1988.

Anyone who has ever worked in media or public relations will know just how difficult it is sometimes to get the job done. "The job", and there are times when one despairs of ever being able even to define it, is often made much more difficult by obtuse managements, by not having quite the information needed and by not having the right tools.

A Journalist's Guide to Nuclear Power is an excellent example of one of those tools which has been missing too long. Michele McMaster, who compiled the volume, has done a magnificent job of compacting an enormous amount of information into a small and very approachable package. Anyone inclined to belittle this accomplishment is encouraged to try to summarize all the safety reports, the major AECB guides, the BEIR and UNSCEAR reports, plus a few tons (sorry, tonnes) of associated guff, and do it such that somebody with a five minute attention span can find just what they want on any topic.

Those who have worked in media or public relations will also be painfully aware that the trade has well-known pitfalls, into which it is inevitable that one will tumble sooner or later. One of the most damaging of these is putting the best foot forward at the wrong time. *A Journalist's Guide to Nuclear Power* has, unfortunately, fallen into this pit. There are other problems with it as well, and now that we are onto the critical path ...

To start with the minor problems, the expansion of the acronym CANDU, given on the first page of the *Guide*, is not correct. This may seem like a very minor point, but it is just the sort of nit-picking frequently indulged in by the industry when it comments on the press. There are other minor errors of this nature, such as a certain confusion as to how many stations there are at Pickering and Bruce. One station at each site? Two?

A more serious apparent problem relates to whether the content and general tenor of the *Guide* conform to its expected use. It is intended for the working journalist with little or no knowledge of the topic and although it could be consulted for background information on a leisurely "public interest" story, it is likely to be of most use when turned to "in anger". If a journalist is told "Something's happening at Pickering. Get the goods on it quick", and he (non-gender) refers to the *Guide*, what will he find?

First of all he will not find much specifically about accidents. There is no chapter on accidents. There is no chapter on emergency response. The word "accident" does not appear in the index. He will also not find any clear statement as to what the hazard is from nuclear stations. There are lots of reassuring words about barriers, defences, unlikelihoods, the excellence of the whole marvellous thing. Our hard-pressed muckraker will find no statement that radioactive fission products are produced in the fuel, that they remain there unless driven out by accidents, that all the exotic safety hardware has as its sole purpose to prevent the escape of fission products from the fuel, or if all goes awry, at least to keep them in the building.

The same sort of comment applies to the section entitled "Understanding Radiation". Right at the beginning, instead of coming out with a statement of the problem, the *Guide* thrusts forward the complaint that radiation is all terribly misunderstood. A bit more hand-wringing ensues, and then there is the ominous statement "The danger of radiation to living things spans the whole range of possibilities". What does this mean? Our clock-racing journalist won't actually find out what the specific health implications of radiation are (in effect, *how* it is dangerous) for another fourteen pages.

Similar instances of the tendency to "put the best foot forward" appear throughout the book. The good news is trumpeted first, and only then, maybe, is it allowed that there could be a downside. Several examples could be cited, but, to be particularly unfair, a very minor one will be picked on. On page 33, in a discussion of probabilistic and deterministic safety analyses, the following statement is made: "the probabilistic approach uses sophisticated computer programs". Aside from remarking that this is making a virtue out of a necessity, the cynic (there are one or two among the ranks of the fourth estate) might wonder just what nasties lurk behind these words. ("Someone", our cynic would note wryly, "may drive an expensive car, wear the best clothes and drink only the finest single malts, but he could still be a nasty little swine".)

The criticism of this publication is strong, for a good reason. *A Journalist's Guide to Nuclear Power* is potentially a very positive and useful document but its success could be made much more likely at the cost of only modest additional effort. These comments are an entreaty to expend that effort. To stress once again, everyone associated with *A Journalist's Guide to Nuclear Power* should be highly commended on a fine job. The appearance of an improved Second Edition will be awaited with interest.

Keith Weaver

The Acts of the Apostles

The Red and the Blue – Intelligence, Treason and the Universities, Andrew Sinclair, Coronet Books, ISBN 0-340-41-687-4

Oh dear! Not another episode in the long-established British scab-picking exercise on the treason of Philby, Burgess, Maclean and Blunt. Well, not really. Despite the subtitle this interesting volume is not another blow by blow account of Cambridge's notorious quartet, but rather an examination of the Cambridge intellectual environment in the twentieth century.

What precise conclusion the author is aiming for in this book isn't absolutely clear. In general terms he seems to be arguing that the true Cambridge tradition is not exemplified by the activities of the latter day Apostles, but rather by the achievements of the Cavendish laboratory – and certainly no reasonable person would dispute this. But the book is much more interesting, enlightening and provoking – and I suspect more important – than a defence of the Cambridge tradition, however expertly carried out. This is an insightful analysis of a specific intellectual environment and the historical roots of that environment. While Sinclair's scope is much narrower, *The Red and the Blue* invites comparison with *Children of the Sun*, Martin Green's masterly survey of the changing English intellectual environment through the first half of the twentieth century. And Sinclair raises some important questions about the nature of modern scientific research and the conditions under which it may sometimes be conducted.

The Cambridge Apostles figure largely in the book and it's worthwhile taking a moment to establish just what they were. The Apostles were a self-elected Cambridge secret society, based at King's, whose members regarded themselves as the elite among the elite. One had to be invited to join the Apostles and, if one were to be accepted, one was required to take an oath of secrecy. The members regarded themselves as the "best and the brightest" of the Cambridge intellectual firmament. As Sinclair makes clear, the Society's membership was notable by its virtually complete exclusion of scientists. This was a particularly noticeable omission during the period between the two World Wars when, under the leadership of Rutherford, the Cavendish Laboratory was busy turning the world of physics upon its head through the activities of such as Kapitsa, Cockroft and Woolton.

Sinclair, a Cambridge man himself, takes two foci for his discussion: the Apostles and the Cavendish Laboratory and, unfortunately as it turns out, uses the flawed C P Snow concept of "two cultures" as a mechanism for characterizing these organizations. Much of Sinclair's argument seems to boil down to a claim that the nature of the Apostles membership was such that individual members were predisposed to the clandestine work of the "mole", but in fact provided very little in the way of useful intelligence to their Soviet controllers in comparison with the cornucopia of data pouring out through the open scientific literature from the Cavendish.

Sinclair traces the origins of the Apostles back to the Catholic Jacobites of the eighteenth century through to the Conversazione Society, which later became the Apostles. The society, Sinclair points out, therefore grew up with a tradition of opposition to the established order and, because such opposition in the eighteenth century could be distinctly uncomfortable if not positively unhealthy, a tradition of secrecy. And with the nineteenth century division of the Cambridge intelligentsia into what Sinclair categorizes as "arts" and "science" cultures (*pace* C.P. Snow), there evolved an arts oriented tradition.

Included in its membership were such as Keynes, Lytton Strachey, Moore, Wittgenstein, Russell, and Forster as well as Philby, Burgess, Maclean and Blunt. Indeed, as Sinclair argues, this "secret society with latter day Platonic pretensions" did include many of the best minds of the age. However not until the Twentieth Century were scientists included, and then very few. In fact in their long history the Apostles excluded all the notable Cambridge scientists.

Another Apostles tradition Sinclair cites is that of homosexuality, though he is careful enough to note that not all Cambridge homosexuals were Apostles. Since homosexuality was not only held in social disfavour but was also a criminal offence in Britain until the sixties, Sinclair points out that the enjoyment by many Apostles of what they described as "the Higher Sodomy" would tend to intensify their insularity and secretivenes.

The characteristics of inward looking, secretiveness, opposition to the established order, and a highly amplified sense of self-worth, Sinclair suggests, meant that among the Apostles any Soviet recruiter would find numerous ideal candidates for the role of "mole". He spends some time on recounting the establishment of the Cambridge "Comintern" and, in fairness, noting that in the climate of the thirties, communism found adherents among a large number of the better-off and better-educated, particularly undergraduates. For those who attended the other (older) place, Sinclair offers the back-handed comment that at Oxford no Comintern is known to have been formed, either because people were less committed or more discreet.

The appeal of communism to the Apostles (and the subsequent appeal of treason) was, Sinclair suggests, partially the result of the value the "arts culture" attributed to secret intelligence rather than "the open exchange of it" and partially the result of the related desire to be an elite among the elite. (Philby is quoted as remarking on his recruitment to the KGB that one "does not turn down the opportunity to be part of an elite force").

Sinclair contrasts this with the all-inclusiveness and openness of the Cavendish where scientists from 14 countries worked under Rutherford's inspired and inspiring leadership. Open meetings were held weekly in Trinity at the "Kapitsa Club" for discussion of the latest discoveries. The appeal of the communist state to the scientists was based on the fact that they felt that for the first time a country was actually making proper and effective use of its scientific talent. In 1931 a group of scientists (including Cockroft, Haldane and Huxley) visited Russia and were "entranced by the Russian planning and industrialization". The assistance afforded Peter Kapitsa by the Cavendish (particularly by Cockroft) upon Kapitsa's return home was testament both to the faith the scientists had in the future of the Soviet Union and their committment to the tradition of free and open exchange of scientific information.

Sinclair's thesis seems to be that disproportionate significance has been accorded to the work of "spies" in the provision of intelligence to the Soviet Union – "their contribution was as nothing compared to the open and continuous exchange of theoretical information between Kapitsa and the leading physcicists of his age". From this he moves on to argue the irrelevance of the "arts culture" (into which category he places the Apostles and sections of the civil service and government) and its impotence to effect significant changes in society.

First of all, it must be said that Sinclair has chosen an extremely restrictive interpretation of the concept of "intelligence". Of course it's true that intelligence no longer means Carruthers crawling through enemy lines with the plans to the fort tattooed on his left kneecap. And of course it's true that intelligence services the world over spend much profitable time in the detailed scrutiny of a vast range of specialist publications. But surely it's also true that the worth to the KGB of a Philby was not simply a function of whatever scientific information he might be able to supply.

Secondly Sinclair has used "arts culture" in its misleading C P Snow sense, even though he explicitly recognises the flaw by admitting that certainly more than two intellectual "cultures" exist. It was Snow's simplistic (though eloquent) characterization of the "two cultures" that so aroused the ire of F.R. Leavis – and understandably so. Sinclair is (fairly enough) critical of Leavis' intemperance but for balance it should be observed that in the Leavis-Snow confrontation neither party was particularly distinguished. Indeed the whole affair was conducted with all the civility of a bottle fight in a dockside tavern and demonstrated the depressing fact that eminent academics can descend to the intellectual level of politicians and the linguistic level of bargees.

But the point that Sinclair misses (or ignores) is that what he (and Snow) describe as the "arts culture" is about as far removed from "the arts" as it is from the sciences. It should be remembered that the revolution in physics – manifesting itself most clearly in the years 1890-1939 – was paralelled by, for example, a revolution in literature (starting in the middle of the nineteenth century) and in literary scholarship (starting at about the turn of the century), the latter resulting in the evolution of the highly technical analytic technique known variously as "practical criticism" or "critical analysis". Such a field of endeavour would be as far beyond the ken of the classics-educated Apostles as the activities of the lads in the Cavendish.

It is Sinclair's concluding comment which illustrates most clearly the confusion he has regarding the "arts culture". He asserts that the traditions of narcissism, clandestinity, arcane knowledge and esoteric research characterize "... an arts 'culture' that cannot and is not changing human society". First it seems to me that none of the traditions cited above seem to be necessarily limited to any single field of endeavour. All sorts of activities have esoteric and arcane elements and may include narcissistic participants. And indeed science, whether medical, chemical, physical or psychological, has not been without its clandestine aspects – at least since the last war.

And as for any "arts culture" having the objective of "changing human society", Sinclair should have checked with the other place where twenty years or so ago the motion "The function of the artist is to change the world" was joyously defeated at the Oxford Union – principally by the poets and critics. It is possible that a few misguided people (such as social scientists, economists and the odd biologist) may have supported the idea. But then at Oxford almost anything is possible.

David Mosey

Conference Report

Uranium and Electricity Conference - Saskatoon

Sunday, September 17, 1988, broke fine at Saskatoon airport where two chartered aircraft waited on the tarmac to take 30 conference delegates and 55 Saskatchewan teachers to the Key Lake and Rabbit Lake uranium mine sites.

This was the first activity in our recent symposium "Uranium and Electricity" held in Saskatoon.

The programme, which included "teach the teachers" sessions and mine tours, was organized by the Canadian Nuclear Society in an attempt to get the experts from all aspects of the uranium fuel cycle together at one event to stimulate discussion on areas of common interest.

It was a bit of a gamble and it worked.

The event was co-sponsored by the Canadian Nuclear Association, the International Atomic Energy Agency (IAEA), the Chinese Nuclear Society, the American Nuclear Society and the Australian Nuclear Society.

Saskatoon is no stranger to the nuclear industry. Not only is the city the centre of Saskatchewan's uranium mining business, the world's largest source of uranium but also much of the early pioneering work on cancer therapy and radiology was performed at the University of Saskatoon in the 1950s. The first cobalt radiotherapy machine was installed in Saskatoon in the 1950s and the first patient treated for cancer by that machine is still alive today. And the university operates a SLOWPOKE reactor.

Where better to locate a conference dealing with all aspects of the nuclear fuel cycle? Especially when Saskatoon offers big-city amenities and small town-friendliness.

The conference began with a visit by teachers and other attendees to the northern Saskatchewan uranium mines at Key and Rabbit Lakes. The participants returned very impressed, as discussions at the reception on Sunday evening showed, with glowing comments on the well managed facilities. Our thanks go to Fred Thode-Hamilton, Mike Babcock and Josef Spross, the managers of these mining operations, for the warm welcome and excellent presentations.

The teachers' programme occupied Monday. The teachers were given a full day of presentations covering the need for nuclear generation of electricity, the mining and refining aspects of the fuel cycle, electricity power generation and "closing the circle" on the waste issue. The last was the hot topic, with many questions from the teachers. Returning the waste safely to the environment, as described by AECL's Bill Hancox, seemed to relieve many concerns. The afternoon session consisted of questions, answers and discussion in a panel format. Many interesting discussions took place including one stimulated by a member of the audience who decided to take the part of the sceptic. He suggested the nuclear industry had built a marvelous aeroplane, taken off for a worthy destination but hadn't worked out how to land. The panel had fun with that one, as did the audience and the news media.

The teachers were glad of the opportunity to learn more about the industry which is so important to their province and now feel they have sufficient information to enable them to convey a balanced perspective to their pupils.

The introductory plenary session of the technical programme, which took place on Monday morning consisted of a review of the global aspects of the nuclear fuel cycle by Professor John Runnalls, (University of Toronto), Mr Nechaev (IAEA) and Mr Li Can from China. M J Hulst from France wound up the session with a talk on the French fast breeder programme.

George Gatenby was Monday's lunchtime speaker. He is the new Chief Executive Officer and President of CAMECO (Canadian Mining and Energy Corporation), the newly formed combination of Saskatchewan Mining and Development Corporation and Eldorado Resources Limited, the world's largest uranium supplier. Mr. Gatenby expressed, in a refreshingly unambiguous fashion, his very positive views on the future use of nuclear energy and its role in replacing fossil fuels. I asked him the significance of the "E" for "Energy" in the company's name. Could it possibly mean the corporation would be interested in taking the resource industry one step further to sales of energy? George Gatenby's positive response suggests that future prospects may be exciting. Audience response, and the formal Vote of Thanks from Dr Lakshmanan, indicated that Canada's uranium industry - long in search of a central leader, has now found one.

The well attended afternoon technical sessions included papers on uranium exploration and mining and waste management with presentations from France, China and Canada.

Tuesday was a full day with 36 papers presented in three parallel sessions. The session titles give some idea as to the scope of the papers:

- uranium metallurgy, refining and by-products
- irradiated fuel management
- effluent management
- uranium chemistry
- refining and the environment
- environmental protection from low level waste
- fuel design, manufacture and performance

On Tuesday the first Canadian Nuclear Society "Certificate of Recognition Award" was presented to the Honourable Sylvia O Fedoruk QC, Lieutenant Governor of Saskatchewan in recognition of her contribution to the development of nuclear technology in the service of mankind by her pioneering work in radiology and her 17 years of service on the AECB. The Lieutenant Governor indicated that she believes future energy needs will have to be met by nuclear energy and that she knows that the industry is well regulated in this country. Also, to quote from a local newspaper, "as a person who enjoys the north very much, I would much rather see a nuclear power plant in northern Saskatchewan than see further tinkering with the Churchill River system to produce hydro electricity".

Tuesday's lunchtime speaker, A Marchbank (Vice-President Denison Mines) courageously substituted for his flu-infected President. His address endorsed the use of nuclear energy to meet future energy demands and stressed the importance of this energy currency in combatting atmospheric pollution problems. He also laid particular emphasis on the importance of public information programmes to ensure that the general public becomes fully informed about the realities of all aspects of the nuclear fuel cycle.

Tuesday evening saw everyone at the banquet barbeque at the Western Development Museum where steaks were enjoyed to a classical guitar accompaniment. The museum is a mechanical engineer's paradise with cars, engines, tractors and farm machinery available to crawl around. Or you can stroll up an authentic main street from a turn of the century "boomtown". Fun continued after the dinner, with jugglers and a unicycle. Somehow a notable personage (Alan Ashbrook, Vice-President of Eldorado Resources Limited) became enveloped in plastic wrap while indian clubs whistled to and fro around his head. A good time was had by all (even Alan).

Wednesday's sessions included papers on Canadian power reactors, fuel, safety trends, regulation and control of radiological hazards and future developments in nuclear technology.

The conference concluded with a session on international perspectives where Ed Davis, from the American Nuclear Energy Council, gave his reading of the nuclear energy situation in the United States. It is improving and this improvement may continue under a Republican administration. Davis argued that nuclear energy will see a revival in the early 1990s in the United States, provided the political scene remains favourable.

There is a concern in Saskatoon about the possible diversion of Canadian uranium to military uses. This has been highlighted recently by attempts on the part of some people to have the City declared a nuclear weapons free zone. Dave Sinden of the AECB addressed these concerns in his talk on the nuclear safeguard measures in place in Canada.

The conference was closed by Chairman Don Somers (Vice-President CAMECO) who suggested a repeat event in the next three to four years.

In running this conference two Saskatoon businesses afforded us particular assistance. Both the Saskatchewan Mining and Development Corporation (now combined with Eldorado Resources Limited to form CAMECO) and Cambrian Engineering of Saskatoon (part of the Cambrian Engineering Group Limited) were extremely helpful in their support of the conference activities and facilities. Everyone we dealt with was first rate, enthusiastic and competent. Their help was vital in making this conference the success it was.

Some statistics on the event:

- 140 registrations
- 32 delegates from outside Canada
- 16 countries represented
- 50 teachers attended
- 65 papers presented

Comments from our off-shore visitors were extremely complimentary. The technical and organization quality was excellent. We would, however, have liked 50 more registrations. Judging by the enthusiasm of the attendees, we should be able to build on the quality of this event and attain better attendance next time.

The Canadian Nuclear Society must recognize the contribution of the following organizations to the support of conference activities:

- AMOK/Cluff Mining
- CAMECO
- Cambrian Engineering of Saskatoon
- Campbell West Ltd
- Cigar Lake Mining Corporation
- Key Lake Mining Corporation
- Kilborn (Saskatchewan) Ltd
- Teachers Credit Union
- Westwind Aviation
- Uranerz Exploration and Mining Ltd
- Saskatchewan Research Council

Personally, I would like to thank the following people for their help and support:

- Don Somers for able chairmanship
- Lucky(!) Lakshmanan for stimulating papers
- Dennis Brown for stimulating discussion
- Ron Barsi for enthusiastic energy
- Merv Hollingworth for controlling the dollars
- Ed Hinz for organizing organizers
- Michele Panchuk for keeping us all on track

As a postscript, a noble group of people from Saskatoon are considering establishing a Canadian Nuclear Society branch in the city. We will be supporting their efforts and hope they will be successful.

Ken Talbot

CNS Branch News

Toronto Branch

The first meeting of the Toronto Branch's 1988-9 session was held in Mississauga on 14 September, immediately following the CNS Officers' Seminar and Council Meeting. The topic of the meeting was AECL's latest (and perhaps most radical) CANDU development, the CANDU 3.

AECL's CANDU 3 Programme Director, Dr K Hedges, outlined the design philosophy of the new reactor – improvement of inherent CANDU advantages (specifically reliability, ease of maintenance and safety) and reduction of capital and operating costs, man-rem costs and construction schedule.

The CANDU 3 is designed to produce about 450 MWe (using a core with 232 fuel channels), a power level favoured by many utilities around the world. Total unit energy costs will be competitive with those of coal generating units.

Capital costs – the Achilles' heel for nuclear power plant economics generally in an era of high interest rates – will be significantly reduced for the CANDU 3, Dr Hedges emphasized, through measures such as:

- maximizing access for construction and equipment installation
- minimizing (and simplifying) reactor building internals
- minimizing number of components
- simplifying equipment installation
- maximizing off-site (factory) fabrication

The design of the new reactor reflects these imperatives, Dr Hedges noted, since the CANDU 3 uses a single heat transport loop with two core passes (coolant flow is thus in the same direction in all channels) and a single fuelling machine at one end of the reactor.

As well, the CANDU 3 is designed for long station life – a 100 year lifespan may well be a possibility since all station components are designed to be replaceable. Major component replacement operations, including fuel channel replacement, are expected to be completed within a 90 day period.

Dr Hedges' comprehensive presentation on the CANDU 3 certainly aroused great interest, as evinced by a very lively question and discussion period.

Ben Rouben

Central Lake Ontario Branch

Over 100 people attended the November 8 midday meeting of the Central Lake Ontario Branch to learn about superconductivity and superconductors. Dr Peter Mayer, of Ontario Hydro's Research Division, explained the basic theory behind superconductivity and outlined the history of the topic, including recent and apparently quite dramatic developments. He also discussed the potential applications of superconductivity in such areas as power transmission, energy storage and super-computers.

Dan Meraw

Conferences and Meetings

Call for papers

Fifteenth Annual Nuclear Simulation Symposium

Sponsored by the Nuclear Science and Engineering Division of the Canadian Nuclear Society, the Fifteenth Annual Nuclear Simulation Symposium will be held 1 and 2 May 1989 at the Sheridan Park Research Community, Mississauga, Ontario.

The symposium covers all aspects of nuclear reactor modelling and simulation, including reactor physics, thermalhydraulics and components and systems behaviour. Papers which discuss methods under development, present partial results or address unresolved problems are welcomed.

Abstracts of not more than 300 words in length should be sent to Ben Rouben, Atomic Energy of Canada Ltd., CANDU Operations, Sheridan Park Research Community, Mississauga, Ontario L5K 1B2. Abstracts must be received by 27 January 1989. Authors will be notified of paper acceptance by 17 February.

For further information call Ben Rouben (416-823-9040) or John Marczak (416-592-7622).

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.

The Unfashionable Side

Water of life

They crashed into the room with the speed and efficiency of Guderian's panzers, but without all the gunfire. Four of them. They were built like the Forth Bridge. They sounded like Harry Lauder. It was an awe-inspiring combination. I didn't even have time to reach for the tactical device I keep handy for such eventualities before the leader spoke. Well actually he didn't start off by speaking since he had to wave the bladderman to silence first. The skirl of the pibroch at full revs died down.

"Wal, whar ye've doon wi'it ye spalpeen" the leader said, with a cavalier disregard for dialexical consistency and a bristling sporran.

I raised a languid eyebrow (a movement to which I had been devoting much practice) and eyed the hairy pict in what I trusted was a disapproving manner. "My dear fellow" I began "it is indeed a braw bricht moonlicht nicht and a hoots mon to you too. Now in what way may I assist you?" The leader scowled at me and loosened his claymore in its scabbard. "Ye ken weel what's the matter" he roared, "whar's yon Bauer doon wi'it".

The chap was obviously fairly concerned about something but, alas, there seemed nothing I could do to assist him further in his enquiries. I hadn't the foggiest idea of what he was on about. This I explained while, surreptitiously, reaching for the nearest available weapon – Bauer's brolly – which, in an uncharacteristic fit of absent-mindedness, Bauer had left hanging handily from the hat rack.

I was only just in time for the leader, casting diplomacy to the winds, swung what looked like five feet of razor-edged gleaming steel in my direction. I parried in sixte and riposted in the general direction of his sporran. He exclaimed something in what I trust was gaelic and collapsed upon the piper. However his understrapper was already swinging into an attack, which I was ill-prepared to meet. I ducked ignobly, went to guard against a cut in quarte and then ... Bauer's pathological fixation on high-tech came to my rescue for the brolly incontinently burst open like an awakening pterodactyl, trapping my opponent's blade. A quick twist of the wrist and I had disarmed him. I swiftly stepped back, picked up the gasogene and aimed it in the general direction of the disordered tartans on the floor. "And now, gentlemen" I said smoothly, "I am sure you have many calls of a similar nature to make in this vicinity. Please don't let me delay you".

As the shattering sound of the pipes at full chat died away down the corridor I poured myself a restorative brandy and tried to make sense of the situation. But before I could collect my thoughts, the bell in the pigeon loft rang. In the absence of my ... er special assistant, Miss Fairfax, I was constrained to ascend to the avian rendezvous to ascertain what this particular beastly bird (it was Horace in fact) had brought home to roost. The message was simple and short: "Check your FAX for vital message. Bauer".

I was a little nonplussed by this since it seemed to me that transmitting a message via one medium to alert me to a message via another one indicated a degree of supererogation excessive by even Bauer's flexible standards. Besides, why wasn't he using the heliograph I had presented him on his departure for Caledonia? Reflecting moodily on this question I joggled the fax machine into life. Its indicator light glared balefully at me and it began a horrid chirping, grinding and groaning, culminating in the disgorgement of a slimy looking piece of paper. I held it up gingerly. The message was laconic to the point of incomprehensibility:

RNAS LOSSIEMOUTH. BAUER TO WORTHING. THREE (3) VICTOR K2 TANKERS ARRIVING WISTFUL AP 18:00 ZULU. URGENT TAKE DELIVERY CARGO WITH UTMOST EMPHASISE UTMOST SECURITY. WEATHER CONTINUES FINE. BAUER.

What the hell was Bauer doing at Lossiemouth? Wasn't he supposed to be on the other side of haggis-land cornering the year's production of ... and then the penny dropped. Bauer had got all the scotch and bunged it in three bloody great RAF tankers and had it flown over ... for me to handle!

But there was no time to lose, I decided as I mentally added five hours to the present time and realized that the aircraft had probably touched down some forty minutes ago. It didn't take long for me to look up Wistful Airport in my Guide, and I found to my delight that the chap in charge was none other than "Sozzler" Stevens who'd been on loan to my Squadron from the RCAF to learn about RAF night-fighter operational techniques. It was years ago, but I'd always remembered him as a wizard chap. I knew he'd help me out.

I picked up the phone and dialled the airport. The switchboard transferred me to Maintenance, who then transferred me to Administration who, after letting me rest for a few minutes on "Hold", transferred me to Personnel who asked for my social insurance number and then, dissatisfied with my answer, transferred me to Security. Security, after some heavy breathing, switched my call to Sozzler's office and I had merely to negotiate the two remaining hurdles of his Department Secretary and his Personal Assistant. Finally, with direct voice communication via landline I was able to advise Sozzler of my problem. He was curt, not to say brusque. Yes, three RAF Victor tankers had landed. No they couldn't stay there overnight because (a) the machines were the property of Her Majesty and she wanted them back in England, (b) no hangar space was available because all the airport buildings had been taken over for a multi-cultural recreation and craft centre and (c) he had no desire to get mixed up in any irresponsible (and quite possibly illegal) jape. No, he would make available no storage facilities for the cargo which he inferred was a prescribed substance of some description. Yes he was serious.

"whar's yon Bauer doon wi'it?"

I slammed down the phone and worked swiftly with the brandy bottle and gasogene to calm my nerves. I'd always remembered Stevens as a pedantic little prick. He would be of no help to me now. Feeling defeated, I wandered down the corridor thinking to return Bauer's sadly mangled umbrella to his office – if I didn't say anything he might put the damage down to a sudden infestation of voracious moths.

I unlocked the door and, edging carefully past the stuffed raven on his writing desk, placed the umbrella in a dark corner. Glancing around I saw a large ring-binder propped open against a plaster of paris bust of Bismarck. Curious, I picked up the volume, but it was nothing but the Pickering "A" Safety Report – testament to Bauer's bizarre taste in science fiction. It slipped from my hand and fell open to the floor. As I bent to pick it up I glanced at the open page and then, suddenly, the idea came to me. I knew what to do.

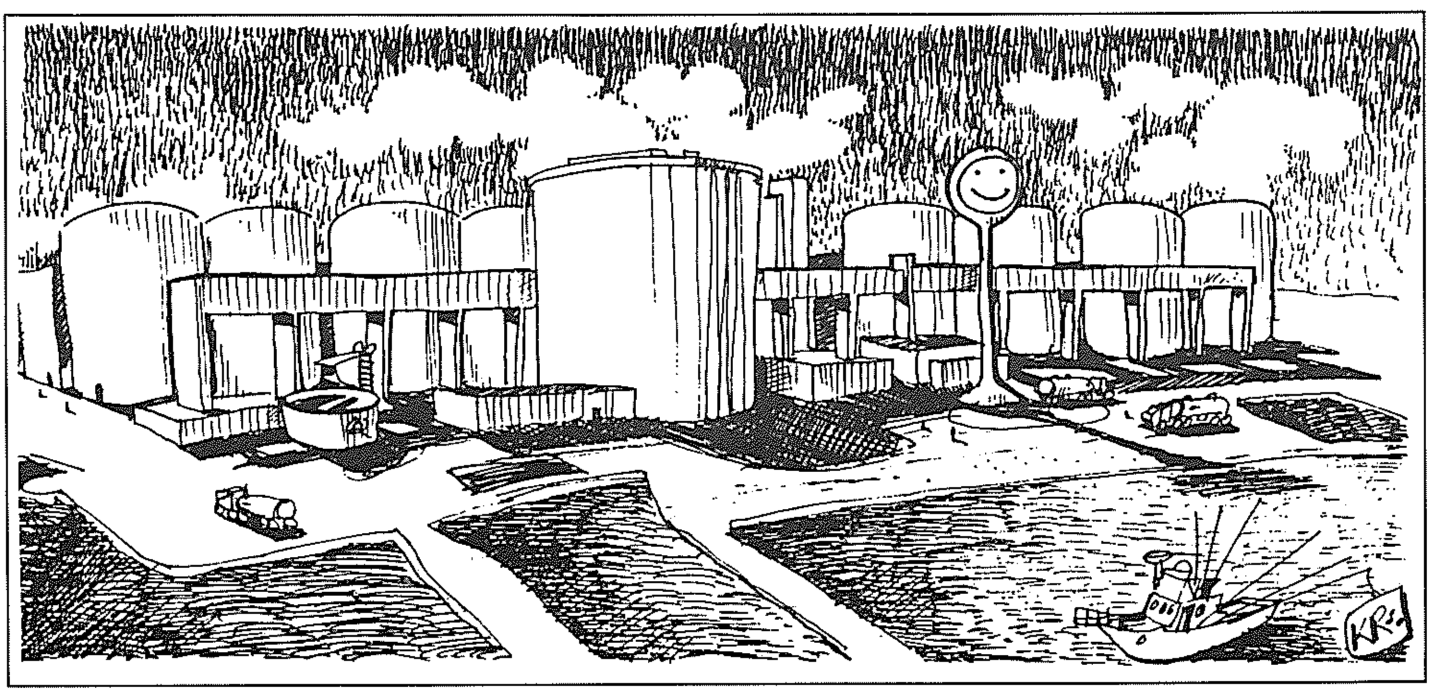
A couple of phone calls to Pickering and the Armitage Apex and Hardcastle transportation company were all I required to set my plan in motion. By the time I arrived at Wistful Aerodrome three full-loaded tanker trucks had already departed for Pickering and three more had almost filled up. By the time darkness fell all 180,000 gallons had been unloaded. The three Victors took off for their return flight and I, after flourishing a pair of valedictory fingers in the general direction of the unspeakable Stevens, departed for Pickering in the wake of the road tankers.

We worked hard through the night and, as the sky paled in the east, we completed the task. I reflected on the irony of a thirsty caledonian station manager sitting in his office, not realizing that virtually within his reach lay 180,000 gallons (minus a bit for "spillage") of the finest single-malt . . .

Two weeks later I drove out to Toronto Airport to pick Bauer up. He must have had a very rough flight because throughout the drive back to Aphasia he was twitching and clenching his fists convulsively. But he soon calmed down after a few pints. "So where did you store the stuff finally?" he enquired, with some concern. I said nothing, but merely passed his copy of the Safety Report, open at the relevant page. He uttered a strangled cry. "You put it WHERE???" he gasped, reaching in his agitation for my beer. "Bauer, old boy, calm yourself" I said in reassuring tones. He sat back massaging his bruised wrist and listened as I explained the many advantages of my scheme – including the vastly increased ECIS inspection frequency that had resulted, much to the delight of the AECB staff. "So you see, Bauer, it's all worked out in a highly satisfactory manner. Where else would you put 180,000 gallons of scotch, but in the injection water storage tank?"

Bauer relaxed and smiled. "You're right, Worthing. A little unconventional, but right." He sipped some more of his beer, then continued "and for next year's supply there's always the dousing tank".

Ernest Worthing



where else would you put 180,000 gallons of scotch?

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