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Addressing the Long Time Horizon for Managing Used Nuclear Fuel

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Abstract

The time horizon that must be considered in developing an approach to managing used nuclear fuel extends many thousands of years. Such a time horizon is without precedent in environmental, economic, social, technical and public policy terms.

As a first step in addressing this issue, the Nuclear Waste Management Organization convened a team of 33 individuals to undertake a formal scenarios exercise. Such an exercise is a way of framing potential futures that might occur. There is no intent to predict the future. This exercise represents the first time that the scenarios technique has been used for such a long time horizon. The approach involved identifying two principle axes of potential change: (1) social – political – environmental well-being; and (2) magnitude of the used nuclear fuel challenge. Using this organizing template, four scenarios were developed reaching out 25 years, and an additional twelve were developed at 175 years branching out from the original four. In addition, a series of sixteen possible "end-points" were identified to span conditions 500 years out and for 10,000 years a large number of "what-ifs" were developed. The scenarios, end-points, and what-ifs were then used to identify a number of criteria that could be used for testing proposed management options and their capacity to deal with future conditions.

This paper describes this work and the role that it has played in the deliberations of the Nuclear Waste Management Organization.

1. Introduction

Over the past several decades a number of techniques have emerged for thinking about the future. Although we cannot know what future societies and conditions *will* look like, we can try to anticipate what they *may* look like by envisioning a broad range of possibilities. Doing so can help strengthen current decision-making by testing its robustness against these possibilities and thereby enhancing preparedness.

Taking advantage of these techniques is particularly important for the issue of managing used nuclear fuel because of the long time frames over which used nuclear fuel remains hazardous to people and to the environment. Decisions we make today will have repercussions for generations to come and to the best of our ability we have to alert ourselves to these implications.

Responding in part to the 1998 recommendations of the Nuclear Fuel Waste Management and Disposal Concept Environmental Assessment Panel (the Seaborn Panel) the NWMO initiated a formal scenarios exercise early in its program of activities.

Scenario technique first emerged following World War II as a method for military planning. In the 1960s the approach was refined as a tool for business prognostication by American futurist, Herman Kahn. However in the early 1970s, scenarios work reached a new level. As part of their review the world socio-political situation and its implications for oil prices, the planning team at the Royal Dutch/Shell Group developed a set of scenarios, one of which included the kind of oil crisis that was brought about by the OPEC oil embargo of 1973. When it did occur, Shell was the only oil company emotionally prepared for the change. In the subsequent years, Shell's fortunes rose dramatically (Schwartz, 1991).

In the 30 years since, many different types of business, government, and non-government organizations have increasingly used the scenario approach. One particularly powerful exercise was undertaken in the early 1990s in South Africa prior to the break-up of the apartheid system. In this case, 22 prominent South Africans – politicians, activists, academics, and businessman from across the ideological spectrum – were convened to consider South Africa's future using the scenario methodology. For the first time, scenarios were applied in a multi-interest forum focussed on a broad social issue. One of those interests was the South African Chamber of Mines. The informal, indirect scenario approach was shown to be a powerful method for approaching the future by a society in conflict (Deeper News, 1996). In the case of nuclear waste, in addition to generating a sense of what future conditions might be faced, the technique provides a safe way to convene a varied group of interests to discuss a controversial issue of public policy in a constructive way.

For its scenarios work, the NWMO convened a 33-person Scenarios Team drawn from a range of interests and locations across Canada and abroad. During the six-month period June – November 2003, four workshops were convened and a final report produced under the guidance of Global Business Network (GBN) of San Francisco.

Throughout the development of the various perspectives on how the future might unfold, conditions were highlighted that would influence today's decision that Canada faces about the choice and design of a management approach for used nuclear fuel. These conditions were then captured in questions to be asked of each alternative management approach. In a final exercise, the process was inverted and four management approaches, crudely drawn together, were used to test the effectiveness of the various scenarios.

As the NWMO process subsequently evolved, the process of assessing alternative management approaches came to be put to an interdisciplinary Assessment Team. The Assessment team undertook a comprehensive multi-attribute utility analysis in a comparative assessment of the three alternatives specified for consideration by the *Nuclear Fuel Waste Act*. As part of this work, a sensitivity analysis was undertaken using the Scenario Team's results.

2. What are Scenarios?

Scenarios are alternative descriptions of the future. They are stories with beginnings, middles, and ends. They derive from a description of the forces driving change and the critical uncertainties leading to different possible future outcomes.

They are not predictions, nor are they paintings of a desirable future – although some of the scenarios may be more desirable than others. Rather, they are stories of different futures, each of which is possible. Such stories are a powerful way of communicating complex and often subtle ideas. They serve to integrate a complex maze of quantitative and qualitative insight based on the knowledge and wisdom of participants. Interestingly, with its base in the use of "story," there is a link between this approach and the oral history tradition of Aboriginal Peoples.

Scenarios very much depend on the values, preferences, and insights of those who create them – in this case, the NWMO Scenarios Team. This characteristic results in both strengths and limitations: strengths because of the insights that such an approach can offer, limitations because in a given group of individuals the full spectrum of society's values and preferences may not be represented or the spectrum that is represented may be over-weighted in a way that skews the results.

Through out this paper, the scenarios that were developed by the NWMO Scenarios team are summarized by title or by short lists of the key characteristics. The full scenarios are in narrative form and their strength comes from the richness and colour of the detail which ties together the internal consistency of each story. The summaries offered here dilute this detail.

3. The Four Time Horizons of the NWMO Scenarios Exercise

Formal scenarios work has never before been applied to an issue characterized by a time horizon of thousands of years. In fact, scenarios work is generally applied within a 10 – 25 year time horizon. This effort broke new ground by working with four distinct time horizons: 25 years (about a generation), 175 years (7 generations), 500 years (20 generations) and 10,000 years (400 generations).

The rationale underlying the choice of each of the four time horizons is summarized below.

25 Years –Time Horizon 1. This time horizon is within the envelope of common projections undertaken today. Within this time period, we can have some degree of confidence that today's social, environmental, and economic conditions can serve as a basis of projecting change. Twenty-five years is about one generation. The design life of Canada's current nuclear power generating facilities extends to about the end of this time horizon.

175 years – Time Horizon 2. Choice of this time horizon draws on a range of factors:

1. 175 years coincides with the Seven Generations concept that emerges from Aboriginal Traditional Wisdom as a target time horizon that we should look forward to when considering the implications of today's decisions.
2. The 175 year time horizon coincides with the period ahead during which site identification, development, licensing, operation, and closure phases of any repository would occur thus it

represents a reasonable dividing line between the active period and the follow-on long term period.

3. From a societal perspective, continuity through this time horizon of institutional and economic structures and activities with those of the present is a reasonable possibility although certainly not a sure thing.
4. From a technical perspective, this time horizon marks the limit to when engineering predictions and the characteristics of human-made objects can be reasonably firm; when environmental and ecological aspects, although undoubtedly changing, can be reasonably assumed to have some similarity to the present.
5. From a scientific perspective, 175 years, more or less, marks a defensible and fairly distinct division in the nature of the hazard to humans and biological life posed by nuclear fuel waste. It is the period when the radioactive wastes produced from 1950-2010 will have cooled to near-ambient temperatures. By about this time, the short-lived radio-isotopes, including many of the highly dangerous ones which account for most of the radioactivity contained in the waste when it is first removed from the reactor, will have decayed to insignificance. What remains is the hazard from long-half-life elements and isotopes. These are present in much tinier quantities but they remain dangerous for a very long time. The reduction in radioactivity during this 175-year period is about a billion times, even though significant hazard remains.

500 Years – Time Horizon 3. This time horizon pushes thinking out to about 20 generations into the future. Looking back 500 years takes us to the "discovery" of the New World. Looking forward this amount is still within our capacity to consider, but just.

10,000 Years – Horizon 4. Ten thousand years is 400 generations. This time horizon takes the analysis into the scale of short-term geological change on the one hand but on the other, social and cultural change that severely tests the capacity of human beings to even imagine. In considering the issue of long-term management of used nuclear fuel, 10,000 years has sometimes been used as a technical design time horizon.

In undertaking the formal scenarios technique using these four time horizons, the NWMO Scenarios Team found that while it was possible to use the process logic to build scenarios with some confidence using a 25 year time frame and with much less confidence using a 175 year time frame, moving beyond is nigh impossible: there are just too many options and too much that is unknown. As a result, deliberations at the 500-year time horizon led to descriptions of what came to be known as "end-points" or short descriptions of sets of conditions but with no attempt to structure a logical story. Furthermore, at 10,000 years, the best that the Team could do with any degree of comfort was to generate a series of short statements describing, "what-if such-and-so might happen?"

Thus, the full assembly of future possibilities came to include:

- ➔ four fairly detailed scenarios extending out 25 years;
- ➔ 12 much briefer scenarios reaching out 175 years;
- ➔ 16 "end-points" at 500 years, and
- ➔ a list of about seventy brief "what-ifs" for 10,000 years.

4. The Scenarios Methodology

The process taken by the NWMO Scenarios Team included the following eight steps:

1. A focal issue was adopted to drive the process; in this case, "what criteria should be applied in Canada for deciding how to manage used nuclear fuel?"
2. A brainstorm of factors influencing the outcome of different management options was undertaken; 180 factors were identified.
3. Related factors were clustered and from all of these, two sets of critical uncertainties were collectively identified that best guided thinking for developing the scenarios. These were adopted as the axes of a 2x2 scenarios matrix.
4. The matrix was used to build the four 25-year scenarios and after their completion, a series of "early indicators" were identified that would serve as signals that society was going towards one or other of the scenarios.
5. The twelve 175-year scenarios were developed branching off the 25-year scenarios.
6. The sixteen "end-points" were developed for the 500-year time horizon.
7. The seventy "what-ifs" were developed for the 10,000-year time horizon.
8. Insights from all of the above were used to develop a response to the focal question identified at the beginning of the exercise

In a final exercise, the scenarios were tested using descriptions of four crudely compiled management approaches. When compiling the final report, a series of concluding observations/insights were developed based on the overall experience of the Scenario Team.

5. NWMO Scenarios Team Principles of Participation

Participants in the NWMO Scenarios Team included a wide range of interests. Some were strongly opposed to nuclear energy, some were strong proponents. Some participants came equipped with a much technical knowledge; others were carried by a deep commitment to do what is right for their community and country. Women and men, Canada east, west, centre and north, the Aboriginal community, young and elderly, environmentalists and industrialists, academics, lawyers, engineers, those active in the faith community, all were reflected in the group's make-up.

To provide a clear set of rules to govern the group's deliberations, the following Principles of Participation were adopted.

Table 1.
NWMO Scenarios Team, Principles of Participation

Our intent is:

1. To explore, not negotiate;
2. To share, not to decide;
3. To inform and when requested, to advise;
4. To understand the diversity of perspectives and build relationships;
5. To consider how to widen the network of connections with which NWMO will need to build complementarity and linkages;
6. To help guide the flow of the discussions in such a way that areas of common ground and of differences are identified along with the underlying reasons; and
7. To respect that participation and contributions are not to be seen as an endorsement by any participant of the NWMO project (or any specific outcome of it).

Attribution of comments:

8. No specific attribution of any comment made by any participant(s) will be referenced in any notes unless specifically requested by the participant(s).

Notes

9. Notes will be prepared from the activity (meeting, workshop) and shared, either with a representative group if identified at the activity or the full group prior to finalization. Notes shall typically be of a summary nature and will include a list of participants.
10. Any notes prepared should include at the beginning, this "Basis for Participation" which shall have been discussed with participants at the beginning of the activity.

Source: Glenn Sigurdson, CSE Group
Vancouver, B.C. Canada

6. The Scenario Matrix

At the heart of the scenarios exercise is the 2x2 matrix with two axes defined by two sets of critical uncertainties: (1) social, political, and environmental well-being; and (2) the magnitude of the challenge (the nature of the hazard) posed by used nuclear fuel (Figure 1). In both cases, the nature of these axes can range from high to low, depending on what unfolds in the future.

So, for example, there are several different forces that could push the future up or down the vertical axis, increasing or decreasing the “challenge” such as

- The quantity of spent fuel to be managed
- Energy demand, which, to the extent that the nuclear industry remains active, might lead to more or less spent fuel
- Economic vitality, which might drive energy demand
- The availability (or not) of technologies for storage and/or transmutation of nuclear wastes.

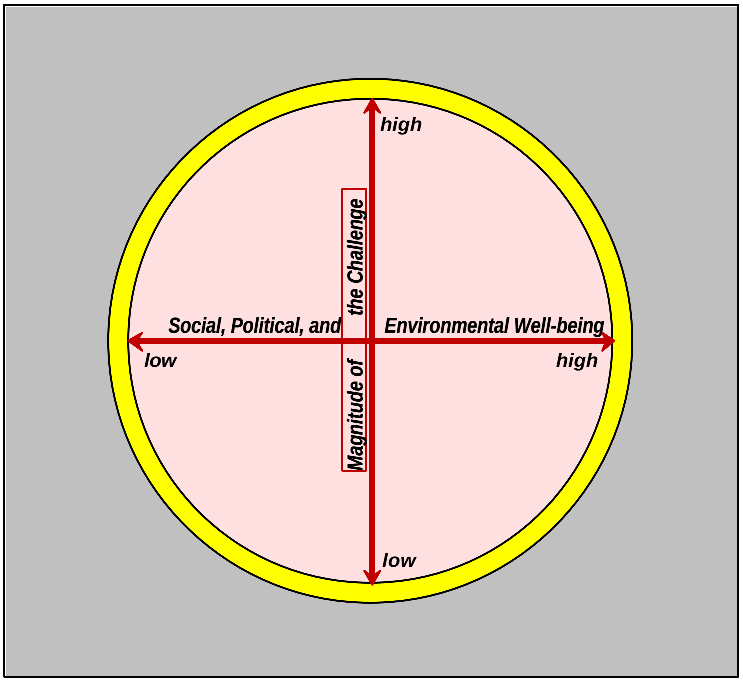

Figure 1. The 2x2 NWMO Scenarios Matrix.

Likewise, a number of different forces or events could push the future to the right or to the left along the horizontal axis:

- Public trust in corporations
- Respect for government—"governability" (think of Russia, or Rwanda)
- War or peace
- The effectiveness of international and trans-national institutions
- The health of the natural environment

The above lists are far from complete but they demonstrate the complexity of each axis. The axes combine to define four quadrants. The upper right is marked by a high degree of social, political and environmental well-being combined with a high challenge related to management of use nuclear fuel. The upper left is marked by a low degree of social, political and environmental well-being combined with a high challenge related to management of use nuclear fuel. The lower left is marked by a low degree of social, political and environmental well-being combined with a low challenge related to management of use nuclear fuel and lastly, the lower right is marked by a high degree of social, political and environmental well-being combined with a low challenge related to management of use nuclear fuel. Thus, the matrix ensures that the sets of conditions that are explored are varied while being comprehensive.

7. Results

The 25-Year Scenarios

Following each quadrant, four scenarios were developed for 25 years as shown below in Figure 2. Note that each scenario is assigned a name that attempts to reflect the essence of the story.

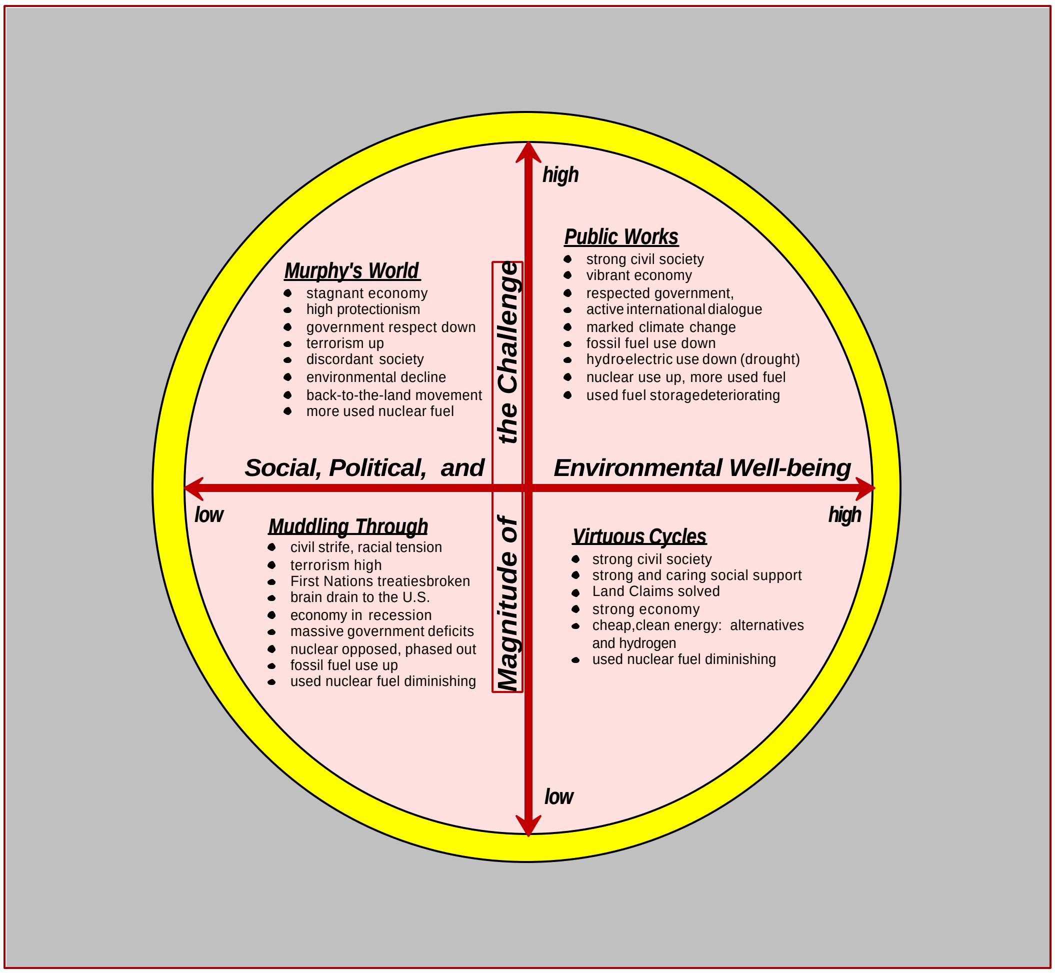

Figure 2. The 25-year Scenarios

The 175-Year Scenarios

When the team extended the scenarios out to seven generations, or 175 years, the basic dimensions of uncertainty developed for the 25 year scenarios remained useful, but the range of uncertainty was so much greater that the four 25-year scenarios quickly splayed into twelve discrete futures, each plausible, and each challenging in its own particular way. The 175-year scenarios are shown below in Figure 3 and summarized in Table 2.

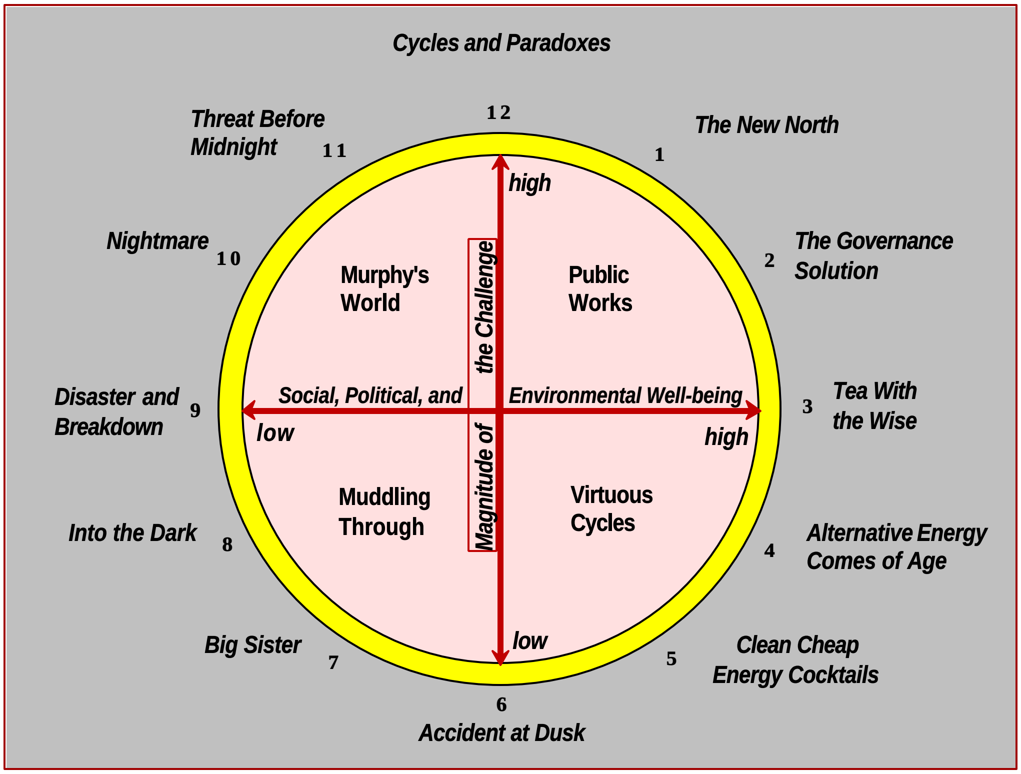

Figure 3. The twelve 175-year Scenarios

Table 2. Summary of the Twelve 175-year Scenarios.
1. The New North Greater sensitivity to bio-regional governance; consumerism spreads to the developing world; high economic growth; energy demand up; small wars but nothing cataclysmic; security risks up science and technology focus on miniaturization and decentralization; population centers disperse; local mini-nuclear sources become a reality but vast energy requirements lead to much used nuclear fuel; development of hydrogen economy steady but slower than expected, restrictions on oil sands and use of petroleum products related to environmental concerns adds up to increased dependence on nuclear to meet energy demand society's capacity to deal with nuclear waste problem improves but not enough to keep up with the problem itself.
2. The Governance Solution After an initial period of increased social inequity characterized by growth in walled cities and increasing security problems, the world finally finds a way to bridge and the rich nations finally reach out effectively to poor nations in ways that are both respectful of local cultures genuinely helpful; inequities decrease; and security risk decrease; Aboriginal land claims are addressed; Increased focus on energy conservation and renewable energy; Widespread success of development leads to increased energy demand and nuclear remains a key component of energy mix no miracle cure for transmutation or re-use of nuclear fuel thus challenge of used nuclear fuel expands capacity to address it – our technical, social and organizational skills – develop even faster
3. Tea with the Wise Values shift away from consumerism towards greater harmony with nature's ways and sustainable economics; "soft energy paths" predominate with a focus on conservation and careful technical balancing of energy use with the

appropriate energy form; biotech and medical advances cause an extension of typical human lifespan to 180 years; older, wiser society focuses on "giving back to society"; overpopulation problem leads to careful control of birthing; children are precious and teaching becomes the most respected profession; a rapprochement between eastern and western values produces an amalgam that allows a high quality of life with a lean diet of energy and materials; heavy throughput of energy and materials shifts to a more sublime mix of information, education, entertainment; base of economy shifts from products to services and experiences; energy demand reduced significantly; nuclear no longer part of the energy mix; used fuel issue is an old legacy problem – there has been no "technical fix" discovered, need for vigilance remains; Thus challenge is reduced while our capacity to address it remains high
4. Alternative Energy Comes of Age Scientific advances lead to major shift in the energy mix from current dependence on petroleum products and nuclear to a rich mix of alternative renewable energy sources and conservation; hydrocarbons and nuclear stays as part of the energy mix (decreasingly so) till about the end of the 21st century and then there uses tails off toward the kind of "negligibility" that alternatives suffered at the beginning of the century
5. Clean Cheap Energy Cocktails Social tensions are reduced by technological advances, cheap energy is easily available; by 2050, scientists have achieved economic transmutation of used nuclear fuel including application at small scale, local reactors; need to transport used fuel eliminated; Much of the used fuel considered "waste" early in the 21st century is now considered a useful fuel; Minimal use of petroleum products for energy; Cultures and economies around the world thrive; more equitable distribution of benefits across the world is achieved
6. Accident at Dusk Challenge of nuclear waste low – nuclear has been abandoned because of a major nuclear disaster and total loss of public trust; greater dependence on fossil fuel with attendant environmental problems; climate change more severe than earlier predicted; leads to return to subsistence lifestyles; huge increases in food costs; mass migrations of people, political instability, population shrinks by 50 %; drought in southern prairies, decrease in water levels in Great Lakes, drastic reduction in use of St. Lawrence Seaway; Canada as a nation is reduced to a shell of what it once was.
7. Big Sister Ongoing terrorism, sabotaged power lines, urban bombings, aerial assaults lead to huge worries about safety and security; However, the cure is worse than the disease – surveillance systems with related information systems and linked centralized control all rationalized as needed for security purposes do provide safety but cost is personal freedom; So controlled, human population drops, energy demand is reduced society enters a Dark Age;
8. Into the Dark Human society as we know it fully collapses (cause could be plague, war, environmental collapse), little trace of civil society as we now know it remains; technical capacity gone; life is nasty, brutish, and short; Production of used nuclear fuel has stopped but capacity to manage legacy is also gone; Danger of nuclear waste are the least of people's worries because they are unaware of the danger; World of ill-educated scavengers and vandals – signs that say "don't dig here" cause the opposite to happen
9. Disaster and Breakdown All out war, all humans are killed
10. Nightmare World is at war – but limited. Nuclear weapons are used and considered for use by others; Huge security problems with rogue states targeting used fuel for potential weapons material; Epidemiological studies after use of nuclear weapons document thousands of cancers and birth defects; chromosomal aberrations alarmingly widespread in humans and other species; Countless well-meaning attempts at disarmament fail; Economies suffer, our descendants wonder why we made such a Faustain bargain with nuclear technology

11. Threat Before Midnight The clock of the Union of Concerned Scientist is brought back and hovers just before midnight without ever going vertical; economies are strong, energy demand is high, and nuclear dependency high; there is no technical solution to the challenge of used nuclear fuel so the magnitude of the problem is great; nuclear capacity and weapons proliferate; technology for those who have it allows the massing of wealth but the gap between rich and poor widens; technology also supports terrorism with disastrous results; nuclear bombs don't fall, nuclear plants don't melt down, nuclear waste remains secure, but life is risky and society teeters.
12. Cycles and Paradoxes Nuclear advocates fear continued nuclear depends on finding a solution to the waste problem while opponents fear a solution will open the door to more nuclear. However, opponents find themselves in a bind: on the one hand they want to ensure safe handling of used fuel – on ethical grounds but on the other, they want others to realize that no matter how safely wastes are managed, the risks are unacceptable – also on ethical grounds. The overall result is a "Paradox" in which no one convinces the other. However, the pressure that results does eventually lead to a "safe" management approach that for many decades functions effectively. Unfortunately in time, long decades of nuclear safety give rise to complacency (precisely because the safety record has been so exemplary) that turns success to failure.

The 500 Year End-points and 10,000 Year What-ifs

When the team extended its perspective from the 25-year and 175-year scenarios out to 500 and 10,000 years, the value of the exercise was qualitatively, not just quantitatively, different. The idea of building discrete scenarios, each with a narrative line extending from beginning, through middle, to end, gave way to a less structured but equally rich way of envisioning conditions.

For the 500 year time horizon, a set of 16 "end-points" were developed, each a single paragraph that addresses what if:

- ➔ Ecological collapse occurs?
- ➔ Oceans cover 70% of the earth's surface?
- ➔ Technology solves the energy problem?
- ➔ Rapid climate change occurs?
- ➔ Human population collapses?
- ➔ The human species evolves in a post-human world?
- ➔ Society declines to tribalism?
- ➔ Space is colonized?
- ➔ A second reformation leads to a new social order?
- ➔ Values shift away from materialism towards nature?
- ➔ Human life expectancy increases greatly?
- ➔ A new economic order evolves based on natural capitalism?
- ➔ New scientific breakthroughs bring new capacity to manage complex systems?
- ➔ New totalitarianism takes hold?
- ➔ A new dark ages fall upon the earth?
- ➔ Things just carry on as they are?

At 10,000 years, the degree of uncertainty is huge. For this time horizon, the team brainstormed a long list of simple "what-if" phrases that further stretched the kind of thinking reflected above. Some of these are optimistic, some pessimistic, and some didn't fit into any logic. Examples include:

What if:

- ➔ Humans develop a higher mind capability; telepathic forms of communication become a reality?
- ➔ Humans become physically and spiritually integrated with the earth's ecosystem – our understanding of ecological "thresholds" leads to a revolution in our sense of the Earth's systems; the relationships between species changes profoundly . . .?
- ➔ Science, religion, and the arts all unite in a single synthesis of knowledge?
- ➔ Global population is managed by global governance?
- ➔ Social isolation becomes the norm?
- ➔ We return to a hunter-gather mode?
- ➔ Some natural catastrophe occurs: major asteroid? major earthquakes, volcanoes, tectonic shifts?; major sea-level rise?; reversal of the Earth's magnetic poles with massive disruption of hydrological cycles? stratospheric ozone layer thins dramatically, radiation protection is reduce, human immune system is compromised 50%? climate change makes 50 % more of the Earth's land uninhabitable? humans freeze in the dark because they lack sufficient energy?
- ➔ A change in surface conditions forces people underground and underwater?
- ➔ Bacteria win the war against antibiotics and infectious diseases go rampant?
- ➔ All knowledge of history is destroyed?
- ➔ Human minds deteriorate from pesticides and malnutrition and lose the capacity to solve problems?
- ➔ Gender differentiation is eliminated? drastic changes in human mode of reproduction occur? the human reproductive cycle extends to 80+ years?
- ➔ Life goes "virtual" – no physicality?
- ➔ Melting of the Antarctic ice cap reveals a previous advanced civilization on Earth?

8. Design-Implications – Future Conditions to Consider

Through its work, the Scenario team was able to articulate some 65 questions to pose of the management strategy to test its capacity to address the kinds of conditions that emerged as possible in the future. These questions grouped easily into six categories: (1) environmental implications; (2) security risks; (3) financial implications; (4) public participation in decision-making; (5) the management process; (6) relationship to the future of nuclear energy/waste production.

Alternatively, these questions can be combined with a review of the scenarios themselves, to facilitate the identification of conditions which may have to be faced by the used nuclear fuel management strategy in the years ahead. For example, do we design for the full collapse of societal institutions, or do we design for continuity of societal institutions and their ability to monitor and manage the used nuclear fuel strategy? Table 3 below summarizes these conditions.

Table 3. Potential future conditions to be factored into the design of the Management Strategy.

1. **The nature of Society – variations in:**
   - ➔ the stability of society and the institutions of governance (from more to less to collapse).
   - ➔ capacity to transfer knowledge over the very long term (from much to little)
   - ➔ capacity to ensure needed human resource capacity (from much to little)
   - ➔ capacity to ensure needed financial surety (from much to little) under a range of societal conditions ranging from stability to loss of stability in societal institutions; from healthy economies to economic recession and massive government deficits
   - ➔ population growth – from significant growth to significant reduction to total annihilation
   - ➔ population migration due to changing global conditions, particularly from current urban centres to areas that are currently rural and remote
   - ➔ population health varying from healthy to collapse
   - ➔ scientific and technological capacity from great enhancement (for example in discovering ways of re-using, reprocessing or transmuting the used fuel) to a collapse in capacity and a loss of knowledge
   - ➔ the degree of terrorism
   - ➔ expectation and/or culture of direct citizen participation in the management strategy from much to little;
   - ➔ Ability to address the development of false confidence and complacency
   - ➔ Ability to ensure financial surety

2. **Environmental Conditions – variations in:**
   - ➔ Gradual environmental change including climate change and associated changes in bio-physical conditions in particular, rise in sea levels; glaciation
   - ➔ extreme natural events including storms, wind, precipitation; volcanic and tectonic activity

3. **The Future of Nuclear – variations in:**
   - ➔ public attitudes towards nuclear power and nuclear waste management – could be a shift to greater support for, to a push to completely phase out nuclear
   - ➔ Evolving use of nuclear as an energy source ranging from status quo to large increase to phase out

4. **The Management Strategy Itself:**
   - ➔ Capacity for expansion should the volume of used fuel increase
   - ➔ Capacity to address both expected and unexpected deterioration in containment
   - ➔ Capacity to retrieve fuel
   - ➔ Contingency to address extreme natural events
   - ➔ Capacity to protect non-human life in the absence of human society
   - ➔ Ability to handle variations in the need to transport the used fuel: could be from many distributed sources or just a few depending how technology and the needs of society evolve
   - ➔ Capacity for dispute management

9. Sensitivity Analysis for the Multi-Attribute Utility Analysis

Following development of a multi-attribute utility analysis assessment methodology, the NWMO Assessment Team undertook a preliminary comparative analysis of the three technical methods specified in the Nuclear Fuel Waste Act: Deep Geological Repository (DGR), Centralized Extended Storage (CES) and Reactor-site Extended Storage (RES) (NWMO Assessment Team, 2004). As part of this work, a sensitivity analysis was undertaken using three of the 175-year scenarios drawn from the work of the NWMO Scenarios Team. This analysis is fully reported in Appendix 5 of the Assessment Team Report. The Test Scenarios are described below.

Test Scenario 1 (Based on 175-year Scenario 3, "Tea with the Wise")

Test Scenario 1 is an optimistic scenario. Key characteristics include: respect for institutions is high and they remain strong in perpetuity; climate change occurs but is at the minimal end of projections; a shift away from consumerism; reduction in tension and attendant terrorism; a doubling of the typical human lifespan through biotech and medical advances; significant population increase leading to careful control of birthing; increased conservation coupled with reduced energy demand; the use of alternative energy technologies increases while the use of nuclear ends with the current facilities running to the end of their design life; the used fuel issue becomes an old legacy problem – there has been no "technical fix" discovered and the need for vigilance remains; a "nuclear priesthood" is established to maintain watch.

In the analysis, Test Scenario 1 was split into two sub-scenarios differentiated as follows:

<u>Test Scenario 1A</u> This Scenario assumes that adequate funds are set aside in a stable instrument during the generation of the used nuclear fuel to ensure that all costs of managing that fuel are covered in perpetuity. This ensures that the "polluter pay" principle is adhered to for all three of the alternative management approaches.

<u>Test Scenario 1B</u> This Scenario assumes that funds are set aside during the generation of used nuclear fuel to the extent that requirements for covering the cost of deep geological disposal to facility closure are covered (thus the polluter pay principle is respected for this alternative) but that for the storage options, funds from future generations will eventually be required to cover the cost of repackaging and maintenance (thus the polluter pay principle is not respected for the two storage alternatives).

Test Scenario 2 (Based on 175-year Scenario 6, "Accident at Dusk")

Test Scenario 2 is more "pessimistic" than Scenario 1. Key characteristics include: nuclear has been abandoned because of a major nuclear disaster and total loss of public trust; political and social instability; greater dependence on fossil fuel with attendant environmental problems including extreme climate change, more severe than earlier predicted; drought in southern prairies, decrease in water levels in Great Lakes, drastic reduction in use of St. Lawrence Seaway; huge increases in food costs; mass migrations of people, population shrinks by 50 percent, many are driven to subsidence lifestyles; Canada as a nation is reduced to a shell of what it once was.

Test Scenario 3 (Based on 175-year Scenario 11, "Threat Before Midnight)

Test Scenario 3 is also "pessimistic." Key characteristics include: economies are strong; energy demand is high – nuclear dependency high; nuclear capacity and weapons proliferate; there is no technical solution to the challenge of used nuclear fuel, and even though used nuclear fuel remains safe, security remains a major concern; the threat of nuclear war is very real but doesn't occur; life is risky and society teeters; technology for those who have it allows the massing of wealth but the gap between rich and poor widens, social instability results, totalitarian rule is imposed while personal freedoms are reduced; technology also supports terrorism with disastrous results; climate change occurs but is not extreme.

The three scenarios were chosen for the sensitivity analysis as a way to provide a range of the kinds of conditions listed above in Table 3. For each of the scenarios considered an assessment of the three options being considered was undertaken using the multi-attribute utility analysis and the results compared with the original assessment undertaken by the Assessment Team.

The sensitivity analysis led to the following conclusions:

1. For the two pessimistic scenarios (either scenarios 2 or 3), the Deep Geological Repository (DGR) scores significantly better than Centralized Extended Storage (CES) and Reactor-site Extended Storage (RES) (the spread is clearly evident). RES scores the worst.
2. For the optimistic futures 1-A and 1-B, all three management approaches score similarly – so closely that minor variations in scoring, well within the bounds of uncertainty, could push any one of the three to the best performing position. When the economic viability and fairness aspects are improved to ensure the polluter-pays principle is maintained in perpetuity (Scenario 1A), there is a slight preference for the on-site storage option.
3. In assessing the significance of future conditions for each alternative management approach:
   - ➔ The scoring of the relative performance of DGR appears to be less dependent on the vision of future conditions than the two storage alternatives.
   - ➔ The scoring of the centralized storage option is heavily dependent on the future – its relative performance differs significantly between the two optimistic scenarios and the two more challenging futures.
   - ➔ The on-site storage option is the most influenced by assumptions made about future conditions.

In summary, two overall conclusions arise. First, it is clear from this analysis that assumptions made about future conditions heavily influence how any given alternative management approach will score as well as the relative positioning of the three alternatives assessed. However, second, DGR generally performs more strongly than the storage alternatives and its lack of dependency on future scenarios implies a degree of robustness not shared by the others.

This analysis served to re-enforce the overall conclusions arrived at by the Assessment Team.

However, in addition, it brought to light sets of conditions which would result in more favorable scoring for the Centralized and Reactor-site storage options. These conditions include:

1. Strong, stable, respected, and vigilant institutions must remain in place in perpetuity.
2. Climate change must be limited to the very low end of what is now projected.

3. The polluter pay principle must be entrenched in a way that provides for an indefinite stream of resources to cover costs of the storage options in perpetuity such that those receiving the benefit from generation of the used nuclear fuel would truly shoulder the burden of providing the resources for its management over the long term.

Turned around, if there is little comfort in assuming the above three sets of conditions, the deep geological option assumes a relatively more favourable position amongst the three alternatives being compared.

10. Insights from the Scenarios Team

The work of the NWMO Scenarios Team served to bring to light a number of important insights.

1. Application of the Scenarios Technique to the Issue of Long-term Management of Used Nuclear Fuel. The formal scenarios technique has never before been applied to an issue bounded by such a long time-horizon. The Scenarios Team discovered that the formalized process worked fine for a 25-year time horizon, was workable (just) for the 175-year time horizon, but beyond that, the exercise quantitatively and qualitatively changed. The idea of building discrete scenarios, each with a narrative line extending from beginning, through middle, to end, gave way to a less structured but equally rich way of envisioning conditions. It was as if we had reached and passed a limit for applying the formal scenarios technique. Perhaps this is not surprising given the rate of change is increasing over time at an exponential rate. A rule of thumb used by some is that to obtain a sense of the degree of change that we will experience in the next 10 years, look back 100.

2. Preliminary Testing of the Management Approaches. In a final exercise, the Scenarios Team ran the three technical methods prescribed by the Nuclear Fuel Waste Act through the scenarios. The following observations arose:

a. **First, it is essential to focus as much on the management systems and the integrity and openness of ongoing decision-making processes as it is on a debate about the alternative technical methods.** Only by doing so will Canadians be able to develop the trust that is needed for the management approach to be successful.

b. **Second, institutional supports, regulatory mechanisms, and mechanisms to achieve financial surety are a critical part of any proposed solution.** While there has been much debate about the alternative forms of physical containment, Parliament is a legislature first and foremost. Its product is laws. The generic institutions that we have in place are likely to be insufficient to provide an adequately robust legal framework for the long-term management of used nuclear fuel. In now moving forward, a key application of these scenarios is to test the current and potential regulatory regimes to identify issues and better understand strengths and limitations. In other words, the “software” of the management strategy is as important as the “hardware.”

c. **Third, a scenarios exercise such as this one provides a broad and safe tent under which widely different perspectives can gain a fair and respectful hearing.** Because the management of nuclear wastes is not just a technical problem, but a social and political and ethical problem, it is crucial for Canada to face the problem by employing a transparent and inclusive process like this exercise.

3. Additional Thoughts. In the course of this final exercise, some additional thoughts arose that are important to report.

a. **Need for Initial Reactor-site Storage.** There was little disagreement, if any, with the current practice of storing used nuclear fuel on site until the main heat-generation and initial radioactivity-reduction phase has passed. (Thus all 25 year scenarios accept on-site storage as logical. Some of the older wastes, now 45 years old, will soon be ready for more permanent placement, if that is desired, but this takes us beyond 25 years.)

b. **Reactor-site Storage over the Long-term.** Discussion of on-site storage led to a sense for some that while the idea of this method may look like a default do-nothing option, it is neither as dangerous as some might fear, nor as permanently viable as others might hope.

c. **Centralized Extended Storage.** No major technical or managerial advantage was identified associated with centralized storage.

d. **Retrievability.** The idea of ensuring retrievability of the used fuel for the foreseeable future was championed by many in the group. However, the idea that the design of any facility should include a mechanism to quickly and relatively easily transform the condition to a state of permanent disposal (for example faced with the threat of terrorism or social collapse) also enjoyed support.

e. **Terrorism.** Discussion of the implications of terrorism – obviously much heightened since the attack on the World Trade Centre – led to a sense expressed by some that the only safe way to guard against the range of possible threats to surface storage would be to opt for a very deep form of repository.

f. **Deep Geological Repository and Risk**. More generally, for 175 years and beyond, deep geological emplacement reduced certain risks arising from the conditions described in many of the scenarios more effectively than extended surface storage. However, a rigorous comparative analysis was not completed.

g. **A Combined Approach May be Best.** A number of participants expressed the view that some period of on-site storage followed by placement in a deep repository seemed to be the best combination of approaches.

h. **Bounding Fuel Production.** In some participants' eyes, a willingness to support any management approach is closely tied to whether or not the volume of used fuel issue is bounded either by a commitment to end the production of further used nuclear fuel, or by some other means. This issue remains to be examined in detail.

i. **The Concept of a Rolling 'Seven Generations" Responsibility.** The question of how far into the future the responsibility of the current generation should extend was raised a number of times. Considerable support was voiced for the idea of a "rolling" seven-generation perspective. That is, each generation should design within a seven generation time frame. Succeeding generations would thus have six generations to learn from and if necessary adjust the decisions made by this one.

11. Retrospective

The scenarios exercise was completed in the fall of 2003, early in NWMO's study leading to its report to government in November, 2005. Now, with a significant more amount of work completed, it is possible to look back and evaluate the role of the scenarios work within the broader set of activities that have been initiated by NWMO. Five overarching observations come to mind.

First, the exercise was surprisingly powerful and accurate in signalling the key issues and in fact, the ultimate course of action that has emerged. That it was able to do so is likely a reflection of both the rigour of the technique and the breadth and depth of the Scenario Team's make-up.

Second, although serving as an effective signaller of things to come, on its own, the exercise did not provide the degree of detailed analytic support (technical and social) that is required to serve as the foundation for the NWMO's recommendation to government. However, combined with the subsequent work of the NWMO, in particular the broad range of engagement activities, multi-attribute utility analysis work of the Assessment Team and the subsequent more traditional cost-benefit-risk analysis, the result is very powerful.

Third, Canadians have made it very clear since the 1977 Hare Report (Aikin et al., 1977) that the implications of today's actions for tomorrow's world must play a significant role in determining the course of action to be taken in this country. There will always be more unknown than known about the future. There is little point in trying to predict that future. However, there is every need to try and foresee the range of potential futures – to prepare for the worst while hoping for the best. It is this capacity for preparation that is provided by the formal scenarios methodology. There is no alternative. It is both an essential response to the concerns of Canadians as well as good engineering practice.

Fourth, in considering the ranges of future conditions that arose – were there any moments of "ah-hah!"? The answer lies in a review of Table 3. The long time horizon that governs this issue means that we have to think beyond today's conditions. As a society, we are not well-trained in this arena. Political decision-making is tied to the election cycle, much financial decision-making is quarterly, and personal decision-making is often shorter in scope. Some industrial activities – forestry is an example – reach out 70 to 100 years in their planning process. And yet, for the issue of managing used nuclear fuel, we are having to push thinking out well beyond, to when the current distribution of population, population health, environmental conditions, the very nature of human society is different than today's, perhaps dramatically so. The insight that is strongly re-enforced through all of this – the "ah-hah!" – is not the recognition of a single factor of change, but rather it is a re-enforcement of the idea that the critical need in any management strategy is to entrench a capacity to learn continuously, accept the inevitability of surprises, and to entrench a capacity to adapt to change.

This perspective is consistent with a change in systems thinking that has occurred over the past several decades. This change has seen an evolution in focus from the idea of optimizing a system with crisply defined objectives to an approach based on articulating and implementing systemic learning related to an issue that may well have poorly-defined and/or changing objectives, a variety of possible pathways for achieving them, and a world of evolving values. In other words, the focus of “systemicity is shifted from the world to the process of inquiry into the world” (Checkland and Scholes, 1990 p. 277).

Lastly, formal scenarios work calls on a special mix of skills. It is a mix that bridges the disciplinary camps so entrenched in our society. On the one hand, a well-founded understanding of the science and technology of nuclear waste is essential. On the other hand, the approach of scenarios work is through narrative, synthesis and an integrating sort of wisdom. This is the stuff of the humanities, not the hard sciences. As one set of authors has put it:

> *(Though subjectivity) . . . is never a problem for those whose inclinations are towards arts and humanities, it can be difficult for numerate scientists and engineers whose training has not always prepared them well for the mixed drama, tragedy and farce of the social process.*
>
> Checkland and Scholes, 1990, p. 31

Not surprisingly, reaction to the stories that comprise the scenarios is mixed. The business of nuclear waste is a serious, highly technical business and what role do fanciful stories have to play in such a serious business? The point is the scenarios technique described here pushes thinking out of the box. To find the innovative ways of addressing this challenge, that is exactly what is needed.

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