Energy Issues

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The following is based on information from scientific and technical publications, from the reports of various panels and committees on issues pertaining to the nuclear fuel cycle, and from discussions with individuals working in health physics, risk research, energy generation and management, and reactor engineering.

Summary;

- ✓ The SaskPower Customer pays lifecycle cost, not just construction cost
- ✓ Saskatchewan wind turbines operate at ¾ or better of rated capacity for 20% of the time.
- ✓ Wind turbines parts wear out quickly and need frequent replacement.
- ✓ The fluctuation of wind speed destabilizes the grid and limits wind energy to less than 10% of the power sources of any grid of which it is a part.
- ✓ The quotes for nuclear reactors for Ontario are misleading, but we don't yet know what reactors will really cost.
- ✓ Ideas offered to make wind power available as base load are novel, but not realistic.
- ✓ All decisions lead to non-zero risk. Risk can only be minimized, not avoided.
- ✓ Societal dollars spent on risk mitigation should be spent where they can do the most good.
- ✓ Part of the cost of nuclear energy is an unfortunate byproduct of the political process.
- ✓ Decisions made by society with regard risk are not rational.
- ✓ An estimate of occupational risk for workers in nuclear power plants that has been quoted in Saskatchewan is based on an erroneous calculation that is off by a factor of 1000.
- ✓ Risks to both workers and the general public from nuclear reactors are low, difficult to separate from naturally occurring risks, and remain the subject of debate.
- ✓ A reactor does not use up water and deposits 100 times less radioactivity into the environment compared to an equivalent coal facility.
- ✓ Anyone harmed by a nuclear reactor incident has access to a special insurance fund specifically designed for the nuclear industry.
- ✓ The use of nuclear energy is expected to grow by 50% by 2020.
- ✓ The lifecycle greenhouse gas equivalent emissions from nuclear energy are low and comparable to those from renewable energy sources.
- ✓ Canadian uranium may not be sold for use in the production of nuclear weapons.
- ✓ At present rates of use and without any expansion of the use of nuclear energy, and with reprocessing, the world now has 2000 years of uranium supply.
- ✓ There are no technical problems with the safe management of used fuel from reactors.

A: Cost Issues

Introduction

The mint makes it first, it is up to you to make it last. Evan Esar (1899 - 1995)

The capital cost to construct a nuclear reactor is frequently cited as a reason why Saskatchewan should not consider nuclear energy as part of the provinces' mix of electrical energy sources.* In determining the cost that will actually be paid by the consumer of electrical energy produced by a power facility it is necessary to consider more than just the cost of building the facility that will produce the energy. There are other costs. They include the operating costs and the fuel costs, if there are any.

The interest charged on the money used to construct the facility will also affect the cost paid by the energy consumer. The cost per unit of energy will also be affected by the length of the productive lifetime of the facility, over which time the initial construction cost must be paid off from revenue from the sale of the energy produced by the facility.

Cost calculated this way is referred to as the "lifecycle" cost.

A complete analysis of all of the factors that should be considered in the calculation of the lifecycle cost for any energy source is lengthy and technical. Our goal is only to put on the table some basic issues that seem to get left out of discussions about costs of various energy sources in the province so far. We will, nevertheless, review some estimates of costs made by others who have been assigned the task of carrying out the complete analyses.

It is important to remember that costs may be paid either directly to the power company by the energy consumer, or by all taxpayers through taxes that become subsidies for energy sources whose use is deemed to be in the public interest, or which need to be assisted until their use reaches competitive economies of scale.

There may still be other implied costs beyond those mentioned above for any energy source, such as the cost of an enhanced grid system or the cost of a back-up system.

The reactors that are under consideration for use in both Saskatchewan and Alberta are Advanced CANDU Reactors, Generation III+. They generate 1200 megawatts (million watts, MW) of power. They use up some of their own power in their operation, leaving 1100 MW to be output to the electrical grid.

New scalable reactor designs are now coming onto the market. "Scalable" implies that they can be built to provide whatever amount of power output is asked of them without significant changes in the cost per MW of output. This new technology has arrived on the scene very recently and will now require careful consideration. Scalable reactors would address the most important issue that needs to be addressed if CANDU III+ reactors were to be used in Saskatchewan, which is their size relative to the total Saskatchewan grid demand. Total electrical power demand in Saskatchewan can be as low as 1700 MW on a June night. Although they are scalable, that doesn't necessarily mean that these new reactor designs are necessarily as cost competitive as a CANDU III+? Should we assume that they will be as free from breakdowns as are CANDU III+ reactors?

Wind

If the wind will not serve, take to the oars. Latin proverb

Focusing first on the capital cost of wind as an energy source, turbines typically cost $3 million for a 2 Megawatt (MW) unit. We would need 550 such units to produce 1100 MW of power. That means a total capital cost of $1.65 billion CAD. This includes the relatively large cost of land leasing or purchase and the cost of installation. At first glance, $1.65 billion would seem to make wind a very competitive energy source.

A 2 MW turbine produces 2 MW of power only under a limited range of conditions. The most obvious is that the wind must blow. The main turbines used in Saskatchewan are typical. They are designed to start producing power when the wind speed reaches just 15 kph. However, if the wind is too strong the turbines will be forced to rotate too fast and the forces on the rotating components of the turbine, needed to hold them together, will be stronger than they can withstand without being damaged. That limit would be reached at a wind speed of 50 kph, but Saskatchewan's turbines are designed to deliberately become inefficient in gathering wind energy and rotate slower than the wind could drive them when the wind speed is above 50 kph. This allows them to still be used up to speeds of 90 kph. Beyond that, they are turned 90 degrees to the wind and shut down.

Another factor affecting the availability of wind power that is seldom considered in discussions to date is temperature. The ability of all materials to withstand forces is affected by temperature, including the materials used to construct wind turbines. Below roughly -30 C wind turbines must be shut down to avoid damage. Saskatchewan's wind turbines have been placed in the southwest corner of the province where the number of hours when the temperature is below -30 C per year is a minimum for the province. There are three "wind farms" in that area, capable of producing a total of 172 MW under ideal circumstances.

The ratio of the actual energy produced over a period of time by a wind turbine, to the maximum possible if ideal conditions of wind and temperature were available all of the time and they needed no maintenance downtime, is the capacity factor. The capacity factor is highest for windy places like the great planes, including Saskatchewan, and off-shore sites. Experience shows that the capacity factor for wind turbines in Saskatchewan can reach 40%, which is higher than for most places.

We can look at the availability of wind energy another way. SaskPower keeps statistics on the combined output of the three wind turbine farms. In 2008, they operated at three quarters or better of the full 172 MW for 20% of the time.

The capacity factor for a nuclear power plants is typically 90%, or 2 ¼ times that for Saskatchewan wind.

If we wish to make wind a base-load power source, we must first find cost-effective energy storage devices, or other creative solutions to address both its intermittency and the variability of its output while in operation.

Another major issue that affects the cost of an energy source is its usable lifetime. For nuclear power reactors experience suggests that that number is in the range of 50 years. We have less experience with the use of wind turbines over long periods, but we would expect that the moving parts, which must work while under stress from wind forces, will have a limited life expectancy. SaskPower has already discovered that some such components, generators and gears, last less than three years. Some components, such as the blades, are expected to last much longer. Budgeting for wind energy is usually based on an overall 20-year life expectancy.

Wind speed varies continually while wind turbines are operating. But the voltage in our power lines needs to be maintained at 110 volts and the frequency of the alternating current (AC) needs to be maintained at 60 cycles per second (Hertz, Hz) or various electrical devices will fail. Clocks are a trivial example. The precise operation of voltage transformers depends on frequency. Fluctuating wind speeds not only challenge the ability of the grid into which it provides power to maintain a constant voltage of 110 V, but it also pushes the frequency of the grid up when the power increases, and down when it decreases.

The other sources of power on the grid are responsible for compensating for both voltage and frequency fluctuations and for insuring that the fluctuations remain small enough to avoid disrupting the whole system. This has two consequences. First it puts an upper limit on the fraction of the total energy in a grid that can be generated by wind. That number is somewhere between 5 and 10%, depending on the nature of the other sources.

We have only become aware of another consequence of using wind from experience with wind energy as part of an electricity grid. The other sources in the grid must be operated in such a manner that they can react quickly to continuous fluctuations in the output of the wind turbines. Experience with power grids with a significant fraction of the source being wind has shown that for the other components of the grid to be able to adjust to fluctuations and changing demands on themselves, they must be operated at less than their own maximum efficiency. This extra cost from lowered efficiency in the rest of the power sources in the grid is created by the presence of the wind turbines. The cost of operating at lower efficiency is attributed to the presence of the wind sources in the calculation of energy costs.

It should be possible to overcome these problems by converting wind energy to direct current (DC) type electrical energy, or producing it as DC, and then storing that energy in batteries. WE could then generate AC power from the batteries with a precise and constant voltage and frequency. This would allow wind energy to reach much greater use, even 100% of the total energy in a grid. But of course the cost of doing that would be far from trivial.

Politics and cost

Whenever you have an efficient government you have a dictatorship. Harry S Truman (1884 - 1972)

The cost of constructing a 1100 MW nuclear power reactor has escalated from approximately $3 billion CAD roughly a decade ago, to a maximum of $13 billion today, based on the quoted cost to Ontario from Atomic Energy of Canada (AECL) for two reactors, whose construction has been postponed.

AECL is federal crown corporation. The government of Canada has announced that it wishes to sell AECL.

Where did this extreme cost escalation come from? The obvious first reason is the general escalation of all construction costs that took place over the last three years. But that should add no more than perhaps 50% to the cost. It would seem that there is more here than meets the eye. There are two additional reasons for the anomalous quote of $26 billion for the two Ontario reactors. First, the two reactors are the first of a new generation of reactors, incorporating refinements learned from years of operating the current generation of reactors. The federal government has decreed that the developer of this new design, (AECL itself) must recover all of the development costs as part of the first sale of the new technology and the cost may not be spread over expected future sales. Next, both the federal and provincial governments have required AECL to incorporate the cost of all financial risk into its cost estimates.

On the surface, that would seem perfectly reasonable. But what are those financial risks that must be taken into account? Why have so many reactor projects had cost overruns in the past? The risks in question have mostly been caused by governments themselves, by changing the design specifications for reactors after construction had begun, or by delaying the project after the financing had already been arranged. Restarting the project has obvious cost implications. Delays mean that interest and inflation drive up the cost while the project waits.

Why do governments dither when there are such cost implications? They know from past experience that they will not be blamed by the voting public for the cost overruns. By demanding small changes in specifications they hope to be seen to be taking public concerns about safety more seriously. By allowing time for those opposed to the use of nuclear energy to try to make their case yet one more time, they hope to avoid being seen as arrogant, thereby allowing the opponents of nuclear energy to gain public support from the undecided.

Do the delays and design changes lead to any improvements in the design and the lowering of health related risks? Perhaps, but any safety improvements have been minimal. If the same money had been spent elsewhere, such as on better road lighting or on better ventilation in homes, the amount by which risk to humans might have been lowered would probably have been thousands of times greater.

In Ontario we now seem to have a dithering government whose reason for dithering is that governments may dither and thereby drive up the cost of nuclear energy.

The reality is that the federal and provincial governments are involved in some very tough negotiations. Ontario needs to start the planning and construction of new energy sources soon to meet growing demand for electricity and for the replacement of older components of their existing generating system, as do most provinces and states in North America. As base-load sources, hydrocarbons like coal and gas are threatened by new carbon penalties and most major hydroelectric sites are already developed. The only other realistic option is often nuclear energy. AECL may think that it has a negotiating advantage over Ontario. On the other hand, AECL needs to make a sale in order to make the company itself more attractive for sale to the private sector. Ontario may think that it has an advantage over AECL.

The aforementioned $13 billion figure for a 1100 MW reactor should be regarded as no more than an opening negotiating stance. Nevertheless, we don't know where any agreed compromise price will settle. SaskPower has made a best guess to conclude that nuclear energy would lead to a cost of 8 to 10 cents per kilowatt hour (kWh). The ranges of cost for clean coal and wind energy are similar. For reference, SaskPower has given the cost of energy from its existing system as 5.78 cents per kWh. Murray Mandryk correctly notes that this has been achieved by not reinvesting enough in the system to maintain its integrity.

Governments could dispense with the cost of insuring against their own mischievous interference and indecision by agreeing to pay for that cost separately and transparently, if they choose to create it. Of course the result would probably be an absence of interference and indecision.

What happens when governments agree to contracts to build new nuclear reactors and then comply with those contracts, without changing designs or delaying? AECL has built and brought on stream seven reactors in China, South Korea and Romania. All reactor construction projects were completed either on time or ahead of schedule and on or under budget.

These observations are not an argument for the abandonment of our democratic form of government, but it does point to some of the strange consequences when the public, government, and the media try to deal with political issues that depend on a relatively sophisticated knowledge of several serious academic disciplines; science, engineering, cost accounting, risk estimation, etc. We will invoke Churchill's comment that democracy is the worst form of government except for all the rest.

Wind as base load power

Reality is that which, when you stop believing in it, doesn't go away. Philip K. Dick (1928 - 1982)

Wind turbines can't provide electrical power when the wind isn't blowing, but also when it's blowing too hard. Wind turbines must be shut down when the temperature is below -30ºC. We sometimes have periods of a few weeks in Regina in January when the temperature exceeds -30ºC for only a few hours per day during the afternoon.

Gas turbines would be the most probable backup energy source for wind, implying a major reliance on natural gas, with the occasional substitution by wind when available. Gas might also serve to back up nuclear energy, but it is unlikely that gas would end up being used more than the nuclear energy that it is backing up.

The Canadian Renewable Energy Alliance has presented a document that discusses six ways to provide base-load power from wind. The document offers interesting ideas worthy of consideration, but all methods are problematic. Some provide relatively small amounts of base-load power. Some are prohibitively expensive, and some are based on data that is inconsistent with that easily available on the net from a variety of sources. But let's pursue two of their more interesting proposals and see where they lead.

The CREA proposes to duplicate a wind farm large enough to provide a major portion of Saskatchewan's energy needs many times over at a variety of sites, on the assumption that at all times, one copy will find itself in a place where the wind is blowing in the right speed range and where the temperature is above – 30°C. The obvious problem here is that the capital cost, already high, would need to be multiplied by the number of duplicate wind farms. In order to avoid frequent down times, the family of wind farms would need to be spread over an area greater than Saskatchewan, probably including a coastal area of British Columbia, in order to avoid the – 30°C limitation. Transmission costs would also soar.

There are a few days per year when there is no wind anywhere in the entire British Isles. We would therefore still need an emergency back up system if we aren't prepared to go for while without any electrical power at all.

The other idea is downright ingenious. It originating in the book "*Sustainable Energy; without the hot air*, written by David MacKay of Cambridge University. He suggests that we switch all road transportation to battery power and make the batteries interchangeable. Gasoline stations would be replaced by stations that charge and replace spent batteries with similar fully-charged batteries.

How many batteries would be needed? In 2006 there were a quarter billion vehicles in the U. S. and 20 million in Canada. Taking into account growth since then, and the fact that trucks would need multiple batteries, over 300 million batteries would be in use at any time. At least an equal number would need to be charging at any time. Then at least 600 million batteries would be needed in total. Of course that leaves out Mexico and the rest of the world. Those 600 million batteries could be used for transportation and, while waiting for use for transportation, the batteries would serve to store energy generated by wind turbines while the wind is blowing. Then that stored energy would be put back into the grid system when the wind is not blowing. Ingenious indeed, but let's think about how we would implement this idea. And there is that little problem of showing up for battery replacement after a long period of drawdown on the energy in the batteries because of a lack of wind.

The battery used by the all-electric car capable of serious intercity travel, the Tesla, costs about $100,000 USD. Mass production and improving technology would clearly bring that cost down, perhaps to one third of $100,000 USD. That implies a bill of $20 trillion USD for batteries alone, and a means of discarding all existing vehicles and replacing them with electric-powered vehicles. The earth may not contain enough of the needed materials to manufacture that many batteries.

There is a similar but more plausible alternative to using batteries. The excess electrical capacity from large wind farms when the wind is blowing could be used to generate hydrogen through electrolysis. That hydrogen could then be reacted with CO_2 scrubbed from coal and gas power facilities to form a liquid fuel that in turn could displace some gasoline. There are hurdles to overcome; for instance, it is difficult to store large quantities of hydrogen. The total cost for the scheme would still be far from competitive with alternatives.

Conclusions

Conclusions arrived at through reasoning have very little or no influence in altering the course of our lives Carlos Casteneda (1925-1998)

The forgoing is not an attempt to estimate the costs of various sources of energy. That would require an analysis that would be longer and more technical. We have only tried to explain some of the issues that must be included in any calculation of relative cost and which have been overlooked so far in public discussion about the possible use of nuclear energy in Saskatchewan.

But highly detailed estimations of cost exist.

The United Kingdom's Royal Academy of Engineering has carried out sophisticated estimates of the life cycle cost of various schemes for the major use of wind energy and concluded that it is roughly two thirds higher than nuclear, not accounting for the cost of standby power generation for wind. That study is available at
http://www.raeng.org.uk/news/publications/list/reports/Cost_Generation_Commentary.pdf

An evaluation of the costs, availability and environmental impacts of a full range of possible energy sources has been carried out for Alberta. The findings have been published in a document with the long title *Nuclear Power Expert Panel Report on Nuclear Power in Alberta.* Its title is misleading because it considers all potential forms of energy. It is accessible at
www.energy.gov.ab.ca/Electricity/pdfs/**NuclearPower**Report.pdf The issues and conclusions would not be significantly different for a similar study that might be written in Saskatchewan. The members of the group that authored the Alberta report are all people respected in their fields of expertise, all affiliated with universities. Collectively they have expertise in the areas of energy costs, finance, safety, risk and environmental sciences.

The information in these reports was assembled before the quote of $26 billion CAD for two reactors from AECL to Ontario. It is unlikely that this number will ever be used in the actual terms of a reactor sale It will be subject to negotiations and may lead to commitments by governments to not change the rules after the game has already been partly played out. AECL has competitors and they may step up to the plate. However, any competing reactor builder will still face some of the problems that affect the AECL quote until governments get their act together. We don't know where the final price will eventually settle.

The aforementioned Alberta report gives ranges of lifecycle costs for several energy sources depending on various assumptions, but the results agree with the United Kingdom study. In general, these studies do allow for the cost of spent nuclear fuel management and facility decommissioning for nuclear reactors.

Solar energy may be a cost effective way to provide heat for hot water and for home heating under certain conditions, but recent data offered by Consumer Reports show that it would take 15 to 30 years to save enough from lowered heating costs to pay for the solar hot-water system. Estimates of the cost of electrical energy generated from solar energy put it at three times the cost of nuclear energy.

Other indicators of cost are less favourable to wind and solar energy. Energy subsidies in Ontario seem to assume that wind energy is roughly three times as expensive as existing conventional energy sources and that solar is over ten times as expensive. New technology and mass production may bring the cost of solar energy down over time, but it would be unlikely to reach equivalency in cost as compared to more conventional sources of electrical energy, like coal, hydroelectricity or nuclear. Nevertheless, it appears that the cost of both coal and nuclear energy will increase faster in the future than could be predicted from inflation alone.

Other energy sources like biomass, wave energy, geothermal, ocean geothermal, in-flow hydroelectric, etc. will have specific applications but as candidates for base-load power they all have capacity or cost limitations.

A source of information on the amount of electrical power available from a wide range of energy sources, written in layman's language, is the aforementioned book "*Sustainable Energy; without the hot air*, written by David MacKay of Cambridge University. The author focuses on the amounts of energy that might be made available from various energy sources and only alludes indirectly to issues of costs for those energy sources. The book is free and downloadable at http://www.withouthotair.com/download.html

*The words "*power*" and "*energy*" are often used interchangeably. They do have specific meanings. *Power* is the rate at which *energy* is generated, transmitted or used. Electrical energy is usually measured in kilowatt-hours (kWh), which is the amount of energy generated, transmitted or used during an hour at the rate of 1000 watts of power. A watt is a unit of power and is equal to one joule per second. There are 3600 seconds in an hour so a kWh contains 3,600 x 1000 joules, or 3,600,000 joules. The heat energy gained from burning natural gas is measured in gigajoules. A gigajoule is 1,000,000,000 joules or 278 kWh. However, the word "electricity" herein is used in the vernacular, to approximately mean "electric power."

B: Risk Issues

Risk Estimation

Take calculated risks. That is quite different from being rash. George S. Patton (1885 - 1945)

Much of the discussion about the use of uranium involves the concept of *risk*, which on the surface may seem to be a simple concept, but recent history suggests that risk is not well understood. There are scientific journals devoted to both risk and the perception of risk. We will try to shed some light on both.

As decision makers in our own lives, we frequently find ourselves trying to assess the risks associated with each of the courses of action from which we must choose, particularly with regard financial decisions. However, in the nuclear discussion, the risk in question is mainly one of health and longevity, or "human risk." Similar considerations apply to both financial risk and human risk.

A simple way to approach the assessment of human risk that is created as a result of making a particular choice would be to list all of the conceivable events leading to negative consequences, estimate the probability of those events actually happening over a period of time, and multiply each event by the probable consequences of it happening. When we have all the products of "event probabilities" times "event consequences", their sum is the total risk resulting from making that choice.

Of course we may miss some events because they have never happened before and we have not thought of them. Data with which to estimate the probability of events may be scarce, and we must agree on which negative consequences are relevant. "Deaths of humans" is the usual important consequence that is considered, but other things, like injury, economic costs, environmental costs and the grief of survivors may also be considered if we wish.

Such calculations are obviously based on many very rough guesses, but, on the other hand, the results often differ by powers of ten; i. e., one choice may lead to a hundred or a millions times less risk than another. Therefore, the exercise of risk estimation may still provide useful, even if inaccurate, information.

Risk estimation should normally be used with a similar calculation of the benefits of taking a risk, which may involve the saving of lives.

I have found that many people dislike the forgoing way of looking at risk. They find it to be disturbing logical cold and mathematical. They would like some emotional aspects of risk to be taken into account. But when emotion is injected into consideration of risk, people's, lives become subjected to additional and unnecessary risk.

The Precautionary Principle

The policy of being too cautious is the greatest risk of all. Jawaharlal Nehru (1889 - 1964)

A concept known as the *precautionary principle* is often raised in discussions of risk. The precautionary principle formally states that:

If an action or policy might cause severe or irreversible harm to the public or to the environment, in the absence of a scientific consensus that harm would not ensue, the burden of proof falls on those who would advocate taking the action.

Or simply: *if any action might lead to a risk, one should not take such action, even if risk has not been proven.*

The precautionary principle raises several questions, such as how much agreement is needed in order to claim a consensus. Of greater importance, it assumes that a consensus could be formed that "harm would not ensue," or that there could be absolutely no risk resulting from a choice. But for every choice that any decision maker might make, one can always imagine a scenario involving an event with significant negative consequences. The probability may be very low, or perhaps *ridiculously low*. This is entirely consistent with our observation above that risk is usually discussed in terms of powers of ten.

Quantities that are best discussed on scales involving powers of ten are common and are mathematically known as logarithmic quantities. There is no "zero" on a logarithmic scale. There are no choices leading to zero risk, only more or less risk.

We can illustrate the process of imagining low-probability events by considering how the disposal of used nuclear fuel might lead to an exposure by humans to high levels of ionizing radiation[#]. We would first need to assume that a decision had been made to not reprocess the fuel, because if we did reprocess the fuel it would be less dangerous than the ore from which it was mined after 200 years. There is then the possibility that the used fuel would somehow get into the water supply.

It would probably have been stored a quarter kilometer or more below the surface, in caverns sealed with bentonite clay, in which water is not now present. It would have been vitrified (made into glass) and then sealed in very-low solubility metal canisters. All theses barriers could be broached over periods of hundreds of thousands of years if certain other improbable events took place, but the kicker is in what happens next. Research with less-well-prepared radioactive material has shown that the radioactive components would remain trapped in the bentonite and would never reach the sphere of human activity even if water seeped through the bentonite.

The only way for it to interact with humans would be for humans to find a way to get to the used fuel. Over geological time involving many millions of years the surface could wear away until the used fuel is exposed. But by that time it would no longer be dangerous.

In order to expose ourselves we must dig it back up and ignore its radioactivity. Why would we do that? Perhaps within a period of tens or hundreds of years the human race destroys most of itself through war; perhaps a nuclear war sparked by a need for access to a secure energy supply. All of the attributes of civilization, including records of where used nuclear fuel is buried and our knowledge of radiation, are lost. Enough humans survive the war to start a rebuilding process over hundreds of years, and a new human civilization emerges. For whatever reason, that civilization never discovers the concept of radiation but does learn how to drill down to where we have buried our unprocessed used nuclear fuel.

[#]Ionizing radiation is the kind of radiation that can be dangerous. There are other kinds of radiation. We see with visible light which is a type of electromagnetic radiation. Henceforth, however, we will use only the word "radiation" to mean "ionizing radiation."

Risk Identification

Life is a risk. Diane Von Furstenberg

Rates of cancer and other diseases associated with occupational exposure or proximity to a potential source of risk are the subject of many studies. However, any health effect that appears as the result of a new study will usually be a small deviation from large background effects, and may be usefully discussed only with the language of statistics and probability. Debates invariably ensue, first as to how probable it is that the effect is evidence of a real elevated or excess risk and not just a random fluctuation. Secondly, the discussion will be about what the source of the excess risk might be if it is indeed probably real.

Statistical risk studies first ask if two things, like proximity to a reactor, working at a reactor site, having a higher education degree, having a higher or lower than average chance of getting a certain type of cancer, using a cell phone, having a shorter or longer than average life expectancy etc. tend to occur in the same place or the same time. More formally we ask if any two things, A and B, are correlated? Studies are carried out on the first question and they may not all produce the same result.

The next step is to ask if A causes B or if B causes A, or if A and B are both caused by something we will call C and may not yet even have been identified. Most people have a tendency to choose whichever of the three options is consistent with their preconceptions about cause and effect. Resolving the second step without recourse to personal bias will involve making use of additional information and careful reasoning.

Random deviations from an average can be illustrated with a simple virtual exercise. (By "virtual," I mean that you don't need to really do it; just think it through.) Imagine that you have purchased 1000 darts. Mentally have yourself blindfolded and imagine throwing all of the darts, one by one, in the general direction of a wall. When you take off the blindfold you will surely find some clusters of darts on the wall. It is unlikely that you could convince anyone that those clusters were evidence of any phenomenon other than the fact that clusters are a natural part of randomness.

Risk Perception

No passion so effectually robs the mind of all its powers of acting and reasoning as fear. Edmund Burke (1729 - 1797),

Psychologists have studied the characteristics of things that humans fear and the things that get debated in the public forum on the basis that they may involve unacceptable risk. Much has been written about what generates risk perception, or simply “fear.” Some of the things that influence perception of risk are characteristics of the risk other than the actual size of the risk. Factors such as lack of “familiarity” with the risk, lack of “control” of the risk, the “lumpiness” of the risk distribution and the absence of “equitable distribution” of risk-and-benefit are all factors that generate or enhance ones fear. We will elaborate.

The simplest characteristic that enhances risk perception is a lack of familiarity with the source of a risk. Most of us are more familiar with travel by road than by air. Most people fear air travel more than road travel. Fear of air travel varies from being almost non-existent among frequent flyers to a need to achieve a state of enhanced inebriation on the part of some air travelers with whom we are acquainted.

If we happen to be the driver of a vehicle on the road we have a sense of control over our fate. It may be less than we think. As a passenger in a vehicle we have less control but at least we can express our feelings to the driver. If we sit in a passenger seat of an aircraft, we have no say in the control of the airplane. Nevertheless, experience shows that air travel is much safer than road travel.

Fatal accidents involving vehicle crashes lead to relatively small numbers of deaths from each incident, but there are many more incidents of vehicle crashes than there are involving airplane crashes, while airplane crashes often involve many deaths. Referring to the language of our earlier discussion about the calculation of risk, risks that involve events with large consequences but low probabilities of happening are feared more than risks with larger probabilities of occurring but involving smaller consequences, even when the lower consequence risk is larger overall because of the much greater probability that the incident will take place. In other words we fear consequences more than probabilities.

Consider the impact on the cigarette industry if all people who will die from cigarette smoking in a given year in Canada could arrange to get together and die at one place on December 31, rather than each dying in isolation.

At least with regard the risk of cigarette smoking, the main risk is assumed by the smoker, with lesser risks of respiratory decease inflicted on involuntary bystanders. However, in many cases of risk, the main risk is imposed not on the person or persons who causes the risk, and presumably benefit in some way from the cause of the risk, but it is born mostly by others. In other cases it may be that the risk is not spread equally among the beneficiaries. Such risk is said to be not equitable.

This latter factor, although most complex, seems to be the source of much of the reaction to any proposal for the use of nuclear energy to generate electrical energy. There is an assumption that those who live near a nuclear reactor, and those who work with it, and those who live near a facility for the management of used fuel, are subjected to significant risk while the benefits of nuclear energy accrue to the wider population.

We have discussed the risk associated with used fuel management elsewhere, but consider the possibility of every user of electrical energy generated from nuclear energy burying their portion of the used fuel a quarter kilometer deep under their own backyard. It doesn't sound very practical but it would spread any risk associated with used fuel management equitably.

Regardless of whether those who campaign relentlessly to oppose nuclear energy are aware of the forgoing discussion of risk perception, they seem to instinctively use the information contained in it. They focus on imagined affects on workers and those living near a reactor. They focus on very-low-probability events with large consequences. They focus on the lack of familiarity most people have with nuclear energy, stressing that "radiation is invisible".

We would hope that if we understand what can cause us to overestimate risk, we should recognize when we are being manipulated.

Reactor Risks; chronic exposure

Definition of "chronic exposure" : Repeated, continuous exposure to a hazardous substance, over an extended period usually from 7 to 70 years (a lifetime). Opposite of acute exposure.

It is more common to find small decreases than increases in cancer rates among people who work or live in proximity to radiation sources. The debate is whether this should be attributed to the so-called "healthy worker effect" or to a phenomenon known as "hormesis." People who work in the nuclear industry, many of whom live nearby, have higher levels of education and training than the general public and most will have good access to health care than the general public.

It is well known that people who take good care of their minds by reaching higher levels of education than does the general population, are also likely to take good care of their bodies, by eating right, by not smoking and by exercise etc. Such people are healthier, and will have lower rates of various illnesses, including cancer. Nevertheless, the size of the healthy worker effect is difficult to accurately predict.

"Hormesis" refers to the fact that most threats to our health at high doses or exposures have beneficial effects at low doses. Selenium and fat consumption are well-know examples. It is postulated that our bodies have evolved to react to a small increase above natural background radiation levels as a signal to increase the production of repair enzymes. These enzymes go about the body fixing damage that might lead to cancer, whether caused by radiation or not. There are many epidemiological studies that support the hormesis hypothesis but the experts remain divided.

Most studies of Canadian reactor workers show lower rates of cancer than for the general population. As we mentioned above, not all studies of risk agree. One that has received some local attention is a 15-country study which includes a Canadian component. One of the authors of the Canadian part of the study was a fellow graduate student with me at McMaster University and I have asked him for clarification of his own study. It showed a positive excess relative risk of cancer for a person who works in a facility that generates nuclear energy of 52.5%. That means that a reactor worker would be 1.525 times as likely to get cancer as would a member of the general public if he or she received one unit of radiation. A unit of radiation is awkwardly large and is called a Sievert.

Several people who have been involved in the discussion about nuclear energy in Saskatchewan seem to have used faulty logic, to conclude that an excess relative risk of 52.5% means that reactor workers are 1.525 times as likely as the general public to get cancer. But that would assume that the average reactor worker received that one full Sievert of radiation. No reactor worker has ever received one Sievert of radiation. It is not easy to find a study of the radiation dose received by Canadian reactor workers.

A report by the United Nations Scientific Committee on the Effects of Atomic Radiation cites a dose of 1.8 thousandths of a Sievert (mSv) per year for all uranium cycle workers in all countries, but this includes underground miners who receive much more radiation than reactor workers and it includes workers in countries that tend not to worry as much about occupational safety as do modern western nations.

People who work with radioactive materials in industry and medicine typically receive one-quarter of that amount of excess radiation per annum. If we assume for simplicity a value of 1.0 mSv per annum for Canadian reactor workers and that people work for up to 30 years in the industry, they would receive 30 milli-Sieverts (mSv), or 0.03 Sv. That would be in addition to the typical background radiation dose received by Canadians in general which is roughly double that. 30 mSv implies that reactor workers could be expected to be 1.016 times as likely to get cancer compared to a member of the public. The range of uncertainty in that number is large, and as we wrote elsewhere, this is one of many studies and many actually show a decrease in cancer incidence.

Durham County in Ontario is home to both the Pickering and Darlington nuclear generating stations, with four reactors each. The populations around them have been the subject of numerous studies. No statistically significant effects of radiation have been found. One such study is available at http://www.region.durham.on.ca/departments/health/health_statistics/radiationHealthReport2007.pdf

Among studies of people who live near a power generating reactor, the example cited most often during the UDP hearings is the reported increase in leukemia among people living near the Krűmmel reactor in Germany. Again many studies of that population have been conducted. The government of Germany has appointed a commission to study the situation. It has yet to file a final report, but preliminary reports fail to find any evidence that the increase might be caused by the presence of the Krűmmel reactor. The reactor was placed in the area called Krűmmel because it had previously been the site of a munitions factory dating back in the 19th century, including during the Second World War and the land was chemically contaminated. It seems more plausible that the pollution from the previous activity lead to both the citing of the reactor and to any excess cancer risk in the nearby area that may or may not be more than a random statistical fluctuation.

The most plausible evidence of elevated cancer among the general population is associated with the Chernobyl accident. There are increased rates of childhood thyroid cancer in Belarus and The Ukraine that are thought to be associated with the Chernobyl accident. However, the incidence of thyroid cancer varied widely in the area before the Chernobyl accident. For obvious reasons, no background studies were carried out in the specific area where the claimed excess cancers appeared. Other studies show a strange inverse relation between exposure to radiation and thyroid cancer in the nearby areas. An increase of other cancers, not associated with the thyroid, would also be predicted if the increase in cases of thyroid cancers were to be assigned to the Chernobyl accident, but they have not been observed.

In general, these studies of the incidence of increased rates of cancer associated with working at a reactor site or living near one show very small effects, and they are highly inconsistent and difficult to interpret.

Reactor Risks; accidents

Man blames fate for other accidents, but feels personally responsible when he makes a hole in one.

It is not possible for CANDU reactors, or for any other reactors used for the generation of electricity, to detonate like a nuclear weapon. A catastrophic accident or an attack on a power reactor could possibly spread the radioactive material in the reactor core over a wide area and make that area unusable for decades. Any device that spreads radioactive material over a wide area is what has been referred to as "a dirty bomb."

Modern reactor cores are protected by meters of concrete, enough to withstand the direct impact of a crashing Boeing 747. It would take massive amounts of conventional explosives to breach the protective barrier, which would be difficult to conceal. It would seem that the only practical way to make a power reactor into a dirty bomb is to use a nuclear weapon to destroy the protective barrier and spread the radioactive material in the core. Even then, that radioactive material in the core would not itself contribute to the energy of the explosion.

Power reactors used in the western world are designed with multiple negative feedback mechanisms. That is, mechanism that shut down the reactor without human action if anything goes wrong.

For instance, reactors require the presence of a material to slow down neutrons produced by the splitting of uranium atoms. This material is called the moderator. Neutrons must be slowed down so they can be captured by another uranium atom, and then cause it to split in turn. One way to build negative feedback into a reactor is to automatically remove the moderator. The "D" in CANDU stands for deuterium. Deuterium is the moderator for CANDU reactors. It is part of so-called "heavy water." If something begins to look dangerous involving the operation of the reactor, the heavy water will automatically be removed by gravity, or if that fails, it will boil off.
Reactors also can be shut off quickly by adding a material to the reactor core that absorbs neutrons. Neutron absorbing rods are suspended above the reactor core and held there by electromagnets. When the power is shut off the electromagnets loose their ability to hold the rods and they drop by gravity into the core and shut it down.

The Environment

Although it is difficult to demonstrate because it is such a small fraction of the natural radiation background and variations in the background, there is general acceptance that nuclear reactors increase the radiation levels in their vicinity. The amount, however, is minuscule. It has been compared to the amount of radiation one would receive by using the same bed as ones spouse, given that everything is radioactive, including people. A comparison with greater relevance is the amount of radiation deposited into the environment by the most realistic alternative to nuclear energy in Saskatchewan, which is coal.

It has been stated often in discussions of radiation and energy production that coal deposits up to 100 times as much radiation into the environment as does nuclear energy for the same amount of energy produced. That upper limit is represented by Saskatchewan coal, which contains relatively large amounts of radioactive material. This is not surprising given that we also have the earth's richest uranium ore and high levels of natural background radiation such as from radon gas. However, the main affect on human health from coal-fired plants is not from radioactivity. It is from other components of the emissions from coal-fired plants such as sulfur dioxide, nitrous oxides, mercury, heavy metals and small solid particulates. Many studies claim tens of thousands of deaths from this pollution annually in North America. These deaths are not related to CO_2 production or to acid rain.

Risk and Liability

Much has been made of the fact that there is a $75 million government guaranteed liability limit for nuclear power reactors. There is indeed a $75 million liability limit but it has been interpreted reversely to its original intention. Large disasters, like the failure of hydroelectric dams, major oil spills, the Lake Nyos naturally-occurring poisonous gas release and the Bhopal chemical disaster, take years for liability, if any, to be assigned and for lawsuits to wind their way through the courts. Governments, and therefore the tax payers, usually are then drawn into the process of settlement, which invariably takes more years. The Exxon Valdese incident occurred 20 years ago and is only now being settled. The $75 million liability limit is a unique provision that only applies to the nuclear industry. It is designed to avoid legal swamps, costs and delays and compensate victims quickly. A federal government bill is under consideration to increase the limit to $650 million.

Risk Mitigation

An individual can lower their total risk by a variety of measures, by being careful and by removing sources of risk under their control from their daily lives. But many sources of risk are not under our control. Mitigation of risks associated with public transportation, health care, pollution, poorly designed tools, exposure to disease etc. must involve our collective action through our elected governments.

Actions by governments to mitigate risk include the establishment of regulations, but they usually also involve money. Some taxpayers might ask government to get rid of all risk. But zero risk in any activity is never achievable. We can only lower risk, not eliminate it. If governments had access to huge financial resources, all risks could presumably be lowered to very low levels. But government financial resources are limited to what can be taxed from its citizens and businesses without strangling the economy. Furthermore, risk mitigation is only one of the responsibilities of government and all tax revenue can't be spent on risk mitigation. We need schools, roads and police services etc.

Our risk mitigation actions involve both paying taxes for use by government and the things that we can do for ourselves. Surely we should use those resources wisely. That would mean spending them where they can save the most lives. Should we spend more money adding additional backup safety systems for CANDU reactors, or for burying used fuel deeper, or for better street lighting, or for better air-exchange systems for housing, or for more rural hospitals, or for more anti-smoking campaigns, or for organic vegetables, or for more safety devices in cars?

To answer that question we need first to estimate the size of a risk, using the simple process discussed elsewhere. We would also need to consider how much it would cost to lower a risk, regardless of its size. We recognizing that in most cases the outcome of a rational process like this will remain little better than a best guess, but any attempt to allocate resources to save more lives is surely better than allocating those resources randomly.

How do we, as a society, allocate our finite risk-mitigation resources? Much has been written about the answer, and about the difference between expert opinion with regard risk and the opinion of the average voter. That difference is illuminated by our previous discussion about risk perception. Experts are not always right, but we would hope that they are right more often than they are wrong. Nevertheless, governments who wish to get re-elected will choose the opinion of the average voter over that of the expert. Referring to our previous discussion about factors that tend to influence perception of risk, the consequence is that risk mitigation resources are spent in a manner more characterized by randomness than rationality.

C: Say What?

A long habit of not thinking a thing wrong, gives it a superficial appearance of being right.

Thomas Paine (1737 - 1809)

Other countries have achieved high levels of wind energy use.

It has been claimed that Denmark has achieved 20% wind power in its mix of electrical energy sources, and that Germany has achieved 45%. Let's look closer.

So then how does Germany achieve 45%? The simple answer is that it doesn't. Information is easily available through the internet that shows that the official figure provided by German utilities a few years ago was 4.5%, not 45%. It has recently reached 7%.

The situation in Denmark is more complex. Denmark's power system is part of the larger Scandinavian alternating current (AC) grid, which is itself connected to a larger European grid. When taken as part of the whole grid of which it is one component, wind provides a much smaller fraction of the total. Of the 20% less than half is used Denmark itself. The rest tends to be produced when demand is low and is easier met with base-load power. The excess is sold into the European grid at considerable loss for the country.

Saskatchewan is tied into a large North American AC grid that stretches all the way to New York. The problem is that the so-called "interties" that link us into the larger grid carry relatively small amounts of power, which makes it difficult for us to rely on power sources in the larger grid to hold our voltage at 110 Volts and our frequency at 60 Hz when fluctuating wind power tries to push the voltage and frequency off the proper values. We have emphasized AC here because our interties west to Alberta are direct current (DC) interties and information about AC voltage and frequency does not pass through DC interties.

The world is abandoning Nuclear Energy.

The fraction of electrical energy produced by nuclear reactors around the world has indeed been decreasing over the past two decades because some reactors have been decommissioned, but mainly because world demand for electrical energy has been growing and demand has been met over recent decades without the use of nuclear energy. There are currently 436 reactors producing electricity. Another 47 are currently under construction. 133 more are on order or planned and are past the "proposal" stage. Another 282 have been proposed and may or may not be built. Those under construction and planned will increase the world's annual production of electrical energy from nuclear reactors by 50%.

It is claimed that Germany is abandoning nuclear energy. Indeed, in the year 2000 Germany committed to limiting the lifetime of its existing nuclear reactors to 32 years. The consequences have been that Germany will miss its Green-House Gas commitments by a wide margin and will soon be importing roughly ten times as much electrical power from neighbouring countries as is used in Saskatchewan, almost all of it produced from nuclear energy in other countries. Germany is now debating its options for the generation of power.

Several other countries in Europe are building or planning major reactor projects. Italy, which imports 85% of its power, has just announced plans to build four reactors.

Nuclear Reactors will remove scarce water from Saskatchewan's environment.

There seems to be an assumption that the water used to carry away excess heat from nuclear reactors is somehow removed from the environment, but water can't disappear. It is part of the underlying nature of the process whereby heat is converted to other forms of energy, such as electrical energy, that a predetermined amount of that heat must be deposited to the environment. That cannot be changed without changing the basic physical laws of the universe. That is true regardless of whether the heat was generated by a chemical reaction, as in the burning of coal or gas, or in a nuclear reaction, as in the splitting of U_{235} nuclei.

The cooling water that is taken from the environment and then returned to the environment is called the secondary coolant. The secondary coolant does not become radioactive. It cools the cooling fluid that circulates in the reactor core, the so-called primary coolant, not the reactor core itself. In some reactor designs it cools water that itself cools the primary coolant, and is twice removed from any radioactivity. The secondary coolant is returned to its original source after having been heated up, not used up or made radioactive.

Years of operation of many reactors lead to one coolant accident, the primary coolant accident at Three Mile Island. The amount of radiation released to the environment from that accident was much too small to lead to even one case of cancer and no excess cancers have been detected.

Nuclear Energy emits large amounts of CO_2

Some opponents of nuclear energy claim that activities such as mining, transportation and the construction associated with the production of nuclear energy produces large amounts of CO_2. On the face of it this seems absurd. Without even considering emissions from the burning of coal, the vastly greater volumes of fuel used in a coal-fired plant would imply greater CO_2 emissions without even looking at what goes up the stack.

The numbers from full-lifecycle calculations agree. Recently published studies by the International Atomic Energy Agency, the World Energy Council and the International Energy Agency, which is an arm of the Organization for Economic and Cultural Development (better known as the OECD) estimate that on a life-cycle basis the emissions intensity of nuclear power is between 2 and 59 tonnes[+] of Green House Gases (GHG) per GigaWatt hour (GWh) of electricity produced. The huge variation in the numbers arise because of varying assumptions; assumptions about fuel reprocessing, transportation distances, mining conditions etc.

Another study compared nuclear energy with other sources of energy and found GHG emissions from the full nuclear-energy chain in the range 9-21 tonnes of GHG of CO_2-equivalent per GWh of electricity produced, compared to 385 to 1343 for various fossil fuel chains and 9-279 for various renewable energy chains. A third reviewed 103 studies of GHG emissions by the uranium fuel cycle and found numbers ranging from 1.4 to 288, with a mean of 66. Coal-fired plants are at the upper limit for fossil fuel plants and gas-fired plants produce roughly half as much GHG as coal. Various other studies show that the upper and lower limits of the range of estimates of full cycle GHG emissions for wind energy to be higher than those for nuclear energy.

[+] Emissions intensity is expressed in CO_2-equivalent tonnes. There are other GHG gasses in addition to CO_2. For simplicity they are converted to an equivalent amount of CO_2 that would produce the same effect. Some authors us tonnes of CO_2.equivalent per GWh. Others use grams per kWh. A GWh is one million times as much as a kWh, and a tonne is one million times as much as a gram, so the units are the same.

Saskatchewan Uranium is used to make nuclear weapons.

Although this issue is only vaguely related to the question of whether nuclear energy should be considered for part of the mix of electrical energy sources in Saskatchewan, it has been inserted into the discussion. An act of the federal government of Canada prohibits all uranium mined in Canada from being used in the production of nuclear weapons. However, all un-enriched Uranium is basically the same, so it is considered fungible. That means that if Canadian Uranium is easily available where needed for military use, it may be so used, provided that an equal amount of uranium is removed from military use and placed into the Canadian civilian-use chain somewhere else. The benefit of fungibility is that transportation costs are reduced, including any GHG costs. The ultimate fungible entity is cash.

Canadian heavy water reactors, such as the CANDU III+, don’t need their uranium to be enriched. For that reason it is more difficult to use them to contribute to nuclear weapons proliferation than the more common reactor designs that do use enriched uranium.

We are soon going to run out of Uranium.

At present rates of use, we have enough uranium reserves identified to supply roughly 100 years of use. Exploration has been ramped up substantially over the past few years, and based on past experience that should approximately double the known reserves over the next decade. Of course demand for uranium may also double over the same time period, leaving the number of years of supply the same. We would like to know how much is left to be found but that depends on the price. A doubling of price should lead to a ten-fold increase in potential reserves because it makes the more numerous lower-grade ore bodies economically viable for mining. The cost of uranium has a small impact on the cost of nuclear energy.

The foregoing assumes that used fuel will not be reprocessed. When used reactor fuel is removed from a reactor, only about 5% of its ability to create energy has been utilized. Reprocessing involves separation of the used fuel into two parts. One part consists of new radioactive materials created during the most recent pass through of the reactor and which can be mixed with fresh uranium and reused in the reactor. The other part needs to be disposed of permanently and will produce significant amounts of radiation in the short term. It will gradually decay and after 200 years of storage in a permanent disposal site it will produce about the same amount of radiation as would the original ore from which it was extracted.

Reprocessing multiplies the life expectancy of the world's uranium reserves, known and unknown, by a factor of about 20.

Several countries, most notably Britain, France and Japan, now reprocess their spent nuclear reactor fuel, along with enriched uranium from decommissioned nuclear weapons. They do this for a variety of reasons, including national security and to rid the world of weapons grade enriched uranium. However, at the moment, fresh uranium is cheaper than reprocessed fuel. The UDP recommended that Saskatchewan not get involved in the reprocessing industry, at this time. If and when the price of uranium returns to its recent high values and appears to be stuck there, more counties will probably show interest in reprocessing.

We don't know how to safely dispose of nuclear waste.

The Canadian Nuclear Waste^ Management Organization (NWMO) was established in 2002 to plan for long-term management of Canada's used nuclear fuel. Its work is monitored by an advisory council of senior university natural scientists and social scientists and other Canadians with backgrounds in government and industry. Its work is also monitored by a second group of international experts. The NWMO released its recommendations in 2005. In 2007 the government of Canada agreed to implement the recommendations. The report recommends an "Adaptive Phased Management" approach. That means that it recognizes that management of used fuel must accommodate decisions to be made in the future about recycling, by advances in technology, and by changes in public policy etc. Its recommendations rely on well-proven existing technology to easily and safely manage used reactor fuel, with or without reprocessing.

Approximately eight billion dollars from the sale of electricity generated by nuclear energy have already been put aside in Canada to pay for used fuel management and for reactor decommissioning. Used fuel is first stored in drums under water until short-lived radioactive components have decayed away. The time will come when the used fuel will need to be stored underground. The NWMO is now starting the process of looking for a site.

The challenge with regard used fuel management is associated with the equity aspect of risk perception. Any facility for the management of used fuel will be localized in a community. It will bring high-paying jobs to that community. However, if there are individuals in that community who think that the presence of the facility brings significant risk to the community they will be certain to make their views known and they will quickly find external help in raising their voices. The argument based on a lack of equity (Many benefit from the electricity produced from the used fuel, but we alone must deal with the "waste".) will be employed. This is the well-known "Not in my back yard" or "NIMBY" syndrome.

^We now recognize that "waste" is not the most appropriate word to use for something that has been used once and could be used 19 more times. We will call it "used fuel."

D: Credibility

Credibility is like virginity. Once you lose it, you can never get it back.

The forgoing is based on refereed published scientific research, reports of various panels and committees, and conversations with individuals with specific areas of expertise related to the uranium fuel cycle. In short, it conveys the opinion of the "establishment."

Many, particularly those who strongly oppose the use of nuclear energy, including those who have been calling for more "information," will dismiss it as some form of propaganda.

The word "establishment," as it refers to the science, technology and engineering" establishment is worthy of some elaboration. First, it is important to realize that we are talking about somewhere between 50,000,000 and 100,000,000 people, depending on how one defines the terms "scientist" etc. Only a fraction work in areas related to nuclear energy, but most have a reasonable understanding of the issues involving nuclear energy that appear in the popular media. Unanimity is never possible among that number of people, but consensus is. The word "consensus" can mean anything from a simple majority to "nearly all" of a group of people. Science progresses when the theory supported by the consensus is overturned by a new one first advanced by a minority, based on the evidence. It is part of the *dna* of science that minority views deserve and must be provided with a fair hearing. If and when the minority view is deemed to be lacking substance, the minority and the majority seldom agree on whether a hearing has indeed been fair. But in many cases, the minority eventually establishes itself as the majority.

It is difficult to estimate the fraction of the members of the scientific, engineering and technical community who disagree with the consensus about the merits of nuclear energy as a source for electrical energy. Those who actively oppose nuclear energy tend to have been doing so for a long time and those of us who have been following this debate for many decades will probably have encountered them at least once already.

The process of consensus formation and change is also relevant when considering scientific debates relating to public policy on major issues. There will always be a minority view. When public policy is involved there is an additional element to the dynamic, the news media.

Those who write for the media are attracted to stories that will draw readership. That includes stories that involve controversy and which might suggest suppression of news that is in the public interest by the agents of special interests. That allows the minority to greatly amplify their voice in matters of public policy. The phenomenon is further advanced by the general absence of any scientific postsecondary education on the part of most reporters and the supportive role of activists who promote an "anti-establishment" and "conspiratorial" point of view with regard issues associated with the environment.

It is no surprise then that members of the general public seldom have an inkling of what the view of the majority of scientists might be on a particular subject. I am frequently asked by people with a good education, and who are aware of my background, what my views are with regard the use of nuclear energy. I continue to react with surprise and some frustration, in spite of being aware of the origin of their lack of knowledge.

How might it be that all or most of what I have written is wrong? Perhaps I have been misled and the strong consensus that I claim does not exist. Perhaps I have been compensated by some organization with a stake in the nuclear fuel cycle to mislead you. Or is the consensus itself corrupted by undue influence and a massive cover-up conceals the truth? If so, the fictional cover-up in *The Da Vinci Code* would be trivial by comparison.

Or, finally is the consensus itself simply wrong by accident? The conventions of science whereby the reigning consensus must defend itself against all comers is far from perfect. Scientists are people and people don't like to admit that they are wrong. However, supporters of a consensus can't shield themselves from evidence to the contrary forever. Frequently, as when Einstein's relativity overthrew Newton's laws of motion, the new theory does not refute the old, it just expands it to wider application.

Nuclear Energy is not a theory. It is large body of knowledge, based on many scientific and engineering disciplines, but also on decades of experience. It is inconceivable that all of that knowledge could either be falsified or completely misinterpreted.

There are important issues to be discussed in making choices about new sources for electricity in Saskatchewan. Instead the issues that we have tried to deal with in the forgoing have taken the limelight. They are only controversial in the mind of some elements of the public and some members of the media. Massive amounts of information is freely available on these issues mostly based on research and solid evidence, but some seeming to have been pulled out of a hat. It needs to be both accessed and evaluated carefully by anyone who takes their civic responsibility seriously. We have provided the doorway to that information in the forgoing.

E: The important issues.

There are some people who live in a dream world, and there are some who face reality; and then there are those who turn one into the other. Douglas H. Everett

We should be discussing how we might fit a large energy source such as CANDU III+ into our small grid system. We would need to upgrade that grid, add more natural gas turbines and strengthen our interties to neighbouring grid systems to allow for both scheduled maintenance downtimes and to be ready for unscheduled downtimes. Similar issues arise if we wish to expand our use of wind power, but for somewhat different reasons.

Should we consider new but unproven scalable nuclear reactors?

If we expand our reliance on coal and penalties are imposed on GHG emissions, how will we react? How far will more conservation measures take us?

If we are concerned about the radiation risk associated with nuclear energy, how should we react to the radiation risk associated with the use of coal, which is two orders of magnitude greater?
If we are concerned about the risks associated with radiation and energy sources in general, how should we react to other health risks associated with coal which are again many orders of magnitude greater than those from radiation?

Are there markets for the excess electricity that a CANDU III+ would produce? If so, can we move our electricity across the states and provinces between Saskatchewan and those markets? If so, what would be needed in new intertie and grid infrastructure?

Can we find a way to use the waste heat from any new thermal-based electrical-energy facility, nuclear, coal, or gas, to replace the hydrocarbons used to heat the tar sands extraction process?
How can we prevent the politics of fear from artificially inflating the cost of nuclear energy?

All of the foregoing assumes that the Province of Saskatchewan wishes to not become overly dependent on other states or provinces for its source of electricity. If that is not a problem, we have other options.

We don't have large undeveloped hydro-electric resources in Saskatchewan, and those available would bury some of the most beautiful country in the world. But large potential hydro-electric resources are available to Manitoba, on the Nelson River, with a huge water flow. There remain 5000 MW of capacity that can still be developed on the lower Nelson River. Do we want SaskPower to start discussions with Manitoba Hydro to jointly develop some of that for use in Saskatchewan? Hydroelectric projects alter the ecology of the rivers on which they are built both above the dam in the headwaters and below the dam by changing flooding and flow patterns. Is that a small or large price to pay for energy?

Or we could turn west and commit to the purchase of large amounts of energy from Alberta. That would probably enable Alberta to proceed with a multi-reactor facility that would be large enough to be able to provide its own backup power.

Let’s start a more productive discussion about energy for electricity in Saskatchewan?