nwmo
NUCLEAR WASTE MANAGEMENT ORGANIZATION
SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

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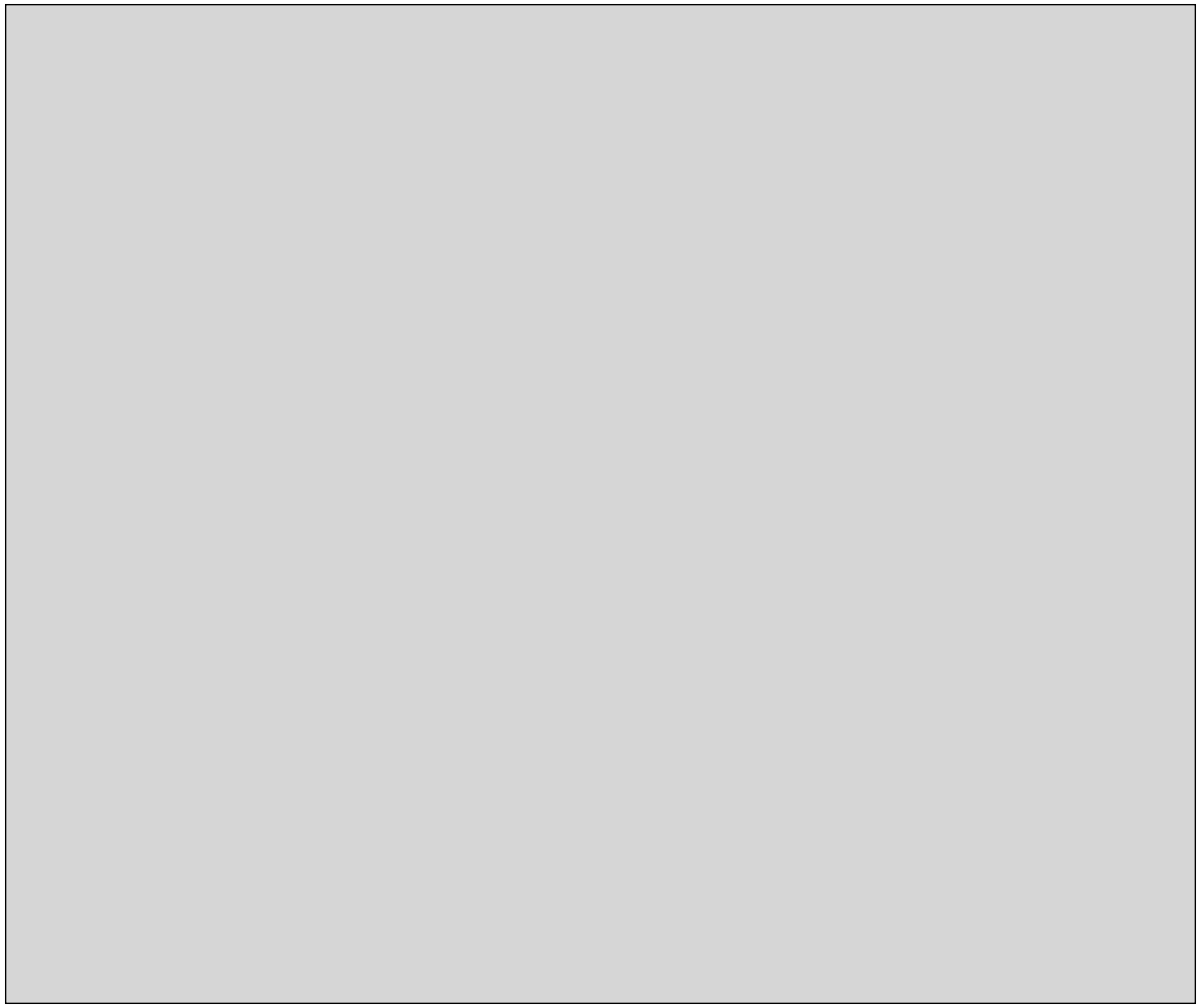
NWMO BACKGROUND PAPERS
1. GUIDING CONCEPTS

1-3 ADAPTIVE MANAGEMENT IN THE CANADIAN NUCLEAR WASTE PROGRAM

Kai N. Lee
Williams College



NWMO Background Papers

NWMO has commissioned a series of background papers which present concepts and contextual information about the state of our knowledge on important topics related to the management of radioactive waste. The intent of these background papers is to provide input to defining possible approaches for the long-term management of used nuclear fuel and to contribute to an informed dialogue with the public and other stakeholders. The papers currently available are posted on NWMO's web site. Additional papers may be commissioned.

The topics of the background papers can be classified under the following broad headings:

1. **Guiding Concepts** – describe key concepts which can help guide an informed dialogue with the public and other stakeholders on the topic of radioactive waste management. They include perspectives on risk, security, the precautionary approach, adaptive management, traditional knowledge and sustainable development.
2. **Social and Ethical Dimensions** - provide perspectives on the social and ethical dimensions of radioactive waste management. They include background papers prepared for roundtable discussions.
3. **Health and Safety** – provide information on the status of relevant research, technologies, standards and procedures to reduce radiation and security risk associated with radioactive waste management.
4. **Science and Environment** – provide information on the current status of relevant research on ecosystem processes and environmental management issues. They include descriptions of the current efforts, as well as the status of research into our understanding of the biosphere and geosphere.
5. **Economic Factors** - provide insight into the economic factors and financial requirements for the long-term management of used nuclear fuel.
6. **Technical Methods** - provide general descriptions of the three methods for the long-term management of used nuclear fuel as defined in the NFWA, as well as other possible methods and related system requirements.
7. **Institutions and Governance** - outline the current relevant legal, administrative and institutional requirements that may be applicable to the long-term management of spent nuclear fuel in Canada, including legislation, regulations, guidelines, protocols, directives, policies and procedures of various jurisdictions.

Adaptive Management in the Canadian Nuclear Waste Program

Kai N. Lee
Center for Environmental Studies, Williams College, Williamstown MA 01267 USA
e-mail: Kai.N.Lee@williams.edu — *comments welcome*

***Adaptive* management is the process of conceiving and carrying out a program as an experiment, so that learning from experience becomes an explicit objective. An adaptive approach to nuclear waste management may enable NWMO to build and sustain public trust while accelerating technical progress.**

Introduction

The Nuclear Waste Management Organization (NWMO) faces a striking challenge: to gain and keep the trust of the Canadian people while making choices that will affect the nation's inventory of nuclear waste and possibly the future of nuclear energy. These demanding goals must be pursued in a situation in which scientific knowledge is necessarily limited.

While no one can say with assurance whether the dual objective of gaining trust and managing nuclear waste can be achieved in Canada, a transparent and open-minded approach to the social and technical hurdles seems both prudent politically and wise from a scientific perspective. Much is already known about the properties and long-term isolation of radioactive and hazardous wastes, although some uncertainties remain. Science faces unknowns squarely: that is one way of defining the scientific enterprise. Recognition that knowledge is both limited and substantial forms the foundation for a discussion of how a society should fulfill its responsibilities for highly toxic materials that have already been produced. And this discussion, in turn, would naturally turn to the controversial and difficult choice of whether to continue generating such materials to meet social goals.

How might a transparent and open-minded process of social choice be constructed? If people are to accept choices, they need to have confidence in the way those choices are made. That confidence is the cornerstone of legitimacy, the willingness of a people to accept the decisions of its government. Legitimacy is the foundation of democratic rule: a government chosen by the electorate can make hard choices in the knowledge that the voters have given a genuine but limited mandate. Because of the uncertainties that worry anyone who has heard of nuclear waste, it is appropriate to build the NWMO's decision-making process in a way that can strengthen the legitimacy of the choices made.

Adaptive management is such an approach. *Adaptive* management means implementing policies recognizing that they are necessarily experimental. This paper provides a brief introduction to this concept and how it might be used in the learning that the Nuclear Fuel Waste Act (NFWA) was designed to foster. Adaptive management calls for NWMO to put before the government and people of Canada a *safety case* from time to time, explaining how NWMO believes its plans would assure safe management of nuclear wastes, and describing the uncertainties in that assessment. The safety case provides an opportunity to criticize and to reaffirm the course on which NWMO is proceeding. Affirmation of a safety case that has been revised in light of public debate strengthens and sustains the legitimacy of the waste management program. Adaptive management focused on a safety case may therefore provide a useful framework for NWMO.

Adaptive management and social learning

Adaptive management treats policies as experiments, recognizing that unanticipated outcomes are inevitable and that they present opportunities for learning. This unusual perspective on policy can be seen in the way that civilian aircraft are equipped with flight recorders, so that if the plane crashes — fortunately, a rare event — the recorders can provide insight into what happened. The detailed study of air crashes has led to the rapid improvement of air safety, largely eliminating accidents that have been diagnosed. This does not make air travel completely safe, of course, but the assurance that errors are swiftly found and preventive action taken has changed commerce and social experience within a few decades.

A systematic approach to policy choices that expects unexpected developments and learns from them is adaptive management. The term was invented by the Canadian ecologist C.S. Holling in 1978. It has been used in some natural resource policies, which can be thought of as experiments conducted in ecosystems. Because ecosystems are complex and fluctuate due to external changes such as drought or invasion of pests, surprising behavior is frequent and often beyond the control of human managers. The concept of adaptive management was advanced as a way to improve understanding of valued ecosystems over time. The idea that program managers cannot forestall or predict all surprises is not limited to natural resource policies, of course. Unanticipated developments are unavoidable, particularly when facing novel engineering challenges such as isolating radioactive waste from the environment. Yet there is considerable knowledge of engineering and human behavior that can be used to address problems, particularly when surprises are expected and when preparations have been made to learn from them. This is what is meant by thinking of policy implementation as an experiment — to set up instruments to detect and to study surprises. Paradoxically, it is by expecting that the unexpected will happen that it becomes possible to gain knowledge from surprises and to limit their unwelcome effects.

Adaptive management contributes as well to *social* learning — the often messy and confusing process by which societies embrace knowledge, turning emergent understandings into cultural shifts, institutional arrangements and policies, and creating new technological and social capabilities. Societies learn to do things differently over time; this is social learning. An example of social learning is the gradual adoption of macroeconomic policies in the world's parliamentary democracies. In the decades following the Great Depression of the 1930s, economists debated theories and politicians reacted to recessions and times of prosperity. Through trial and error, better data-gathering and improved theories, a consensus gradually emerged among stakeholders, politicians, academic analysts, and the wider public on how government spending, interest rates, and better analysis could stabilize the economies of industrial societies. By the turn of the 21st century, the members of the European Union had adopted common limitations on their budget deficits, a remarkable voluntary constraint on the decision-making powers of sovereign nations. This is a reflection of social learning in economic management, with wide-ranging and notable changes in the gathering of economic statistics, journalism, and political competition, as well as in levels of unemployment and inflation. Note that the growing understanding of economic management took place through political conflict, with elections often decided because one side successfully criticized the economic record of its opponents. This aspect of social learning — the inevitable but indispensable role of conflict — is discussed further below.

Adaptive management accelerates social learning deliberately by making use of the practices of laboratory science. In a laboratory, scientists pursue the unexpected by formulating hypotheses. Hypotheses are expectations of how a population will respond to the experimenter's manipulations — whether the experimental population is comprised of electrons or people suffering from an illness or trees in a rain forest. When expectations

are confirmed, the theory from which a hypothesis is drawn is supported. More interesting is the situation in which a hypothesis is disconfirmed; this is a signpost to new knowledge.

This is surprise that is welcome. In testing hypotheses, scientists seek to control the conditions of their test populations, isolating the behavior to be studied in a test tube or experimental chamber. Then they search for the unexpected, varying experimental conditions, measuring with care, and repeating experiments to confirm their ripening understanding of what happens. Policy choices cannot be put in a test tube, but the idea of controlling conditions can nonetheless be useful, as is the idea of replicating experiments to confirm one's understanding of the processes at work. Implementing policies as experiments is adaptive management.

Adaptive management is uncommon. Most choices are made ignoring the possibility of unanticipated results and with no attention to collecting information about what happens. In trial and error learning, there is awareness that unexpected outcomes may develop. Flight recorders on airplanes reflect that awareness. Adaptive management goes beyond trial and error learning in one important respect: the adaptive manager identifies hypotheses being tested and sets out to measure them against experience.

In a complicated situation, like a scheme for storing used nuclear fuel, it to specify expectations in a systematic fashion. The hypotheses being tested are organized into a conceptual model that articulates the current understanding: how toxic materials interact with the technological and social systems meant to isolate them from humans and the environment. Then monitoring is designed to probe the actual behavior of the isolation mechanisms. The idea is to look for surprises: ways in which the assumptions that go into a management system are shown to be incorrect in light of experience. Thus, adaptive management is a kind of organized skepticism. It is an attempt to put managers' beliefs on the line, so that mistaken beliefs can be flushed out and modified. Small surprises lead to better understanding, and this better understanding improves the likelihood that catastrophic failures can be prevented. Over time, confidence in the nuclear waste management system should then increase, even if there are unanticipated outcomes. The conceptual model, explained in terms accessible to the lay person, is the centerpiece of the safety case: a periodic public discussion of how safe management and isolation of nuclear wastes is being pursued.

How these ideas might apply to used nuclear fuel in Canada

Although the management of used nuclear fuel is now being done in a conservatively designed fashion, there are bound to be surprises in the future, even if used fuel is simply left at its current locations. Reactors will come to the end of their useful lives, raising the question of whether their fuel inventories should be moved. Fuel elements will fail and need to be repackaged. Cooling systems may fail in unexpected ways. Even if used fuel is to be moved to a deep geologic repository, that choice is likely to be made against a background in which no nation will have yet completed a repository. Accordingly, much will remain to be learned along that path to handling long-lived radioactive wastes. And centralized storage of used fuel is tailored to the specific characteristics of the materials to be stored; here too much will likely be learned in the course of building and using a central storage facility.

The uncertainties in each of these alternatives (or others) seem likely to produce surprises, some of which may undermine public confidence. As NWMO has found in its initial research, the Canadian public understands little about used nuclear fuel and expresses little concern about it, so long as it is far away from them. That is a situation in which crisis and surprise may have a large and abrupt impact on public perceptions and support for any program. Because surprises are probably unavoidable, it is important to be candid about their likely occurrence. Adaptive management provides a means to do so.

An experimental approach to the long-term management of used nuclear fuel cannot provide the thorough assurance of learning that is found in the flight-data recorder in an airplane. Some of the hazards in used nuclear fuel endure for very long times. The half-life of plutonium, a highly toxic element created as a byproduct of nuclear fission, is 24,000 years. That means that the risk to human health, if plutonium were released, will be substantial for hundreds of thousands of years. This is far longer than the span of human history thus far. In that respect, no direct experimental verification of safe containment is possible. By contrast, each airline trip provides a concrete test of the airplane and air-traffic safety system.

That there are limitations on direct tests of safety does not mean that nothing can be learned from adaptive management, of course. The near-term predictions of engineering design and assessments of performance have improved the technical and organizational understanding of designers and managers in the consideration of geologic repositories in a dozen countries. Much more can be learned by using the waste management program as a test-bed for experimentation and innovation. Moreover, every means of managing nuclear waste faces the open-ended problem of dealing with very long-lived risks. It is surely unwise to keep highly radioactive used nuclear fuel at power reactor sites for hundreds of thousands of years, if only because reactors have been located near rivers and lakes to provide convenient access to cooling water. Those bodies of water would disperse leaking materials widely into the environment, exposing human populations and ecosystems to radioactivity and hazardous chemicals. So the long-term problem of dealing with these risks entails learning what to do, and that includes studying alternatives to what is now being done. Adaptive management is a framework for that learning.

It is also important to bear in mind, however, that any scientific approach like adaptive management will be complicated and hard to explain to a disengaged public. That means that surprises erupting in the mass media may not be much less disruptive for having emerged from an orderly process of learning. If journalists are aware that the management program is designed to promote organized skepticism, however, they may regard particular surprises as signs of learning rather than incompetence.

At this early point in the NWMO program, the application of adaptive management would be conceptual: to admit uncertainty and to explore whether the social conditions for learning from experience can be built and sustained through the decades ahead. Some ideas on how the ideas of adaptive management might be put to use can be drawn from a recent study by the National Academies of Science (NAS) in the United States.

The safety case

In a report entitled *One Step at a Time*, a committee of the NAS chaired by the Scottish-Swiss physicist Charles McCombie considered the idea of adaptive staging. This means that the development of a geologic repository would be done in stages, each of which is designed so that it can be reversed or redirected if information collected and analyzed during that stage suggests that the program is on the wrong path. The analysis is applicable to NWMO, even though in Canada no decision has been taken to proceed with a geologic repository. In the language of the NAS study, NWMO is at the very first stage, in which a commitment to a long-term approach is being considered but has not been made, except in the sense that an inventory of used nuclear fuel already exists.

The McCombie report argued that a geologic repository is a first-of-a-kind, complex undertaking, in which it would be inadvisable to commit at the outset to a fixed plan of engineering development. That diagnosis draws in part upon the Canadian decision to back away from a geologic repository and to re-frame choices within the NWMO. As the McCombie committee recognized, public trust is an essential element of a durable approach to waste management: "If stakeholders recognize their right to provide input to program

decisions, they may be more likely to acknowledge the benefits of Adaptive Staging, may develop greater trust in the implementer and the process, and they may acquire more confidence in the safety of the repository." (p. 5) In addition, the nuclear waste system is evidently complex and contains unprecedented challenges; in that respect the idea of adaptive staging is aligned with the charter of NWMO.

At the heart of adaptive staging is a series of explicit decisions to move forward with the project. At each of these decision points information is gathered into a safety case, a statement that explains the basis for believing that the project would result in safe management of the long-lived wastes. The safety case is a coherent articulation of the hypotheses being tested by adaptive management: a statement intended to be read by a lay audience, that spells out the assumptions on which the expected performance of the program rests, as well as the uncertainties in and limitations on current understanding.

By articulating the safety case, the project implementer sets out a basis for choosing the next stage of the project. The idea of adaptive staging is to make clear that flexibility and reversibility are important values in the program. Each option for proceeding would be evaluated against the safety case, and at least one option would reverse course, moving the program back to an earlier stage for further study or to address deficiencies that have come to light. The existence of multiple credible options is a concrete sign that the project implementer expects the safety case to be challenged and revised in a public arena where social acceptance and credibility will be weighed. Not all surprises would lead to reversal, of course, since many unexpected developments are either benign or easily remedied by well-known means. Yet the periodic public review of the safety case assures that deficiencies are identified and addressed, not only by the project implementer but in a publicly accountable fashion. Decisions reached in this way can be both technically credible and accepted by stakeholders and the wider public. The latter is the societal acceptance described by the Seaborn Panel as lacking in the Canadian program in 1998.

The idea of adaptive staging, with its multiple options at each stage of program development, suggests that the three options specified in NFWA may complement one another, rather than being mutually exclusive alternatives. In an adaptive approach, a decision to leave used nuclear fuel at the reactor sites would, be regularly reviewed against a safety case that examines this management regime against other options, including both central storage and a geologic repository. If a decision were made to embark on centralized storage, it too would be regularly reviewed as the storage facility is sited, built, and loaded. At each stage, the option to go backward would be available. The same logic would apply to a geologic repository, although that implementation process would be likely to take decades, rather than the time period of perhaps a decade needed to develop a central storage facility so that it would be ready to accept used nuclear fuel.

Social conditions for learning over long times

Adaptive management would make sense if public policy were only a matter of handling scientific uncertainty. But of course, nuclear waste management is not a matter of science alone. It is an arena caught up in conflict: conflict between host communities and the larger society that has benefited from nuclear technology, between supporters and opponents of nuclear power, between environmentalists and proponents of economic growth. Even though adaptive management may provide the most efficient way to strengthen the *scientific* basis for managing wastes, one must ask whether the *social* basis for an adaptive approach can be built and sustained. At the current state of understanding, one cannot give a confident answer to this question. Political judgment and gumption are needed along the way, as is skill in marshalling and sustaining public support.

The essential problem is simply explained. Adaptive management requires the identification and testing of hypotheses. From a political perspective this means that those making

decisions must first admit that they are unsure what will result from their choices, and then proceed to test their choices against experience in a transparent and rigorous process. Neither comes naturally to people or bureaucracies. As a result, those who see the value of adaptive management face challenges, as summarized in the table below.

Institutional conditions and challenges affecting adaptive management

There is a mandate to take action, despite significant uncertainties.

> *But learning is typically a secondary objective. Experimentation that conflicts with primary objectives (such as expanding nuclear power or demonstrating environmental prudence to voters) will often be pushed aside or not be proposed.*

Decision makers are aware that they are experimenting anyway.

> *But specifying hypotheses to be tested raises the risk of perceived failure.*

Decision makers care about improving outcomes over the decades in which a program will be developed and implemented.

> *But the costs of transparency and adaptive staging are substantial. Individual decision makers will stay in office for times much shorter than the duration of the program, so they may reap few benefits from long-term studies and monitoring.*

Deciding not to have used nuclear fuel is not an option, and yet technology and institutions cannot assure complete safety and isolation over the millennia ahead.

> *And management actions cross jurisdictional boundaries and require coordinated implementation over long periods. Permanent disposition in a geologic repository, in particular, is bound to raise concerns among indigenous peoples and to require consideration of environmental ethics.*

Resources are sufficient to monitor technical performance and to provide transparency.

> *But data collection is vulnerable to external disruptions, such as budget cutbacks, changes in policy, and controversy. After changes in the leadership, decision makers may no longer be familiar with the purposes and value of an experimental and transparent approach.*

Theory, models, and field methods are available to estimate and infer the long-term behavior of engineered barriers, institutions, and ecosystems disturbed by the waste management operations or a repository.

> *But interim results may create panic or a realization that the experimental design or initial safety case were faulty. More generally, experimental findings will suggest changes in policy, including controversial changes that have the potential to disrupt a process that takes learning seriously.*

Hypotheses can be formulated.

> *And accumulating knowledge may shift perceptions of what is worth examining via adaptive staging. For this reason, both policy actors and technical staff must adjust the tradeoffs among experimentation and other policy objectives during the implementation process.*

Organizational culture encourages learning from experience.

> *But the advocates of adaptive management are likely to be staff, who have professional incentives to grasp the logic of a complex process and a career situation in which long-term learning can be beneficial. Where there*

is tension between staff and policy leadership, experimentation can become the focus of an internal struggle for control.

There is sufficient stability to measure long-run outcomes; institutional patience is essential.

But stability is usually dependent on factors outside the control of experimenters and managers, notably stable funding, public trust and political support.

A theme that runs through all these challenges is the need to recognize and to reconcile conflicting aims, priorities, and values.

Conflict, trust, and social learning

The burdens and benefits of nuclear energy are distributed unevenly, and the human and natural systems bearing the burden are not the same as those that receive the benefits. Future generations and possibly the natural environment will face risks and experience changes from waste management, even after the electricity produced from existing nuclear plants has been consumed. Wastes are localized but the benefits of electricity are shared among provincial and national populations. Although the attention paid to safe management of wastes is high by comparison with other industrial sectors such as mining, many people highlight the risks, a burden that technology and institutional arrangements cannot wholly remove.

All these factors stimulate conflict. The conflicts are played out within and influence provincial and national political choices and public policies, the relations among ministries and corporations, the activism of non-governmental groups, and the life of bands, settlements, and individuals. While there is a concern for safe management that unites all the actors and institutions, there appears to be widespread lack of engagement and knowledge among the citizens of Canada. That lack of engagement is a reservoir of potential support, particularly for those who seek to link nuclear waste management to broader social issues such as economic development, environmental protection, or indigenous rights. Conflict over nuclear waste thus becomes an element of the larger drama of self-government.

Any waste management program must take these conflicts seriously, responding to them prudently and with an understanding that, in a conflict, no single party can control events for long.

A critical resource for a program that needs the support of government and the public is trust. The history of nuclear energy in Canada and elsewhere has led to a cultural perception that radioactive materials are dangerous and have not been handled well. Trust has been impaired, not only for specific agencies and professions but for all who work on nuclear matters. This impairment is a condition that NWMO cannot erase and should not ignore.

Because safety is the central concern, public confidence is a prerequisite of trust. For the technical staff of NWMO, there is an important practical test that needs to be passed repeatedly: as informed lay observers ask about and watch the unfolding of the program, are they likely to gain confidence and to feel their trust is well-placed?

- when asked, do the program managers provide answers that are responsive and that stand up to further scrutiny?
- over time, are the commitments made fulfilled?
- do leaders seek to reward the recognition and correction of problems among their subordinates?

- does the program leadership act with integrity?

The test of confidence bridges technical and moral spheres.

Adaptive management, and the commitment to learning and correction that it organizes, can be a way to demonstrate willingness to recognize error and to act transparently. This is a significant reason for senior managers and politicians to tackle the challenges spelled out above. Then, as hypotheses are tested against experience and the safety case is revised, there will be an understanding among the media, government, and activists of why changing the safety case might be reasonable rather than nefarious.

Adaptive management does not forestall conflict. Indeed, learning requires conflict, because of the understandable reluctance of individuals and organizations to recognize their own errors and to undertake inconvenient changes. Successful people try to repeat their successes, and they are slow to acknowledge that approaches that have worked in the past are no longer appropriate to a new circumstance. Similarly, controlled studies show that experts tend to underestimate risks in areas where they are expert. Thus, learning from surprises becomes harder over time, as success breeds its own narrowness. One should accordingly expect internal resistance to acknowledging omissions in the safety case, especially if surprising information comes from outside the NWMO program.

Yet conflict that is constructive remains bounded: change should come without destroying the social capacity to pursue the underlying goal of safe management of the existing inventory of used nuclear fuel, both in the short and long run. There is, however, no bright line separating destructive from useful conflict, because the resilience of people and organizations is difficult to estimate accurately. Moreover, as conflicts escalate, short-term tactical advantage typically overshadows the larger aims of the disputing parties.

Conflicts that spill over from an organization's program find their way into courts, politics, and protest. Political leaders are drawn into these widening disputes, and their leadership often shapes how the conflict evolves. The challenges in the table above are or can become tests of political skill, often in circumstances where the political choices at stake affect the scientific integrity of adaptive management and the morale of technical staff. The need to combine scientific understanding with politically astute leadership is a demanding attribute of the adaptive approach, stemming from the difficulty of combining science and governance.

These general considerations have a practical consequence: it is important to build consensus — among critics as well as proponents — on the safety case before concrete actions commence. The safety case then provides a continuing forum for testing and affirming the social acceptance of the waste management program as it proceeds. This requires creating and affirming a consensus on the questions to be studied at each decision point in an adaptively staged program. The political capacity to achieve such a consensus is a pragmatic test of the flexibility that is cultivated by adaptive staging.

The safety case forms the agenda of hypotheses to be investigated. That agenda needs to be agreed upon, so that the testing of hypotheses can proceed in a social setting in which all sides have an interest in the integrity of the process, whatever answers they want to see emerge. That shared commitment helps to keep the conflicting interests at arm's length, enabling technical issues to be sorted out with a measure of detachment. Otherwise, the scientific process becomes entangled with the political conflict, and the technical staff's credibility will be undermined for reasons having nothing to do with their competence. Even more important, the results of testing hypotheses will not be regarded as reliable guides to future choices.

Contingencies and questions

Although adaptive management is a rational and sensible approach to the technical challenges facing NWMO, it is less clear that the social conditions needed for successful implementation of an experimental approach can be created and sustained.

Adaptive management has been attempted in only a handful of cases. Above, some of the social conditions required for an adaptive approach are set down. The conditions seem necessary but it is less clear that they would be sufficient to assure success, because there has been so little experience yet. Moreover, when there are competing interests, no single set of actors can assure that these social conditions can be built or maintained in the face of conflict. It is clear that conflict can raise the political risk of failure to such a degree that the perceived value of learning can be lower than the perceived cost of untoward surprises.

A related question is that of transitions across management generations. NWMO is designing a commitment that will take decades to implement, much longer than the term of service of an organization's managers. The challenge of scrutinizing the safety case periodically, and collecting the information needed to keep that scrutiny rigorous, requires maintaining trust, credibility, and an adequate degree of stability. It is not clear whether this is possible. In the U.S., the long-term management of hazardous and radioactive waste sites remains uncertain.

Are there alternatives to adaptive management? As noted earlier, most choices are made without consideration of surprises. The AECL program analyzed by the Seaborn Panel encountered social surprises that overshadowed the technical accomplishments that the program's staff thought would be the measure of success. A trial and error approach, in which no safety case is set down, offers program managers more flexibility in avoiding blame. Yet, as the Seaborn Panel's public commentators made clear, critics of a complex project like nuclear waste management will bring their own models of the social and technical system forward. The safety case provides a means to establish a system model that has been debated, and which then organizes the implementing program.

The most likely alternative to an adaptive approach is probably a failed attempt at waste management: not a logically coherent alternative but rather a dissipation of energies due to apathy or loss of budget or some other erosion of the social wherewithal to carry out a reasonable engineering program.

What happens if the NWMO program falters? One thing that society may learn is that radioactive wastes cannot be managed responsibly. The NWMO should take this possibility into account, by analyzing different ways in which the program might fail. With an inventory of failure modes available for discussion, NWMO should then engage government and the public in a discussion of failures and how adaptive management might be designed to provide warning before toxins are released into the environment. Even to acknowledge the possibility of failure in this way would be a notable innovation. Yet, the long-lived hazards and unavoidable burdens posed by used fuel make such an acknowledgement important for both political and moral reasons.

In sum, an adaptive management approach responds to the leading conclusions of the Seaborn Panel. First, an adaptive perspective acknowledges that safety and operational soundness rest upon hypotheses subject to the test of experience. Second, by explicitly framing and testing hypotheses, NWMO and its successors would make a commitment to learning from experience. Third, such a rigorous approach is a necessary (but not sufficient) condition for public trust and confidence. It is too early to say, however, whether the social conditions for adaptive management are feasible and sustainable in the circumstances of the NWMO.

Further reading

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