CANADIAN NUCLEAR SOCIETY

Bulletin

DE LA SOCIÉTÉ NUCLÉAIRE CANADIENNE

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IN THIS ISSUE:

- We've done a hell of a lot
  Bill Morison reflects on the CANDU programme
- Risking the end of the world
  a technical note on the anthropic principle
- Nuclear costs in Ontario
  the enquiry findings summarized
- Permutations in the arts and sciences
  in review

Contents

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In all respects ready?...

On March 24 the supertanker *Exxon Valdez* ran aground in Prince William Sound, Alaska, near the fishing villiage of Valdez, ripping open at least eight of her oil tanks and releasing about 40 million litres of crude oil. Attempts to contain the spilled oil and clean it up promptly were were not notably successful.

It is doubtful that those who originally opposed the Alaskan oil venture on environmental grounds will derive much comfort from the accuracy of their forebodings, but they, and indeed all those who share a concern about environmental quality, may wish to consider a few interesting points.

Large tankers pose unique safety problems, and not just by virtue of their cargoes. With the possible exception of marine oil drilling platforms they are the largest mobile objects humankind has ever constructed. They require much searoom and ample draught. They are typically single-screwed vessels and so lack both the safety feature of redundancy and the advantage of better manoeuvrability afforded by multiple screw arrangements. A 250,000 ton vessel moving at 16 knots will, making "best effort", take over twenty minutes to come to a halt (and travel over three nautical miles in the process). When the depth of water beneath such a vessel's keel is 40 per cent or less of her draught, manoeuvrability is sharply reduced – the turning circle of the vessel is doubled. When the depth beneath the keel is reduced to a few feet, the vessel becomes virtually unsteerable. Regardless of the depth of water, at speeds of less than about 5 knots these vessels cannot hold a course.

All these features would argue that close inshore tanker operation in restricted waters should be avoided where possible. And where such operations are deemed unavoidable then extensive shore-based navigation aids and handling assistance should be provided. It is not clear that such facilities were adequate at Valdez.

Double hull design, an established technology, is a more expensive form of ship construction but does afford some protection (in the form of a second barrier to release of pollutants) in the event of hull damage resulting from grounding. The *Exxon Valdez* was not of double hull construction.

The possibility of large oil spills resulting from grounding cannot be realistically described as remote. Therefore plans should be in place, and equipment and trained personnel available, to contain and mitigate the effects of such spills. In the case of the *Exxon Valdez*, accident response appears to have been dilatory and ineffectual.

The promptitude with which reports surfaced that the skipper of the *Exxon Valdez* had been drinking and left his Third Officer in charge of the bridge at the time of the vessel's grounding is interesting. Regardless of the truth of this allegation – and it should be noted that the skipper's alcohol test is reported to have been administered some ten hours after the grounding – if those provisions (both technical and procedural) for safe navigation of Prince William sound could be set at naught by one man and a bottle, then surely the adequacy of those provisions must be questioned.

Statements by various authorities about the childishly simple nature of the task of navigating a supertanker up Prince William Sound display a frightening lack of appreciation of the nature of the difficulties and hazards inherent to handling any vessel in restricted, tidal waters, let alone something of the size and unhandiness of a supertanker.

The *Exxon Valdez* grounding reveals neither new phenomena, nor hitherto unsuspected vulnerabilities associated with supertanker design or operation. The lessons have been around for more than two decades. So has the knowledge of the devastating impact on marine life of large oil spills. When are we going to do something substantive about it – or are we so addicted to cheap oil that we are willing to discount the future of the marine environment to zero?

World-class...

Low temperature fusion?

To borrow from Edmund Burke, an event has happened upon which it is difficult to speak, but impossible to remain silent. It may be ironic, or appropriate, that seventy years after the nucleus had been split, and fifty years after the discovery of uranium fission had opened the way to fission energy, some scientists in Utah announced the discovery of a "room temperature" fusion reaction.

Fusion, the current Holy Grail of the energy questers, has for several decades been pursued implacably, expensively and (so far) unsuccessfully by large numbers of talented people operating very complicated machines. The news that a couple of chaps with a few bobs' worth of palladium and a bucket of heavy water had achieved a net-energy gain reaction which, by virtue of its production of neutrons and tritium, seemed to be a deuterium-deuteriun fusion reaction, was startling to say the least.

The Fleischmann and Pons results suggest a generous net energy gain and high energy densities but with anomalously low neutron production – which either suggests a mechanism additional to fusion is involved or our understanding of fusion needs some radical modification.

At the time of writing there's not enough information available to be able to hail the Utah experiment as the discovery of the century, or to dismiss it utterly from serious consideration. There's a strong temptation to want to believe it. After all, if the experiment did achieve fusion, then this is one of those "once in a century" discoveries that may cause considerable revision in our understanding of the physical universe – to say nothing of the implications of the discovery for the world's future energy supply. As well, there's something so attractive, at a visceral level, about the idea of a couple of people using relatively simple apparatus to attain what has eluded large teams of researchers using massively expensive and complex machines. Someone like Rutherford would have loved it!

But ... there's this uneasy feeling that Nature doesn't work quite like that. There is no free lunch and while the Utah experiment may not be exactly "free", it certainly appears very generously subsidised. Added to which, early reports suggest that so far other workers have not yet been able to completely duplicate the Utah experiment. And there's also the nagging memory of another "discovery of the century" from about twenty years ago – polywater.

Such reservations should not be construed as any reflection on the competence or ethics of the people involved. Quite the contrary. Faced with a novel, and not completely explicable result, two respected scientists have behaved honourably and – in view of the implications of the work – with some courage, in presenting their findings before the scientific community for scrutiny. Their parallel presentations to the news media, while not a usual proceeding in the scientific world, will presumably speed things up a bit.

By the time these comments appear, less equivocal results may be available. The prospects are tantalizing.

Leaky But Still Afloat

One could not ask for better French farce. Feydeau would be green with envy.

The subject, of course, is the Federal Budget. Amid stories, swirling like a Berlin mist in November, of rendezvous in ill-lit and vacant shopping centre car parks, a poker-faced Michael Wilson makes a dash for freedom, budget papers hoisted aloft. Opposition party leaders snap at his heels and try to make their baying suitably Baskervillian. Although budget season usually has all the dignity and predictability of a kindergarten class on a sugar fix, the extra splash of low drama adds a certain "personne ne sait quoi". (At the time of writing, Act I (Scene I) is scarcely finished. The piece could easily lurch toward tragedy or comedy before the interval.)

Beyond the histrionics unfolding on the stage, things are not well in the orchestra pit. Strings and winds seem to be disastrously out of tune.

There are the obvious inconsistencies, possibly more blatant than expected. In the present budget, one rule seems to be that all things which leak the specific combination "cash, credibility, confidence and poll ratings" should be quickly staked out on the financial ant hill. Thus Via Rail is set to jump the tracks; submarines which float perfectly well in other countries are found to sink in Canada; and it is shown once again that there really do exist three magic wells, which produce not only alcohol, nicotine and volatile alkanes but also cash. Our confidence is reaffirmed that the cash reservoirs tapped by these wells are truly infinite.

At the individual level, balancing the domestic budget is thought to involve variables which are conserved and algebras which are closed under the four arithmetic operations. These rules are enforced by a hideous creature, sporting all the appeal of Grendel's mother, called the Bankruptcy Act. At the federal level, budgetary matters are at best a zero sum game, but in general are ruled by something which might be called the Second Law of Fiscaldynamics. This law incorporates some 312 parameters and 58 variable constants. No matter how able the translators, each attempt to convert it from Newspeak to natural language produces a different result. Thus, it is perfectly reasonable to have revenues, expenditures and the deficit all vary as though they were independent quantities.

Optimists might have expected that the budget deficit and the accumulated debt, which has been milked for weeks in the press as the greatest evil since matutinal brandy, might have been the subject of a systematic and thorough assault, involving the formulation of a consistent set of priorities. There are short, medium and long term priorities. Which ones are most important? Which can be pared down with least overall pain? Where is money now being spent (money which we don't have) that could be deferred or eliminated? What costs will be incurred in the future by cuts in spending today, and which mix of spending cuts can be judged to involve the least future pain?

No such priorities are evident. Subsidies on one aspect of transport are viewed as an unspeakable dragon, and slashed with a glee which is unseemly, given the proximity to St. George's day. At the same time, a sheet is carefully pulled over other much larger transport subsidies and we are entreated to walk past softly. "Don't disturb them. They're sleeping."

In the fiscal as well as the mathematical arena, there exists a complex plane and cuts were duly made in this plane. The submarine programme, which doesn't actually exist, was cut. This has the consequence, vaguely disquieting to those weaned on physical reality, of greatly raising confidence and satisfaction while leaving revenues, expenditures and the deficit untouched.

We are thus going to war with a watered down "art of the possible" which is at once our siege engine, battle strategy and marching orders. Will it succeed? One might expect that the odds offered by Ladbrokes will be long. The objective is a well-fortified, well-provisioned redoubt located on high ground. One metaphor by itself falters under the descriptive load.

All the hype and noise of the past weeks seems to have been generated only to induce us to open our mouths. Nurse isn't quite sure what you've got but this medicine tastes foul and should cure anything.

From the Gallery

In splendid isolation

Cam Campbell

These are wilderness years for one Charles Caccia, Member of Parliament for the Toronto riding of Davenport, a man with more than a touch of the quixotic about him.

He was once Canada's Environment Minister, perhaps the most popular incumbent ever with Environment Canada staff. But his lack of enthusiasm for John Turner as leader of the Federal Liberals earned him the post-election rebuke of being dumped as Liberal environment critic (staunch Turnerite Sheila Copps took the job in his place). What the Liberals may have forgotten was that Charles Caccia didn't view his environment critic's mantle as a job to work at for awhile before moving on to something else – he acted like it was more of a calling. Undaunted, Mr Caccia announced he would carry on in his role of environment critic with or without the party's blessing, and established a "Parliamentary Centre for Environmentally Sustainable Development", albeit one made up of he and his executive assistant, Glen Okrainetz.

Already beset by a sea of troubles, Liberal house leader Herb Gray knew better than to make an embarrassing end to this one, and merely wished Mr Caccia luck.

Mr Caccia's interests are wide-ranging. The one-time Vienna University forestry graduate found it natural to get on the "stop acid rain" bandwagon when environment minister, thus raising his profile substantially. He is now passionately engaged by the issue of global warming, taking up that cause at every opportunity. Most strategies to combat the greenhouse effect make nuclear a weapon in the struggle.

Mr Caccia dislikes nuclear energy. He wasted no time after the throne speech in getting a host of motions on the House of Commons order paper. He filed motions against 12-hour shifts at nuclear plants and food irradiation, for a tougher policing mandate for IAEA, for a new "Nuclear Control Board", and on his favourite subject, a national energy plan to fight the greenhouse effect by boosting energy conservation and alternative energies at the expense of fossil and nuclear.

Most recently, he took an April 4 *Globe* editorial to task for its praise of nuclear at the expense of coal and hydropower. "Were we to make available to potential renewable sources of energy", Mr Caccia wrote, "massive subsidies and tax incentives ... we could move along the "soft" energy path defined by Amory Lovins a decade ago". Where the *Globe* had suggested (much in the manner of the House of Commons' Energy Mines and Resources Committee last summer) increased reliance on nuclear, Mr Caccia retorted disingenuously: "Isn't Ontario Hydro's deficit of $25-billion a sufficiently clear lesson?"

At a time when the greenhouse effect debate is turning a large number of formerly anti-nuke environmentalists reluctantly toward nuclear, (to "revisit the nuclear option" is how it's often put), Caccia's adherence to the Lovins school of conservation, wind and solar limits his waning influence.

At a time when the global warming is the catalyst for new alliances between nuclear's fans and foes, those pushing the decade-old Lovins catechism will likely remain in the energy wilderness – where a former environment minister pursues his lonely fight.

Cam Campbell is a Senior Analyst with Ontario Hydro's Government Relations Department, covering the Ottawa energy and environment scene.

We've achieved a hell of a lot

Bill Morison

In keeping with the retrospective spirit of the fiftieth anniversary year of the discovery of uranium fission, the Bulletin *asked Ontario Hydro's Bill Morison to look back on the Canadian nuclear power programme from his personal perspective. Despite his mild demur that what he said "seemed to ramble", we print below the transcript of his remarks.*

How did you get started in the nuclear business, and where did you think it might be leading at the time?

I suppose I really got started in 1957 when I went up to Chalk River. I was working at Ontario Hydro's Research Laboratory at the time, for the then Director of Research, Dobson who was Ontario Hydro's contact with Chalk River from about 1952. I was in a study group, which included Larry Woodhead, I seem to remember, and we were busy trying to learn what we could about this nuclear fission business using what little information was available. You must remember that at that time an awful lot of information was classified so were were using relatively few straws to get an idea of pretty complex bricks. But we did have some straws, so when I did get up to Chalk River I arrived with some general idea of what the science was all about and what we were supposed to do.

Now it is true that the first thing that happened when I arrived there was that they cancelled NPD-1 [vertically oriented pressure vessel heavy water moderated reactor concept] which perhaps wasn't the most auspicious start!

But in spite of that I had a feeling of excitement and elation – euphoria even – because I (and everybody I had to do with) had the feeling that we were going to be developing something really new in the field of energy. Our backgrounds were in the area of using water or fossil fuels to generate electricity and here was such a totally new system with such interesting challenges and such vast scope. The mystery of fission was very much part of this – getting all that energy from such a small mass – so there was a sense of amazement at this incredibly concentrated energy source. (I suppose for the physicists it may not have been the same way).

It was that atmosphere that spawned a whole lot of new ideas on how to use this energy. A whole lot of different concepts of different ways in which fission energy could be used were being examined. Different moderator materials. Different coolants. Reactors with pressure vessels or with pressure tubes. Different kinds of fuel. Even the homogenous reactor – which was quite a big thing in those days. Well when you got into that kind of mix – all those different ideas – you couldn't help but be really very excited, knowing you were in the forefront of something really new.

How did this influence the people who were there and the environment in which you worked?

Well one thing was the fact that everybody was at it all the time. By this I don't mean you saw people working away in their offices past midnight – for the simple reason that at Chalk River if you didn't get onto the buses with everyone else, then you were there all night! – but on the buses, at home, at parties, wherever two or more of us got together, the discussions went on and ideas were exchanged. People were keeping their minds on the problems most of their waking hours. Chalk River at that time was in direct competition with the rest of the world. We saw ourselves up there as being one of the world's centres of knowledge on fission. We had regular seminars (weekly I believe) from leading figures in the business from around the world. And that was an inspiring kind of thing, because we were hearing this stuff first hand – from the people who'd actually done (or were still doing) the original work. For me it was enormously valuable – I gained so many insights into so many different areas of science.

What was your role at Chalk River? A sort of Ontario Hydro observer evaluating what was going on and how it might be used?

At Chalk River there wasn't an "Ontario Hydro group" but a group of people from a number of different utilities and industries who were there to learn. For myself the first thing was to find out what people were doing. And at the same time do a lot of reading just to get up to speed. But I soon got involved with Jack Horsma's group which was working on fuel development and fuel testing, the development of systems for producing the heat and removing it. Fuel experiments were a big thing – trying to come up with some idea of a potential fuel's performance – using test rigs in NRX and NRU (NRX mainly). Oxide fuel was very new – until then reactor fuel had universally been metallic. We had to discover how to make oxide fuel, how to make it dense enough, how to make sure it didn't burst its sheath and how to control the fission gas inside. We were conducting engineering assessments of the fuel in parallel with looking at how this stuff could be used in a power reactor.

Do you have any particular recollection of any of the personalities of that time?

Well, there was Jack Horsma, who was head of the group, and he reported to Dr Laurence. Archie Roberston was on the fuel side and we had a lot of interaction with him – after all he was one of the "high performers" in that area at that time. I think he joined AECL the same day I did because I can remember him coming into the office and not knowing where the hell to go – and I didn't know where the hell to go either – so we got talking to each other.

John Melvin was involved in the engineering group (he's still there). David Keys was still there at that time, and he was very much the grandfather figure. Lewis was clearly scientifically in charge and driving the place, and the dominating personality on the site. I mean he overwhelmed people like Laurence with his personality and his singlemindedness. Of all his characteristics, most noticeable was this force to get things done. He forced people to do things ... he challenged them ... and if he wasn't happy with them he'd let them know. He clearly stood out with his drive towards what he believed was the goal. He had formulated his concepts and he pushed pretty hard for them. At the frequent meetings he called to discuss scientific matters it was very clear that he was pushing hard in a very specific direction.

Could you compare that intellectual environment with the one that existed when Douglas Point was being brought into operation and the design for Pickering going ahead – when you'd moved from a period of great scientific excitement to one of great engineering excitement?

At Chalk River the excitement was in the analysis and research – we were trying to develop pieces which would contribute to the answers we were looking for. When we got to the stage of completing Douglas Point – which took a little longer than we thought – and moving on to Pickering, yes we had moved into an engineering kind of undertaking. We had to make a lot of innovative decisions based on our best judgement using the information available at the time. That's very challenging and exciting for an engineer – knowing you have to build something and it has to work. There was a lot of innovation at Douglas Point, but we made a lot of changes when we went from Douglas Point to Pickering. And we thought we'd sorted out the good from the bad – the things we really wanted to keep we built into Pickering, and the things we thought weren't quite so good we let go.

Who were "we"?

We had Ted Beynon, who in my view was a really solid engineer, at Douglas Point and Pickering. Willy Wilson was the main driving force with Douglas Point – a lot of his ideas went in there whether anybody wanted them or not – but he was an outstanding person with a lot of excellent ideas. He was very good at maths and physics and so on. It was a sort of second language to him. But he pushed Douglas Point in directions that some of the engineers felt were a bit too far. So when we went to Pickering we got ourselves sorted out a bit better and balanced things. We had Al Hart at Douglas Point and Bob Renshaw – he was a very good process engineer, a little bit dogmatic, but what engineers aren't? And we had Fred Kee. Phil Stratton was a tower of strength in his field. And then there were John Stevens and Ernie Siddall – an ideal combination. John reported to Ernie, who was very much the innovator while John looked after putting things right.

Bill Morison: "In engineering you don't do much by yourself"

At the time that Pickering was due to be started up one couldn't have known how it was going to turn out. There must have been a few sleepless nights?

Well we were extrapolating Douglas Point to a station more than ten times its size. Yes, I think there were some sleepless nights. For example we knew we had a lot of problems with the pumps and the motors. We had a lot of problems with the fuelling machine. So we had to sit up and sort out what those problems were, then we eliminated them. But we learned a lot from Douglas Point. I can remember one time being in Harold Smith's office with Lorne McConnell – we were probably up there to ask for more money – and we were speculating what the capacity factor might be for Pickering. Lorne said that he thought we could get a 50 percent capacity factor from Pickering and that would be doing pretty well. And I just wouldn't have any part of that – at least 70 percent or nothing – and by and large we achieved what we set out to do. While we may have had some sleepless nights my own feeling is that we had some outstanding engineers and I think they learned very well from NPD and Douglas Point what not to do. I don't say we did everything right, because we didn't, but we eliminated a lot of the problems and I think did a thorough job in engineering.

So you think Douglas Point was money well spent?

I think it was. Certainly I can think now that there are some things I'd have done differently if I'd been in charge, but we learned a lot from Douglas Point. And you learn as much from your mistakes as you do from your successes – maybe more. There's no question about it, I think the guys learned very quickly when they saw what happened at Douglas Point. I was kind of sorry to see it shut down because I think people could have learned some more. I think eighty percent of what we needed to know we got from Douglas Point.

Almost all the pioneers are retired or in sight of retiring. The industry is now populated with people who mostly have had no experience in the early days – who virtually had no experience at all on prototype machines – and a lot of whom don't have the benefit of your type of overview experience, having worked in research and then design and then construction and then commissioning and then operations. There are very few people like that around now. Is the venture going to suffer at all from that lack do you think? From your point of view was it useful having gone through that whole mill?

Well I think it was useful. But remember that any industry can only go through that pioneering process once. Let's take an analogous case such as the automobile. You take a look at Ford or Mclaughlin – all the old pioneers who developed the very first cars. They developed pretty good cars. They set the industry on its footing. But if you look at the cars we have today, they're marvellous vehicles compared to the old ones. Somebody's put an enormous amount of effort and some excellent engineering into those cars to make them run the way they do. Now we're in the same business – we've evolved a process, a concept, and you can really only go through that evolution once. Then you've got a whole lot of other things that subsequently have to be sorted out, to be put right, to be brought to perfection – or at least as close to perfection as you can get. So I think it's the same thing for the nuclear power programme in that there's a lot of improvement that can be made in anything that we're building – we can make it substantially better. But we don't have to evolve the basic concept over again. We can refine what we've got, adding all sorts of new things that can make it an unrecognisably better performer than it was originally. Take instrumentation and control, for example – it's just revolutionary what's been and is being done in that area. Not only have enormous strides been made in giving the operators more detailed and precise information about what's going on in the plant, and so increasing the operator's ability to protect that plant, but also we're developing an ever increasing capability to protect the plant even without the operator.

We'll be approaching 60 percent nuclear contribution in Ontario when Darlington comes on stream. This may be a point where some people would say "Have we gone as far as we can go? How much further can we go?"

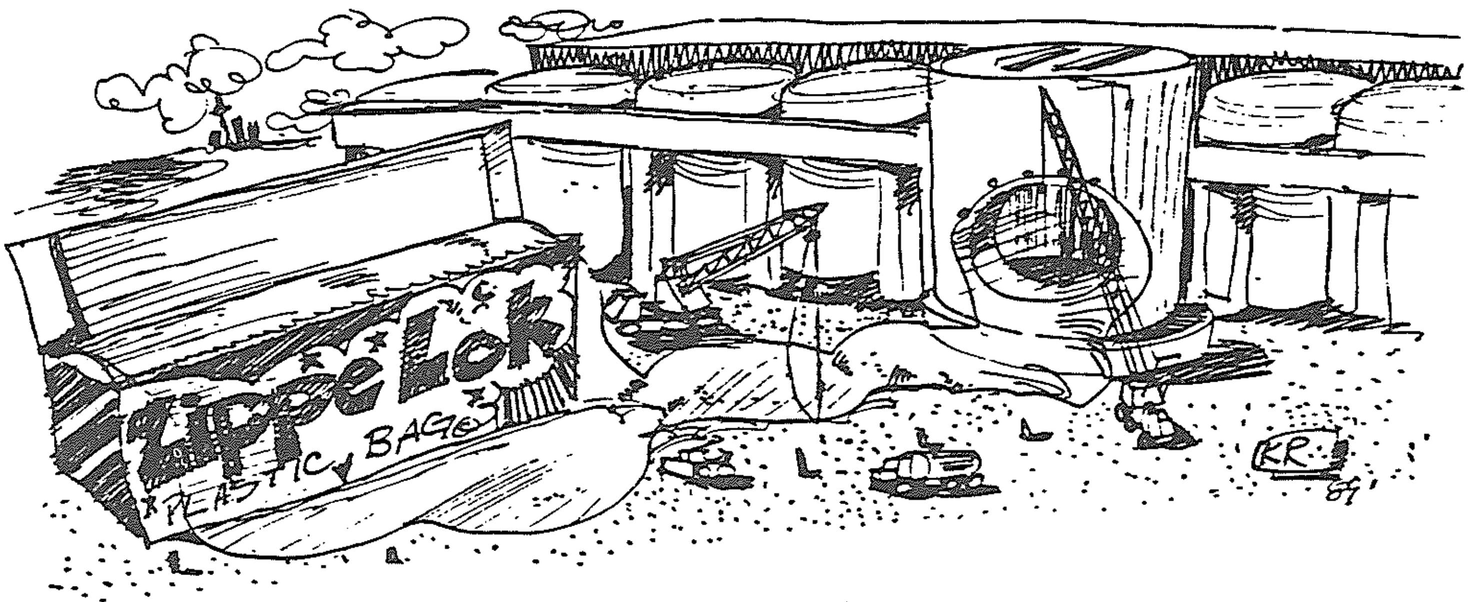
I guess that I'd say that we've achieved a hell of a lot. Perhaps we've gone further than anybody expected back then. But I think we're really only just beginning to take over responsibility for supplying mankind's energy. The intimations of the greenhouse effect have demonstrated that we've got to do things differently than we've done in the past. If we've got to take over the responsibility for most of the energy that mankind is using – not just 20 percent like we do in this province – then we have a major challenge in providing a sufficiency of safe, reliable and environmentally acceptable facilities. We've got other problems to satisfy as far as society in general is concerned – for example with respect to the way we handle our waste and so forth. I don't think we will be standing still, or should even think of standing still, if we're going to continue to produce what I think is needed for mankind.

What do you see as the major problems remaining? What are the opportunities?

I think electricity is likely to be the main vehicle for energy for mankind, for transportation, heating, lighting, process energy and so on. Most of the energy we're going to be producing will come from fission or fusion and it will mostly be in the form of electricity. Now what have we got to do for the future? I think there's no doubt that we're going to have to do much better in the utilization of our fuel. At the moment we're getting a very little bit of energy out of our fuel: we can get a lot more. So one way or another I think we've got to move to more and more energy extraction from the fuel we have. A first step would be low enrichment – a very very minor step forward. Then in the future obviously there's the opportunity to do some form of reprocessing. In the plant itself, if we're sticking with CANDU, we should be thinking about pressure tubes. We'd like to have pressure tubes that would last indefinitely. Failing that we'd like to have ways of replacing them very efficiently. In the whole area of waste management it's clear that it's very important that we do it well, show the world how to handle toxic wastes and provide a long term solution. Whether we'll go to another concept after CANDU is something else I don't know. I think there's a lot of potential, a lot of very good ideas, a lot of very good features in the CANDU system. It stands up as well as any system I've seen and it's likely to be around for a long long time. But you can't close your eyes to what might come along. If there are better systems, then Canada shouldn't stick with "Model A". Someday I'm sure that what we know as CANDU is going to look pretty antiquated.

In your career, do you have one thing you regard as an outstanding success?

I guess I've never felt that *I've* done anything. I've been involved in a lot of good achievements, but they've been team efforts. In engineering you don't do much by yourself. The thing I take great pride in is to have been a part of a process – a member of a team at a utility that began by getting its energy from water and evolved into one of the leading utilities in the world in the nuclear business. Being part of that is what I feel is one of my most satisfying achievements. It's not one person who does that sort of thing. But I have been part of it and I've been one of the leaders in getting Ontario Hydro into what is a very strong position. For example we have a vacuum containment system that nobody else has – I mean that was an outstanding piece of work.



"Maybe concrete would be a bit better."

How did the vacuum containment system come into being?

Well in about 1964 we were trying to convince Dr Laurence [then of the AECB] that a place called Pickering was a suitable site for a nuclear plant. He didn't think it was that safe and pushed us towards coming up with a better containment system. So we racked our brains and came up with a vacuum containment system. And it came in pieces – it didn't all come at once. The first thing we thought of was a big plastic bag lying on the ground with nothing in it. Then we thought "Jesus, that doesn't look too good, maybe concrete would be a bit better". Then we came up with "what about a big, empty concrete bottle". So I can remember going over to Hydro Research – and I came from Applied Mechanics so I knew we were strong in concrete – to ask if we could make a concrete cylinder that would sit there with the vacuum in it and not leak a lot – we didn't want to put liners in it or anything. So we did a few little tests to find out what the leak rate was for good concrete. And sure enough it turned out that you could build a concrete wall about that thick and it would let hardly any air through. But there were a whole lot of things that came together – the idea of having a vacuum, how do you keep it and so on. We needed vacuum pumps, some kind of vessel, a dousing system the big valves and so on. I can remember coming up with a valve that was rather like the big gasholders – the rolling diaphragm seals – I devised that one and it worked fine. Willy Wilson was trying to come up with one that was like a piston with piston rings in it. You know, you had to have this six foot diameter piston – well I managed to convince him that we weren't going to get that one to go!

Things like this grow one upon another – you don't have this light bulb flashing on and illuminating everything at once – you work at it bit by bit. It's just a normal piece of engineering. I don't think that system's got anything to do with the success of the CANDU – I mean it's never been used. It may have some success in convincing society that the stations are safe. But as far as the plant itself goes it was off to the side – it was a piece of work that needed to be done. The more significant stuff is a bit less showy – the reactor itself with its process systems, chemistry and the controls and all that stuff – that was work and hard work that actually had to be done to make something work. The control systems are another example– I think Canada led the way in the use of computers for reactor control. Right from Douglas Point we used computers when no-one else dared to.

As we get more familiar with running these machines are we running into the danger of just giving pro-forma attention to operational safety?

Yes, there's a potential problem. You can't take nuclear power for granted or treat it casually. I don't really foresee the day when our engineering people or the regulatory body – whatever it might be – is likely to relax attention to public safety or the safety of the plant. After all these things cost a lot of money and you can easily put your assets in a big black hole if you're careless or take things for granted or don't do things in the proper way. That has got to be part of this "safety culture" that people talk a lot about. I believe that the lesson that came out of Chernobyl – and came out of Three Mile Island as well – if you don't do things right – if you don't do them the proper way – then you can lose your whole investment very quickly. That ought to keep the executives and managers and all the people involved in nuclear power alert to what their duties should be. So, yes, there's a little bit of concern, but on the other hand I think there's enough motivation there to prevent anything untoward happening.

And I expect that we will have some more accidents – it's unrealistic to think that we'll continue to have nuclear power without more accidents. There'll be some more accidents but I don't think they're going to be severe public concerns. I think there's going to be some big investments lost about the place. But that's the price you pay for trying to push the frontiers.

Now when the plants get older there's going to have to be some decisions made about whether we keep these plants running or not. Just as with aircraft ageing – the airframes fatigue, systems wear and so on – our plants are ageing and we have to take account of this. Those are going to be very important decisions. I think we need to have a better handle on the stresses and ageing processes in a nuclear plant than we have on aircraft. But I think it's the same principle – there are going to be problems resulting from ageing and they're going to have to be dealt with. That's one reason why we're going to start seeing some of these accidents.

I don't think for a minute we're talking about Chernobyls or things like that. But nevertheless, Pickering A in 2012 will be 40 years old. Someone in 2000-and-something is going to have to decide: are we going to extend this thing for another 40 years or not? That means a lot of really good engineering is going to have to be done to see if they can save millions of dollars by reusing what's there. Or take it all apart and build another one someplace else. In parallel with that, along come these chaps working on fusion and I'd like to think that they'll make a breakthrough. When, I don't know, but eventually there's going to be competition with what we've got.

That's an exciting future. What's life if it's not exciting? For engineering the exciting part is having new problems to solve.

Canada's most eminent nuclear engineer, and recognised as "the engineering father of the CANDU", Bill Morison is Vice-President, Design and Construction at Ontario Hydro. Incidentally he was the first contributor to the ***Bulletin****, ten years ago.*

Speakers' Corner

Whelk stalls and shipping lines

David Mosey

Or a couple of related questions:

– is the customer always right?

– does it all come down to the bottom line?

Over the last few years the corporate dynamic of a wide range of organisations has become (superficially, at least) informed by a number of (for the want of a better word) "philosophies" which seek to breed excellence, efficiency, effectiveness, competitiveness, pride in service, and so on. These "philosophies" or "systems" carry with them a combination of the strident echoes of TV evangelism, the whiff of snake oil and the mindless simplicity of Orwellian slogans. Now it may well be that in principle there's not much wrong with this. After all slogans can be quite cheery things, and if senior executives get their jollies that way, who would be such a spoil-sport as to deny them? Certainly the more time such people spend in devising hortatory slogans to be printed on every scrap of corporate stationery or standing in front of the mirror murmuring "every day in every way we are getting better and better", then the less time they have to interfere with the people who actually get the work done.

But dangers arise when such slogans begin to be taken seriously and actually applied through the corporate hierarchy in a simplistic and literal fashion, by those who have little idea of the physical and technical reality of the tasks which must be accomplished to provide the good or service in question. Consider "the customer is always right", or the many variations thereon. As originally articulated, this slogan almost certainly was meant to reinforce the imperative for the supplier of a good or service of courtesy to the "customer" and, acting at a figurative level, underline the idea that no effort should be spared to meet the "customer's" requirements. And the welfare of the supplier of the good or service is ultimately predicated on the satisfaction of the customer. Fair enough. The problem is that not all the customer's requirements may be understood or explicitly articulated and that the nature of the operations necessary to meet both explicit and implicit requirements may be imperfectly understood.

Just how serious the problem can become is seen when the case of the capsizing of the cross channel ferry *Herald of Free Enterprise* is examinined. The vessel capsized on 6 March 1986 just outside Zeebrugge harbour with a loss of 186 lives. The ship's bow loading doors had been left open (the man whose duty it was to close them was asleep in his cabin) and, as the vessel built up speed upon leaving harbour, water rapidly flooded the open vehicle deck and, due to free surface instability, caused an immediate and rapid list to port. Had the ship not taken the ground in shallow water the loss of life would have been much higher.

It can be clearly inferred from the Wreck Commissioner's report on the loss of the *Herald of Free Enterprise* that the senior management of the ferry company had a firm understanding that ferry passengers placed a very high priority on punctuality and economy. This led to extraordinarily strong pressures on all staff to achieve rapid turn around, as exemplified by an internal memorandum from the Zeebrugge Operations Manager to assistant managers:

> *There seems to be a general tendancy of satisfaction if the ship has sailed two or three minutes early. Where a full load is present, then every effort has to be made to sail the ship 15 minutes earlier ... I expect to read from now onwards, especially where FE8 [Free Enterprise* VIII] *is concerned, that the ship left 15 minutes early ... put pressure on the first officer if you don't think he is moving fast enough. Have your load ready when the vessel is in and marshall your staff and machines to work efficiently. Let's put the record straight, sailing late out of Zeebrugge isn't on. It's 15 minutes early for us.*

The author of this memorandum subsequently described it as being for purposes of "motivation". The effect of such "motivation" was to effectively eliminate the possibility of establishing even the most rudimentary procedural measures to establish positively that an operation critical to the vessel's safety (closing the loading doors) had been carried out. It's not unreasonable to suppose that similar "motivation" resulted in vessels frequently sailing with an unknown tonnage of cargo (cited as "working practice"), an unknown passenger complement (also cited as "working practice") in unknown stability conditions (cited as "policy") and maintaining full speed in dense fog ("policy" again). There's no doubt that ferry passengers like to arrive at their destination on time – and clearly company officials, from the highest levels of management downwards, exerted themselves considerably to provide what they saw as effective and efficient service. The series of specific, written protestations from Masters drawing attention to both the hazards and the illegality of such "policy" and "practice" were ignored.

Economy, too, is a vital factor. The cross channel transportation business is a highly competitive market where "it all comes down to the bottom line". Any potential expenditure must receive minute scrutiny. The request by ferry captains for an arrangement for indicating loading door status on the bridge was dismissed out of hand by managers who perceived it as a totally supererogatory item. After all, as one manager observed in a marginal note to the proposal, "don't we already pay someone" to close the doors and another added the comment "assume the guy who shuts the doors tells the bridge if there is a problem". At no point does any manager seem to have understood the serious nature of the problem – sailing with the loading doors open – to which their attention had been carefully drawn by captains on a number of occasions. To them the situation was simple: a man was assigned the task of closing the doors – if he was derelict in this task, he should be disciplined. The inherent vulnerability of the open deck ferry design was not a piece of arcane technical knowledge – it had been clearly demonstrated in 1982 when the ferry European Gateway (also owned by Townsend) capsized after a collision off Harwich.

It is difficult to avoid the conclusion that while the senior management of the ferry company may have been excellent businessmen, their degree of maritime expertise or understanding was of a level insufficient to manage a rubber duck in a bathtub, let alone a fleet of open deck ferries operating in some of the world's most congested sea lanes. The Wreck Commissioner was quite explicit on this point, noting:

> *... those charged with the management of the Company's Ro/Ro [roll-on roll-off] fleet were not qualified to deal with many nautical matters and were unwilling to listen to their Masters, who were well qualified.*

It is possible to speculate that something of what we saw going on in Townsend Car Ferries Ltd. is attributable to that philosophy which states that management is management and requires the same talents whether you're managing a whelk stall or a shipping line. The business principles are the same and the bottom line is still the bottom line. This is surely not the case – "management" must be informed to at least some degree of the specific nature of what is being managed. The whelk stall manager presumably should at least have (or have access to) enough specialised knowledge to distinguish between whelks and other shellfish. It may well be true that the laws of business efficiency are the same for a shipping line as for a whelk stall – or indeed any other enterprise. It is equally true that the various laws of motion, friction etc are the same for all transportation technologies, but that doesn't mean you drive a Ferrari like a railway locomotive. Aha! you will probably remark, but the good manager has qualified staff to operate these vastly different vehicles. That is true, but if that manager insists that the railway locomotive compete in the Le Mans 24 hour race while the Ferrari hauls a load of box cars to Sault Ste Marie, some problems are going to be caused.

Essentially what's being argued here is that the "art" or "science" or "craft" (or whatever it is) of management cannot be divorced from the nature of the enterprise being managed. Blanket application from above of "simple business principles" (whatever they may be), or any other trendy nostrum, without regard for the physical and technical reality of the particular enterprise is a course fraught with peril. This is especially true in the management of any enterprise involving large scale technology. The technical realities cannot be left in a watertight black box relegated to "operations" or "the design people". They must inform the management philosophy. If they do not, then the stage has been set for, at best, severe economic consequences, and at worst, human tragedy.

Technical Note

Risking the World's End

John Leslie

The Doomsday Argument

Among policies which mankind might pursue, some appear to carry a risk of ending all human life. For instance, allowing greenhouse gases to accumulate surely involves at least some slight risk that the world will overheat disastrously.

The temptation is to treat all such risks as tiny and to forget them. However, a frightening argument – let us call it the Doomsday Argument – suggests that the risks have been severely underestimated. The crux of the argument is that if human life is due to end shortly then you personally are a fairly ordinary human: the human race has grown so rapidly in recent years that perhaps 10 percent of all humans who have ever lived are alive today. If, on the other hand, human life is going to continue for very many more years then you are a *very untypically early human*. And unless you have specially strong reasons to believe that, you ought not to believe it.

Besides defending the Argument, this paper will discuss one particularly interesting way in which the human race could go extinct. Various experiments in high-energy physics could give rise to a new Big Bang, perhaps starting somewhere in the USA, or to replacement of a metastable vacuum by a stable vacuum – which would be a second type of rapidly expanding disaster.

The special interest of this lies in the fact that we could do something about it. We could take care not to carry out the experiments in question.

One's Name on Just One Ball

The Doomsday Argument is probabilistic. A way of entering into the spirit of it is to consider balls drawn from an urn. Suppose you know that the urn holds either a million balls or else just twenty, and that just one of the balls is labelled with your name. Suppose you start off by estimating that the probability that the urn holds only twenty balls is a mere 2 percent. Balls are now drawn from it, one by one. On only the tenth draw, "your" ball appears. What should you now believe?

Clearly, your probability estimate should now shift. You now have far more reason than before to think that the urn contained twenty balls only. For in that case the chance that your ball would be drawn by the tenth draw would have been fully one half – whereas if the urn contained a million balls then the chance of its being drawn so early would have been only one in a hundred thousand.

Various points should be noted.

First: Your probability estimate ought indeed to shift on the basis of this one trial, a trial concerned with the time of appearance of just one ball. (Compare how the life to which the Doomsday Argument points, the life which you personally are living, is just one life.)

There is nothing wrong here despite all the books which thunder that no conclusion should ever be derived from a single test and that probabilities come into play only where there are repetitions. Those books are simply in error. Consider the case where you have two urns. One contains a million black balls and only one white; the other, a million white balls and only one black. Not having a clue as to which urn is which, you pick one of them at random – perhaps with the aid of a tossed coin. You then draw just one ball from it. The ball is white. What are the odds that it came from the urn containing the million white balls? Answer: A million to one in favour.

To arrive at this answer, simply consider the million and one equally probable ways in which a white ball could have been drawn. A million of them involve draws from the urn with a million white balls; only one involves a draw from the other.

Notice that odds of a million to one in favour of some hypothesis are far better than those normally required of hypotheses deserving our trust. There is no magical unreliability attaching to results just because they are results of single trials! Consider the hypothesis that a coin is double-headed, arrived at when seventeen tosses yield seventeen Heads. The odds against that occurring with a fair coin are much less impressive than a million to one. (Repeating the urn experiment several times, in each case replacing the drawn ball and then shaking vigorously, can in some sense "greatly improve" the reliability of the judgment that the urn is a million-white-ball one. But this just means that after, e.g., three successive whites have been drawn, the odds favouring this judgement are increased to a million million million to one. In another sense, those odds are not a great improvement because the first odds were already overwhelmingly good.)

Second: The estimate of probability ought indeed to shift because of "your" ball's being drawn *early on*. Suppose it is protested: "What is so special about being early? Every ball has to be drawn at some time or other! Being drawn *in the first ten* is no more obviously special than being drawn between draw 767,422 and draw 767,433." The answer to this protest is that "your" ball's being drawn in the first ten is "special" when you have a plausible theory – in the case discussed, the theory that there are only twenty balls in the urn – which makes its being drawn in the first ten *specially to be expected*. Compare how an opponent's getting a hand of thirteen spades is specially to be expected when you are playing cards against a cheat, which is why you must not just shrug your shoulders and comment that hands of thirteen spades are no more unlikely than any other hands of thirteen cards.

Whether you ought to be influenced by this kind of consideration is not just a matter of taste. All else being equal, you have a firm duty to see situations as much to be expected rather than as wildly extraordinary. In the case where it is known that there are only the two possibilities, namely, that an urn contains only twenty balls, and that it contains one million, the strength of such a duty may actually be calculable mathematically. Thus, suppose you have two urns which you have filled yourself. You know for sure, therefore, that the one contains a million balls and the other just twenty, and that in each there is exactly one ball bearing your name. The urns look identical and you have entirely forgotten which is which. You pick an urn with the aid of a tossed coin, draw balls from it, and get a ball bearing your name within the first ten draws. Any mathematician will tell you that the chances are now fifty thousand to one that the urn contained twenty balls only.

Third: A shift in your probability estimate is necessary even when you started off with just a guess as to how likely it was that the urn from which the balls were to be drawn contained twenty balls only.

Imagine, for example, that you are almost sure you remember which urn contains a million balls, and which only twenty. Forced to give a figure for your degree of confidence, you estimate that the likelihood is only 2 percent that the left-hand urn contains the twenty. (While by no means picked out of the air, this figure is still insecure enough to be called a mere guess.) You then draw out ten balls from that urn – and behold, one of them has your name on it. You now have a firm duty to revise your estimate. You must now judge it *much more likely than you did* that this urn is the twenty-ball one.

Exactly how much more likely? When mere guesses enter into them, probability calculations become a bit controversial, but I think Bayes' Rule covers such cases nicely. (Application of this Rule would be provably correct when you had a hundred urns, two of them filled with twenty balls and the other ninety-eight with a million, and had utterly forgotten which urns were which. Here your confidence that an urn picked at random contained twenty balls would stand entirely securely at 2% before you drew a ball from it.) Writing $P(L|A)$ as the estimated probability that the left-hand urn is a twenty-ball one, granted that a ball bearing your name has actually been drawn within ten draws from it; and $P(A|L)$ and $P(A|M)$ as the probabilities that such a ball would be drawn within ten draws if the urn contained, respectively, twenty balls and a million balls; and $P(L)$ and $P(M)$ as the initially estimated probabilities – the probabilities prior to all ball-drawing – of the urn's being or not being the twenty-ball one, we get

$$P(L|A) = \frac{P(L)\ P(A|L)}{P(L)\ P(A|L) + P(M)\ P(A|M)}$$

$$= \frac{(.02 \times \frac{1}{2})}{(.02 \times \frac{1}{2}) + (.98 \times 1/100{,}000)}$$

$$= .999, \text{ plus a little.}$$

In other words, whereas you started off by believing that the probability of the urn's containing only twenty balls was a mere 2 percent, a draw of a ball bearing your name within ten draws should shift your estimate of this probability all the way upwards to over 99.9 percent.

MORAL: If we are to have much confidence, even after we have considered the Doomsday Argument, that the human race will survive long, then we shall have to take so much care to avoid all risks that our confidence prior to considering the argument can be very great indeed.

98 percent "prior" confidence may be severely insufficient.

Why Risk Estimates Really Must Shift

To illustrate that moral, let us simplify everything enormously and say that there are just two possibilities. The first is that the human race will end before AD 2050; the second, that it will survive for many million years but that (unlikely though this seems) it will be confined to the solar system. Simplifying again, let us say that the chance that any particular human, picked randomly out of the entire temporal career of the race, is a human *alive in 1989*, is 1/10 if the race ends before 2050, while otherwise it is only 1/1,000. And finally, let us suppose that after considering all threats to humanity's survival – greenhouse effect, a change in the AIDS virus making it transmissible by sneezing, nuclear warfare, huge rocks rushing in from outer space, etcetera – you conclude (very optimistically?) that the chance of the race meeting with disaster by 2050 is only 1 percent . That is to say: 1 percent is your estimate prior to letting the harsh light of the Doomsday Argument shine on the indubitable reality that 1989 falls inside your very own lifetime. But when you now apply the Argument, using Bayes' Rule as before, you find that the probability that disaster will strike before 2050, once that indubitable reality is taken into account, is

$$\frac{(.01 \times 1/10)}{(.01 \times 1/10) + (.99 \times 1/1{,}000)}$$

which is just over 0.5. In other words, your estimate of the chance of disaster should be revised upwards to a frightening 50 percent .

When it is assumed that the human race, if it passed 2050 safely, would spread so widely beyond the solar system that 1/1,000 needs to be replaced by 1/1,000,000, then the estimated chance of disaster rises much further, to almost exactly 99.9 percent.

Certainly these figures are far from reliable. This does not mean we have a right to disregard them. If one's best guess has been that the chance of the human race going extinct thanks to some contemplated policy would be, say, a mere 0.001 percent (and so might reasonably be disregarded in view of the huge benefits expected from the policy), then a Doomsday Argument revision of that best guess to, for instance, 35 percent, is not something lightly to be dismissed.

It is perhaps worth spelling out just why population size in various eras affects the Argument. It is NOT correct to reason that if a race lasts for n years then the chance of any particular person's existing in any particular year is just $1/n$. Suppose there are five hundred and fifty-five prisoners. Five will be executed on Monday, fifty on Tuesday and five hundred on Wednesday. As one of those prisoners you can *prima facie* strongly expect to be executed on Wednesday. Now, what applies to people being executed can apply also to people being born: five million, perhaps, in one year, fifty million in another, and five hundred million in a third.

Imagine getting a chain letter. The letter invites you to post ten dollars to the sender, then yourself sending similar invitations to a dozen others. Following the invitation is not a sure way to get rich quick. True, very many chain letters "reproduce themselves" very successfully, numbers growing maybe seven-fold with each new "generation", but it is the unfortunate senders of the *last* generation of letters – the generation after which no further spread is possible – who then form the large majority. Lacking evidence to the contrary, you have fairly strong grounds for thinking that by attempting to get rich quick you personally would be joining such a majority.

You must not protest that humans do not have birth times allocated by the drawing of balls from urns, for you would then be missing the moral of the prisoner-executions case and the chain-letter case. What these cases show is, first, that if you have no special reason to think of your own fate as non-ordinary then there is a need for you to think of it as ordinary, and second, that in estimating the strength of this need you should treat that fate *as if* it were settled by urn draws giving equal likelihood to all the various possibilities. (If I am among 555 prisoners, only 5 of whom will be executed today, then it is *prima facie* to be expected that I shall survive the day. I should see the odds of survival as 550 to 5. When told that I am indeed to be executed today then, before shrugging my shoulders and saying that I am just very unlucky, I should look for some reason which made my misfortune much to be expected, such as that I had insulted one of my gaolers. And all this is true regardless of whether prisoners ever are selected for execution through having their names on balls drawn from an urn.)

Some Final Objections Countered

When the Doomsday Argument considers the idea of your being an unusually EARLY human it does not of course deny that you exist LATE in human history *as it has unfolded up to the present date.* The matter which the Argument exploits is that whereas you are *for the moment* fairly ordinary, since maybe 10 percent of all human lives lived so far are being lived at this very moment, your ordinariness will not continue – it will not be ordinariness inside the career of the human race in its temporal entirety – if the human race is going to survive for many million more years. (Unless, perhaps, the race is going to survive only on a massively reduced scale, say of a few thousand people in each generation; but such a prospect is surely implausible. It seems far more likely that if the race manages to get through the next few decades safely then it will grow enormously by colonizing its entire galaxy, which might take a few million years only.[1])

Might you not protest, though, that you personally could not exist later in human history, because you would then not be *you*? Or that later generations *are not there yet* so that the only people able to consider the Doomsday Argument are people who *must* exist in a period which would be unusually early in the temporal career of the race, if that career were going to extend for many million more years?

No, such protests are inadequate. Admittedly, people who were contemplating the career of the race from points unusually early in that career could not (one presumes) be exactly as they were, and (certainly) could not have been given the gift of existence precisely as early as they were in fact given it, without existing then and not later. And these people would be considering a Doomsday Argument which *could not yet* be considered by people who would exist only later. But these truths are as trivial as the truth that if just the first ten balls drawn from an urn are marked with red paint as they are drawn, then any ball marked with red paint and bearing your name was drawn before draw number eleven. And *that* could not remove your grounds for suspecting that the urn contained twenty balls only, so that "your" ball's being drawn by the tenth draw was *not* a matter of its being drawn unusually early.

It is futile to object that any Stone Age men who had hit on the Doomsday Argument would have been led by it to the erroneous conclusion that the human race would end shortly afterwards. You might equally well object that any prisoner executed on Monday will have been sadly disappointed in the argument which gave him odds of 550 to 5 of surviving until Tuesday. It is not a *fault* in probabilistic arguments, that they encourage people with unordinary fates to reach unfortunate conclusions. The conclusions are not thereby proved to be unwarranted. (If I state with considerable confidence that the fair coin I am about to toss ninety times will not land Heads every single time, then the confidence is justified. It will have been *justified* even if the coin does happen to land in just that way.)

Again, one must not object that perhaps long-lasting intelligent races are extremely common in the universe whereas short-lasting ones are extremely rare, and that if this were so then the Argument would be misleading. You might equally well object that urns containing a million balls *might be* vastly more common than urns containing just twenty and that therefore nothing in particular should be concluded when a ball marked with your name was drawn from an urn within ten draws. Such objections are failures to see that *shifts* in probability estimates are what are being called for. Whatever reasons you may have for thinking that long-lasting intelligent races are by far the most common, are just reasons which should influence your "prior" estimate of how long the human race will survive: the estimate which you reach *before* considering the Doomsday Argument. What the Argument then exploits is that if the long-lasting races were indeed by far the most common then your own position would be a very unusual one. This supplies a powerful reason for revising your estimate of how common they are.

My depressing conclusion is that the human race is unlikely to survive long unless either (A) the "prior" chance of its being rapidly wiped out will be low no matter how we behave, or (B) that chance *is made* low by our deciding to behave with special care. ("Prior" here means "as estimated in ways taking no account of the Doomsday Argument".)

I think we ought to have little confidence in (A). As a contribution towards (B), let us now look carefully at the risks of high-energy experiments.

Vacuum Metastability Risked?

A first way in which high-energy experiments might prove disastrous was examined in 1983 by P. Hut and M.J. Rees.

TECHNICAL SUPPLEMENT

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CANDU ADVANCED PLUTONIUM BURNER
THE CANADIAN RESPONSE TO THE ALWR

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Abstract – *A CANDU based concept that utilizes energy produced by subcritical multiplication in a fertile region designed for accelerated plutonium production is presented. Its feasibility is based on incorporating the channels with fertile material into the primary heat transport circuit. Calculations with multigroup transport codes predict very high fuel utilization due to the production and burnup of fissile plutonium in the fertile region.*

INTRODUCTION

The neutron economy of CANDU and consequently its ability to burn natural uranium has been one of its desirable attributes. The low U235 content of CANDU fuel is one of the reasons why the contribution of plutonium to energy production is high, making the CANDU fuel cycle extremely efficient in terms of fuel utilization. Unfortunately, during the past two decades, this advantage has been diminished due to the availability of cheap uranium. Consequently, the significance of fuel utilization to the cost of producing nuclear energy has been reduced. As an example, it is now predicted that the fuelling cost of the next CANDU, if built in Canada, may comprise only 5 percent of the Total Unit Energy Cost (TUEC).

Furthermore, the prospects of advances in enrichment technology, such as Atomic Vapour Laser Isotope Separation (AVLIS) means that the CANDU advantage of better fuel utilization will be reduced further. The effect of enrichment efficiency on the CANDU advantage is shown in Table 1.

TABLE 1

CANDU Advantage in Fuel Utilization

Isotopic Percent U235 Extracted From Natural Uranium	CANDU Advantage in Percent Utilization Over LWR
0.398	48
0.520	17
0.620	0

What Table 1 indicates is that if AVLIS makes it feasible to extract 0.62 of the 0.72 isotopic percent U235 contained in natural uranium, the CANDU advantage will disappear.

In addition, it is now predicted that the next generation of LWRs (ABWR & APWR) will utilize fuel cycles that increase the energy contributed by plutonium. Such fuel cycles will compete effectively with the present CANDU fuel cycle.

THE CANDU ADVANCED PLUTONIUM BURNER

The prospect of a reduced CANDU advantage in fuel utilization over the LWR in the longer term is the major incentive for this study. We demonstrate that the present CANDU design concept has potential for increased conversion and resource utilization compared with other reactor concepts, so there is potentially a CANDU conversion which offers an excellent response to the ALWR.

The principle behind the conversion can be understood by looking at Table 2 where the energy dependence of the U238 and Pu239 absorption cross sections is given. A significant amount of Pu239 is produced by neutrons in the 4 to 75 eV energy range, whereas it is destroyed mostly by neutrons in the 0 to 0.625 eV energy range. Hence, plutonium production should be carried out in a spectrum that is rich in 4 to 75 eV neutrons and plutonium burnup should be carried out in a spectrum that is rich in 0 to 0.625 eV neutrons. Such spectra can be created in a CANDU lattice by adjustment of the moderator volume. Furthermore, due to the fuel handling capability available (a necessity for on-power fuelling) in CANDU the fertile material can be held in close proximity to the fissile material which allows (as will be shown below) the creation of a large interfacial area between the fertile and fissile material.

Based on the above considerations, we have investigated the neutronic implications of a reactor concept that has two insurmountable advantages over other converter concepts in that it (a) circumvents fuel reprocessing and (b) produces marketable energy during the conversion.

We cannot over-emphasize the fact that this study was carried out to illustrate a principle and that the results should not be considered as constituting a new reactor design. It is quite obvious that there are engineering problems to be addressed (especially in the area of fuel handling) and the feasibility of this concept will primarily depend on the success with which these are solved. Furthermore, the configurations that we are presenting are by no means optimum from operating and capital cost viewpoints.

GENERAL LATTICE CONFIGURATION AND FUELLING SCHEME

The reactor lattice is divided into two zones (Figure 1); a hard spectrum zone (HSZ) that is relatively rich in 4 to 75 eV neutrons and a soft spectrum zone (SSZ) that produces the normal complement of 0 to 0.625 eV neutrons as in the standard CANDU lattice. The HSZ consists of a group of fuel channels with reduced moderator volume. This hardens the spectrum and increases the plutonium production rate. Fuel is first irradiated in the HSZ and after the plutonium concentration has increased, it is irradiated in the SSZ. The SSZ has sufficient moderator to produce a spectrum which is soft enough to burn the accumulated plutonium.

Due to the lack of moderator, the HSZ is a subcritical region. The SSZ therefore has to be reactive enough to make the multiplication factor for the superlattice of HSZ & SSZ high enough to support neutron leakage from the reactor and parasitic neutron absorption in reactivity devices. This is a key issue that determines the neutronic feasibility of this concept and to test it will ultimately require an extensive set of measurements in zero energy and other integral facilities.

At this stage, some indication of the feasibility was obtained by simulation.

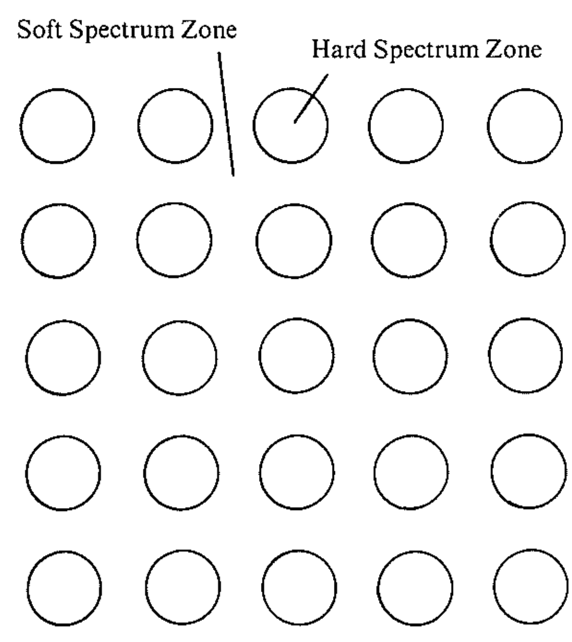

FIGURE 1 Schematic Representation of Hard and Soft Spectrum Zones as Part of the CANDU APB Core

TABLE 2

Energy Dependence of U238 & Pu239 Cross Sections

Energy (eV)	Microscopic Cross Section (barns)	
	U238	Pu239
10^7 to 8.2×10^5	20	7
8.2×10^5 to 1.11×10^5	20	10
1.11×10^5 to 9.11×10^3	20	15
9.11×10^3 to 9.07×10^2	20	15
9.07×10^2 to 1.49×10^2	20	28
1.49×10^2 to 7.5×10^1	100	40
7.5×10^1 to 4.8×10^1	500	100
4.8×10^1 to 2.77×10^1	4000	60
2.77×10^1 to 1.6×10^1	4000	100
1.6×10^1 to 9.9×10^0	8	300
9.9×10^0 to 4.0×10^0	3500	900
4.0×10^0 to 3.3×10^0	9	22
3.3×10^0 to 2.6×10^0	9	23
2.6×10^0 to 2.1×10^0	9.5	27
2.1×10^0 to 1.1×10^0	9.5	35
1.1×10^0 to 1.02×10^0	9.5	50
1.0×10^0 to 6.25×10^{-1}	9.5	95
6.25×10^{-1} to 3.0×10^{-1}	9.5	600
3.0×10^{-1} to 1.4×10^{-1}	9.5	1750
1.4×10^{-1} to 5.0×10^{-2}	10	800
5.0×10^{-2} to 2.5×10^{-2}	10	950
2.5×10^{-2} to 0	12	5000

SIMULATION METHODOLOGY

Simulation of the hard spectrum in the HSZ required multigroup lattice calculations. Proper representation of the HSZ & SSZ configuration required a two-dimensional model. Furthermore, since the spectrum in the HSZ is generated by subcritical multiplication of neutrons migrating from the SSZ, it was necessary to represent correctly the magnitude and shape of the interfacial area between the HSZ and SSZ.

The WIMS-CRNL[1] code with the Pij option was used with the WINFRITH (1985) 69 group neutron cross section data. The transport equations were solved in 22 energy groups. The latter were chosen with special consideration of the U235 and Pu239 resonance energies.

The Pij option in WIMS allows representation of each fuel pin at its proper location in the HSZ and the SSZ. The important requirement, of regenerating the correct neutron spectrum by subcritical multiplication of neutrons entering from the SSZ, is satisfied with this representation. This then gives the proper plutonium production and burnup rates in the HSZ and in the SSZ.

SPECIFIC LATTICE CONFIGURATION AND FUELLING SCHEME

To demonstrate the principle of this reactor concept, we present results for a specific HSZ and SSZ configuration. The HSZ consists of a 4 × 4 array of 16 fuel channels in contact with each other (Figure 2). A single calandria tube is used to separate the fuel channels from the moderator. The SSZ consists of four channels (each with its own calandria tube) that surround the HSZ and are separated from it by 25 cm of heavy water moderator.

Natural UO_2 fuel (the 37 element bundle was chosen for this study) is introduced into the outermost channels of the HSZ (designated as 1 in Figure 2). After an irradiation of 150 full power days (FPD), it is shifted to the channels designated as 2 and then following another 150 FPD into 3. The final irradiation step in the HSZ of 150 FPD is carried out in channels 4. Following irradiation in the HSZ, the fuel is irradiated in the SSZ for 150 FPD.

Due to the absence of moderator, the HSZ is a subcritical region and neutrons are produced in the HSZ by subcritical multiplication of neutrons born in the SSZ. Consequently, a large fraction of the neutron population in the HSZ has the energy spectrum of the SSZ. This limits the number of hard spectrum neutrons in the HSZ and therefore limits the rate of plutonium production in the HSZ. Even then, the plutonium production is high enough to provide a fuel exit burnup of 22,500 MWd / teU (compared with 6000 MWd/teU with the normal CANDU lattice). This extremely high burnup is a result of utilizing the energy produced by subcritical multiplication in the fertile region (the HSZ) by incorporating

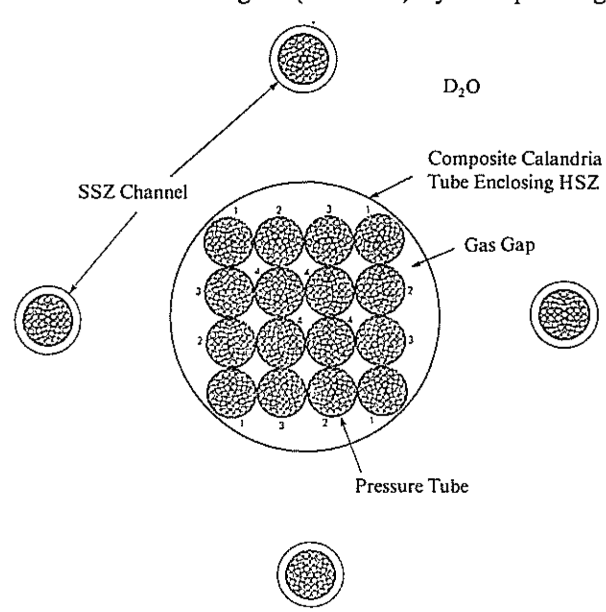

FIGURE 2 Supercell Showing Hard and Soft Spectrum Zones

the latter into the PHT system, a concept that is feasible in CANDU due to the versatility of its fuel handling system. If the HSZ could be made critical by the use of enriched fuel, the plutonium production and the exit burnup could be increased several times these values. More will be said about this when discussing the use of Recovered Uranium fuel.

Since the HSZ is subcritical, the neutron flux level in the HSZ is between 2 and 3 times lower than in the SSZ. The power density (rate of fuel burnup) and the rate of fission product formation is significantly lower than in the SSZ. As fission products accumulate, the fuel is progressively placed in the inner channels of the HSZ, i.e., into regions of lower neutron flux. As a result, neutron absorption by fission products is only a fraction of the neutron absorption in the normal CANDU lattice at comparable fuel burnup. In contrast, the fissile plutonium concentration increases with fuel movement into the inner channels (Table 3). On exit from the HSZ, the fuel contains 0.5 atom percent fissile plutonium compared with 0.2 atom percent from the normal CANDU lattice. At equilibrium burnup, the nuclide compositions at two consecutive irradiation periods of 750 FPD are shown in Table 2. The closeness of the two sets of values indicates that a dynamic equilibrium in the refuelling process has been reached. The multiplication factor of the superlattice once equilibrium is reached is in excess of 1.05.

The fuel burnup on exit from the HSZ is 13,000 MWd/teU. This indicates that the amount of energy produced in the HSZ by Pu239 fission and by fast fission of U238 is about four times that in the normal CANDU lattice.

When transferred into the SSZ, the fission product absorption increases by 30 percent due to the higher neutron flux level in the SSZ. However, the increase in the Pu239 absorption is greater because of the response of the Pu239 cross section to the softer spectrum. This limits the fractional absorption (or reactivity load) of the fission products in the SSZ to 0.049 (or 49 mk). The total fission product load in the superlattice (HSZ + SSZ) is 77 mk. The relatively low absorption rate in the fission products eliminates the need for fuel reprocessing (separation of plutonium from fission products) in contrast to a conventional fuel cycle that uses recycled plutonium.

TABLE 3

Nuclide Concentrations in the HSZ and SSZ Using Natural Fuel
($\times 10^{24}$ nuclides/cc)
Equilibrium Exit Burnup = 22,500 MWD/teU

STAGE A:

ZONE		U^{235}	Pu^{239}	Pu^{240}	Pu^{241}
	Outer*	1.0009×10^{-4}	5.3646×10^{-5}	9.1967×10^{-6}	1.2527×10^{-6}
	Middle	7.0501×10^{-5}	7.6022×10^{-5}	2.1422×10^{-5}	3.9311×10^{-6}
HSZ	Inner	5.2490×10^{-5}	9.0012×10^{-5}	3.2596×10^{-5}	6.7097×10^{-6}
	Centre	4.0684×10^{-5}	9.8805×10^{-5}	4.2968×10^{-5}	9.4359×10^{-6}
SSZ		9.9836×10^{-6}	5.8456×10^{-5}	6.0593×10^{-5}	1.3010×10^{-5}

STAGE B:

ZONE		U^{235}	Pu^{239}	Pu^{240}	Pu^{241}
	Outer*	1.0011×10^{-4}	5.3635×10^{-5}	9.1915×10^{-6}	1.2515×10^{-6}
	Middle	7.0513×10^{-5}	7.6027×10^{-5}	2.1417×10^{-5}	3.9286×10^{-6}
HSZ	Inner	5.2981×10^{-5}	9.0042×10^{-5}	3.2605×10^{-5}	6.7071×10^{-6}
	Centre	4.0508×10^{-5}	9.8917×10^{-5}	4.3125×10^{-5}	9.4688×10^{-6}
SSZ		9.9291×10^{-6}	5.8483×10^{-5}	6.0767×10^{-5}	1.3052×10^{-5}

(* outer, middle, inner and centre refers to channels 1, 2, 3 & 4 in Figure 2)

ALTERNATIVE FUELS

As stated earlier, the HSZ is a subcritical region and produces neutrons by the subcritical multiplication of neutrons that migrate from the SSZ. This process continues until the fissile content of the SSZ fuel is reduced to a level such that the absorption in the HSZ cannot be supported. Any increase in the initial fissile content of the fuel leads to a remarkable increase in the fuel exit burnup. This occurs due to a combination of reasons:

- the subcritical multiplication in the HSZ is higher and the residence time of the fuel in the HSZ is increased. This increases the energy production in the HSZ and also the plutonium accumulation
- the higher plutonium content of the fuel discharged from the HSZ increases the residence time of the fuel in the SSZ as the fuel can now support a higher accumulation of fission products.

Calculations with Recovered Uranium (a product of reprocessing spent LWR fuel) with an initial U235 content of 1.0 wt percent (compared with 0.72 wt percent for natural uranium) indicates an exit burnup of 52,500 MWd/teU. Since recovered uranium is not reusable in the LWR without enrichment, the CANDU APB is an attractive concept for countries that plan to recycle plutonium in an LWR and consequently have large quantities of recovered uranium at their disposal.

At equilibrium burnup, the nuclide compositions at two consecutive irradiation periods of 1750 FPD are shown in Table 4. In this case over 5.7 times the energy from U235 is produced by fissile plutonium and U238 fast fission.

The higher initial fissile content of the Recovered Uranium increases the subcritical multiplication in the HSZ leading to a higher power density.

CONCLUDING REMARKS

There are indications that fuel utilization in CANDU can be improved substantially by adopting a concept that allows a spectral shift during the fuel life to increase the energy contributed by fissile plutonium. These indications are based on analytical work and confirmation of this concept would require extensive experimentation.

The results presented here are to illustrate the principle of the CANDU APB. Major engineering design

TABLE 4

Nuclide Concentrations in the HSZ and SSZ using Recovered Uranium

($\times 10^{24}$ nuclides/cc)

Equilibrium Burnup = 52,500 MWD/teU

STAGE A:

ZONE		U^{235}	Pu^{239}	Pu^{240}	Pu^{241}
	Outer*	8.6828×10^{-5}	7.8632×10^{-5}	2.5955×10^{-5}	4.9668×10^{-6}
	Middle	4.5100×10^{-5}	1.0110×10^{-4}	5.0111×10^{-5}	1.0942×10^{-5}
HSZ	Inner	2.6997×10^{-5}	1.1655×10^{-4}	6.8436×10^{-5}	1.5806×10^{-5}
	Centre	1.6958×10^{-5}	1.2523×10^{-4}	8.3749×10^{-5}	1.9882×10^{-5}
SSZ		1.1617×10^{-6}	5.4464×10^{-5}	7.4067×10^{-5}	1.6629×10^{-5}

STAGE B:

ZONE		U^{235}	Pu^{239}	Pu^{240}	Pu^{241}
	Outer	8.6825×10^{-5}	7.8615×10^{-5}	2.5953×10^{-5}	4.9639×10^{-6}
	Middle	4.5109×10^{-5}	1.0108×10^{-4}	5.0103×10^{-5}	1.0931×10^{-5}
HSZ	Inner	2.6932×10^{-5}	1.1649×10^{-4}	6.8503×10^{-5}	1.5820×10^{-5}
	Centre	1.6825×10^{-5}	1.2522×10^{-4}	8.3946×10^{-5}	1.9923×10^{-5}
SSZ		1.1533×10^{-6}	5.4461×10^{-6}	7.4147×10^{-5}	1.6649×10^{-5}

(* outer, middle, inner and centre refer to channels 1, 2, 3 & 4 in Figure 2) problems need to be addressed before the feasibility of the concept is confirmed.

There is some potential in the use of the CANDU APB concept as a response to the high utilization fuel cycles being predicted for the ALWRs.

REFERENCE

[1] J.V. Donnelly, "The CRNL Version of the Lattice Code WIMS", AECL 8955, January 1988.

Even a vacuum is not mere emptiness. For a start, it is known to be filled with a ferment of quantum fluctuations: 'virtual' particles spring into being and then disappear before the energy accounts become more unbalanced than is permitted by the Heisenberg uncertainty relating energy and time. Next, it is believed to be occupied by one or more scalar fields which are hard to detect because their intensities are the same throughout the now visible universe. A scalar field could make its presence felt by giving masses to elementary particles. Now, the particle masses would in turn help to settle the relative strengths of Nature's fundamental forces.[2] When the Big Bang cooled, either the universe as a whole or else the region visible to us may have become characterized by an intensity of its scalar field(s), or[3] an energy density of its quantum fluctuations, which did not correspond to the state of least energy. As Hut and Rees express it,[4] "it is possible that the vacuum state we live in is not the absolute lowest one. In many spontaneously broken field theories a local minimum of the effective potential, which can be quite stable, can exist.... The Universe, starting at a high temperature, might have supercooled to such a local minimum. If such a metastable minimum is separated by a high enough barrier from the absolute minimum, the tunneling rate from the 'false' to the 'true' vacuum may be slow enough to not have occurred in one Hubble-spacetime-volume. In that case our vacuum state might suddenly disappear if a bubble of real vacuum formed which was large enough for the bulk energy gain... to exceed the surface energy density of its walls. Such a bubble would expand at close to the speed of light, with enormous energy release... we can ask whether a new generation of particle accelerators could trigger such an unfortunate event."

A metastable vacuum would be like a statue balancing upright. Might a high-energy accelerator experiment provide a disastrous push?

As others have helped to show, the transition to a stable vacuum would be irremediably catastrophic. Besides releasing energy enough to destroy all life, it would probably ensure that "before we realized what swept by us our protons would decay away".[5] Not only would there come to be "new constants of nature", but no "structures capable of knowing joy" could evolve in this altered environment because it would undergo gravitational collapse "in microseconds or less".[6]

Hut and Rees reach the comforting conclusion that the chance of disaster is "negligible". However, they do not do so through speculative calculation of the height of the barrier which could be protecting a metastable vacuum. Rather they consider the fact that the visible universe "has already survived some 10^5 cosmic ray collisions at centre of mass energies of 10^{11} GeV and higher" – though they concede that energies exceeding 10^{12} GeV have probably not been reached in "even one collision".

There we have it. If the Hut-Rees estimates are correct it may well be safe to make particles with 10^{12} GeV energies collide head-on, whereas the Supercollider now planned for Texas will produce head-on collisions only of particles of 10^4 GeV. But Hut and Rees note that the probability of the most violent collisions "is, of course, very uncertain". For one thing, "a homogeneous distribution of ultrahigh-energy particles" was assumed when they calculated it. What if the assumption were wrong? Might that not make a big difference? Not so, they suggest, for while clumping of the particles would reduce the probability of their colliding inside average volumes of space, collisions would be specially probable "at the place of production" of the particles. Yet this would seem to invite the protest that at places of production – and maybe everywhere else too – clumping (perhaps channelling by magnetic fields) might operate so as to keep apart particles moving very fast in opposite directions, which are precisely the particles one needs to get very powerful collisions. A collision of a 10^{11} GeV particle with a stationary nucleon would in contrast produce a collision energy of only $10^{5.5}$ GeV, as the two authors themselves remark.

It may follow that something as low as 10^6 or 10^7 GeV is the figure on which any suitably pessimistic risk assessment should be based. And new generations of accelerators may quickly erode the margin between that and the collision energies actually attainable. Plasma particle accelerators, for instance, might operate with fields thousands of times stronger than that of the Texas Supercollider.[7]

I am not saying that the risks involved would be large enough to seem serious *before* one considered the Doomsday Argument. But afterwards...?

Risking a new Big Bang?

Next let us look at the chances of producing a new Big Bang by mistake.

The Inflationary Cosmos, nowadays very much the Standard Cosmos, starts off in a false-vacuum state with extremely high mass-energy density yet with a total energy which can be zero thanks to how gravitational binding energy – like all binding energies in physics – enters the equations as a negative quantity. Without any violation of Energy Conservation, therefore, a tiny initial blob of false vacuum can double in size again and again, ending each doubling with the same energy-density as before. (There may be no limit to the number of doublings which could occur. A fairly popular theory is that everything now visible to us is just a bubble inside which the doubling process ended at a time fixed by chance alone. Outside the bubble, Inflation continues.) There is no special problem in "the creation of all the matter in the observable Universe (10^{50} tons) by gravitational forces operating inside a domain which originally contained less than 10^{-5} g of matter and was less than 10^{-33} cm across", A.D.Linde comments.[8]

How does 10^{-5} g compare with the mass-energy which human experimenters might concentrate inside a region 10^{-33} cm in diameter? Might they start a new Big Bang before AD 2050? Linde has voiced dark forebodings, cosmologist friends tell me, but I have not yet found him expressing them in print.

Print does however include two relevant papers co-authored by A.H. Guth. (Although Guth did not actually originate the idea of Inflation, his article of 1981 made it very popular.[9]) In the first of the two, "An Obstacle to Creating a Universe in the Laboratory",[10] Guth and E.Farhi consider compressing "a modest amount of energy" to start Inflation anew. The obstacle is that perhaps no amount of compression would do the trick; all known solutions to the equations suggest that one would need a state of indefinitely high density *which had no prior history* so that no laboratory could have produced it; but this difficulty might vanish thanks to "a sufficiently weird bubble geometry" or to effects permitted by a quantized version of general relativity. Guth and Farhi do make the reassuring claim that the inflationary expansion would merely be that of a "child universe", and "at no cost to the parent". "We would not be destroyed by a universe that we might create"; instead it would expand into a space of its own, owing to "the non-euclidean nature of the geometry". To us it would look like a black hole only. Yet the paper is dotted with such disquieting phrases as "we cannot be decisive" and "we have not excluded". One dreads to think what surprises a quantized version of general relativity might have in store for us here.

In the second paper,[11] this time written in concert with S.K. Blau and E.I. Guendelman, the lack of threat to the parent universe is considered in more detail. When the child inflates, its wall *as seen from inside the parent* is constantly accelerating *inwards*; however "the false-vacuum region is inflating so quickly that the motion of the wall does not prevent its volume from increasing exponentially". No matter how much this goes against common sense, it can be plausible in cosmology! Still, a thing's being plausible need not mean that we should have great confidence in it. In view of the complexity of the relevant mathematics, the distance at which all such speculations stand from well-established scientific fact, and the current lack of any properly quantized version of general relativity, there must be at least some slight risk that the child would inflate into the innards of its parent.

Controversial, too, is the same paper's figure for how much mass-energy one would need in compressed form: namely, about 10^{28} GeV or roughly 20 kg. As the authors comment, such a figure would seem to render academic the question of "whether or not it is possible in principle to produce an inflationary universe in the laboratory"; 10^{28} GeV is "totally inaccessible"; yet the calculations yielding the figure are (in view of how much could be at stake) frighteningly complex, frighteningly far removed from well-established fact. At one point, for instance, a guessed energy density is raised to its fourth power. Remember as well that the equally expert Linde suggested that less than 10^{-5}g would be enough to start the inflationary process. A universe originating as some kind of quantum fluctuation – the nowadays most popular suggestion for how our universe originated – would, other things being equal, seem more probable the smaller that fluctuation, a point made by E.P. Tryon in his seminal paper of 1973.[12] The maximum initial diameter for a quantum fluctuation universe would be the Planck length of roughly 10^{-33} cm, Linde insists; and while he demands of its mass-energy only that it should be finite, the "10^{-5} g" which he mentions is the Planck mass. Planck scales are often viewed as "natural" where universe-creation is in question.

Let us therefore ask how readily we could compress a mass-energy of 10^{-5} g into a region stretching 10^{-33} cm. With a large nuclear bomb explosion, far higher mass-energies could become available: even the several kg called for by Blau, Guendelman and Guth. The main problem is the need for compression into an extremely small volume. Yet might we not, for example, use nuclear bombs to power X-ray lasers, much as in the SDI (or Star Wars) scheme, then concentrating the output of those lasers?

SDI X-ray laser outputs are secret but an article in the December 1988 *Scientific American* reveals (page 87) that the most powerful *optical* lasers deliver 100,000 joules of energy in less than a billionth of a second. Well, this energy is itself only about ten thousand times less than the amount for which Linde calls. And though one billionth of a second would seem far too long for present purposes, could we not solve this problem with a little ingenuity, perhaps sending successive parts of the same energy pulse via routes of different lengths so that they arrived at the target together?

Maybe so. But all present-day lasers have wavelengths very many times greater than 10^{-33} cm, thank heaven. When the same *Scientific American* article states (page 91) that there appears to be "no magic barrier to the wavelengths which can be achieved" those words can scarcely be taken as saying that a gap of over twenty orders of magnitude can be much narrowed, neither would the difference between 10^{-5} g and the perhaps 10^4 g of a nuclear bomb explosion do much to compensate for this. The spatial spreading out of the energy, because of how the wavelength must be comparatively large, is too great to be counter-balanced by the fact that the bomb makes so much energy available. It would appear, then, that although (as is often said) SDI threatens to be very destabilizing, creating a Big Bang by mistake (e.g., through different parts of a laser pulse chancing to arrive at the same point by routes of different lengths) is beyond its capabilities. A catastrophic jolt to vacuum metastability may be the most it could achieve.

Physicists are inventive types, though. It would be rash to claim that concentrating the energy of a nuclear bomb to a density of the kind envisaged by Linde will be beyond their ingenuity for ever, or even for the next century. (Maybe they will find out how to change laser pulses to almost any desired wavelength.) Let us pray that they will restrain themselves from reaching out for the holy grail of experimental physics, the production of conditions like those which existed in our universe's earliest moments. While such conditions could superbly display the workings of a Theory of Everything whose formula could be written on a T-shirt, there might very soon be no one left alive to describe them.

Doomsday and the Anthropic Principle

The Doomsday Argument is not just of my own invention. It or something much like it has been toyed with by cosmologists for some years. Yet nobody seems keen to take the credit for having invented it: not altogether surprisingly in view of its depressing nature and the unpopular way in which it suggests we should stop taking risks. I know of no discussion of it in the journals. It may, however, first have been suggested by Carter's "The anthropic principle and its implications for biological evolution.".[13]

The anthropic principle is that the situations which conscious beings observe must be ones which permit conscious beings to exist. Although this might at first seem as boringly obvious as that bachelors are never bigamists, it does point towards possible observational selection effects of kinds often overlooked. Such selection effects, Carter's paper demonstrates, could concern the circumstances in which observers *are at all likely* to find themselves, and not just those in which they *must* find themselves.[14]

In the Discussion following the paper Carter comments that "something like a man-made ecological disaster... might well be discussed with reference to the anthropic principle."

Notes

1 Even nuclear war, if it failed to wipe the race out, would seem likely only to delay for a century the awe-inspiring progress of science and technology. But suppose I am wrong here. Would that show that the Doomsday Argument could safely be disregarded? Not at all. An Argument suggesting that humanity's survival is gravely at risk is hardly unimportant if the way of escape from it is to say that what is risked is instead that war (or something) will make population figures plummet in a way from which they will never recover.

2 See, for instance, papers in *Scientific American* by M. J. G. Veltman (Nov. 1986, pp. 76-84), C. Quigg (April 1985, pp. 84-95), and G. 't Hooft (June 1980, pp. 104-138).

3 See, e.g., P.Davies in *New Scientist* May 27, 1982, pp. 580-582.

4 **How stable is our vacuum?**, *Nature* April 7, 1983, pp. 508-9.

5 M. S. Turner and F. Wilczek, *Nature* August 12, 1982, p. 634.

6 Page 314 of S. Coleman and F. De Luccia, *Physical Review* D, June 15, 1980, pp. 3305-3315.

7 J. M. Dawson, *Scientific American*, March 1989, pp. 54-61.

8 *New Scientist* March 7, 1985, pp. 14-18. Linde has been one of the main developers of the Inflation theme.

9 *Physical Review* D, Jan. 15, 1981, pp. 347-356.

10 *Physics Letters* B, Jan. 8, 1987, pp. 149-155.

11 *Physical Review* D, March 15, 1987, pp. 1747-1766.

12 **Is the Universe a Vacuum Fluctuation?**, *Nature*, Dec. 14, 1973, pp. 396-397.

13 *Philosophical Transactions of the Royal Society of London*, A 310, 1983, pp. 346-363.

14 I have examined the anthropic principle in several papers – the first in *American Philosophical Quarterly* April 1982 – and also in *Universes* (Routledge: London and New York, 1989). Carter's first treatment of the subject, dating from 1974, and other relevant writings, are reprinted in J. Leslie, ed., *Physical Cosmology and Philosophy* (Macmillan: New York, 1989).

John Leslie is a member of the Philosophy Department at the University of Guelph and a specialist in cosmology. The argument he pursues in this paper (and in another to appear in The Philosophical Quarterly*) raises some very complex issues so he would welcome any comments/discussion. He may be contacted at the University of Guelph (Ontario N1G 2W1) or through the* Bulletin *Editors.*

Background

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

An Introduction to Radiation

W.M. Smith

Radiation is a physical phenomenon which plays an important role in a very wide range of natural processes. It has been put to use in various contexts, and in some cases (the applications of nuclear technology, for example), the term "radiation" has acquired a peculiar nuance which is associated with that context.

This sort of response is natural, since different types of radiation have different significance in everyday terms. For example, X-rays and laser beams have very different effects on matter, and although they are both forms of radiation, their applications are different and different precautions are necessary when using them. Inevitably, then, they are thought of in different terms. Nevertheless, there are certain common underlying elements which the term "radiation" embodies and aspects of this commonality will be described in what follows.

Like many other phenomena associated with the structure of atoms, the nature of radiation has been understood in detail only in fairly recent times. In 1895, Roentgen noticed that the operation of a cathode ray tube could be made to cause a screen at some distance from the tube to glow or fluoresce. This was true even when the tube was completely covered in dark paper. He also found that placing different thicknesses of various materials between the tube and the screen reduced the intensity of the fluorescence appearing on the screen, but did not eliminate it completely. It was discovered subsequently that a photographic plate would darken if it was located near an operating cathode ray tube, and that the rays coming from the tube could ionise a gas. What Roentgen had discovered was X-rays.

In 1896, Henri Becquerel noticed, by chance, that a sample of material containing uranium which had been placed next to a photographic plate had caused the plate to become foggy, or to darken. Rutherford showed later that this was due to radiation which was given off by the uranium. He also showed that two types of radiation were involved: these are the types now known as "alpha" and "beta" radiation. Rutherford demonstrated that alpha radiation was absorbed by matter after it had travelled only a short distance, whereas beta radiation required a considerably greater distance to be attenuated. Rutherford also showed that the radiation emitted by uranium could cause a body which had been charged with electricity to lose its charge.

Other types of radiation were discovered as well. In 1932, Chadwick showed that the radiation produced by the reaction of alpha particles with beryllium carries a large amount of energy, dependent on the amount of energy carried by the initial alpha radiation. As a result of this study, Chadwick discovered the neutron and proved that the radiation emitted by the alpha-beryllium reaction is a stream of neutrons.

With this bit of history as background, a general definition of radiation can now be given.

Radiation can be described as a flow of energy which travels through space and can interact with matter, depositing energy in this matter in the course of the interaction.

This is a very general definition, since it makes no distinction between radiation associated with named particles, such as neutrons, electrons, alpha particles, etc. on the one hand, and that associated with flows of photons (e.g. visible light, microwaves, radio waves and X-rays) on the other. This distinction is not made in a general definition because under many conditions flows of "solid" particles and flows of photons can behave similarly. In particular, they can interact with matter in very similar ways.

In practical terms, such a general definition is of limited use and some distinctions have to be made. One of these is the need to distinguish the various types of radiation which exist and to note their characteristics. Another, and perhaps more important distinction, is to classify radiation according to the nature of its effect on matter. These effects can vary from insignificant to extreme. Certain types of radiation produce effects which have special significance for living things and are of particular interest. This class is known as ionizing radiation and from this point onward we will restrict our attention to it.

Ionizing radiation consists of all those forms of radiation which are energetic enough to ionize atoms or molecules in the matter they interact with. This is the source of the particular interest in ionizing radiation because it can result in chemical bonds being altered or broken and it can change the internal organization of matter.

Characteristics of Radiation Types

Radiation can be divided into two types: radiation which has a charge associated with it and radiation with no associated charge.

Radiation with an associated charge involves particles which interact electromagnetically with matter. Such radiation tends to have a shorter range than does radiation with no associated charge. Radiation with an associated charge is typically of two important types: alpha and beta radiation.

Alpha radiation is a flux of particles which have the structure of the nuclei of helium atoms, $^4He^{++}$. Alpha radiation has the shortest range of all ionizing radiation and it can be stopped completely by a sheet of paper or by a few millimetres of air.

Beta radiation consists of free electrons (β^-) or positrons (β^+) and each beta particle is about 8000 times less massive than an alpha particle.

The other of the two broad types of radiation, that which does not have a charge associated with it, tends to have a longer range in matter. This type of radiation is of two principal types: gamma rays and neutrons.

Gamma rays are very energetic photons. Visible light is also a stream of photons, but the difference between the two is the energies associated with them. Photons of visible light have energies of a few eV, whereas gamma ray photons typically have energies much greater than one keV. X-ray photons, with energies in the low keV range, arise from electron shell transitions in atoms, as distinct from gamma rays which originate in the nucleus. Since photons are electromagnetic in nature, they can interact with the electromagnetic fields associated with matter. If the photon energies are high enough, these interactions can result in ion pairs and excitation events. This is the case with X-rays and gamma rays and consequently they are forms of ionising radiation. The ability of gamma rays to penetrate matter is considerable. As an example, they can have a range of up to a few metres in water and concrete, depending on their energy.

Interactions with Matter

The interactions of radiation (both radiation with an associated charge and that with no associated charge) with matter becomes evident in three main ways:

(i) an ionization event can result, in which an atomic electron is removed completely from an atom. The atom, which was electrically neutral formerly, then becomes a positively charged ion and forms an ion pair with the ejected electron. Tens to hundreds of electron-volts are needed to form an ion pair. For air, water and organic matter, the energy range is 20 to 40 eV. (An electron-volt is the amount of energy imparted to a body which has a charge equivalent to that of the electron as it is accelerated through an electric field with the potential of one volt.);

(ii) an atom can become excited by having an atomic electron moved to a higher energy level;

(iii) bremsstrahlung ('braking' radiation) can be produced, and this can occur when a charged particle passes through an electrical field, for instance the field near another charged particle. When this happens, the moving particle's speed and direction may change and X-rays are emitted in the process. It is these X-rays which are called "bremsstrahlung".

The significance of these events and the extent to which they occur are related to the amount of energy deposited by the incoming radiation. Beta particles produced by natural sources may have energies of a few keV to a few MeV. Alpha particles normally range from 1 to 10 MeV. Thus, in air, water or organic matter, the formation of hundreds to hundreds of thousands of ion pairs could result from the passage of one alpha or beta particle.

Atoms are bound together electromagnetically and thus have electromagnetic fields associated with them. This means that the entire volume of the atom, most of which is empty, can be involved in the interaction with radiation associated with charged particles. It is for this reason that such radiation is usually of fairly short range. For both alpha and beta radiation, the range in matter is dependent on both the energy carried by the alpha and beta particles and on the nature and density of the material they are interacting with.

Gamma rays interact with matter (and exchange energy with it) in three ways.

(1) They can interact with loosely bound electrons, losing energy and being scattered in the process (the Compton effect). This effect is important for low to medium energy gamma rays (up to 10 MeV). A change in the direction of the gamma ray is a result of the conservation of momentum.

(2) Gamma rays can interact with a bound atomic electron, producing a phenomenon called the photoelectric effect. This commonly occurs for low energy gamma rays, i.e. those in the keV range. In this interaction, the electron is ejected from the atom and the energy of the gamma ray is completely absorbed by the electron and the ionized atom.

(3) The third interaction of gamma rays with matter is in pair production. If a gamma ray approaches a nucleus closely, it can produce a positron-electron pair. In order for pair production to occur, the energy of the gamma ray must be at least 1.02 MeV, which is the combined rest mass of a positron and an electron. Pair production becomes the dominant form of gamma ray attenuation for photon energies above 10 MeV.

Of the types of radiation mentioned so far, neutron radiation is somewhat anomalous since it consists of discrete particles without any associated charge. Because of this, neutrons are unaffected by electromagnetic fields and can interact with matter only through the nuclear force. This force is very powerful but of short range (about 10^{-15} metre). Therefore, in order to interact with matter at all, neutrons must make very close approaches to nuclei or to nuclear particles. The types of interaction which can result are varied, and fall into two broad categories: scattering and absorption events.

Neutron scattering can be either elastic or inelastic.

In the case of elastic scattering, the total kinetic energy before and after the event is the same (it is conserved), but is differently distributed between the neutron and the nucleus involved.

For inelastic scattering events, the total kinetic energy before and after the event is not conserved, since some of the energy of the incident neutron may be used to cause a change in energy level (excitation) in the affected nucleus. In both cases, the direction in which the neutron travels after the event is generally different than that before the event: the neutron is scattered.

There are three types of neutron absorption interaction: radiative capture, capture followed by the emission of other nucleons from the affected nucleus, and nuclear fission.

Radiative capture occurs when the incident neutron is absorbed by the nucleus and a gamma ray is emitted. In contrast, following capture of a neutron a nucleus may emit a charged particle (commonly a proton or alpha particle) or two or more neutrons. The third type of capture, that which results in fission of the nucleus, occurs easily only for a few heavy nuclei (e.g. U-235 and Pu-239). Fission may occur in other nuclei when neutrons with high energy (greater than 1 MeV) are involved.

Because they interact with nuclei, which represent only a tiny fraction of the volume occupied by matter on the macroscopic scale, neutrons can also have long penetration ranges, from a few millimetres to several centimetres in solids, depending on their energies and on the material they interact with. Neutron energies typically encountered can range from tens of MeV down to less than 1 eV. At the lower end of this spectrum, neutrons which approach equilibrium in their exchange of energy with nuclei of the host material are referred to as "thermal" neutrons.

Ionizing radiation is emitted by materials that are both naturally occurring (such as the radioactive elements present in rocks, food, our bodies, and the air) and man-made. Manmade radiation sources include those isotopes which are produced artificially for medical or industrial use or as byproducts of fission and fusion reactions, as well as X-ray machines, and some high voltage equipment. A full description of the nature of these sources and their relative importance is too lengthy to include in this Background article.

The main purpose of this article has been to try to summarize the nature of radiation very briefly, to discuss ionising radiation in somewhat more detail, and to show the general nature of its interactions with matter. To be able to protect living things from the harm that radiation can potentially cause, an understanding of the nature of radiation and their effects is necessary. However, that forms another topic in its own right, beyond the scope of this discussion.

Mr W M Smith is a radiation physicist at Atomic Energy of Canada Ltd CANDU Operations.

Special Report

Nuclear cost enquiry – summary of findings

compiled by David Mosey

In October 1988 Ontario's energy minister, Robert Wong, announced the establishment of an enquiry into nuclear costs in Ontario as a result of a recommendation by the provincial Electricity Planning Technical Advisory Panel that Ontario Hydro's cost estimates for nuclear generation should be subjected to a thorough review before any further committent to nuclear power was made. The review was carried out by a panel comprising Ralph Brooks (former Vice-Chairman of the National Energy Board) and Howard Bowers (consultant to the IAEA on power plant costs and formerly of the Oak Ridge National Laboratory). M Georges Moynet, of Électricité de France and chairman of the International Union of Producers and Distributors of Electrical Energy (UNIPEDE) working group for electricity generation cost calculations, served as special advisor to the enquiry.

The enquiry's mandate was to:

- examine the assumptions and methods used by Ontario Hydro in making a cost estimate of power from a CANDU station
- carry out sensitivity analyses to assess the impact of variations in assumptions on nuclear costs
- examine the assumptions and methods used by the utility to estimate power costs of other generating options
- determine whether or not all appropriate costs are included by the utility in its assessments of generating options.

Released in early April, the enquiry's findings were contained in a substantial report which included a detailed report to the enquiry by Georges Moynet and Michel Monteil. The general tenor of the findings was that Ontario Hydro's nuclear cost estimates were meticulously prepared, methodologically sound and consistent with international practice. A summary of the enquiry's conclusions and observations follows.

... omitting all the details and caveats ...

Ontario Hydro's estimates of the total initial capital costs for a new 3500 MW station are $14 to $17 billion in dollars of the year 2002, the earliest such a station could be in service. This estimate assumes an average annual inflation rate of 5 percent over the next 13 years. Removing inflation, the cost would be $7 to $8.5 billion in 1988 dollars. The lower figure in each case refers to a station built at an existing site.

In their review of the details of these estimates, the Panel found nothing to suggest that any significant item had been omitted nor any evidence of any errors in method. As well, it was noted that where questions of judgment or assumptions subject to debate appeared, these were clearly identified. The report notes:

> Estimating requires that assumptions be made on the basis of the best information available at the time. There is always room for reasonable people to differ. Estimates which make provision for an uncertain future are the product of opinion and judgment.

In this respect the panel pointed out that the Ontario Hydro estimates for a future station were intended to reflect median values – i.e. there exists a 50 percent chance that final costs will be higher or lower than the base cost estimate and "the 80 percent confidence range reflects a 10 percent chance that the total energy costs would be either 20 percent higher or 15 percent lower". Noting some uncertainties which represent unquantifiable potential cost increases, the report cautions that in the view of the Panel the cost of energy from a future station would probably fall "towards the high end" of Ontario Hydro's confidence range.

The report emphasises the complexities and uncertainties inherent to the task of estimating capital costs for very large scale projects and has a mildly caustic comment on the Electricity Planning Technical Advisory Council's complaint that it could not verify the accuracy, validity or reliability of Ontario Hydro's nuclear cost estimates. The report points out that this is scarcely surprising and that "it would be literally impossible, given the uncertainties surrounding some of the future costs, particularly those that would not be incurred well into the next century".

... Judgment plays a significant role ...

The Panel's report draws attention to five specific items of concern which, it noted, "can be labelled as recommendations":

- contingency allowances are not explicitly identified in the Ontario Hydro estimate and should be included and identified as discrete items
- cost estimates for operation, maintenance and administration are based on experience gained during the earlier years of operation of a nuclear station, essentially the "first half" of a station's lifetime, and as a station ages such costs may be expected to increase. It is important that experience with ageing stations be factored in to cost estimates "on a continuing basis"
- for future cost estimates Ontario Hydro should consider the sensitivity of total energy costs to variations in the real escalation rates of the various principal cost components
- while judgment must always be a factor in dealing with uncertainties in cost estimates, Ontario Hydro should make greater use of probabilistic cost analysis methods
- fluidized bed coal plants should be included among the alternatives to nuclear generation.

... We have found no omissions ...

The economic method used by Ontario Hydro to estimate costs, in common with many other North American and European utilities, is the present value technique. To facilitate comparison among base-load supply options installed at different times and having different capacities, the "levelized unit energy cost" concept, based on present value calculations, is applied. This uses a single cost in cents/kWh which represents the present value of the component cost over the lifetime of the particular installation under consideration.

The panel's report confirms that the methods used by Ontario Hydro to arrive at a single value for total lifetime cost of a nuclear station are appropriate, internationally recognised and consistent with those used by other authorities, including the US Department of Energy, the Electric Power Research Institute, UNIPEDE, OECD and IAEA. However the report does note that the discounting of future costs inherent to the LEUC approach tends to de-emphasize the impact of very large costs which may not be incurred until late in a generating station's lifetime, such as fuel channel replacement or irradiated fuel disposal.

Because nuclear stations are high capital cost items, the report observes, the cost of capital (or the "discount rate") is a vital factor in cost estimates. Selection of a high discount rate biases against a nuclear plant, while selection of a lower one biases against generating options with low capital costs but high operating costs. The Panel suggested that selection of a discount rate for large public projects is "more of a political matter as distinct from economic or financial", and noted that they had referred the question of the discount rate used by Ontario Hydro to the Ontario Ministry of Treasury and Economics, whose comments form an Appendix to the Report and that "generally the Panel believes that the Ministry of Treasury and Economics is supportive of Hydro's position on the discount rate".

Plant performance over its operating lifetime is another fundamental consideration, and the panel felt that Ontario Hydro had presented "convincing evidence" in support of the assumption of an 80 percent capacity factor over a 40 year lifetime. But the report notes that, since these assumptions relied principally on operating experience with existing plants which were only now approaching the halfway point in their operating lives, Ontario Hydro was "less able to support its estimate of performance during the last half".

... a thorough and complete assessment ...

Against an international background, Ontario Hydro's capital costs for nuclear plants have compared favourably with those of Électricité de France, a fact attributed principally to the use of standardized designs and multiple unit plant construction characterizing both utilities' programmes.

Some uncertainty in future capital costs, the report points out, could be attributed to design changes which might be required by the regulatory authority between committment of a station and its completion, and a higher degree of uncertainty was attributable to possible design changes required in the course of the station's 40 year lifetime. However the Panel did not believe that there existed any way in which such costs could be quantified.

Addressing the question of the attribution of CANDU research and development costs to Ontario Hydro's nuclear stations, the Panel unequivocally concluded that such costs should not form part of future station cost estimates.

Ontario Hydro's decommissioning cost estimates of $820 million ($232/kW) for a future station were noted to fall within the same range as estimates from the US and Europe, however the report cautions that as yet there has been no decommissioning experience with large commercial plants.

Operating, maintenance and administration costs of Ontario Hydro nuclear generating plants compare favourably with those of US installations, however the report notes that there exists some added uncertainty about these costs during the latter half of station life and that ageing equipment may well significantly increase maintenance costs.

While the uncertainty of fuelling costs "is relatively small" due to extensive Ontario Hydro experience with the acquisition, irradiation and on-site storage of irradiated fuel, the report notes that there is no practical way in which the validity of cost estimates for final disposal can be checked. Since the time-frame for final disposal extends well into the next century, although expenditures will be very large when they are incurred they comprise a very small proportion of the LEUC, the report points out.

... such estimates provide only the basis for comparisons ...

The report concludes by addressing a concern raised by the Electricity Planning Technical Advisory Panel that:

> the cost of nuclear generation is so much lower than the costs of alternative possible kinds of generation that nuclear costs appear likely to drive the evaluation, outweighing other considerations and maintaining a central role for new CANDU stations in Hydro's plans.

Agreeing that the existing and estimated costs of nuclear generation in Ontario are indeed low in comparison with alternatives, the report argues that this does not necessarily mean that costs would outweigh other considerations. Intangible or unquantifiable factors, it notes can sometimes weigh heavily in favour of options that "on the basis of costs alone, would appear unattractive". While there seems to be no better way to provide a basis for assessing electricity supply alternatives than to carry out the kind of "comprehensive estimates" Ontario Hydro has produced it must be remembered, the report emphasises, that such estimates do provide only the basis for comparison, and every option will have factors that require additional public and political consideration.

Book Reviews

The changing impact of science

Permutations: Readings in Science and Literature, Edited by Joan Digby and Bob Brier Quill, New York.

Reviewed by Rick Fluke

Permutations is a collection of readings about science, and its four classical fields: astronomy, physics, chemistry and biology. Within each chapter, one field of science is summarized in an essay that discusses the scientific developments, and the associated ideas expressed during the relevant time periods. A selection of readings then follow in chronological order, which the editors have cleverly selected from the great philosophers and poets: Plato; Edgar Allan Poe; Pliny the Elder; Emily Dickinson; Robert Frost; and, John Updike, to name a few. Also included are selections from the scientists: Galileo; Johannes Kepler; Charles Darwin; Nicolaus Copernicus, and others. The introductions are quite complementary to the readings, which combine to demonstrate that science has led to discovery, to change, and to fear; science has led to permutations in thought, expressed in the literary art of the philosophers and poets. *Permutations* is provocative and enjoyable; it is the "fire side rocking chair" collection of science and literature, expressions of mind and nature.

The book begins with science in general, and addresses an important problem: science is misunderstood. It is often viewed as precise, logical and methodical, and not always productive. As explained in the first chapter, it is quite possible to be a good scientist and not make any progress. (Read as: One can do good work and not meet a Key Event!) Science has resulted in many significant contributions to humanity, but it is not always productive nor beneficial, nor is it always welcomed. A common view of poets is that science looks at nature as something to dissect, rather than an essence to be appreciated for its intrinsic beauty. The selected readings express these views quite explicitly, and are often extreme in their contrast. Edgar Allen Poe resents science because it takes away the pleasure and wonder of myth. Francis Bacon believes that knowledge is power, and portrays science as the monster of riddles which gives "dilaceration to those who do not solve them, and empire to those that do.". The literature is an expression of the permutations of thought, affected by the philosopher's ideas about science. It is certainly enlightening to an engineer who must understand science and apply it for the benefit of a social humanity that is not always understanding or warm hearted (while meeting Key Events).

Although the readings in *Permutations* display considerable variety, there seemed to me to be a consistent theme about how attitudes and ideas toward science changed over three distinct periods: the early period, the Renaissance and modern times. The readings of the early period express conflict and preoccupation with a central authority. The Renaissance was a period of relative peace, harmony, and the search for truth. Modern readings portray conflict and preoccupation with a central authority. Thus swings the pendulum of opinion. Science in the early period evolved from myth and religion, in support of the central authority which was the church. Astronomy developed from empirical observation and logical induction. It was logical to assume that God created the heavenly orbs and that they must be perfect spheres. Plato, writing in Republic, rejects empirical data, and reasons that the heavenly motion of the orbs must make a sound, and that the combined sound of the planets must be in harmony. It doesn't matter that we hear no sound, because logic, which is held to be greater than observation, is used to conclude that we are conditioned with this harmony from birth, and being so accustomed by familiarity, it is a background subtracted from consciousness. (Aristotle suggests that we hear no sound because there is no sound.) Physics developed from engineering, using empirical data to build the great cathedrals and weapons in support and protection of the central authority. Chemistry developed from alchemy, consistent with the theologian's fixation with transformation of the soul, and a small amount of lead to gold. Ben Jonson's play *The Alchemist* is a good example of the deceptive transformations of alchemy. Biology developed from Egyptian religion (mummification) which was documented by the Greeks. There were scientific theories that challenged authority (Copernicus), but these resulted in condemnation for blasphemy and disrepute because such "radical" theories could not be substantiated at that time. The science was held by the central authority, in the ancient texts that ordinary people could not read. The central library of Greece was frequented only by scientists and scholars. Science was incomprehensible and inaccessible to ordinary people. The authority held as blasphemous any new theory that challenged the theological view.

This changed during the Renaissance period. Mathematics had advanced enough to enable the modelling of new theories, and Sir Isaac Newton developed the optical instruments to prove these theories by observation. He appears to be the main topic of the writers and poets, because his work was relevant to current interests: forces of attraction and the divine properties of light. No longer did the people have to accept the authoritarian view of Aristotle, that a stone falls to the earth because all things go to where they belong. Newton demonstrated the truth in ways that ordinary people could understand and verify. Interestingly, although Newton's telescope "destroyed the myth" (for E.A. Poe) of the heavenly orbs as perfect spheres, most readings suggest that he brought people closer to God by showing that light is composed of all colours which can be seen with the aid of a prism. The Origin of the Species was a head on clash with the church, but Darwin, who also studied theology, presented physical evidence that proved overwhelming for the "old school" theologians. New revelations in biology included the discovery of the cell, which became to be considered as the most fundamental form of life, and the popular new metaphor of the poets. This was a period of inspiration and revelation because science provided the new truth, verifiable by the instruments and experiments. Science received "good press" because science could now be explained and understood, and indeed it often proved beneficial to society. Emily Dickinson wrote that "Faith is a fine invention when Gentlemen can see – but Microscopes are prudent in an Emergency".The writings of Louis Pasteur, Benjamin Franklin and Sir Humphry Davy provided clear explanations that could be understood, which helped to provide permutations of thought about science which tended to be expressed in terms of benevolence.

In modern times provocative and fearful new theories and discoveries arose. Einstein inspired a modern poetry much beyond my time, such as the twisted permutations of Erica Jong's *Half-Life*, with bizarre analogies relating the "mushroom cloud of you above the smoking chasm that you leave in me". The electron microscope unravelled the double helix, inspiring the analogy in May Swenson's *The DNA Molecule* of the "Nude Descending a [circular] Staircase ... descending and at the same time ascending". With it, came the power to put asunder the bliss of understanding that becalmed the previous era; the power to alter creation. Indeed, microbiology was discovering new life forms beyond understanding, leading to fears about virus infection and cancer. Nuclear weapons became the new "instruments of peace". Once again, science is in conflict with theology, not because of a difference in views about the makeup of nature, but on ethical questions about scientific research on recombinant DNA, life form patents and weapons development. Once again, science is in the hands of a central authority. Ordinary people no longer understand modern science. The "tools" to observe the new phenomena are not available to ordinary people. (Hast thou coveted thy neighbours new linear accelerator lately?) Science has once again become, in a sense, incomprehensible and inaccessible. Thus swung the pendulum.

Nuclear science and technology suffers a lot from bad press, because it is not understood nor accessible to ordinary people. Newton turned such a situation around by providing the tools for understanding, and by making science accessible. The nuclear industry should follow the example of Newton by "opening the doors" to nuclear science. Public science fairs should include more demonstrations, in plain simple terms. A sort of nuclear "prism" should be developed and made available that permits ordinary people to "see the composition" of nuclear technology. Nuclear science must be made more accessible and comprehensible, especially within the educational system.

The selected readings in *Permutations* are by no means complete, and I believe the book suffers from a major deficiency because the editors did not include even one of the writings of Sir Isaac Newton, a man who inspired permutations within the church for benevolence towards science, as well as a Renaissance of creative ideas, the search for truth, and general peace and harmony. I did not like every selection, and Emily Dickinson is somewhat ahead of my time. However, I did find the book enlightening because it invoked the idea that permutations in thought, as expressed in literature or in the press, provide an indicator of some of the problems of perception that engineers face when attempting to put science to work for the benefit of humanity. Basically, the problem boils down to presentation.

Rick Fluke is a Senior Design Specialist with Ontario Hydro's Nuclear Safety Department.

CNS News

The China CANDU Syndrome – special report

Ken Talbot

How refreshing to receive your morning paper and see the headline "Nuclear Industry is Imperative". Of course, you'd have to be in China at the time, reading the English language edition of the *China Daily* of 16 March 1989. If, as I was, you were there as member of a combined AECL, Ontario Hydro and Ontario Government team touring the country to promote the CANDU, you'd certainly feel that the auguries were promising.

In the course of our two-week visit we were scheduled to give a series of seminars on the CANDU system and Ontario Hydro's nuclear power programme to a group of Chinese officials from Jiangsu Province, which by the way is twinned with Ontario.

In the 1970s China was investigating both heavy water and light water (PWR) technology and, in 1981, decided to build one CANDU type and one PWR demonstration reactor.

In 1983 a decision was made to concentrate on PWR technology for the first phase of a programme that was intended to put 10,000 MWe in service by the year 2000 using standardized 1000 MWe PWR units. In 1986 this plan was scrapped in favour of one using domestically produced 300 and 600 MWe PWR units.

At this time the nuclear power development programme was under strong central direction by the national government ministries of power and (later) nuclear energy. However in 1988, with the formulation of a new economic development programme, a certain amount of decentralization took place and the individual provinces were given more autonomy in their energy development programmes.

What is the energy picture in China? China is a bit like Canada in several ways, including the location of its energy sources. In terms of land area it is the third largest country in the world (USSR and Canada are larger). Most of the population lies in a relatively narrow band down the Eastern side of the country (try turning Canada ninety degrees anticlockwise). There are some notable differences, too. China's population is 1.1 billion (compared to Canada's 25 million). The average Canadian uses 16,000 kWh per year whereas the average Chinese uses about one thirtieth of this (500 kWh). So in fact the electrical production in both countries is of the same order of magnitude. (In 1988 China generated 542 TWh and Canada 489 TWh.)

Most of China's vast resources of coal and hydraulic potential are in the north and west, well away from the industrial centres. Here lies a major problem; at the moment 75 percent of the country's electricity is generated from coal but there is not the transportation capability to get the coal to the numerous coal fired generating stations that are being built. In fact, at present, 25 percent of industry is idle at any one time due to electricity shortages. Coming into land at Nanjing, a city of some six million, one wondered where all the city lights were? Walking round the back streets of Guangzou, many of the shops were open but lit by candles or lamps supplied from small petrol driven dynamos. This is the background to the categorical statement in my copy of the *China Daily* that "The worsening shortage of energy has made it imperative that China develop its nuclear industry".

Despite all this, China's average annual GNP growth over the last eight years (1980-88) has been an impressive 10.2 percent. In 1987-88 GNP increased by 11.2 percent and industrial production by 17.7 percent. Electricity production has grown at an average annual rate of 7.6 percent since 1980 but industry has grown faster – at 13.4 percent.

China's total installed electrical generating capacity in 1988 was 113 GW from 77 thermal and 36 hydraulic installations. Of the total 542 TWh generated, 438 TWh came from thermal stations and 110 TWh from hydraulic. By way of comparison, of Canada's 489 TWh, 306 TWh (62 percent) came from hydraulic, 108 TWh (22 percent) from fossil and 75 TWh (16 percent) from nuclear.

The change in emphasis from a strongly directed central energy programme towards greater provincial involvement has been accompanied by the allocation of a high priority to all energy projects by the central government. The greater autonomy allowed the provinces means that their plans may include reactor systems other than PWR so long as those plans are technically and economically compatible with that reactor system. And a good plan from any province will receive central government support at a level of intensity commensurate with the urgency the Chinese feel informs their energy plans.

In this situation the CANDU system appears attractive. It is complementary to the PWR fuel cycle. It uses simple, easy to manufacture components, easy to produce fuel with no enrichment necessary. As well, China has a domestic heavy water capability and a large number of scientists and technicians well versed in CANDU technology. Of course the performance record of the CANDU doesn't hurt either.

Although China does not at the moment have a commercial operating nuclear generating plant, they have committed nuclear one domestically designed 300 MWe PWR at Qinshan near Shanghai (to enter service in 1990) and two 900 MWe PWRs at Daya Bay (30 miles from Hong Kong) due to enter service in 1992. (70 percent of this station's output is destined for Hong Kong.) Last year the government approved extension of the Qinshan plant by 2 × 600 MWe PWR units

Ken Talbot and Chinese Nuclear Society President Jiang Shengjie sign renewed agreement.

with a possible third phase of another 1200 MWe to follow. The total projected capacity to be on-line by the year 2000 varies, depending on who you talk to, from 5000 MWe to 10,000 MWe. Clearly the nuclear market is potentially large.

Before any major nuclear technology exchange can take place between Canada and China our two federal governments have to agree on the terms of our cooperation, terms which will have to accommodate the fact that China is a nuclear weapons power. In this regard a team of External Affairs officials will be going to China in June to negotiate an appropriate agreement.

While in China I visited to my counterpart in the Chinese Nuclear Society, President Jiang Shengjie. The agreement between our two Societies, signed in 1984, only ran for three years and was therefore in dire need of renewal. We thought it would be opportune to strengthen the cooperative efforts between our organizations and hence signed an extension for another three years with additional provisions as follows:

1. Each Party will designate an official to act as the main contact between the two Societies. These officials will be responsible for establishing effective communication and will meet at least once a year to initiate, coordinate and review programs of inter-society activities.
2. Each Party will forward complimentary copies of regular publications, conference 'calls for papers', and other conference information including one copy of published proceedings from conferences sponsored by either of the two Societies.
3. Each Party will encourage and coordinate interchanges of nuclear scholars and researchers between universities and research organizations of the two countries.
4. The two Societies will jointly investigate fields of mutual interest with a view to holding joint symposia or conferences in the near future.

Ken Talbot, CNS President 1988-89, is Manager of Corporate Programming (Nuclear) at Ontario Hydro.

NSED Election Results

The following candidates were elected by acclamation to the CNS Nuclear Science and Engineering Division Executive:

- V. S. Krishnan (WNRE)
- B. Rouben (AECL-CO)
- C. Snoek (CRNL)
- P. D. Thompson (NBEPC)

WMEA call for nominations

The CNS Waste Management and Environmental Affairs Division requests nominations for the election of its 1980-90 executive. Nominations for Chairman, Secretary and members-at-large should be sent to the Returning Officer, David Jefford, Ontario Hydro, H11F21, 700 University Avenue, Toronto, Ontario M5G 1X6. Fax (416) 592-5723.

Conferences and Meetings

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.

Fourteenth Uranium Institute International Symposium
To be held **6-8 September, 1989** in London, England. Contact: **Conference Associates UIS,** Congress House, 55 New Cavendish Street, London W1M 7RE, England, 44 1 486 0531.

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.

Second International Conference on CANDU Fuel
Sponsored by the Canadian Nuclear Society and co-sponsored by the American Nuclear Society the Second International Conference on CANDU Fuel will be held **1–5 October 1989** at Chalk River, Ontario. Contact: **Dr I J Hastings,** Chalk River Nuclear Laboratories, Chalk River, Ontario K0J 1J0, (613) 584-3311.

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.

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.

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

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

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

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

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The Unfashionable Side

The Armitage anemometer

"What are you doing?"

Helga doesn't normally disturb me when I'm in the bathroom. Helga is my live-in housekeeper and I really must take this chance to try once again to dispel the persistent rumours about her. It simply is not true that she is a 24-year old raver. Helga is a mature professional housekeeper, with excellent references. Now, it may be true that she is rather short of grey hair, and that her jeans fit very well, but these are merely signs of one who takes care of herself.

"What are you doing?" she repeated.

"I'm conducting an experiment."

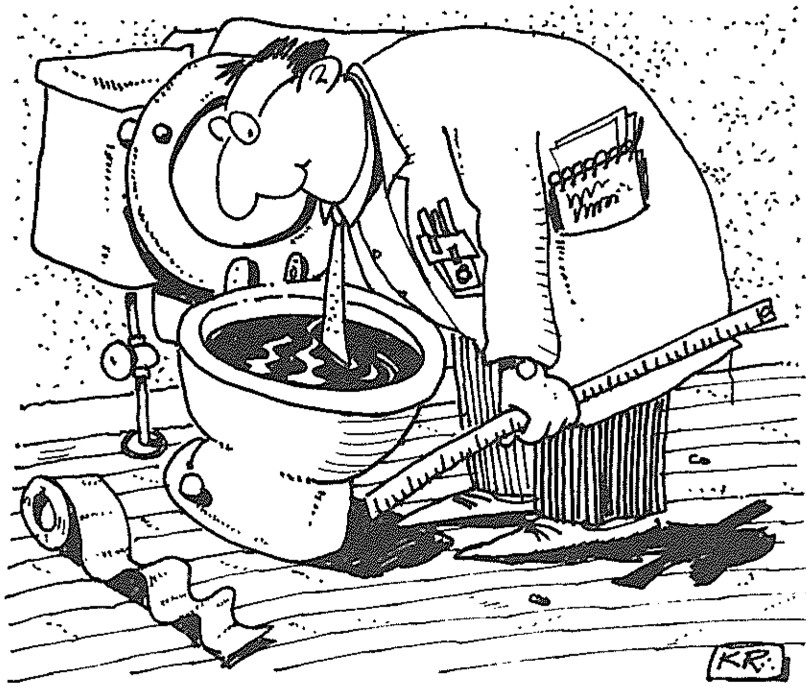
"In the toilet bowl?" she queried, somewhat irrelevantly, I thought.

Proprietary interest in what is perceived to be one's area of responsibility is one thing. But such unabashed disregard for the progress of science is quite another. I would have to speak to her about it.

"Could you get me a ruler, please", I asked serenely, hoping to elevate the intellectual tone of the moment.

Helga instantly turned ashen.

Has it ever happened to you that just when you think you are on the verge of a major discovery, there are always elements of the universe ready to counter-attack? Good grief! Where would we be today if Becquerel's housekeeper had thrown out all his old fogged photographic plates? If Alexander Fleming's sister had scoured all those revolting, mouldy



The answers to very few things are to be found in the toilet bowl.

Petrie dishes? If an interfering busy-body had nagged Scheele about boiling horses' hooves as part of his experimental programme? Or if some trick cyclist had advised Kekule that all this talk of snakes with their tails in their mouths was a load of codswallop and he should go and take a valium?

On the other hand, it wasn't fair to have Helga think that I had suddenly turned unwholesome. My explanation overcame her alarm but left her curiously unmoved, although resigned. For some reason, she hasn't been reassured by subsequent events, although they are almost all positive.

To understand it, you need some background.

A number of my friends treat their W.C.s almost like library reading rooms. This I have always steadfastly refused to do, believing that the potential for learning things from the bathroom has long since been exhausted. This had been my unshakeable position, until the day in question, which was a rather windy morning last March.

It all arose originally out of a project that Worthing and I dreamt up. Naturally it has to do with the weather. As most people are aware, the weather is poorly understood. It's not so much a lack of data as a lack of appropriate data. Go to any fairly large weather station. There you'll find fancy gizmos whirling about at the tops of towers, you'll find rain gauges, snow gauges, insanely expensive barometers. At most of the large weather centres in Canada you can find a large radar dish pointing straight up. What does it do? It tells you how fast the raindrops are coming down (!). (Hint: some slow day, try releasing a flight of pigeons near one of these things, but tie small radar reflectors to the pigeons' feet. That evening's weather report will be interesting.) All this equipment provides information of some value, I'm sure, but it would have depressed L.F. Richardson desperately.

The answers to very few things are to be found in the toilet bowl, but insight into the weather, strangely enough, is one of them. This was the essense of a paper that I presented late last year to a gathering of the Meteorological Society. There was a ruffle of consternation a week after my paper was accepted, when a very generous support grant was offered by the Armitage Research Foundation. How they found out about, and became interested in this particular conference, I really can't say.

The paper, entitled "The Toilet as a Precision Meteorological Instrument", was controversial. My conclusion was that a wealth of information on the weather is there for the taking in the nation's toilets. With it one can predict rainfall, and wind velocities and directions at least 12 hours in advance. My assertion that the humble toilet can provide excellent information on the height of the mixing layer and on the degree of low level cloud cover prompted sharp intakes of breath from the conferees. (It has been my experience that original insights often have this effect.) Looking ahead, one could envisage that computerized toilets linked via local area networks, would do away with centralized weather stations and save large amounts of money.

In the weeks following the conference, the hate letters disturbed me somewhat but that has eased now. Last week, however, was the vindication of my suffering. On a trip to the nuclear station at Pickering, I noticed with delight that all the station's toilet bowls had been fitted with level gauges!

For those of you who may still be puzzling over the toilet as a precision instrument, watch the water level in your toilet on the next windy day.

And remember Legendre's equation.

George Bauer