NUCLEAR WASTE MANAGEMENT ORGANIZATION
SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

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NWMO BACKGROUND PAPERS
7. INSTITUTIONS & GOVERNANCE

7-11 METHODOLOGIES FOR ASSESSING SPENT NUCLEAR FUEL MANAGEMENT OPTIONS

ETV Canada Inc., OCETA, Risk Wise Inc., Science Concepts International

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.

TABLE OF CONTENTS

METHODOLOGIES FOR ASSESSING SPENT NUCLEAR FUEL MANAGEMENT OPTIONS 1

TABLE OF CONTENTS *2*

LIST OF TABLES *7*

LIST OF FIGURES *7*

ACRONYMS *9*

EXECUTIVE SUMMARY *11*

1 INTRODUCTION/BACKGROUND 15

2 OVERARCHING CONSIDERATIONS 16

2.1 ENSURING CREDIBILITY 16

2.2 TRANSPARENCY 16

2.3 WORKING WITHIN BOUNDARIES OF LEGISLATION AND ESTABLISHED RULES 16

2.4 USING DECISION ANALYSIS APPLICABLE TO NUCLEAR WASTE MANAGEMENT 17

2.5 ELICITATION OF EXPERT JUDGMENT 17

2.6 SUSTAINABILITY 17

2.7 SECURITY 18

2.8 ETHICS 18

2.9 ALTERNATIVE PERSPECTIVES 19

2.10 INSTITUTIONS AND GOVERNANCE 19

3 AN ASSESSMENT FRAMEWORK 22

3.1 GENERIC ANALYTICAL APPROACHES 22

3.1.1 The Scientific Method *22*

3.1.2 Environmentally Sound Technology Performance Assessment (EST-PA) *23*

3.2 GENERIC ASSESSMENT FRAMEWORK FOR NWMO 23

3.2.1 Eight-Step Process *23*

3.2.2 Bootstrapping/ Feedback Loops *27*

3.2.3 Public Participation and Outreach *27*

3.2.4 Risk Assessment Applied Throughout the Process *29*

3.3 THE NWMO FRAMEWORK 33

4 QUALITY ASSURANCE AND RISK ASSESSMENT 34

4.1 WHAT IS RISK? 35
4.2 A GENERIC FRAMEWORK FOR RISK ASSESSMENT 35
4.3 TECHNOLOGY RISK ASSESSMENT 38
4.4 TRANSPORTATION RISK ASSESSMENT 38
4.5 (ENVIRONMENTAL) HEALTH RISK ASSESSMENT 39
4.6 ENVIRONMENT/ECOLOGICAL RISK ASSESSMENT 40
4.7 USE OF MODELLING IN RISK ASSESSMENT 43
4.8 DEALING WITH UNCERTAINTY: PROBABILITY AND JUDGMENT 43
4.9 ASSESSING QUALITY OF DECISION INPUTS 44
4.10 ACCOUNTING FOR PUBLIC CONCERNS OVER SAFETY IN RISK ASSESSMENT 45

5 ASSESSMENT METHODOLOGIES 48

5.1 SOCIAL ASSESSMENT METHODS 48
5.1.1 Decision Science *49*
5.1.2 Decision Science Models *50*
5.1.3 Applied Research Methodologies for Measuring Public Attitudes and Values *51*
Focus Groups 52
Surveys/Public Opinion Polling 52
Public Consultation 53
Econometric Approaches 55
Quality of Life (Health Benefit) Measures 55
5.2 TECHNICAL ASSESSMENT METHODS 56
5.2.1 Legal and Regulatory Issues *57*
Existing Legal Framework for Licenses and Permits *57*
5.2.2 Performance Assessment: Geological Repositories *58*
5.2.3 Assessment Approach for In-Situ Storage and Central Storage Options *59*
Above Ground and Near-Surface Options 60
Assessment Tools 60
Radiological Assessments 61
5.2.4 Transportation Assessment *62*
5.2.5 Generic Methods for Technical Assessment *62*
Hazard and Operability Studies 62
Root Cause Analysis as Applied in Pollution Prevention 63
5.2.6 Modelling *65*

5.2.7 Engineering Trade-offs 66
5.2.8 Adaptive Staging 66
5.2.9 Radiological Safety Regulations 67
Radiological Safety for Nuclear Industry Workers in Canada 68
Radiation Protection and Dose Limits 68
The ALARA and ALARP Concept 69
Dose and the Safety Case 69
Radiological Assessments 70
5.2.10 Outline of the Safety Case 71
Defining the Safety Case 71
Nature and purpose of the Safety Case 73
Elements for documenting the Safety Case 74
General considerations when presenting the Safety Case 75
5.3 ENVIRONMENT ASSESSMENT METHODS 76
5.3.1 Site Selection 76
The "Technical" Siting Approach 77
The "Voluntary" Siting Approach 78
5.3.2 Environmental Impacts 78
Environmental Impact Assessment 79
EIA Processes in Relation to Disposal of Spent Nuclear Fuel 79
Environmental Impact Assessment Methodologies 82
5.3.3 Environment and Sustainability 85
Strategic Environmental Assessment (SEA) 85
Methods for Impact Identification in SEA 85
Comparison of EIA and SEA 86
5.3.4 Biosphere and Geosphere Modelling and Assessment 86
Biosphere Modelling 87
Geosphere Modelling 88
5.4 ECONOMIC ASSESSMENT METHODS 89
5.4.1 Cost assessment methods for a nuclear waste repository 89
EPRI Methodology 89
5.4.2 Socio-economic analysis 90
Cost-Effectiveness Analysis (CEA) 90
Cost-Benefit Analysis (CBA) 90
5.4.3 Macroeconomic impacts 91

Input-output models 91
General Equilibrium Models 92
5.4.4 Methodology for economic analyses of spent fuel storage *92*
Engineering-economic cost calculation 92
Strategic projection of spent fuel management system 92
Specific project financing assessment 92

6 INTEGRATION METHODOLOGIES FOR ASSESSMENT 93

6.1 ASSESSMENT AND INTEGRATION EXPERIENCE IN CANADA AND INTERNATIONALLY 93
6.2 WHAT IS MULTI CRITERIA DECISION ANALYSIS (MCDA)? 94
6.3 APPLYING MCDA 94
6.3.1 Selected MCDA Methods *95*
Multi-Attribute Utility Theory (MAUT) 95
Evamix 96
Regime 96
6.4 WEIGHTING OF CRITERIA 96
6.4.1 The Analytical Hierarchy Process (AHP) *96*
6.4.2 Simple Multi-Attribute Rating Technique (SMART) *97*
6.4.3 Decision Support Software *97*

7 INDEPENDENT VALIDATION 97

7.1 VALUE OF INDEPENDENT VALIDATION 97
7.2 ENVIRONMENTAL TECHNOLOGY VERIFICATION (ETV) IN CANADA, US AND INTERNATIONALLY 98
7.2.1 Environmental Technology Verification (ETV) in Canada *98*
7.2.2 ETV in the United States *98*
The US EPA Environmental Technology Verification Program 98
7.2.3 UNEP/IETC Perspective on ETV *99*
7.3 EVALUATION AND VERIFICATION IN THE ASSESSMENT FRAMEWORK 100
7.3.1 Safety Case *100*
7.3.2 Environmental Technology Verification *101*
7.3.3 Special Expert Panels *101*
7.4 THE POLITICAL PROCESS 101
Appendix I *103*

Appendix I: Environmentally Sound Technology Performance Assessment (EST-PA) *104*
Appendix II *109*
Appendix II: Existing Models for Environmental Risk Decision-Making *110*
Appendix III *117*
Appendix III: Summary of Evident Practice in Public Consultation *118*
Appendix IV *121*
Appendix IV: Repository Modelling- Concepts, Issues and Activities *122*
Appendix V *131*
Appendix V: MCDA – Case Studies *132*
Appendix VI *141*
Appendix VI: Software Review for MCDA *142*
Appendix VII *144*
Appendix VII.1: Highlights of Assessment Experience in Selected National Programs *145*
Appendix AVII.2 .... *162*
Appendix AVII.2: Highlights of Assessment Experience in International Programs *163*
Appendix AVII.3 .... *165*
Appendix VII.3: The Port Hope EA Process for Low Level Wastes and Its Potential Relevance to Extended Storage of Used Nuclear Fuel *166*

LIST OF TABLES

Table 3.1: Primary Emphasis and Concerns of Stakeholders 28
Table 5.1: NWMO Milestone Documents 54
Table 5.2: Example library of relevant deviations for process section types 62
Table 5.3: Comparison of EIA and SEA 86
Table AII.1: Examples of Channels. 113
Table AVII.1: An overview of referenda for Storuman and Malå. 146
Table AVII.2: Structure of the EIA process. 148

LIST OF FIGURES

Figure 3.1: Assessment Framework 23
Figure 3.2: ALARA 31
Figure 3.3: The NWMO Model 33
Figure 4.1: CSA Q634-91 Framework for Risk Assessment Process 36
Figure 4.2: CEPA Human Health Risk Assessment for Priority Substances 40
Figure 4.3: CEPA Ecological Risk Assessments of Priority Substances 42
Figure 5.1: Cause and Effect Diagram 64
Figure 5.2: The ALARP Concept 69
Figure 5.3: Steps in the EIA Process. 80
Figure 5.4: The waste system flow diagram, ... 87
Figure 7.1: Integration of EnTA, ETV and EnRA 99
Figure AI.1: Characteristics of ESTs in Relation to Sustainability 105
Figure AI.2: The EST-PA Process 106
Figure AI.3: Process for Evaluating Environmental Soundness of Technologies: Generic Technology Level vs. Site Specific Application Level* 108
Figure AII.1: The National Academy of Sciences “Red Book” Model 110
Figure AII.2: A Continuous Model 114
Figure AII.3: A Policy Analysis Model 115
Figure A IV.1: Schematic Concept Illustrating the “Safety Case” 123
Figure AIV.2: “Third Case Study” - Repository Modelling Scheme Proposed by OPG 128
Figure AV.1: Hierarchical representation of objectives, sub-objectives and criteria for the Nirex case study (Adopted from DTLR). 134

Figure AV.2: Scheme of the evaluation process 135
Figure AV.3: Overview of ETV-AM process.. 138
Figure AV.4: Selection process for manure management technologies 140

ACRONYMS

AECL	Atomic Energy of Canada Limited
AHP	Analytical Hierarchy Process
ALARA	As Low as Reasonably Achievable
ALARP	As Low as Reasonably Practicable
ANDRA	National Agency for the Management of Radioactive Waste, France
ASI	Aggregated Statement on Importance
BATs	Best Available Technologies
BEES	Battelle Environmental Evaluation System
BIOMASS	Biosphere Modelling and Assessment Methodology
CAIB	Columbia Accident Investigation Board
CBA	Cost-Benefit Analysis
CEA	Cost Effectiveness Analysis
CEAA	Canadian Environmental Assessment Act
CEPA	Canadian Environmental Protection Act
CLAB	Sweden's Central Interim Storage Facility for Spent Nuclear Fuel
CNSC	Canadian Nuclear Safety Commission
COI	Cost Of Illness
CV	Contingent Valuation
DALY	Disability Adjusted Life Year
DEFRA	Department of Environment, Food and Rural Affairs, UK
DiP	Decision in Principle
DSIN	Division of Nuclear Safety, France
EA	Environmental Assessment
EC	European Commission
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
EnRA	Environmental Risk Assessment
ENRESA	The Spanish Radioactive Waste Agency
EnTA	Environmental Technology Assessment
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
EST-PA	Environmentally Sound Technology Performance Assessment
ESTs	Environmentally Sound Technologies
ETV	Environmental Technology Verification
EZ	Czech Power Enterprise
GIS	Geographic Information System
HAZOP	Hazard and Operability Analysis
HLW	High Level Waste
HPB	Health Protection Branch
HYE	Healthy Years Equivalent
IAEA	International Atomic Energy Agency
IBT	Industrial Bio-Test Laboratories
ICRP	International Commission on Radiological Protection
IETC	International Environmental Technology Centre

IJC	International Joint Commission
KASAM	The Swedish National Council for Nuclear Waste
LNT	Linear No Threshold
LQI	Life Quality Index
MAUT	Multiattribute Utility Theory
MCA	Multi Criteria Analysis
MCDA	Multi Criteria Decision Analysis
MOTIF	Model of Transportation In Fractured/porous media
MRS	Monitorable Retrievable Store
MTI	Ministry of Trade and Industry
NAGRA	National Cooperative for the Disposal of Radioactive Waste, Switzerland
NFWA	Nuclear Fuel Waste Act
NGOs	Non Governmental Organization
NRI	Nuclear Research Institute
NIMBY	‘Not in my backyard”
NUMO	Nuclear Waste Management Organization, Japan
NWMO	Nuclear Waste Management Organization
NWPAA	Nuclear Waste Policy Amendments Act
OECD	Organisation for Economic Co-operation and Development
OHSA	Occupational Health and Safety Act
PA	Performance Assessment
P2	Pollution Prevention
QALY	Quality Adjusted Life Year
RAWRA	The Radioactive Repository Authority, Czech Republic
SEA	Strategic Environmental Assessment
SKB	The Swedish Nuclear Waste Management Company
SKI	Swedish Nuclear Power Inspectorate
SMART	Simple Multiattribute Rating Technique
SSI	Swedish Radiation Protection Institute
STUK	Radiation and Nuclear Safety Authority
SWIFT	Sandia Waste-Isolation Flow and Transport
TEC	Technology Evaluation Centre
TSTP	Technology Specific Test Plan
TVO	Teollissuuden Voima Oy
UNEP	United Nations Environmental Programme
URL	Underground Research Laboratory
US NCR	United States Nuclear Regulatory Commission
VA	Viability Assessment
VALSE	Valuation for Sustainable Environment
WASSC	Waste Safety Standards Committee
WTA	Willingness To Accept
WTP	Willingness To Pay

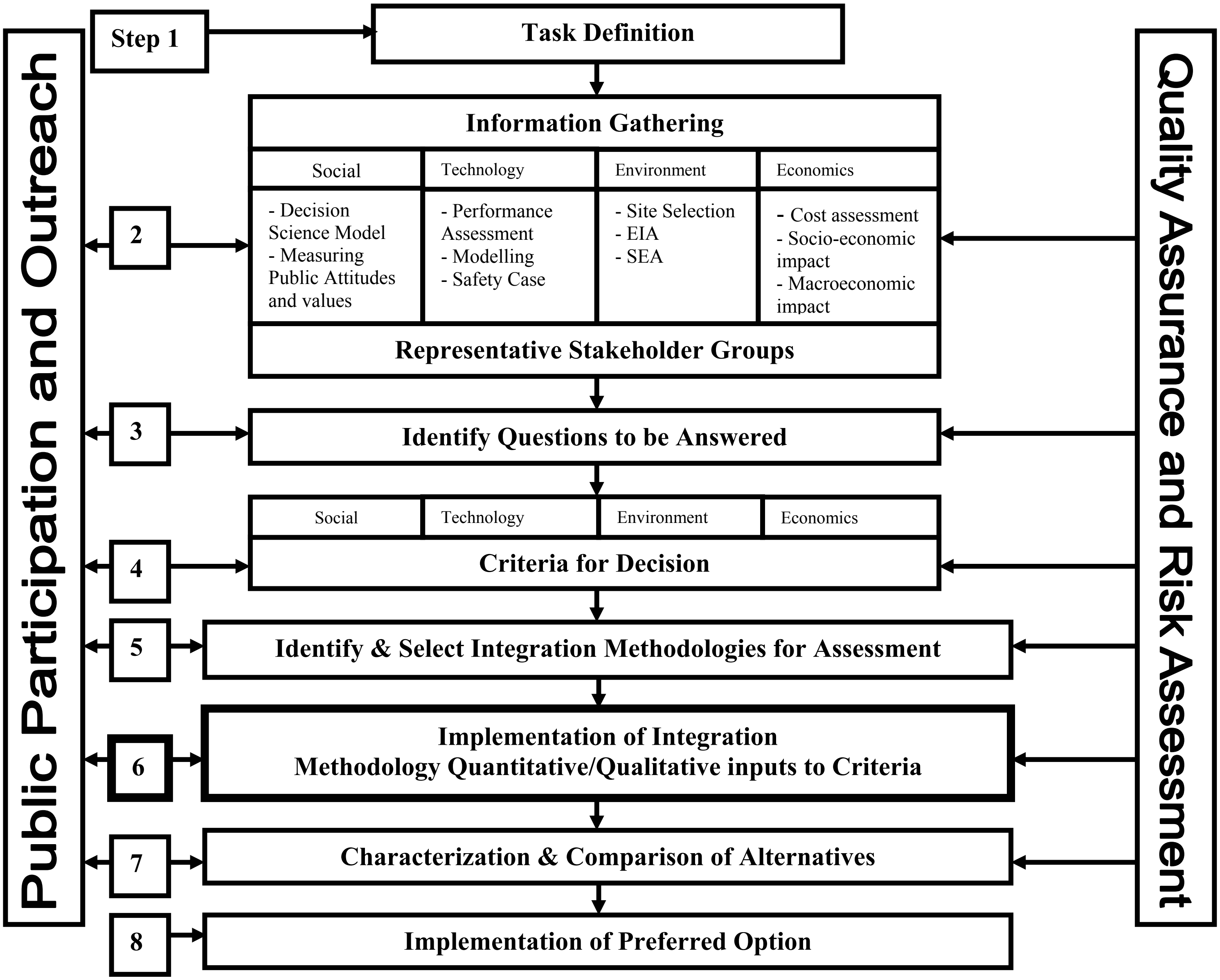
EXECUTIVE SUMMARY

The mandate of NWMO is to conduct a comprehensive study of approaches for the long-term management of used nuclear fuel, to recommend a preferred approach to the Government of Canada and to implement the approach approved by the government on the recommendation of the Minister of Natural Resources.

The primary objective of this report is to compile a comprehensive inventory of available methodologies and tools which may be applicable to the assessment of options for the long-term management of used nuclear fuel, and to present them within an overall assessment framework. The assessment framework utilized is a generic model, developed through a review of methodologies being utilized in Canada and internationally, to address policy decisions involving social, ethical, technical, economic and environmental issues. The report is intended to provide input to the NWMO assessment process in developing recommendations for preferred approaches for waste management based on three technical methods – deep geological disposal, storage at nuclear reactor sites, centralized storage either above or below ground, or possible additional methods which could combine two or more of the above three methods, and/or another technical method. It is beyond the scope of this report to recommend which assessment methodologies should be selected by the NWMO.

A number of overarching considerations are presented as a prelude to the main discussion, reflecting the NWMO approach to public consultation, as well as recognition of the experiences in other countries in attempting to obtain social and ethical “buy-in”. The following overarching considerations are considered to be fundamental – (1) credibility, (2) transparency, (3) compliance with legislation, (4) sustainability, (5) security, (6) ethics implementation, (7) perspectives of aboriginal communities, (8) learning-by-doing, and (9) institutions and governance mechanisms applicable to present and future generations.

In approaching the task of creating an inventory of methodologies, the research team identified some generic or universal analytical approaches which have been developed and utilized that could serve as an assessment framework for the inventory. As shown in the figure below, the Assessment Framework can help create an understanding of where and how generic and individual decision support tools fit into an overall analytical approach. The assessment process for addressing complex problems such as waste management for nuclear fuel must integrate many threads of information and earlier stages of decision making, and then must be capable of comparing various alternatives, with weighted and hierarchical criteria.


Public Participation and Outreach
Quality Assurance and Risk Assessment
Step 1
Task Definition
2
Information Gathering
Social
Technology
Environment
Economics
- Decision Science Model
- Measuring Public Attitudes and values
- Performance Assessment
- Modelling
- Safety Case
- Site Selection
- EIA
- SEA
- Cost assessment
- Socio-economic impact
- Macroeconomic impact
Representative Stakeholder Groups
3
Identify Questions to be Answered
4
Social
Technology
Environment
Economics
Criteria for Decision
5
Identify & Select Integration Methodologies for Assessment
6
Implementation of Integration Methodology Quantitative/Qualitative inputs to Criteria
7
Characterization & Comparison of Alternatives
8
Implementation of Preferred Option

This generic assessment framework is consistent with the broad decision analysis approach of NWMO, as outlined in its first discussion document,*"Asking the Right Questions…"*. The assessment framework also reflects the commitment of NWMO to involve the public and key stakeholders throughout the decision making process.

A substantial body of technical work has already been completed to build a credible safety case for any one of the primary waste management methods under consideration. However, there will be considerable new work that is necessary to augment the safety case for the selected option. NWMO wishes to review augmentation of existing management strategies, such as the safety case, and to go beyond the Seaborn [1]environmental assessment panel, that addressed many of the technical and environmental issues. In this inventory of methodologies, the only included methodologies are those that have relevance to the NWMO's mandate.

Some Canadians may still view these waste management options with concern. For them, risk tolerance at the level of *"what does it mean to me?"* is a key issue, particularly in relation to their expectations about health, safety, and environmental protection. Thus, a precautionary approach is needed, incorporating risk assessment throughout, and characterized by the following questions:

- What can happen (i.e., what can go wrong or right)?
- How likely is it?
- What are the consequences (including costs, and potential losses and rewards)?

Risk assessment methodologies attempt to respond to these questions by developing and applying:

- Scenarios outlining potential hazards and benefits
- Sets of consequences for the scenarios (providing a full accounting of potential benefits, losses and costs)
- Probability distributions
- Timeframes over which the risk will be considered, in order to establish the scope of the risk
- A perspective of reality.

In further describing the key underpinnings of integrated assessment, the report presents decision support and assessment methodologies relevant to the following areas:

- Social, including methodologies for measuring public attitudes and values (e.g. surveys, polling, public consultation, etc.)
- Technical, including methodologies that can be used to make quantified estimates, or "predictions", and to quantify the uncertainties in these predictions (e.g. safety analysis methods, root cause analysis and geological repository modelling).
- Environment, including Environment Impact Assessment (EIA) and Strategic Environmental Assessment (SEA), as well as biosphere and geosphere modelling.
- Economic, including economic assessment methods based primarily on cost valuation of options (e.g., Cost Effectiveness Analysis, Cost Benefit Analysis, and Multi-Criteria Analysis).

Integration of all inputs must be the culmination of the information gathering and criteria identification phase of the assessment process. Therefore, the choice and implementation of the integration methodology is the most critical part of the process (steps 5 and 6 of the Assessment Framework).

Questions concerning sustainable management of nuclear waste are characterized by conflicting and/or overlapping economic, environmental, social, technical, and ethical objectives. It is difficult to arrive at a straightforward and unambiguous solution without the assistance of one or more decision support tools that provide for the integration and structuring of complex information. Multi-criteria decision tools have been found to be useful to support decision making under such conditions. Criteria can be assessed on both quantitative and qualitative scales. An example of such an approach is Multi Criteria Decision Analysis (MCDA), which serves as an aid to the analysis and decision-making process of an expert assessment group. Software support is available and its use can be considered where the specifics of the analysis may be enhanced. A further aid to analysis is to apply weighting criteria in different ways to emphasize several different perspectives (e.g. an economic emphasis, or an environmental emphasis).

The topic of independent validation is introduced in the final section of the report. In developing a management approach, NWMO is involving many experts, and many segments of Canadian society. As the NWMO process evolves, biases are likely to emerge, and incomplete examination of some key points could occur. Furthermore, given that there are many different specialized knowledge areas which combine within the assessment framework, the possibility exists that, as a result of the integration, some important factors may not have been considered or adequately addressed in the assessment. Thus, there may be a role for independent, third party, validation of all or part of the assessment process, particularly for those steps of the assessment process where it is important to demonstrate credibility.

In preparing this report, the research team also examined some of the assessment methodologies being utilized in other countries addressing the issue of long-term nuclear waste management. The intent of this was to identify some of the experiences of other jurisdictions. Although this survey is not comprehensive, it is apparent that the NWMO approach to involving Canadians in the decision process is the most thorough and comprehensive approach to date.

1 Introduction/Background

The Nuclear Waste Management Organization (NWMO) was established by Canada's major owners of used nuclear fuel to meet their obligations under the Nuclear Fuel Waste Act (NFWA). The organization's mandate is to conduct a comprehensive study of approaches for the long-term management of used nuclear fuel, to recommend a preferred approach to the Government of Canada and to implement the approach approved by the government on the recommendation of the Minister of Natural Resources.

The NWMO has committed to "develop collaboratively with Canadians a management approach that is socially acceptable, technically sound, environmentally responsible and economically feasible". The NFWA requires the organization to consider three methods: deep geological disposal, storage at nuclear reactor sites; and centralized storage either above or below ground.

To ensure that development of the analytical framework is driven from the outset by the values of Canadian society, a series of activities were completed aimed at identifying issues, concerns, challenges and uncertainties. From this foundation, questions on a range of issues have been identified that will form the basis of an analytical framework. This framework will be augmented by development of assessment criteria that will be applied to create a comparative analysis of the various methods and the management approaches under consideration.

As part of the process to address these questions and criteria, NWMO has initiated a comparative review of methodologies and decision support tools for assessing spent nuclear fuel management options. This review is required to identify and create a descriptive inventory of protocols and methodologies that have been applied to screening and assessing possible management approaches. The focus of the report is to examine those methodologies that can be applied to the assessment of spent nuclear fuel management options. This would include an examination of those relevant to technology, environmental and socio-economic aspects, and the associated application of risk assessment. A particular goal is to identify methodologies that have been developed and are being utilized for integration of these factors into a comprehensive assessment process.

Specific deliverables required for this report, "Review of Methodologies and Decision Support Tools For Assessing Spent Nuclear Fuel Management Options" include:

a. A comparative review of methodologies and decision support tools for assessing spent nuclear fuel management approaches.
b. A background paper based on the review suitable for posting on the NWMO website.
c. A formal debriefing in the form of a presentation to NWMO staff.

2 Overarching Considerations

The development of an inventory of assessment methodologies that have been designed and utilized to help decision makers address issues of social, ethical, environmental, economic and technical matters, allows for great scope and selection of many options. The research, however, is constrained by seeking those assessment tools that have relevance to addressing the issue of used nuclear fuel. In addition, although rigorous science and sound statistics are necessary in an assessment approach, many dimensions and overarching considerations must be taken into account, and these influence the methodologies that should be selected or recommended for use.

Methodologies and decision support tools for assessing management approaches to nuclear waste must incorporate the means to fulfill mandatory requirements that overarch the entire set of issues. Some of these overarching considerations are discussed below.

2.1 Ensuring Credibility

Obtaining public support is a necessity. Insofar as possible, the successful implementation of the assessment frame must attempt to engage and address public concerns, values and inputs and consider the impact on future generations. Further, the NWMO must achieve a high level of credibility with all the communities of interest in order to establish trust and obtain support for the preferred waste management approach.

2.2 Transparency

The NWMO assessment process requires the engagement of many expert consultants individually, as teams, or within evaluation processes to provide analysis and to produce reports on various aspects of its mandate. In parallel to this technical, economic and environmental work there is a stated goal to achieve full public participation. This latter objective can only be achieved if there is complete transparency throughout the assessment process. This implies that expert groups must clearly record the background information to their work and provide the assumptions and rational to support any conclusions or recommendation they make. This information and input to the assessment process must then be made available to all participants and stakeholders, such that each potential contributor can access the “whole picture”.

Transparency not only improves the quality of the inputs from all participants but builds trust among the various communities of interest.

Since transparency is desirable, the choice of assessment methodology, ideally, would not be so technically complex that it could not be followed by the stakeholders.

2.3 Working within Boundaries of Legislation and Established Rules

The Canadian Nuclear Safety Commission (CNSC) regulates and licenses nuclear fuel waste management facilities. The Canadian Environmental Assessment Act (CEAA) has overriding requirements that must be met in regard to all proposed nuclear waste management sites.

Any assessment methodology that is recommended for adoption must yield an output within the boundaries of the present relevant legislation. The key legislative and administrative arrangements would include:

- Transportation of used nuclear fuel – licensing of the transporter, in compliance with the Nuclear Safety and Control Act, and compliance with the Transportation of Dangerous Goods Act
- Compliance with the Nuclear Liability Act
- For the proposed site of a waste management facility – Environmental Assessment (EA), in compliance with the CEAA; and compliance with Canadian Environmental Protection Act (CEPA) regarding interprovincial shipments
- Under the International Atomic Energy Agency (IAEA), the Joint Convention on the Safety of Spent Fuel Management and Safety of Radioactive Waste Management, to which Canada is one of fifteen Contracting States.
- Anticipated future legislative or administrative arrangements

2.4 Using Decision Analysis Applicable to Nuclear Waste Management

Many decision support tools have complete, or partial, applicability to selected issues of nuclear waste management. The overarching consideration is finding the appropriate methodologies that balance these inputs so that a recommendation has combined and integrated the separate streams of decision support.

In order to meet the necessary standards of transparency and credibility, it is critical that the integration and balancing of these inputs be documented as to the value and weighting applied. This may require the selection of an "assessment methodology" that structures the integration process and demands the recording of all assumptions, questions, criteria and answers and outputs generated.

2.5 Elicitation of Expert Judgment

The management approach adopted by NWMO involves drawing upon the expertise of many individuals and the assessment methodology must allow for the elicitation of expert judgment. However, it must be recognized that "experts" do not necessarily have expertise in integrative processes. This precaution will allow NWMO to receive the intuitive judgment of recognized experts, while reserving the right to be selective in the use of these inputs.

The overall assessment process, however, must integrate these expert inputs in a way that provides for a balanced output. Thus the assessment methodology utilized for integration must allow for such expert judgment to be weighted and valued.

2.6 Sustainability

NWMO's assessment methodology must be capable of addressing sustainability as a necessary aspect of the preferred management option. This is especially important given that the timescale impacting waste nuclear fuel may extend hundreds if not thousands of years. The decisions being made affect all Canadians, and in particular the community or communities at sites affected by the recommendation. There is a need to consider the interest of future generations, environmental consequences and the economic societal costs. All these issues are aspects of sustainability.

Nuclear power generation has several major characteristics that present challenges to achievement of sustainability, as noted by David Runnalls in his paper[2] for the NWMO, such as (1) waste products with high longevity (2) security (from terrorist diversion of the wastes) concerns for past, present and future waste (3) economics of nuclear power are questionable because of lower comparable costs of alternative methods of generation (This may be not be a realistic view of the problem, when true costs such as climate change, and preservation of the fossil fuel supply are included) (4) unfavourable operating experience in Ontario. Each of these challenging situations must be addressed within a sustainability framework. Risk assessment and inclusion of precautionary measures appear to be useful methodologies for this purpose.

In view of the characteristics noted above, it would appear that risk could be lessened by the use of an adaptive management approach (see NWMO's concept paper[3] on Adaptive Management) Adaptive management is iterative, cyclical, and continuous, i.e., moves from detecting new knowledge to using it, to suggesting improvements, to creating again, and so on. Adaptive management recognizes that new knowledge and understanding takes time to be incorporated into the mainstream of society and is designed to accommodate this learning process. A further example of gradual learning by society over time is the sustainability concept, at first viewed as idealistic and academic, but which is now generally agreed as necessary. In fact, the development of best practices in sustainability might be viewed as an example of adaptive management. Utilizing the concepts of sustainability and adaptive management might thus be viewed as synergistic, each contributing to attaining the goals of the other.

2.7 Security

The security framework in which nuclear waste is managed[4] must be cognizant of (1) the potential for plutonium from Canadian nuclear power reactors to be diverted to manufacture of nuclear weapons and (2) the potential for accidental release of high level radioactivity into the environment. In both instances, national and global security is compromised. If society in general and the political decision makers perceive that the management approach for nuclear waste is not able to guarantee safety from these security risks over the long term, it is unlikely that it will receive support. The assessment methodology must, therefore, include security as a critically important issue.

2.8 Ethics

Balancing the rights of many different interest groups, over millennia, is a daunting challenge, but it can be assisted by developing a framework that raises ethical questions. The areas for consideration could include:

- Environmental ethics
- Intergenerational ethics
- Ethics related to site location
- Sustainability

More generally, ethical implications are embedded in:-
- Optimization of public benefit
- Minimization of risk to health of any individual

Overall, the any assessment methodology must have the capacity to include ethical judgment. The assessment methodology itself is a means of thoroughly examining the issues from all perspectives, and thus fulfils an ethical obligation. Stakeholders will gain trust in the assessment procedure if a strong component examines ethical issues.

2.9 Alternative Perspectives

The alternative perspective of the aboriginal people is to be fully integrated into the NWMO process. This reflects the increasing recognition by Canadian society as a whole of the value of aboriginal ecological knowledge and traditional methods of making decisions. This is often based on an oral history rather than a formalized documented procedure. Therefore, the integrative assessment methodology to be employed by NWMO may have to be adapted to allow full inclusion of this alternative perspective and to maintain transparency for those participating on behalf of the aboriginal community.

Establishing trust and transparency in the aboriginal community is particularly vital in this case because two of the three management options for waste have a high probability of siting on or near aboriginal lands. A challenge will arise in providing a demonstration of present and future benefit to the community. However, inclusion of the "seven generations" approach of the native peoples of Canada could integrate a traditional approach with the mainstream of the NWMO assessment methodology. Aboriginal wisdom advises that the present day actions should be undertaken with consideration of the impact into the next seven generations, thus coinciding with the designation of "future generations" as a major stakeholder group, in NWMO terms.

2.10 Institutions and Governance

When the management approach for long term handling of waste nuclear fuel is accepted by the Government of Canada, there will be a requirement to establish an institutional framework of laws, regulations and institutions that is capable of delivering that management approach. The institutional arrangement must meet many of the overarching considerations, in order to retain the confidence of stakeholder groups. In addition, the governmental must fulfill its obligation to legislate and regulate – at all levels of government. To support the requirement for operational management over an extended multi-generation multi-stakeholder influenced time frame, the selection of the correct institutional framework is paramount.

In its discussion document "Asking the Right Questions", NWMO identifies the following questions regarding Institutional Arrangements and Governance:

- Are institutional arrangements and systems of governance in place?
- Do they provide certainty and confidence that government, companies, communities, and residents have (or will have) the capacity to address project or operational consequences?
- Will this capacity exist, and continue to evolve, in the foreseeable future?

These questions need to be answered. If, however, the NWMO is to recommend a preferred management approach for dealing with waste nuclear fuels that has broad stakeholder support; the development of a specific governance framework would be pre-requisite for achieving this support.

The long timeframes associated with management of nuclear wastes pose unique challenges for governance. In a report dealing with nuclear wastes, the National Research Council quoted Alvin Weinberg's classic statement about the "Faustian bargain" that nuclear scientists made with society. "The price that we demand of society for this magical energy source is both a vigilance and a longevity of our social institutions that we are quite unaccustomed to."[5]

For any proposed nuclear waste management approach to be acceptable, Canadians will have to be confident in both the *technical* merit and the strength of the *governance* structures of the organisations and institutions that will operate and oversee any waste repository. Governance structures include (a) the management structure of the licensee that will implement the approach for waste storage and/or disposal, (b) the structure of the agency with regulatory oversight, and c) the structure of the relationship between the licensee and the regulator. The integrity of governance structures will be important whether the selected waste management option involves either storage or disposal or a combination of both. If a repository is to be closed and permanently sealed, i.e. disposed, then management during the pre-closure period will be the main governance issue. It will be necessary to put in place governance structures that ensure the licensee and the regulator hold public safety and the public interest as paramount.

One of the main objectives of the governance structures of the future organization responsible for constructing, operating and sealing a waste repository is establishing and maintaining a safety culture. The Columbia Accident Investigation Board (CAIB) concluded that "the NASA organizational culture had as much to do with this accident as the insulation foam that was damaged during the launch. Organizational culture refers to the basic values, norms, beliefs, and practices that characterize the functioning of an institution. At the most basic level, organizational culture defines the assumptions that employees make as they carry out their work. It is a powerful force that can persist through reorganizations and the change of key personnel. It can be a positive or negative force."[6] The tragedy of the space shuttle Columbia illustrates how failure to engender and maintain a safety culture and to support decision-making can lead to failure of sophisticated technological endeavours.

The critical role of regulatory oversight in protecting the public is illustrated by the tragedy that occurred in May 2000 in Walkerton, Ontario in which contamination of the drinking water system with *Escherichia coli* O157:H7 led to the death of seven people and more than 2300 people becoming ill. The Commission of Inquiry[7] identified a number of deficiencies in regulatory oversight that contributed to the Walkerton tragedy.

Mr. Justice O'Connor in his report concluded: "MOE failed in several respects to fulfill its oversight role in relation to Walkerton's water system. Some MOE programs and policies were deficient because they should have identified and addressed one or both of the two operational problems at Walkerton [failure to install continuous chlorine residual turbidity monitors at Well 5 and improper chlorination and monitoring practices of the Walkerton PUC], but did not do so.

Other programs and policies were deficient because they reduced the likelihood that the two problems would be identified and addressed."[8]

The Walkerton and Columbia examples above demonstrate how deficiencies in governance can lead to technological failure. In developing its comparative assessment framework, the NWMO will have to include consideration of how the proposed institutional arrangements and systems of governance will protect the public interest.

3 An Assessment Framework

In approaching the task of creating an inventory of methodologies, the review team started by attempting to identify whether there were generic or universal analytical approaches that have been developed and utilized that could serve as an assessment framework for this inventory. The study itself was required to examine methodologies utilized in the social and ethical arena, technology, economics and environment, and to identify approaches that integrated these inputs into the assessment process. Having an assessment framework would create understanding of where and how individual decision support tools fitted into this overall analytical approach.

3.1 Generic Analytical Approaches

The characteristics of generic analytical approaches were considered for applicability to this work. Two of these are described below. The scientific method is a foundation of the technical advances of western society. The Environmentally Sound Technology Performance Assessment has a defined scope and a framework that has features with applicability to the NWMO assessment methodology.

3.1.1 The Scientific Method

The scientific method has been utilized for centuries and has been the tool that scientists have used collectively and over time to construct reliable, consistent and non-arbitrary representations of the world. It is the process of thinking through the solutions to a problem and testing each possibility to find the solution. It can be described simply by the following steps:

- Statement of problem
- Research to generate information
- Hypothesis on problem
- Experimentation to generate evidence
- Resolution and conclusion

The scientific method requires experimentation as a means of testing whether the hypothesis is or is not correct and no matter how elegant on compelling the hypothesis may be, it must be supported by experimental data; otherwise, it must be rejected. Some theories of behaviour, for example, cannot be tested experimentally and are, therefore, not regarded as scientific.

The scientific method is intricately associated with the process of human inquiry. While the method appears simple and logical, it distinguishes science from other forms of analytical approaches because of its requirement for systematic experimentation. The “science” approach is utilized throughout many aspects of the problem of identifying what methodologies and management approaches are appropriate for dealing with used nuclear fuels, but does not represent a complete or comprehensive assessment framework on which to structure the inventory.

3.1.2 Environmentally Sound Technology Performance Assessment (EST-PA)

The International Environmental Technology Centre (IETC) of the United Nations Environmental Programme (UNEP) is committed to a mandate based on sustainable development. UNEP/IETC has developed new management methods and decision support tools, particularly designed for developing countries, to address the need to select and apply environmentally sound technologies (ESTs) to achieve sustainable development objectives.

Defining environmentally sound technologies in an absolute sense is difficult since the environmental performance of a technology depends upon its impacts on specific human populations and ecosystems, and the availability of supporting infrastructure and human resources for the management, monitoring and maintenance of the technology. The environmental soundness of technology is also influenced by temporal and geographical factors, to the extent that some technologies may be environmentally sound now but may be replaced in the future by even cleaner technologies. Likewise, what could be environmentally sound in one country or region might not be in another. The EST-PA framework accommodates analysis of a substantial number of those elements that must be evaluated for nuclear waste fuels and these have been incorporated into the proposed generic assessment framework. The process is represented by Figures AI.1, AI.2 and AI.3 included in Appendix I.

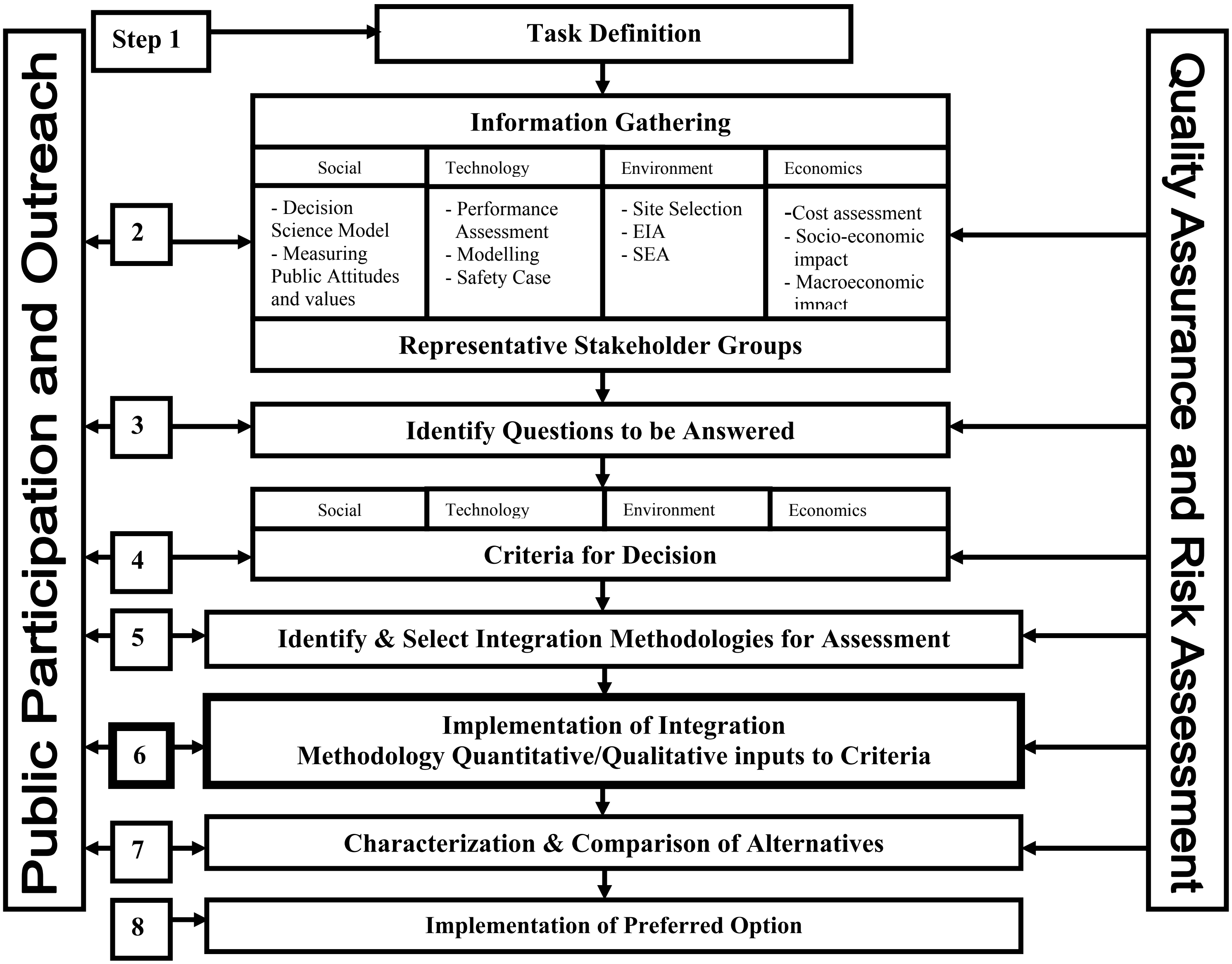
3.2 Generic Assessment Framework for NWMO

Many decision support methodologies are designed to evaluate limited issues that are subsets of a larger and more complex problem. Thus social, ethical, technical, economic and environmental questions often have their own sets of decision support tools that are in common usage. In addressing large problems, such as the issue of used nuclear fuel, each of these areas must provide inputs into an overall assessment framework that compares alternative methods and management approaches. In this background paper, approaches from around the world to used nuclear fuel were examined, and an attempt was made to characterize the main features and steps in those processes. In addition, a number of other large environmental projects were reviewed, where a government agency was typically responsible for approval, and where there was also an attempt to integrate social, technical, economic and environmental inputs into an assessment methodology.

3.2.1 Eight-Step Process

An assessment framework based on this review has been developed as an eight-step process, shown in Figure 3.1.

Figure 3.1: Assessment Framework



Step 1: Task Definition

This stage describes the specifics of the task or issue that are to be addressed by the assessment framework.

Step 2: Information Gathering

In most assessment activities, there is an accountable organization or agency charged with the responsibility for management and implementation of the assessment framework. The agency must attempt to ensure that information inputs in the four areas of concern are balanced and apply the best possible methodologies for generating information. Often, this process employs mechanisms to involve leaders or experts in a representative stakeholder group, assessment panel or advisory committee. Such collective participation and involvement fosters understanding, increases transparency, ensures that all relevant concerns are identified, and promotes the capacity to arrive at an agreed-upon solution that integrates inputs from all areas.
At this information gathering stage, there are many decision assessment tools and research methodologies that are used to generate information on which the future assessment will be based. Many of these methodologies are described in Chapter 5 of this report.

Step 3: Identification of Questions to be Answered

Any assessment process requires the generation of a set of clear questions that must be answered about the method or issue under review. This will facilitate the characterization of the merits and disadvantages of the issue, and lead to a possible ranking against other alternatives.

In most situations, the representative stakeholder group plays a key role, along with the management agency, for developing these questions. The questions can be grouped under the four aspects under consideration, e.g. social/ethical, economic, technical and environmental.

If the process of developing the questions is thorough, and is seen to be transparent, the basis of a comparative analysis is established. The same questions, applied to a number of alternative methods being assessed, allows differences to be identified and if value judgments can be agreed upon and applied to the questions, a consistent and objective ranking of alternative choices can be developed. When different responses to questions are identified, an opportunity is created to examine whether a solution can be generated that would alleviate any significant weakness of the option under consideration.

Step 4: Criteria for Decision

In order to proceed with answering the questions, it is important to establish a set of criteria that will be applied, and against which the answers can be judged. Development of the criteria must meet the same standards of transparency, informed and expert opinion, and participation by the representative stakeholder groups as applied in generating the questions. Use of the stakeholder group, augmented by expert inputs and public input, represents a standard approach to this process of criteria development.

Step 5: Identify and Select Integration Methods for Assessment

Once questions and criteria have been developed and consensus reached, the next task becomes identifying the methodology to be used to integrate these inputs into an "Assessment Process". The commonly accepted methodology being utilized for this purpose is Multi Criteria Decision Analysis (MCDA). This is described in further detail in Chapter 6.

Although the methodology may be well accepted, the design, scope and balance between quantitative and qualitative inputs may vary enormously. The design becomes the responsibility of the management organisations utilising a representative stakeholder group and may well benefit from a certain amount of experimentation or pilot activity to explore the effectiveness and outcomes from the use of the methodology.

Step 6: Implementation of Integration Methodologies Quantitative/Qualitative Inputs into Criteria

In the use of integration methodologies for assessment purposes, the same set of questions and criteria are applied to each alternative method or management approach under consideration. The process requires, however, judgment and consensus to be reached on the relative importance of the questions and criteria being applied, and an agreed means of establishing the weighting to be applied to the answers to specific questions posed. Again, this process can rely on a representative stakeholder group to make these judgments. There is clearly a need and an opportunity to utilize expert sub-groups where necessary to support these choices and judgments.

Step 7: Characterization and Comparison of Alternatives

The bulk of the work involved in the use of the assessment framework is completed in the first six stages. The implementation stage should not be onerous. An advantage of proceeding through this process is that the decision support tool developed allows for substantial flexibility in examining a broad range of options beyond those methods and management approaches identified at the beginning of the task.

The integration assessment methodology can be simplified or made more complex by removing or adding new questions and criteria, and as long as each methodology under assessment is subjected to the same analysis, then the comparison remains valid.

Step 8: Implementation of Preferred Option

The outcome of Stage 7 would be a recommendation for an implementation plan to be developed. In most circumstances, however, when dealing with major environmental issues with substantial social implications, the first stage of a site specific selection process may now be required. This latter process should benefit from the work completed through the assessment framework, but new issues related to the proposed location and community would need to be addressed.

3.2.2 Bootstrapping/ Feedback Loops

The terminology "bootstrapping" relates to a process of learning-by-doing, followed by iterative adjustment. As applied to NWMO's review of available methodologies for assessment, a general methodology could be chosen and applied. The next step is refinement of the selected methodology, on the basis of new information that comes forward. This refinement could be applied several times, and thus the adjustment would be iterative. The bootstrapping process is one that would occur within the assessment framework. A related process would be adaptive management, a process whereby the application of the selected means of nuclear waste management is left open to a degree, pending future developments in policy, technology advancement and socio-economic thinking. Adaptive management would deliberately set up means of detecting and using new knowledge.

NWMO plans a dialogue with Canadians, with the purpose of gaining a mutual understanding of the available choices. This will be one of several feedback loops that informs the selection of the assessment methodology.

3.2.3 Public Participation and Outreach

The assumption of assessment framework approaches used internationally is that at the conclusion of the work, "buy-in" has been achieved from the major stakeholders, and in particular from the public at large. A societal consensus in support of the outcome helps expedite the political decisions required to implement recommendations, and may be necessary to secure financing.

The level to which social and community inputs are integrated into the assessment framework can vary considerably. A number of countries with nuclear industries have adopted an assessment approach that is based largely on the technical safety case, leaving the responsibility for social acceptability to the site specific selection process, which requires community acceptance for what is proposed. At this stage, the issues of economic benefit, safety, security and environmental impact are dealt with at the local level.

Other approaches have accepted the need for a substantially greater level of public involvement and participation in the assessment framework, requiring various methodologies to be applied throughout the process. In this approach, mechanisms and methodologies must be integrated throughout the assessment framework, often utilizing interactive feedback loops that involve the public in the creative process, and then confirm that the outputs are acceptable by further outreach. This approach is illustrated in the generic assessment framework shown in Figure 3.1.

Broadly, stakeholders may be categorized by:

- Government
- Nuclear Industry
- Canadian Public
- Future Generations

Future generations would have a surrogate representation.

NWMO intends to ensure the universal inclusion of stakeholders, each of which is concerned about the full spectrum of the social, technical, environmental and economic aspects of nuclear waste management. Nevertheless, it may be instructive to consider the primary emphasis and concerns of each stakeholder, to enable insight into a stakeholder's viewpoint . In Table 3.1, *a choice is made from one and only one of the four categories of concern.*

Table 3.1: Primary Emphasis and Concerns of Stakeholders

Stakeholder Identification	Primary Concern(s)			
	Social	Technical	Environ-mental	Economic
NWMO	(X)	(X)	(X)	(X)
FEDERAL GOVERNMENT	X			
Natural Resources Canada			X	
Transport Canada			X	
Federal Regulatory Agency (CNSC)		X		
PROVINCIAL GOVERNMENT	X			
Ministry of the Environment: Certificate of Approval		X		
MUNICIPAL GOVERNMENT			X	
NUCLEAR INDUSTRY				X
Nuclear power electricity generators				X
Uranium mining sector				X
CANADIAN PUBLIC				
Aboriginal Peoples	X			
Citizens of Provinces having Nuclear Reactors	X			
Citizens of Provinces w/o Nuclear Reactors				X
Communities of Interest – Transportation			X	
Communities of Interest – Siting			X	
Communities of Interest – Aboriginal Lands			X	
Communities of Interest – NGO	X			
FUTURE GENERATIONS	X			

NOTES TO TABLE 3.1

For aboriginal peoples and citizens of provinces having nuclear reactors, it could be that their concerns are expressed for environmental matters. However, even when informed experts judge that an environmental plan is sound and inherently safe, citizens of both of these communities of interest will hesitate, for complex social reasons, to have nuclear waste facilities in their "backyard". Therefore, the category "social" is designated as their greatest area of concern. As another example, CNSC, as the regulator, is concerned with all aspects. There are environmental, social and economic requirements of the CEAA (CNSC mandated) that are to be separately considered as part of the CEAA, but the technical structure of the regulatory response also includes some of these considerations. Thus, the category "technical" is designated as the area of emphasis.

Stakeholders' concerns centre around their self-interest. This may broaden to encompass regional and national concerns, because this is also self-interest, over a wider range. The communication from NWMO to the stakeholders will, ideally, be structured so that the information is readily accessible and unambiguous, so that the concerned stakeholder can unequivocally judge the impact on their interests.

Communication tools could include the print and TV media, and the Internet, as well as public information meetings and workshops. Drawing on the experience of others, timeliness should be taken as an imperative. If communication occurs before, or simultaneously with expression of a stakeholder concern, then there is less opportunity for mis-information to become entrenched. Communication technology changes rapidly and many useful formats may evolve during the life of the nuclear waste repository. However while NWMO proceeds with reviews leading to recommendations to the Government of Canada in late 2005, a key means for communication with stakeholders would be web-based information, fully accessible by all, and institution of an active "e-dialogue", with fast response.

3.2.4 Risk Assessment Applied Throughout the Process

The assessment framework involves the generation of a substantial stream of information and data and it is critically important that every effort be made to ensure that the inputs are of the highest possible quality. This requires that the assessment tools, methodologies and protocols meet the best available standards of science, statistics, and risk assessments. This does not imply that all inputs need have the same level of quantitative support, but simply that wherever possible, an understanding of the quality of the data is established, and quality assurance methodology is applied where appropriate.

Risk assessment methodologies allow for the evaluation of uncertainty for the qualitative and quantitative data being generated. This fundamental approach must be applied to all of the activities involved in the assessment framework.

Risk is inherent in all human activity, and arises from both action and inaction. With every decision we make or defer, there is risk – risk of success or failure, and risk of unanticipated outcomes, whether they be beneficial or detrimental. This is true of decisions at an individual, organizational and societal level. A defining characteristic of risk is uncertainty. In making decisions, there is uncertainty associated with the potential upside (e.g., the likelihood that we will achieve our objective and reap the associated benefits) and the potential downside (e.g., the likelihood that we will fail or encounter losses along the way). In the field of safety, the focus is on the downside of risk, i.e., avoiding loss or damage to people, the environment, assets, and productivity. There is a growing recognition by organizations that risk is also about the upside, or seeking opportunities and gains in terms of improved health, wealth, and quality of life.

Risk assessment is a methodology aimed at characterizing and quantifying risk for the purpose of informing risk management decisions. Many frameworks for risk management have been published, and most contain the following elements: Identification (preliminary analysis), risk analysis, development and evaluation of risk treatment options, option selection and implementation, and ongoing monitoring and quality control. These standard risk management frameworks have structural elements in common with the assessment framework, Figure 3.1, thus illustrating the complementary work that is performed in parallel to the mainstream assessment. Success in risk management is defined by practical and useful solutions for dealing with uncertainty.

In the past ten years, there has been a great deal of activity and progress in the field of risk management (including risk assessment, decision analysis, stakeholder involvement and risk communication). A growing number of organizations in both the private, public and not-for-profit sectors are embracing risk management. A number of guiding principles for effective risk management form the underlying basis for existing and emerging risk management frameworks in Canada, the US and Australia/New Zealand. These principles include the following[9]:

- The decision process is documented and therefore open and transparent. Values and value judgments are inherent in the risk assessment and risk management processes and for this reason it is critical that participants in the process make their biases and assumptions explicit;
- Recognition of the key role of leadership. In the corporate context, this means both governing board oversight and senior management commitment. In the public sector, it means the support of senior political leaders and administrators;
- Explicit consideration of stakeholders' perceptions of the risk and risk management options through early and ongoing engagement of stakeholder in the decision process. Effective risk communication is about two-way dialogue aimed at understanding stakeholder needs, issues and concerns, not merely about informing the public after a decision has been made;
- Risks are considered in a comprehensive context, considering other public health or environmental health objectives. The organization responsible should have a mandate to direct actions and resources where they will be most effective;
- A balancing of the costs of managing the risks, the benefits to be gained, and the level of risk management that is reasonable to apply;
- A standard set of terminology is used to describe the risk issues, thus contributing to more effective communication about risk issues;
- There is explicit treatment of uncertainty. Risk estimates are subject to many forms of uncertainty (e.g., framing uncertainty, modelling uncertainty, inference-option uncertainty, statistical or parameter uncertainty, decision-theoretic uncertainty, and policy-implementation uncertainty)[10]. To deal with uncertainty, it is best to give a range rather than point estimates of risk. Also, it is important to provide an indication or measure of the confidence boundaries around the risk estimate. Further, sensitivity analysis should be conducted to identify how changes in underlying assumptions can affect the risk estimate;
- The process is flexible and iterative to allow risk managers and stakeholders to revisit earlier stages of the process and to revise earlier deliberations and decisions in light of new information, ideas and perspectives.

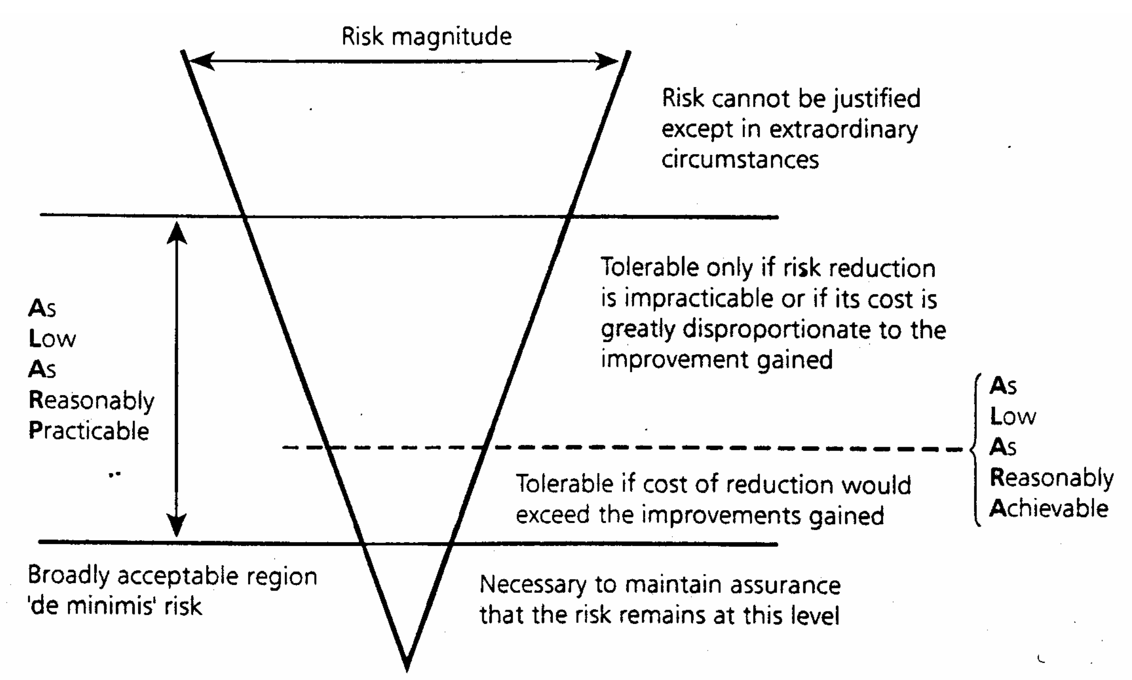
Risk assessment typically relies on scientific data, models, and expert judgment as inputs in the risk estimation process. Risk assessment also attempts to interpret the risk estimates for the decision context. This interpretation of scientific information takes the process away from science and into the world of social and ethical values. The treatment of uncertainty is addressed further in Section 4.8, "Dealing with Uncertainty: Probability and Judgment". Decision analysis is described further in Section 5.1.2, "Decision Science Models".

Strictly speaking, a risk is acceptable if it decided that no risk reduction efforts are necessary and that there is confidence that existing risk controls will maintain the risk at the current level. Reasons why a risk may be accepted or tolerated include:

- The level of risk is so low that specific risk controls are not appropriate given available resources.
- The risk is such that there is no method available to reduce it.
- The cost of risk reduction measures is so excessive compared to the benefit, that acceptance is the only option.
- The opportunities outweigh the hazards to such a degree that the risk is justified.

Figure 3.2 [11] illustrates the relationship between risk magnitude and the tolerability of risk. The width of the cone indicates the size of the risk. The diagram shows three distinct regions of risk acceptability or tolerance, depending on the size of the risk. At the high end, risk is deemed so large that it cannot be justified except in extraordinary circumstances. Risks at the other end of the spectrum are broadly considered acceptable; that is, risks in this region are so low that they are tolerable without any additional investment in risk reduction measures. In the middle region, risks are only tolerable if they are kept As Low As Reasonably Practicable (ALARP); i.e., they are tolerable only if risk reduction is impracticable or its cost is greatly disproportionate to the improvement gained. The As Low As Reasonably Achievable (ALARA) concept states that certain risks in this middle region are tolerable only if the cost would exceed the improvements associated with risk reduction activities.

Figure 3.2: ALARA



Risk managers in the public and private sectors often express frustration with what appears to them as inconsistent expectations on the part of the public about what risks people are willing tolerate. Acceptability of any particular risk is partly determined by the perception of the risk, i.e., "How big is it?" and "What does it mean to me?" (Further information on factors that affect perception of risk, can be found in Section 5.10, "Accounting for Public Concerns over Safety in Risk Assessment"). For waste management issues, risk tolerance is also determined to a great extent by the trust and confidence in the organization charged with building and operating the waste management facility, and in the organization charged with regulatory oversight of the facility operator.

A number of social trends in recent decades have made it increasingly difficult to gain acceptance of risks by the public. These include:

- Higher expectation by the public for protection of health, safety, environment, etc.
- Higher expectation by the public for more direct input into government decision-making, e.g., public consultation processes.
- Decreasing trust in government and regulatory institutions to protect safety and health and the public interest. In Canada, this has been fuelled by some spectacular and tragic failures, e.g., tainted blood, SARS, Walkerton, BSE (Mad Cow Disease).
- Trend towards life cycle stewardship. It is no longer acceptable to limit product obligations.
- The precautionary approach, e.g., the public expects that products be proven to be safe before they are put on the market.
- Simply meeting legal requirements is no longer seen as adequate; the public expects organizations to do the right thing, e.g., expecting environmental performance that exceeds legal requirements.
- Higher expectations for openness. The public expects disclosure; e.g., "right to know" legislation in the US.

The above trends, coupled with growing awareness of environmental damage by past activities, have resulted in a marked decrease in public confidence in industry in general. For example, chemical industry surveys of public confidence have shown it went from high levels of satisfaction with industry and with having industry located in communities in the 1970s to high levels of concern about the industry and wanting it shut down, i.e., the "not in my backyard" syndrome (NIMBY) by the late 1980s.

Trust and confidence are important determinants of perceived risk and risk tolerance, both in terms of the assessment of the magnitude of risk and in terms of the ability of the proponent and regulators to adequately manage the risk. "There is increasing evidence of the importance of trust and confidence to controversies about technological hazards. Public positions about the safety of nuclear power facilities and waste sites, for example are often in conflict with technical risk assessments. Those who do not trust the involved organizations are unwilling to accept that risks of a nuclear waste repository have been technically assessed as low in probability."[12]

Research in the nuclear field shows that trust and distrust are created and sustained in different ways and that there is an asymmetry between the difficulty of creating trust and the ease of destroying it.[13] A leading factor in establishing trust and credibility is "caring" (e.g., caring that the agency operates in a fair and ethical manner, caring about the well being of Canadians). Other factors that influence trust, although apparently to a lesser degree, are technical competence, commitment, and openness.

3.3 The NWMO Framework

In its first discussion document, *Asking the Right Questions? The Future Management of Canada's Used Nuclear Fuel*, the Nuclear Waste Management Organization (NWMO) outlines its proposed approach to decision analysis. A model illustrating this approach is shown in Figure 3.3.

The NWMO approach recognizes that the determination of Canada's solution to the nuclear waste management issue requires public consultation at every stage of the process. NWMO has committed to using a variety of methods for obtaining public input, including public opinion research, conversations with individuals and groups, workshops, commissioned papers, Internet-based publication of written materials (including milestone documents and all commissioned papers, workshop reports, etc.) and internet channel for receiving comments.

Figure 3.3: The NWMO Model

Information Gathering and Public Consultation Activity		Model Stage		Milestone Document
Dialogue with experts, stakeholders, and Canadians at large	→	UNDERSTAND THE DECISION CONTEXT Develop Questions	→	Discussion Document 1 **Asking the Right Questions?**
Engage experts, stakeholders, and Canadians at large	→	DEVELOP ANALYTICAL (DECISION ANALYSIS) FRAMEWORK Refine Questions and Develop Criteria	→	Discussion Document 2 **Understanding the Choices**
Engage experts, stakeholders, and Canadians at large	→	DEVELOP OPTIONS Preliminary Comparative Assessment of Management Approaches	→	Discussion Document 3 **Choosing a Way Forward (Draft)**
Dialogue with Canadians	→	REFINE OPTIONS Refined Comparative Assessment Draft recommendations	→	Final Study **Choosing a Way Forward**
Review by Canadians	→	RECOMMEND OPTION Final submission to the Minister of Natural Resources on Management Approaches		

4 Quality Assurance and Risk Assessment

Risk assessment principles have been applied to a wide range of public policy decisions. Before delving into particular fields of risk assessment, it is helpful to define risk and consider the generic elements of risk assessment and some common issues and challenges.

4.1 What is risk?

A useful definition of risk for the public policy context comes in the form of the following three questions:

- What can happen (i.e., what can go wrong or right)?
- How likely is it?
- What are the consequences (including costs, and potential losses and rewards)?

The answers can be represented as a set of triplets that correspond to:

- A set of scenarios (outlining potential hazards and benefits)
- A set of probability distributions
- A set of consequences for the scenarios (providing a full accounting of potential benefits, losses and costs)

To complete the concept, we should add[14]:

- A timeframe over which the risk will be considered. This is necessary to establish the scope of the risk being considered.
- A perspective of reality. This is needed to reflect the inevitable judgments that underlie any characterization of risk.

4.2 A Generic Framework for Risk Assessment

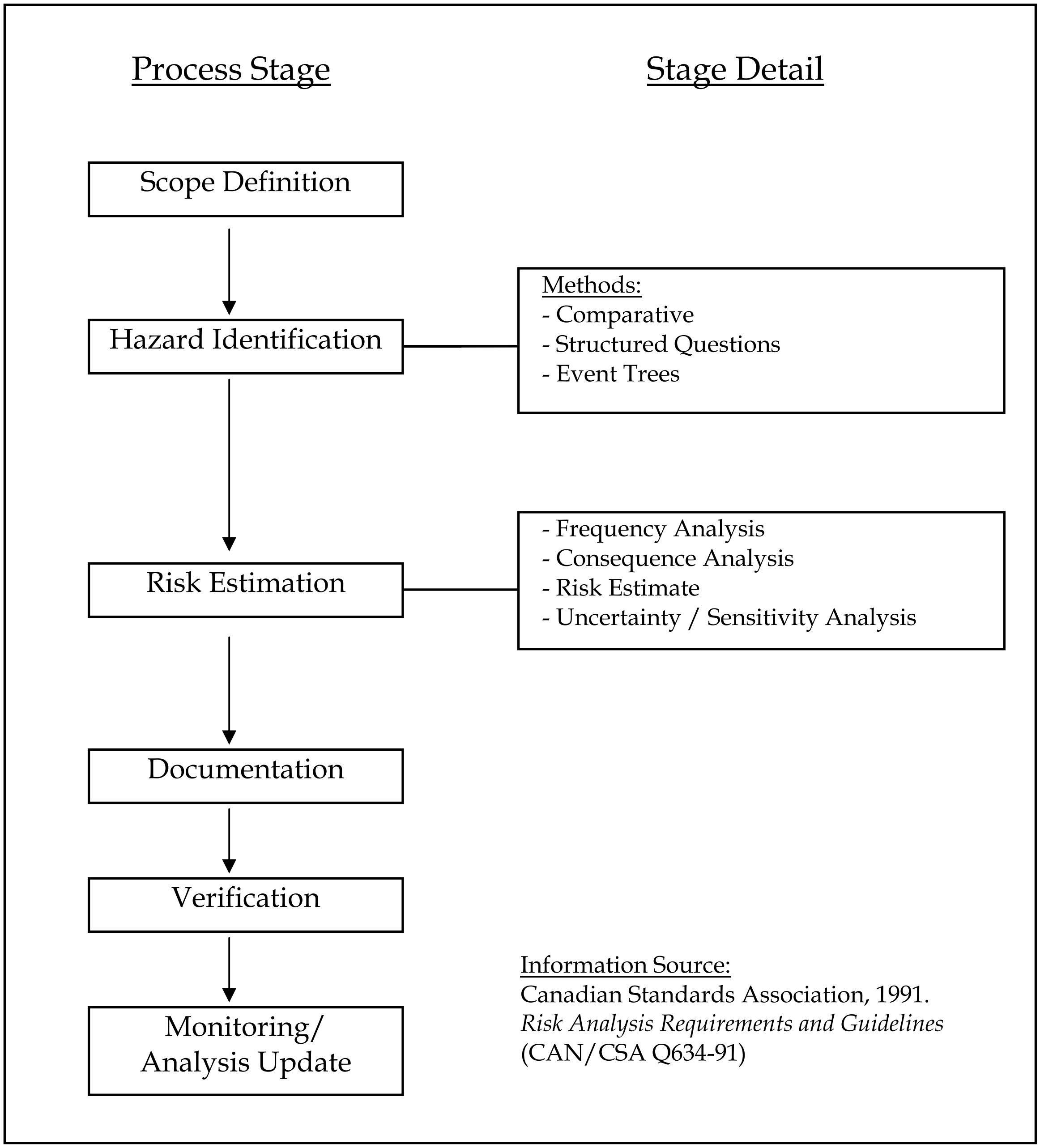
Figure 4.1 below shows the Canadian Standards Association risk analysis framework. The CAN/CSA Q634-91 framework is generic in nature. It includes the classic risk assessment steps:

- Scope definition
- Hazard Identification
- Risk Estimation
- Documentation
- Verification
- Monitoring and Updating of the Analysis

When this framework was published in 1991, it was the first standard for risk analysis in the world. This underlines that risk analysis is a young discipline, with many advances being made as the demand for and use of risk assessment becomes more commonplace in decision-making, particularly for policy relating to societal issues. As the NWMO review is heavily focussed on societal issues, and it is assumed that best practises in methodology are to be applied, then risk assessment is appropriate for this assessment framework (Figure 3.1)

The following sections describe specialized risk assessment methods developed to deal with particular classes of risks in the fields of technology, transportation, human health, and the environment. These fields of risk assessment are all pertinent to the nuclear waste management issue.

Figure 4.1: CSA Q634-91 Framework for Risk Assessment Process



4.3 Technology Risk Assessment

Many methods have been developed for estimating the risks associated with developing a technology, or risk of accident associated with a particular technology or plant design. Of particular relevance to the development and assessment of nuclear waste management approaches is the experience of the high hazard industries (e.g., chemical, oil & gas) which have developed methods to identify and evaluate the hazards associated with different phases of an installation's life cycle. This information provides a basis for planning and responsible management of risk. The Center for Chemical Process Safety[15] recommends the following methods for assessing risk at the conceptual design stage:

- **Checklist Analysis**. A written list of items or procedural steps to verify the status of a system or compliance with key safety principles and objectives.
- **Relative Ranking**. Analysts compare the attributes of several processes or activities to determine whether they possess hazardous characteristics that are significant enough to warrant further study.
- **Preliminary Hazard Analysis**. Focuses in a general way on the hazardous materials and major process areas of a plant. It is most often conducted early in the development of a process when there is little information on design details or operating procedures, and is often a precursor to further hazard analyses.
- **What-If Analysis**. A brainstorming approach in which a group of experienced people familiar with the subject or process ask questions or voice concerns about possible undesired events.
- **What-If / Checklist Analysis**. Combines the creative, brainstorming features of the What-If analysis method with the systematic features of the checklist analysis method.

4.4 Transportation Risk Assessment

Transportation risk assessment has a long history, but perhaps began formally when English insurers began to collect and use data to rate ships bound for trade voyages abroad. Specific techniques have been developed for application in various transport modes: road, rail, marine, and air. Of interest for the NWMO comparative assessment will be methods relating to transportation of dangerous goods.[16,17] Common elements of risk assessment for the transportation of dangerous goods (e.g., nuclear waste) include:

- Facility Location Studies (initial estimation of aggregate risk associated with movements to and from each location, also consideration of the on-site risks)
- Mode selection (includes analysis of mode of transport – e.g., road, rail, marine, air and of shipment type – e.g., truck or rail car design, barge vs. ocean going vessel)
- Route selection (route segmentation, population densities, identification of potential consequences along route)
- Probability Analysis (likelihood of an incident, likelihood of a release of waste given an incident)

- Consequence Analysis (determining the extent of potential losses to individuals and society, including injuries and fatalities, environmental damage, property/asset damage, and business interruption)
- Risk Characterization (integration of Probability Analysis and Consequence Analysis for selected facility location(s) and transportation modes and routes)

Other key issues include: approaches for evaluating acceptability/tolerability criteria. This can be done either at a policy level on a case-by-case basis or through the development and application of numerical criteria. For example, codified numerical criteria for risk acceptability are used in many European countries, as well as in Australia and Hong Kong[18].

4.5 (Environmental) Health Risk Assessment

The primary focus in human health risk assessment is the safety of the individual. Regulators use health risk assessment in determining standards for permissible or acceptable levels of a particular substance in the workplace or the environment (air, water, soil) or in food. Research and policy aimed at understanding and improving population health is not discussed here because it is not directly relevant to NWMO's comparative assessment.

Human health risk assessment involves three steps:

- **Toxicity Assessment**. Hazard Identification and Dose-Response Assessment. Based on laboratory (e.g., in vitro or animal studies) and field (e.g., epidemiological studies) observations and information on extrapolation methods (e.g., making inferences on the potential effects on humans based on in vitro or animal studies)
- **Exposure Assessment**. Based on field measurements and the characterization of populations. Also considers the various exposure routes for humans (e.g., dermal, inhalation, ingestion).
- **Risk Characterization**. The results of the Toxicity Assessment step are integrated with the results of the Exposure Assessment step.

Frameworks and methods for environmental health risk assessment have been developed by regulators in many jurisdictions. For a review of health risk assessment frameworks in other jurisdictions, see Dyck et al.[19] An illustrative example of the risk assessment framework used by Environment Canada is described below. Under the Canadian Environmental Protection Act (CEPA), the Ministers of Environment and Health have the joint responsibility to investigate substances in the environment that may cause environmental or human health effects. The ministers are also responsible for publishing the "List of Priority Substances" and establishing whether or not substances are "toxic". Figure 4.2 shows the process developed by Environment Canada for Human Health Risk Assessment for priority substances under the Canadian Environmental Protection Act (CEPA).

Under the Health Protection Branch Risk Management Framework[20] developed by Health Canada, Risk Assessment includes consideration of both scientific evidence in a Risk Analysis stage, and analysis of socioeconomic concerns in an Options Evaluation stage.

4.6 Environment/Ecological Risk Assessment

The principal goal of ecological risk management is ensuring the overall preservation of one or more threatened species or biotic communities, and the integrity of their mutual ecosystem interactions. One of the key issues in ecological risk assessment is the selection of endpoint(s) and whether a single substance or mixtures will be considered. As with health risk assessment, each jurisdiction will have its own particular approach. As an illustrative example, Figure 4.3 shows the process developed by Environment Canada for Ecological Risk Assessment of priority substances under the Canadian Environmental Protection Act (CEPA). For a review of ecological risk assessment frameworks in other jurisdictions, see Dyck et al.

Figure 4.2: CEPA Human Health Risk Assessment for Priority Substances

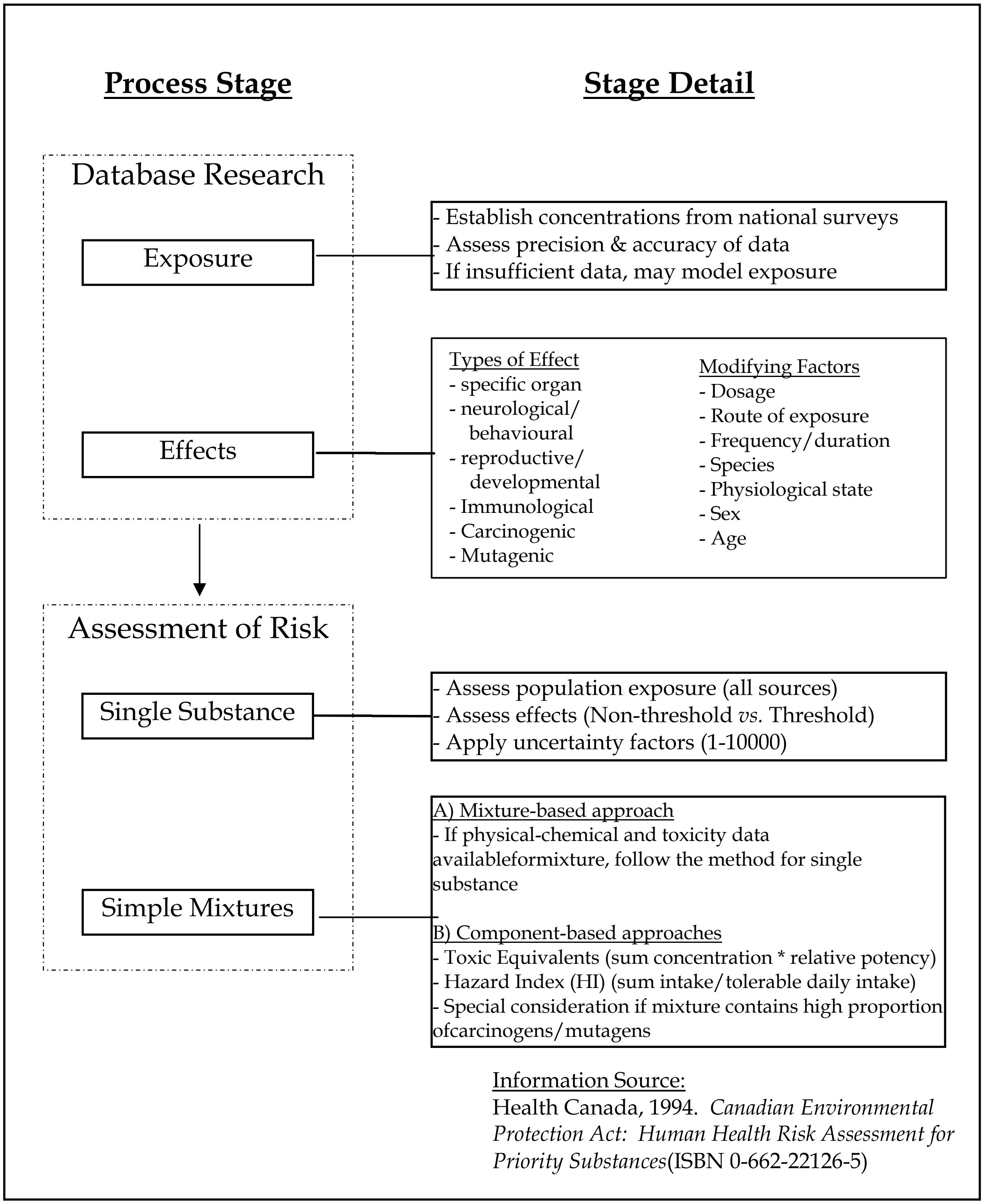
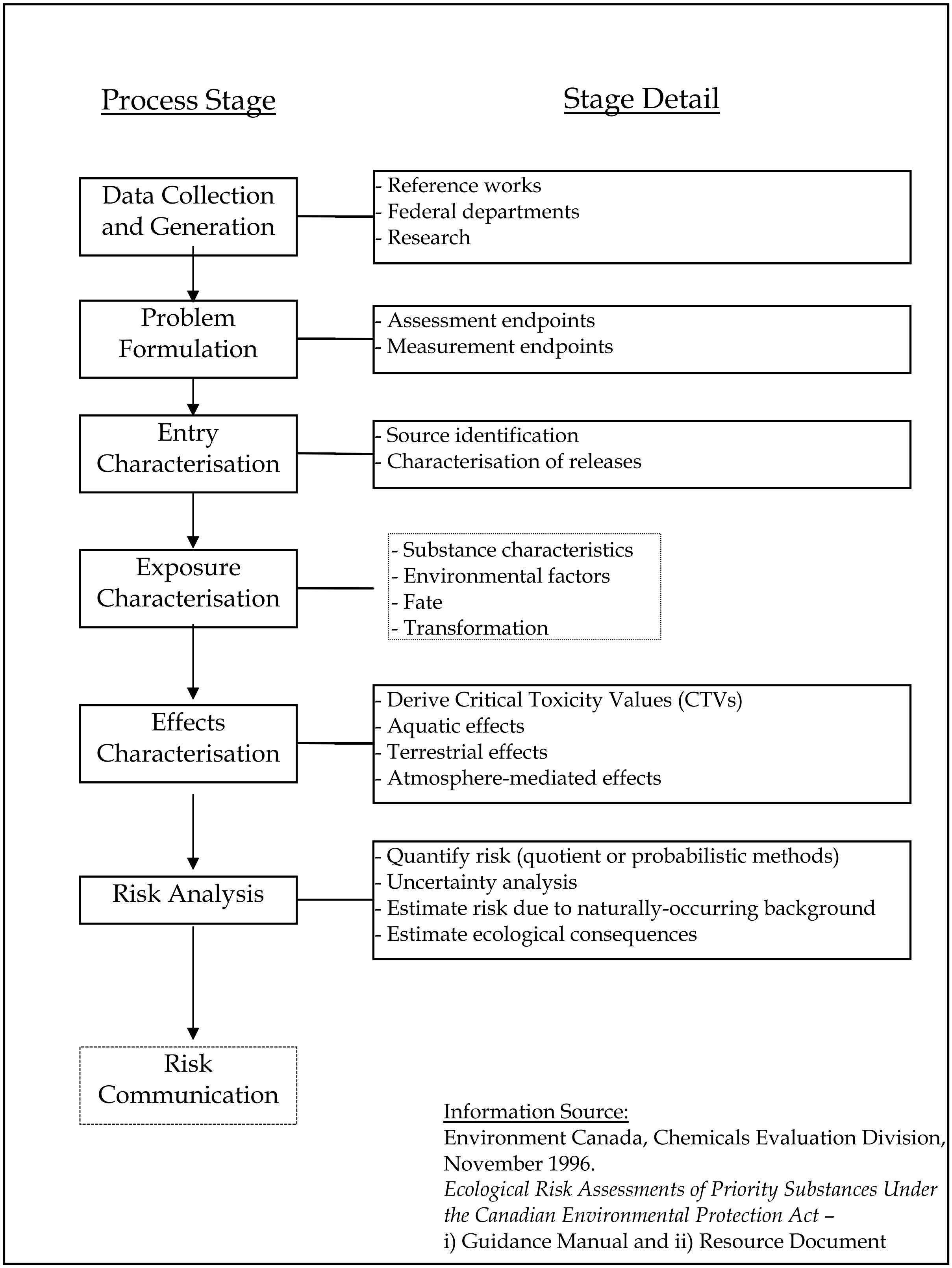


Figure 4.3: CEPA Ecological Risk Assessments of Priority Substances



4.7 Use of Modelling in Risk Assessment

"A model is simply a means for organizing information to express our conception of reality."[21] Models are indispensable in the assessment and comparison of risks associated with a societal decision (see discussion in Section 5.1.1, "Decision Science"). Models are used to make the assessment of risk tractable either from a cognitive perspective or a computational perspective.

The risk analyst (and decision analyst) must find the correct balance between making the model simple enough to be understood and communicated, yet comprehensive enough to adequately represent reality. "All models are wrong; the practical question is how wrong do they have to be to not be useful?"[22] Although developed for environmental health risk, the majority of the following guidelines for the appropriate use of mathematical models[23] can be generalized to assessment of other risks:

- Do not use a model without adequate understanding of its basic assumptions and limitations
- Test the model extensively to assess the sensitivity of risk estimates to uncertainty in model assumptions and data values
- Treat model results as theoretical predictions, with associated uncertainty, not as findings of fact or objective reflections of reality
- Do not accept an arbitrary expression of risk based on a single statistical 'point estimate', instead employ a range of relevant risk estimates based on various model assumptions about dose-response, exposure, and individual susceptibility
- Explain the sources of uncertainty and their potential contribution to overall uncertainty in risk predictions
- Provide a clear non-mathematical narrative of model assumptions and results
- Avoid imparting a false sense of accuracy and precision in risk estimates
- When data are insufficient to calculate a meaningful risk estimate, use the model results only for risk ranking and priority setting.

4.8 Dealing with Uncertainty: Probability and Judgment

> "*Uncertainty* is a capacious term, used to encompass a multiplicity of concepts. Uncertainty may arise because of incomplete information – what will be the US defense budget in the year 2050? – or because of disagreement between information sources – what was the 1987 Soviet defence budget? Uncertainty may arise from linguistic imprecision – what exactly is meant by 'The river is wide'? It may refer to variability – what is the flow rate of the Ohio River? Uncertainty may be about a quantity – the slope of a linear dose-response function – or about the structure of a model – the shape of the dose-response function. Even where we have complete information in principle, we may be uncertain because of simplifications and approximations introduced to make analyzing the information cognitively or computationally more tractable. As well as being uncertain about what is the case in the external world, we may be uncertain about what we like, that is about our preferences, and uncertain about what to do about it, that is about our decisions. Very possibly, we may even be uncertain about our degree of uncertainty. The variety of types and sources of uncertainty, along with the lack of agreed terminology, can generate considerable confusion. Probability is often

> used as the measure of uncertain belief, and the conceptual confusions are often compounded by the controversy about the nature of probability."[24]

Risk is characterised by uncertainty. Rarely is it the case that all is known about a particular risk. Risk assessment is a disciplined way to fill in gaps of knowledge so that we can make better-informed decisions about how to address the risks that affect us as a society.

"The concept of probability occupies an important place in the decision-making process, whether the problem is one faced in business, in government, in the social sciences, or just in one's own everyday personal life."[25] Most decisions are made in the face of uncertainty based on less than perfect information. Probability enters into the process by playing the role of a substitute for certainty - a substitute for complete knowledge. Because in many risk issues, the outcomes and their associated likelihood are not known, estimates of probability are often based on belief (i.e., expert judgment) rather than frequency (i.e., observations or data). Thus, we are forced to rely on subjective expert judgment. This subjectivity is at the same time indispensable and problematic. Methods that have been used to establish due diligence in the use of expert judgment include:

- justification by the expert making the estimate, i.e., explicitly revealing all assumptions and the rationale of both the underlying science and judgment applied,
- peer review

Knowing that we must depend on expert/subjective judgment to estimate probabilities, it is standard practice in engineering design and in environmental and health risk assessment to build in safety factors to provide an extra measure of confidence that we do not underestimate the true risk.

Also, in engineering design, and more recently in security planning, an approach of "defense in depth" is used to ensure that anticipated risks are addressed. Redundancy in safety measures is built into the system, with several layers (or rings) of protection. These cascading safeguards are each aimed at either preventing, detecting, controlling or mitigating the consequences of an undesired event.

4.9 Assessing Quality of Decision Inputs

The quality of a decision is determined to a large extent by the underlying evidence or input used and the objectivity of the assessment process itself. Requiring technical experts to rate the quality of their estimates and the information on which their estimates are predicated will provide a basis for transparency and traceability in decision-making. The following is a hierarchy of classes of risk estimation inputs, listed in descending order of strength or quality of evidence.[26] This hierarchy provides a system for classifying the quality of decision inputs that NWMO may wish to consider employing.

Class A – Data and direct experience. The strongest risk estimates are developed based on historical data for the specific process and location under consideration. In this case, there is sufficient data to inform on all risk scenarios. Furthermore, it is reasonable to expect that future performance can be predicted based on past experience.

Class B – Surrogate data. If sufficient data are not available for the process or location under consideration, then local data can be supplemented with aggregate data for systems that are sufficiently similar (e.g., similar scale and operating conditions) to that under consideration. Typically, the analyst uses expert judgment to calibrate the aggregate data to fit the local situation. Typical sources of aggregate data are governments, industry associations and insurance companies. Databases exist for failure data, incident data, exposure data, health and environmental effects data, etc.

Class C – Models. When sufficient historical and surrogate data are not available, risk performance can be modelled based on information developed from experiments (e.g., testing of material properties under various conditions, in vitro or animal studies, simulations to test human performance), logical structure (e.g., Fault Tree Analysis, Failure Modes and Effects Analysis), and other methods that structure experience and expert knowledge (e.g., What-If Analysis, Neural Networks, Delphi techniques).

Class D – Expert Judgment. This is really "expert opinion" supported where possible by other historical data or other information on expected behaviour of the process or risk under consideration. This is the poorest quality of risk estimate but may be appropriate if the risk is small or if a decision must be made and no other data or information is available.

4.10 Accounting for Public Concerns over Safety in Risk Assessment

Differences in public and expert attitude towards risk and safety often stems not from a difference in the understanding of the risk but rather from a difference in the values used to interpret what the risk means. Factors identified by researchers as particularly important in public perceptions of toxic substances include (after Covello[27]):

1. **catastrophic potential**, i.e., people are more concerned about fatalities and injuries that are grouped in time and space (e.g., simple airplane crash which can kill hundreds of people versus car crashes that kill only a few people at a time)
2. **familiarity**, i.e., people are more concerned about risks that are unfamiliar (e.g., nuclear power) than about risks that are familiar (e.g., car accidents)
3. **understanding**, i.e., people are more concerned about activities characterised by poorly understood exposure mechanisms or processes (e.g., electromagnetic fields) than about activities characterised by apparently well understood exposure mechanisms or processes (e.g., slipping on ice).
4. **uncertainty**, i.e., people are more concerned about risks that are scientifically unknown or uncertain (e.g., modelling data on low doses of chemicals) than about risks that are relatively known to science (e.g., actuarial data on car accidents)
5. **controllability**, i.e., people are more concerned about risks that they perceive to be not under their personal control (e.g., accidents at industrial plants) than about risks they perceive to be under their personal control (e.g., driving a car)

6. **volition**, i.e., people are more concerned about risks they perceive to be involuntary (e.g., exposure to industrial emissions) than about risks that they perceive to be voluntary (e.g., smoking, or mountain climbing)
7. **effects on children**, i.e., people are more concerned about activities that put children specifically at risk (e.g., contaminated milk) than about activities that do not put children specifically at risk (e.g., consumption of alcohol by adults))
8. **effects on future generations**, i.e., people are more concerned about risks to future generations (e.g., genetic effects due to exposure to radiation) than about risks that pose no special risk to future generations (e.g., skiing accidents)
9. **victim identity**, i.e., people are more concerned about risks to identifiable victims (e.g., a child who has fallen in an abandoned well) than about risks to statistical victims (e.g., statistical profiles of drowning victims)
10. **dread**, i.e., people are more concerned about risks that are dreaded and evoke a response of fear, terror, or anxiety (e.g., exposure to carcinogens or radiation) than about risks that are not especially dreaded and do not evoke a special response of fear, terror, or anxiety (e.g., common colds and household accidents)
11. **trust in institutions**, i.e., people are more concerned about situations where the responsible risk management institution is perceived to lack trust and credibility (e.g., criticisms of some regulatory agencies for their ties to industry, Canadian Red Cross) than they are about situations where the responsible risk management institution is perceived to be trustworthy and credible (e.g., trust in the Centers for Disease Control)
12. **media attention**, i.e., people are more concerned about risks that receive much media attention (e.g., nuclear waste) than about risks that receive little media attention (e.g., radon)
13. **accident history**, i.e., people are more concerned about activities that have a history of major and sometimes minor accidents (e.g., nuclear power plant accidents such as Three Mile Island) than about activities that have little or no history of major or minor accidents (e.g., recombinant DNA experimentation)
14. **equity and fairness**, i.e., people are more concerned about risks where the consequences and costs are borne by only some of the individuals/groups who stand to benefit
15. **benefits**, i.e., people are more concerned about hazardous activities that are perceived to have unclear or questionable benefits (e.g., power generation using nuclear power in a nation rich in other sources of energy) than about hazardous activities that are perceived to have clear benefits (e.g., automobile driving)
16. **reversibility**, i.e., people are more concerned about activities characterised by potentially irreversible adverse effects (e.g., acid rain and ozone depletion) than about activities characterised by reversible adverse effects (e.g., injuries from sports)
17. **personal stake**, i.e., people are more concerned about activities that they believe place them (or their families) personally and directly at risk (e.g., living near a hazardous industrial facility) than about activities that do not place them (or their families) personally and directly at risk (e.g., hazardous facilities located in sites remote to them)

18. **evidence**, i.e., people are more concerned about risks that are based on evidence from human studies (e.g., epidemiological investigation of occupational exposures) than about risks that are based on evidence from animal studies (e.g., laboratory studies of toxic chemicals using mice or rats)
19. **origin**, i.e., people are more concerned about risks caused by human actions and failures (e.g., industrial accidents caused by negligence, inadequate safeguards, or operator error) than about risks that are caused by acts of nature (e.g., hurricanes)

5 Assessment Methodologies

5.1 Social Assessment Methods

In a review of the Seaborn panel and associated processes, Páez Victor[28] identified the following social issues and shortcomings of the AECL Nuclear Fuel Waste Management Disposal Concept:

- Deficiencies of the "generic concept", its appropriateness
- Lack of consideration of alternative management options
- Inadequate public participation process including inadequate policy and decision-making
- Inadequate, flawed Environmental and Social Impact Statements including site selection, human health and safety impacts, transportation and costs
- Inadequate, incomplete risk analysis, inadequate modelling, unacceptable levels of uncertainty, insufficient capacity to make predictions over time
- Inadequate development of regulations and standards
- Inadequate ethical analysis
- Culturally inappropriate consultation with Aboriginal people and decision making process that ignored their rights
- Lack of trust or credibility of proponent, the industry , the regulator and the government to undertake or oversee this project.

According to Páez Victor, the issue of social acceptability includes four seminal and interrelated social issues:

- The need to appropriately identify social values
- The solutions proposed do not include reducing or stopping production of nuclear wastes [To put it more generally, the need to appropriately determine the decision boundaries. For example, many public comments (particularly from aboriginals and children) received by the Seaborn panel often reflected the sentiment, 'We didn't ask for this waste. Why should we have to deal with it?' This indicates not only frustration with the limited scope of the current decision(s) but also lingering discontent with past decisions regarding nuclear energy and nuclear fuel waste management.]
- Scientific uncertainty and perpetuity of the risks and challenges to social institutions
- The need for a process that is trusted.

Critical to the issue of assessing and integrating social factors in decision-making is the notion of acceptable or tolerable risk. How NWMO determines that any particular waste management approach is "socially acceptable, technically sound, environmentally responsible, and economically feasible"[29] will depend on subjective values that are strongly influenced by societal norms and expectations about safety and the public interest. Safety is not the absence of risk (zero risk does not exist) but rather the acceptability of risk under certain circumstances as defined by societal norms. The acceptability of any management option is influenced by both the perception of its associated risks, costs and benefits.

A further discussion of the factors that influence perceptions and ultimately the tolerability of health risks is found in Section 4.10, "Accounting for Public Concerns over Safety in Risk Assessment". Section 5.1.2, "Decision Science Models", describes approaches for incorporating social and ethical considerations into the assessment of management options in a way that leads to an acceptable balance between risks, costs and benefits. Specific methods for gathering information about social and ethical values are described in Section 5.1.3, "Applied Research Methodologies for Measuring Public Attitudes and Values".

5.1.1 Decision Science

Decision science (or analysis) identifies a collection of techniques for assisting individuals and organizations in the performance of difficult inferences and decisions.[30] Complex inference and choice tasks are decomposed into smaller, more manageable elements, some of which are probabilistic (or science-based) and others preferential (or value-related). The presumption is that individuals or groups find it more difficult to make holistic global judgments required in complex decisions than to make specific judgments about identified elements of these tasks. A major task in decision analysis is to identify the necessary ingredients of a particular decision task and of related sub-tasks. It is also necessary to have a process for reassembling or aggregating these elements so that a choice can be made. Decisions involving multiple stakeholders are often characterised by conflicting objectives. Trade-offs are used to resolve conflicting objectives. Problem structuring also involves the generation of options or possible choices.

Arsham[31] asserts that everyone makes decisions, but not everyone is a decision analyst. A decision analyst uses quantitative models and computational methods to formulate decision-problems, assess decision performance, identify and evaluate options, determine tradeoffs and risks, and evaluate strategies for investigation and research. The ranking of solutions is the main objective of Multi-Criteria Decision Analysis (MCDA) which is discussed further in Section 6, "Integration, Evaluation and Selection".

Decision science offers a systematic, logical approach for combining information about the probability of certain outcomes with information about desires and interests (e.g., NWMO's stated goal of developing a management approach that is "socially acceptable, technically sound, environmentally responsible, and economically feasible"). Evaluating alternatives requires that a decision-maker's interests be expressed as criterion that reflects the attributes of the alternatives relevant to the choice. The decision analysis approach provides a structured framework for choosing courses of action in a complex, uncertain, or conflict-ridden situation. The choices of possible actions, and the prediction of expected outcomes, derive from a logical, transparent analysis of the decision situation, including an understanding of the decision options and the values of stakeholders.

The key elements of decision analysis are understanding the problem selecting the correct criteria (i.e., asking the right questions), and then determining the value/number for each criteria. In many cases, the application of decision analysis is 90% defining the problem and 10% calculating the answer. The primary benefit often lies in the improved understanding and communication developed during the problem formulation stage.

Arsham advocates "the bootstrapping approach, in which the decision maker and the decision analyst work together to develop first a simple model that provides a crude but understandable analysis. After the decision-maker has built up confidence in this model, additional detail and sophistication can be added, perhaps progressively only a bit at a time. This progressive model building is the most important factor in determining successful implementation of a decision model. Moreover, the bootstrapping approach simplifies the otherwise difficult task of model validating and verification processes."

Like other models, decision models are an approximation of reality. They aim to capture the structure of decision-making process, that is, the important variables and their interactions. For this reason, it is important to represent all variables in the decision model even if they are qualitative in nature. "Omitting structures or variables known to be important because numerical data are unavailable is actually less scientific and less accurate than using your best judgment to estimate their values."[32] This conclusion is particularly relevant in addressing social, political, and ethical aspects that are critical in finding solutions that citizens can support.

5.1.2 Decision Science Models

Freudenburg[33] argues that technical controversies almost invariably combine three types of questions relating to facts, values and blind spots. These questions typically take the following form:

- *How safe is it?* In principal, a question that can be answered by science (and expert judgment).
- *Is that safe enough?* A question that cannot be answered by natural science. Rather, it requires application of social science to understand stakeholder values.
- *Are we overlooking something?* Essentially an issue of perspective, or more precisely limited vision. Blind spots arise due to *unknowns* and to *unknown unknowns.* Unknown unknowns arise when we are unaware that we don't know some key element of the issue.

Based on a review of the literature, Freudenburg concludes that

> "Most scientists are susceptible to the same malady that afflicts most other mortals, namely, a pervasive overconfidence, or to put it differently, a pervasive tendency to *under*estimate how many unknowns still remain to be discovered within the field we think we know something about… While it is possible to hypothesize that experience will breed accuracy, in short, a growing number of studies suggest just the opposite: in all too many fields, familiarity appears to generate at least complacency, if not a kind of contempt. The 'cognitive dissonance perspective' suggests a stronger conclusion: it may be that persons in "risky" occupations will generally tend to ignore, minimize, or otherwise underestimate the risks to which they are exposed, thus reducing the "dissonance" that might be created by focusing on the risks that are implicit in an occupational choice that has already been made". [34]

Is it not entirely possible that policy makers are susceptible to the same overconfidence in their ability to strike a balance between conflicting objectives and values of stakeholders or to accurately foresee the implications of their decisions?

Morgan and Henrion[35] suggest attributes of good policy decision analysis that are consistent with NWMO's defined process for developing its assessment framework and conducting its comparative assessment of the management approaches for nuclear fuel waste management. These "Ten Commandments" for good policy analysis are:

1. Do your homework with literature, experts and users.
2. Let the problem drive the analysis.
3. Make the analysis as simple as possible, but no simpler.
4. Identify all significant assumptions.
5. Be explicit about decision criteria and policy strategies.
6. Be explicit about uncertainties.
7. Perform systematic sensitivity and uncertainty analysis.
8. Iteratively refine the problem statement and the analysis.
9. Document clearly and completely.
10. Expose the work to peer review.

Models for decision making from the environmental arena are useful for the nuclear fuel waste management issue in Canada. Similar to the nuclear fuel waste management issue, environmental problems require societal decisions on matters that are characterised by high levels of complexity and uncertainty. Subsequently, they demand that we bring to the table both our best understanding of the underlying science and our best understanding of Canadians' ethical and social values on the issue.

Cothern[36] provides a comparison of existing models for environmental risk decision-making. He lists several models which are described in Appendix II: Ideal model; The [US] National Academy of Sciences "Red Book" model; cost benefit analysis; a framework model; a channel model; an overlay model; and a continuous model. In addition, a policy analysis model is discussed in Appendix II.

5.1.3 Applied Research Methodologies for Measuring Public Attitudes and Values

> "Values are determinants of attitudes. … a single attitude is "caused" by many values – by one's whole value system, in fact. [An] example will serve to crystallize this understanding. If I am shopping for a new car, my value system tells me the relative importance of economy, power, comfort, durability, roominess, safety, style, and so forth. My attitude toward a particular car (in fact, toward every particular car) is determined by my hierarchical ordering of these values and by my beliefs regarding the extent to which each car is associated with the fulfillment of each value. … Attitudes constitute an immensely important component in the human psyche. They strongly influence all our decisions: the friends we pick, the jobs we take, the movies we see, the foods we eat, the

> spouses we marry, the clothes we buy, and the houses we live in. We choose the things we choose, to a large extent, because we *like* them."[37]

A number of methods are available for engaging the public to determine attitudes and values of citizens and interest groups. There are methods (including focus groups, surveys/polling, and other forms of public consultation) that focus on understanding values in terms of what we care about, which issues are important to us and why we are interested in certain outcomes of a decision versus others. There are also methods for determining how people value costs and benefits (e.g., econometric measures and quality of life measures).

Focus Groups

This subsection is based on a review by Gibbs of focus group methodologies.[38] Focus group research involves organized discussion with a selected group of individuals to gain information about their views and experiences of a topic. The size of focus groups varies, but is typically within the range of four to fifteen members. It is standard practice to use an explicit interview guide and to explore the subjective experiences of participants in relation to predetermined research questions.

A distinguishing feature of focus groups is the insight and data produced by the interaction between participants. This interaction highlights participants' views of the world and their values and beliefs about a situation. The main purpose of focus group research is to draw upon respondents' attitudes, feelings, beliefs, experiences and reactions in a way in which would not be feasible using other methods, e.g., observation, one-to-one interviewing, or questionnaire surveys. These attitudes, feelings and beliefs may be partially independent of a group or its social setting, but are more likely to be revealed via the social gathering and the interaction achieved through a focus group setting.

Focus groups elicit information in a way which allows researchers to find out why an issue is salient, as well as what is salient about it. Focus groups are particularly useful when there are power differences between the participants and decision-makers or professionals, and when one wants to explore the degree of consensus on a given topic. They are, however, limited in terms of their ability to generalize findings to a whole population, mainly because of the small numbers of people participating and the likelihood that the participants will not be a representative sample.

Participants of focus group research can find the process empowering both through the opportunity to be involved in decision making processes and by being valued as experts who work collaboratively with researchers. Not everyone will experience these benefits, as focus groups can also be intimidating at times. Hence other methods may offer more opportunities for some participants.

Surveys/Public Opinion Polling

Although we are perhaps most familiar with polling on political issues, it can also be a useful research tool for public policy formulation. Polling can be used to determine:

- What people are thinking
- What people know
- How people perceive issues and political objects

- Characteristics of people
- Links between the above parameters.

"A poll is a systematic, scientific, and impartial way of collecting information from a subset, or sample, of people that is used to generalize to a greater group, or population, from which the sample was drawn. A poll is not designed to persuade or identify individuals – there are cheaper and more efficient ways of doing that (telephone canvass, for example). Confusing these goals with those of a poll can seriously bias the information you receive. A poll also is not intended to describe any one individual in depth. Again, a case study is a cheaper and more efficient way to do that. A poll is a measurement at one point in time that reveals attitudes, behaviours, beliefs, attributes and the interrelationship of all of these parameters. These generalizations can then be extended to the larger society."[39].

In a poll, information is obtained in a scientific, controlled way from a selected subset of people. A properly selected subset enables the researcher to generalize the findings reliably to a greater population after attributing a known margin of error to the sampling. Careful interviewing, questionnaire construction, and analysis also minimize other forms of error that are difficult to measure.

A poll can be conducted via personal interviews or through surveys administered via mail, Internet or telephone. Because a poll is not designed to influence or persuade people, it should never identify the organization or goals in such a way as to influence the respondents' answers. Any interviewing should be kept as neutral as possible.

Public Consultation[1]

Sterne and Zagon[40] have produced a practical document for the purpose of assisting public service managers considering or undertaking consultation initiatives. It reviews the changing relationship between Canadians and their governments and situates public consultation as one of several tools that have emerged to serve the changing relationship. It sets out principles and guidelines for effective consultation. It offers four different ways to approach the what, where, when, who and how of public consultation.

- *The 4-P Pyramid Model* – a conceptual framework
- *The Topographical Model* – a strategic framework
- *The Rubick's Cube Model* – a planning framework
- *The Roadmap Model* – a process framework

[1] For international practice in public consultation see Appendix III

The document also lists other popular public consultation activities, mechanisms or techniques, including:

- Advisory Board/Committee
- Brainstorming
- Briefing/Debriefing
- Call for Briefs/Submission
- Charrette
- Coffee Klatch
- Computer-Assisted Participation
- Conference
- Delphi Process
- Dialogues
- Discussion Paper
- Electronic Conferencing/Highway
- Focus Group
- Information Communication
- Internet
- Interviews
- Open House
- Panel
- Parliamentary Committee
- Participatory Television
- Public Hearing
- Public Meeting
- Public Seminar
- Round Table
- Royal Commission
- Site Visit
- Study Circle
- Survey
- Task Force
- Toll-Free Telephone Line
- Workshop
- Written Submission

Examples of the information gathering and public consultation activities in the first stage "Understand the Decision Context", NWMO's dialogue with Canadians included:

- **Early Conversations.** Public opinion research and conversations with individuals and organizations to learn about the issues and views of Canadians
- **Envisioning the Future.** Scenarios[1] development to "test" adequacy of long-term approaches for nuclear waste management
- **Exploring Concepts.** Commissioned background papers on key topics, including the many public policy challenges issues raised during the early conversations with Canadians
- **Alternative Perspectives.** Commissioned papers and expert workshops to identify broad questions and requirements on a range of topics including ethics, traditional aboriginal knowledge, environment, nuclear waste host communities, science and technology, finance and law, and international best practice.

Table 5.1 lists the NWMO milestone documents, along with the target release date and purposes of each document.

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[1] Consideration of future possibilities, using scenario envisioning, will factor into the NWMO assessment process. For example – what happens if more reactors are built in Canada?

Table 5.1: NWMO Milestone Documents

MILESTONE DOCUMENT	TARGET RELEASE DATE
Discussion Document 1 **Asking the Right Questions?**	December 2003
Discussion Document 2 **Understanding the Choices**	Mid 2004
Discussion Document 3 **Choosing a Way Forward (Draft)**	Early 2005
Final Study **Choosing a Way Forward**	By Nov 15, 2005

Econometric Approaches

Willingness to Pay (WTP), Contingent Valuation (CV), and Cost of Illness (COI) are examples of econometric approaches.

The WTP measure is typically used in evaluation of environmental and transportation related risks. The approach is to determine the damage function, where damages refer to negative impacts on human health or the environment, the converse being benefits, which refer to reduction in damages which occur in relation to a given policy or program activity. A more comprehensive monetary measure of the value of changes in health outcomes is the minimum willingness to accept (WTA) compensation to incur health risks and all associated costs. There are techniques that use market data, and there are techniques that attempt to elicit WTP and WTA measures directly.

The CV method is an alternative approach used to generate WTP estimates. This method "uses survey questions to elicit people's preferences for goods by finding out what they would be willing to pay for specified improvements in them. … It circumvents the absence of markets … by presenting consumers with hypothetical markets in which they have the opportunity to buy the good in question".[41]

COI estimates are based on medical costs incurred as a result of experiencing a health effect (e.g., such as an asthma attack from air pollution) that results in admission to a hospital. These types of estimates may also include lost wages as a value of lost productivity. COI measures do not reflect the value individuals place on avoiding restrictions of or reduced enjoyment of leisure activities, discomfort, or inconvenience to family members and others.

Quality of Life (Health Benefit) Measures

The Quality Adjusted Life Year (QALY) measure is typically used in medical and public health fields. QALY measures the value of a health profile in terms of the duration of an equally preferred health profile free of any health impairment. Two other methods that are closely related to QALYs are Disability Adjusted Life Years (DALYs) and Healthy Years Equivalent (HYEs).

DALYs are similar to QALY's except that they incorporate a weighting factor that depends on age and measure the loss of longevity and health from an idealized health profile. The HYE for a specified health profile is simply the number of years lived in perfect health that the individual judges to be desirable.

The Life Quality Index (LQI) method is a compound social indicator comprising societal wealth and longevity, as a tool to guide the selection of optimal strategies for managing risk. The LQI is also equivalent to a utility function that is consistent with several principles of decision analysis. The proposed framework is intended to satisfy some basic principles of risk management in the public interest, namely, accountability, maximum net benefit, compensation, and life measure[42]. These principles attest to the need for:

1. A unified rationale for application to all risks (e.g., to life, health, or property)
2. A simple and meaningful test of the effectiveness of allocation of scarce resources
3. Compensation to ensure that implementation of a policy is socially beneficial where there is a need to compensate the losers
4. Enhancing a relevant measure of life by maximizing the net benefit of life by maximizing the net benefit in terms of quality of life in good health for all members at all ages.

5.2 Technical Assessment Methods

Methods for assessing the immediate and long term behaviour of a nuclear fuel depository are necessarily specific to its characteristic as a high-level long-lived radioactive waste, thus imposing a requirement for maintenance of safety over a very long period, for both humans and the environment.

Although the nuclear industry and their governing bodies, nationally and internationally, have explored a number of options for spent nuclear fuel storage, the NWMO has a mandate to only those technical options that the Canadian government has selected as potentially appropriate for the Canadian society, and Canadian geography. The Nuclear Fuel Waste Act requires that the NWMO study must include as a minimum, at least one approach based on each of:

(a) Deep geological disposal in the Canadian Shield, as described in the AECL EIS, taking into account CEAA panel's views.
(b) Storage at nuclear reactor sites,
(c) Centralized storage, either above or below ground, and
(d) A possible fourth method that would combine two or more of the three methods.

The first option is the most widely studied world-wide, and the option for which the most extensive literature exists assessing risks and uncertainties. The second option could, in its simplest form, comprise the "do nothing" option, since Ontario Power Generation and other Canadian site operators have adopted dry storage on-site as the preferred form of storage on-site beyond reactor life. An argument can be made that this form of storage, with appropriate administrative measures, is suitable for an indefinite period of on-site storage. The first and third options would require large-scale transportation of wastes currently stored at individual reactor sites.

The technical component of the nuclear industry is highly specialized and methodologies specific to nuclear power generation technology have been developed, and form the bulk of the discussion in the following sections. In addition, generic methods such as hazard and operability studies and root cause analysis are discussed.

Any assessment methodology employed must have an outcome that can comply with the existing legal framework, outlined in the next section, and also anticipates future regulatory moves.

5.2.1 Legal and Regulatory Issues

As noted in the U. S. National Research Council publication[48] "Disposition of High-Level Waste and Spent Nuclear Fuel", the regulator's role is to

1. establish the rules for demonstrating compliance, to be followed by the implementing agencies
2. decide if the implementing agency's license application meets these requirements

A phased and scientific approach to regulation will parallel the phased approach (adaptive staging, 5.2.8) to technical methodology. Thus it is anticipated that there will be a multi-decade process of regulatory approval, in which a highly prescriptive process could be counterproductive, Detailed regulatory guidance, and comprehensive inspection programs will allow the flexibility to achieve the "reasonable assurance" sought by the regulators. There will be a specific regulatory compliance period, determined at the level of public policy.

Existing Legal Framework for Licenses and Permits

Under the current Canadian Nuclear Safety and Control Act[43] and its associated Regulations, CNSC must issue a License for any new construction, major re-work (as in the case of the Pickering Restart Project), decommissioning and abandonment of nuclear facilities. Licenses must also be renewed in accordance with terms under which they are granted, typically two to five years. The relationship between this Act and the Canadian Environmental Assessment Act is prescribed, in that any work deemed to be a "project", impinging on a prescribed "law list", or involving federal lands or funding requires an environmental assessment as the first step towards licensing (refer to Section 5.3.2).

A key element to support the license is a Safety Report, which must be submitted for construction and operation (and updated on a regular basis) for each facility. This document, in addition to describing the facility and its environment, must contain evidence that any chronic emissions as well as postulated accident releases lie within prescribed guidelines.

The CNSC also delegates a number of areas to Provincial jurisdictions for oversight and enforcement. For example, pressure boundary activities are under the oversight of the TSSA in Ontario.

Specifically, with respect to irradiated fuel disposal, the AECB has required[44] that the predicted risk be "sufficiently low so as to allow for uncertainties in exposure scenarios and their consequences".

5.2.2 Performance Assessment: Geological Repositories

Analyzing the *long term behaviour* of a geological repository has been addressed by the scientific stakeholder community through development of a quantitative methodology known as performance assessment. This is a safety assessment capable of providing a basis for decision-making, of the type that would be required before implementation of a geological repository. The performance assessment models, resulting from 20 years of extensive research, conducted by representatives from the fields of engineering, physics, chemistry, earth sciences, and mathematics, allow understanding of the range of potential future behaviours of repositiories.

Performance assessment (PA) can be used to make quantified estimates, or "predictions", of the possible future behaviour of repositories and also to quantify the uncertainties in these predictions, including the information about the site. This methodology is well documented and has been widely applied in many national programs[45,46,47]. Moreover, this methodology has been judged by the technical community as a sufficiently reliable tool for input to decision making[48].

The results of performance assessment are used in an application to the regulating authority for licenses to construct, open, fill and close the repository.

A typical Performance Assessment should include[49]:

- An evaluation of behaviour of the repository under "normal evolution" conditions to sufficient time that any radiation exposures attributable to the stored waste would have returned to near background
- An evaluation of the probability and consequences of natural or man-made deviations from the assumptions made in the "normal evolution" scenario.

The US NRC lists 14 steps, the first 12 of which address technical matters, under "Performance Assessment". The list provides a checklist for the design process. In summary:

1. Characterize the waste
2. Characterize repository design and expected evolution
3. Characterize the site (present and future properties)
4. List all upset events and processes from internationally accepted checklists [e.g. NEA 2000[50]]
5. Screen (review) the list(s) of events for applicability
6. Assess probability of occurrence
7. Model and validate repository behaviour including coupled events.
   Validate using data sources external to the model.
8. Assess uncertainty of each parameter.
   Identify alternative models of the system
9. Create reference scenarios covering expected, probabilistic, and human induced events.

10. Relate these scenarios to regulatory requirements.
    Performance should exceed all regulatory or statutory requirements
11. Determine risk (probability x dose consequence) to Critical Group
12. Perform sensitivity analysis to identify critical assumptions, events, and scenarios. Use these results to refine analysis and repository design.
13. Regulatory authorities provide a judgment based on overall confidence in results
14. Political authorities and public must find the decision acceptable.

According to McCombie et al [46], a robust performance assessment is characterized by (1) being based on either well-validated, realistic models, or else on clearly conservative models and data; (2) assuring that all potentially negative processes are analyzed; and (3) being relatively insensitive to parameter and conceptual model changes. See Appendix IV on Repository Modelling – Concepts, Issues and Activities. Refer also to Section 5.2.6 for further discussion of modelling in this context.

5.2.3 Assessment Approach for In-Situ Storage and Central Storage Options

This report emphasizes the assessment methodologies for deep geological disposal, but it is recognized that two other options will be investigated; in-situ storage at point of origin and central storage.

There is a fairly broad international consensus that deep geological disposal, either on a retrievable design basis, or one where intrusions are designed against, will be the optimal solution. While surface (or near-surface) storage will still have merits in the near term, deep disposal will not rely on the actions of future generations. A recent report from the Nuclear Energy Agency (NEA, a division of the OECD) suggests that this is and will be the preferred option in most member states including Sweden, the UK, Finland and the US.

In another often-referenced report prepared for the nuclear industry by PANGEA in 2001 (PTR – 01-02) a multi- attribute comparison of various storage and disposal options was undertaken. The study was generic and applied to any country with such wastes, and incorporated many attributes including risks to humans, cost, management issues, overall confidence in meeting safety requirements and social stability.

Overall, the generic comparison indicated a clear preference for disposal over indefinite storage for all long-lived radionuclides. From the results it appears that only an emphasis on the very short-term (0 to 100 yrs) would lead to difficulty in choosing between longer-term storage and disposal, and even in this case disposal is still preferred by a narrow margin.

The results of this study are broadly in agreement with other such studies, but differ in the details. Such differences arise partly from how the options are defined and partly due to the treatment of impacts and features of the options that vary with time.

However, from a technical point of view there is no urgent need for final disposal of such wastes for safety reasons, due to the high level of safety associated with existing storage mechanisms.

However, urgency in some jurisdictions (such as the US) is due to depletion of in-situ storage capacity or because of legislated deadlines. Elsewhere, the choice of options appears to be less of a technical and more of a societal decision for each country, and, as such, need not be rushed.

Above Ground and Near-Surface Options

In the absence of a final management solution for high level nuclear wastes, various countries adopt a near-term policy of safely storing such wastes in various above ground (or near surface) storage systems until a permanent solution is identified, agreed-upon and implemented. However, such storage mechanisms can also be utilized as a longer-term solution. This would allow future generations some flexibility in deciding what to do with the radwaste legacy, and allow them to take advantage of any future technological advancements.

DISADVANTAGES

Non-geological storage that becomes a permanent solution places a radiological burden on future generations. In anticipation of early disposal, most such current stores and waste packages were designed to last for decades and not millennia. Any storage longer than 50 to 100 years will place unanticipated demands on structures and packaging. Human interventions, risks to workers and unintended consequences could all ensue as a result of relocation to an alternative site or to prepare the waste for repackaging.

Assessment Tools

As part of any comparative assessment of surface or near surface storage (central or in-situ) the assessment tools and safety requirements will be very similar to those applied to deep geological disposal. Modeling of package behaviour over time, modeling of various potential dispersal mechanisms in the biosphere and modeling of various off-normal events will have to be developed and applied [example: IAEA BIOMASS, EC BIOCLIM]. Similarly, the safety case will be dependent on assurances that the maximum allowed doses to members of the public (critical group) would not be exceeded under any credible normal or off-normal scenario.

However there will be some differences:

1) There will be no need to model rock behaviour or radionuclide transport through deep geological media, or hydrological impacts on such behaviour.

2) Predictive tools for man-induced intrusions will be very different, and will depend on assessment of various credible scenarios local to the jurisdiction, unlike that for modeling natural phenomena.

3) There will be relatively modest but still significant ongoing occupational radiation dose associated with worker exposures in an operational waste management regime.

NOTE: In virtually all jurisdictions extended surface storage as an option has not yet been objectively addressed through performance assessment of likely scenarios. The NEA has recognized this and has recommended that such assessments be made [NEA annual report 1999]

Radiological Assessments

IN SITU STORAGE

The assessment tools that apply to in-situ storage are essentially the same risk-based dose estimation mechanisms that are applied by nuclear regulators in all countries with nuclear programs. These are dominated by radionuclide release and exposure dose limits to the general population (critical group) and to radiation workers who accumulate occupational dose as a result of waste management operational activities.

In Canada, these dose criteria and limits are imposed by the federally mandated Canadian Nuclear Safety Commission (CNSC), and would not be much different from that applied to the dry storage facilities that presently exist at operating CANDU nuclear stations. Accordingly, the assessment tools would be essentially the same as those used to license these operating facilities, but likely applied over a longer time frame.

CENTRAL STORAGE

The basic concept of storage at one central location (surface or near surface) would differ little from the in-situ storage option from the standpoint of scenario assessment and biosphere modeling. However, the differences would relate to the risks and doses associated with additional transportation and handling. This arises from transportation from the site of origin to the central site and then eventually to the site of ultimate treatment and/or disposal. Transportation risk assessment has already been dealt with elsewhere in this report.

The risk based licensing and safety requirements applied in such a case would be an extension of the ones applied to in-situ. The assessment tools would be the same ones applied for licensing existing surface storage facilities and for which there are ample precedents in any country implementing a shorter-term spent fuel storage program.

ACTION LEVELS AND THE SAFETY CASE

One significant difference in the safety case for both in-situ and central storage (as opposed to deep geological disposal) is that operations staffers are actively involved with the radioactive materials management process over a longer time frame. This means that greater occupational radiation exposures are going to be a key issue in the safety case for the regulator (CSNC in Canada) regardless of location.

When applying the principles of ALARA at an operational facility the regulator will usually ask for a definition of an ‘action level’ which is somewhere below the ALARA limit and which would trigger some management response to ensure that any unplanned radiation dose excursions (above ALARA) remain temporary. The NEA and the CNSC are both putting more emphasis on action levels as part of the licensing process.

The performance assessment tools for such facilities would have to model the normal and off-normal occurrences to ensure that ALARA limits were met ‘on average’ and that action level triggers were appropriate and sufficient to ensure timely management response to design basis off-normal events or excursions.

5.2.4 Transportation Assessment

Transportation is a key element of both the geological repository model and centralized on-site storage. Used fuel movement involving rail, barge and road scenarios have been studied in Ontario. These studies have been used to estimate both cost and risk of fuel shipment. In all such studies, the outcome of greatest significance is the risk/km of a traffic accident in which a heavily laden truck is engaged in a road accident. Relatively, there is a very much lower risk of radiation release from destruction of the waste container in the truck.

Although the fuel packages themselves are designed to prevent the dispersal of the irradiated fuel cargo under all credible accident conditions, the number of shipments and the potential visibility of the inevitable traffic accidents creates a strong negative impression. Barge shipment requires special attention to recovery of fuel packages from deep water, means to address public concerns for drinking water pollution, and may come under both US and Canadian scrutiny via the International Joint Commission (IJC). Rail poses unique security and logistic problems for large-scale shipment such as dedicated trains and priority routing.
In general, transportation concerns may be summarised as follows:

1. The state and safety of Canadian highways
2. The feasibility of alternative transport means
3. Potential for accidents
4. Potential for terrorism
5. The integrity of the shipping casks
6. Emergency preparedness
7. Rights of communities along the routes

With respect to the design and performance of the transport casks, the IAEA guidelines[51] that have evolved to govern such shipments have been agreed-to almost universally. They form, along with the Dangerous Goods Act[52], a reputable basis upon which to design and operate fuel shipment packages in Canada. In the US, the continued concern for very low levels of risk from transport accident has generated a dialogue regarding the need for multiple, full-scale, package tests, some of which should take the packages to their failure limits. Such testing has raised industry concerns that only the image of destroyed packages will remain, exclusive of the extreme conditions required to induce such a failure.

5.2.5 Generic Methods for Technical Assessment

Hazard and Operability Studies

Hazard and Operability Analysis (HAZOP) is a technique developed to identify and evaluate safety hazards in a process plant, and to identify operability problems, which, although not hazardous, could compromise the plant's ability to achieve design productivity. In HAZOP analysis, an interdisciplinary team uses a creative, systematic approach to identify hazard and operability problems resulting from deviations from the process' design intent that could lead to undesirable consequences. An experienced team leader systematically guides the team through the design using a fixed set of guidewords. An example of library guidewords and relevant deviations for process section types is shown in table 5.2

Table 5.2: Example library of relevant deviations for process section types

Deviation	**Process Section Type**				
	Column	Tank/Vessel	Line	Heat Exchanger	Pump
High Flow			X		
Low/no flow			X		
High level	X	X			
Low Level	X	X			
High pressure	X	X	X		
Low pressure	X	X	X		
High Temperature	X	X	X		
Low Temperature	X	X	X Group		
Leak	X	X	X	X	X
Rupture	X	X	X	X	X

Root Cause Analysis as Applied in Pollution Prevention

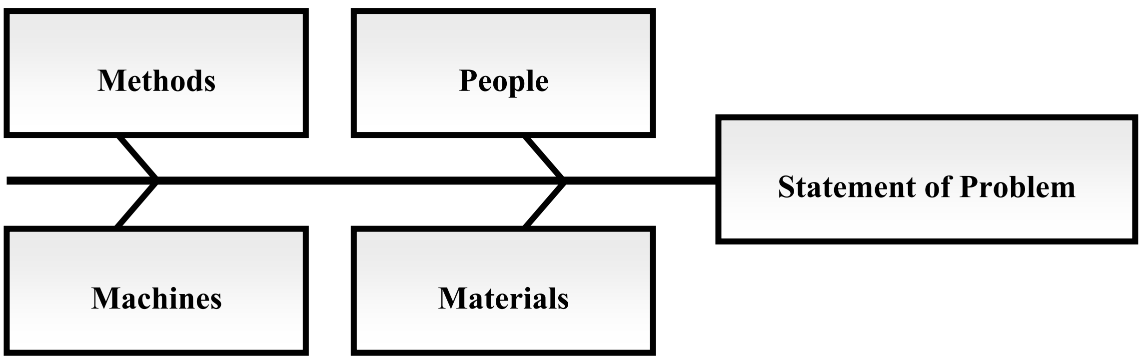
Practitioners of pollution prevention use a methodology derived from root cause analysis. To show how root cause methodology may be used, Pollution Prevention (P2) is described here as an example. In addition, comment is made on the potential use of P2 for high level nuclear waste.

The underlying foundation of the pollution prevention (P2) method is avoiding the creation of pollutants and waste, using the environmental management hierarchy in order of preference. The environmental management hierarchy embeds the P2 principles in its sequence of activities:

Reduce > Re-use > Recycle > Dispose

The goal is to eliminate the cause of waste. In application of root cause analysis to pollution prevention, it is noteworthy that the process to be examined by P2 methodology is usually already functioning, and the analysis is not necessarily directed at analysis of the cause of a past problem, but instead looks at the entire process for the prospects of application of P2 principles, preferably with activities that are high in the P2 hierarchy, i.e. reduction is preferred.
As an aid to this analysis, a cause and effect diagram (also called a “fish-bone” diagram) is often constructed. A simplified version is shown as Figure 5.1.

Figure 5.1: Cause and Effect Diagram



An article by Pojasek[53] in Pollution Prevention Review shows examples of utilization of the fishbone diagram for specific industrial P2 problems, and explains the causes, generically, as follows:

- *People* - all workers and managers, plus their knowledge, training, certifications, and attitudes
- *Methods* – issues such as process work flow, procedures, standard operating procedures, exception handling and operational definition.
- *Machines* – machinery, equipment, instrumentation, adjustments, maintenance and tooling capability
- *Materials* – expendable inputs and their characteristics, including suppliers, changes and variability

Applicability of P2 to high level nuclear waste (a process which may be wholly or partially implemented already) would require an on-site review to discover whether further P2 strategies could be employed. A legitimate strategy, if feasible, would be to extend the life of the nuclear fuel bundle, since only 67% of the U^{235} is utilized before the bundle is declared to be waste material. The technological implications of this extension could be (a) moderate, (b) major, or (c) not within the range of present technology. If additional megawatt hours could be obtained by life extension, then this would illustrate the first part of the P2 principles, i.e. Reduction. While re-use does not appear applicable in this case, processes that may be feasible for recycle are the subject of several international research projects. The cost and management comparison would be made with obtaining the same material from recycling as from mining and subsequent processing. The P2 approach would, in addition, utilize the best management practises and also avoid risk by including backup planning.

In addition, transportation of the spent fuel to a disposal site can incorporate standards and codes of practice that are inherently P2 methods (for example, the transportation segment of the Canadian Chemical Producer's Responsible Care®[54] program does so).

In summary, the choices for nuclear waste disposal can be tested against the following P2 criteria:

- Reduction of amount of waste – can the life of the nuclear fuel bundle be extended? Can other reductions be found?
- Risk reduction in transportation – from the stage of removal from the reactor to arrival at the disposal site - can best management practises in P2 improve the transportation system for the nuclear waste?
- Recycle/re-refining - can valuable material be obtained, in addition to waste reduction?

If, under adaptive staging (see 5.2.8), recycling/re-refining is determined to be viable, then this would have to be factored into the choice of management option for spent nuclear fuel.

5.2.6 Modelling

In its critique of the AECL EIS, the CEAA Panel Report [Seaborn 1998] touched on the criteria for acceptability of modelling studies as follows:

- Do the models consider all of the mechanisms that may be important?
- Are the methods used correct and reliable and is there confidence in the input data?
- Have the results been validated against other data sources, experience, natural analogues etc.?

Notably, the Panel also cited the need for the scenarios to be understood and accepted by the stakeholders . In modelling, therefore, it is important that the modelling approaches used to communicate results to the public and stakeholders employ effective visual techniques to display three-dimensional results in an intuitive form. For repository modelling, the accuracy and sophistication of models has evolved substantially over the last quarter-century. During the last few years in particular, the use of three-dimensional, finite element models has progressed to the point where these models are commercially available and widely accepted in science and engineering. The increase in computer power also offers a substantial advantage to "benchmarking" efforts, since it permits greater integration of model elements in a single module. Application of independently developed models to similar reference conditions, tested by independent groups and giving the same numerical outputs also provides a means to re-assure stakeholders, especially technical observers and regulators. Simplified mathematical models should also be considered to supplement complex models for the purposes of effective communication.

An important element of model validation is the means to "calibrate" models over geologic times, as noted in the third bullet above. An important approach involves the study of 'natural analogues" where changes in physico-chemical conditions in an environment similar to that which may be anticipated in the vicinity of a repository can be studied. The most well-known of these examples is the "Oklo natural reactor" which demonstrates the retention of most of the radioactive inventory of the reactor over a period of 2 billion years. Furthermore, there is "ample evidence of the importance of natural processes of solubility control, sorption and diffusion in attenuating concentrations of species dissolved in porewater"[55].

Further to this point, the residence time of groundwater in contact with buried radioactive waste is an important factor in determining the transport time of radionuclides from a disposal facility to the biosphere and the potential long term doses to human [56]. A technique known as Noble Gas Paleothermometry allows scientists to address the paleoclimatic conditions under which deep shield groundwater were charged by measuring the noble gas concentrations in samples collected from selected mine sites on the shield. Noble gas paleothermometry can estimate the age of water by comparing the temperature of the recharge water determined by the temperature-dependent solubility concentration to the paleoclimatological record for the area of concern.

The model elements and the status of geological repository modelling are reviewed in Appendix IV.

5.2.7 Engineering Trade-offs

In most engineering projects, trade-off studies are performed early on to balance the emphasis to be placed on various design features. The simplest of these may involve a number of parameters related to cost, safety and performance, which are weighted appropriately within each category. This approach is essentially a management tool and a tool for obtaining consensus amongst technical specialists.

More sophisticated methods to employ such tools have been tried in identifying preferred alternatives in the nuclear waste area[57,58]. Experience has shown that great care must be applied when defining the variables (to ensure they are "independent"), when assigning values to the variables (objective vs subjective?) and when weighting the values assigned to variables to produce a single decision parameter (how can this be done uniformly and transparently?).

To introduce such techniques into the public selection of options poses the issue of "heart vs head": for example, the Ministry of Transport in Ontario has long worked with a notional value of the money to be spent to save a human life, and applied these to decisions to implement road improvements. However, discussion based on such an approach would be extremely difficult to present in a public forum, and may leave the project-owners (and approvers) legally vulnerable in any subsequent accident.

5.2.8 Adaptive Staging

Geological repositories are considered the preferred disposal system in the United States for spent nuclear fuel and high-level waste. However, geologic repositories are unique undertakings in that they are first-of-a kind, risk-laden, complex, and long term projects[59,60]. As a result of these challenges, several panels on radioactive waste management recommended adopting a staged approach for repository development.

Adaptive staging is a development strategy based on general principles of the adaptive management approach introduced by Holling (1978)[61]. "Adaptive staging is a cautious and deliberate decision-making and management process, fully consistent with good engineering practices"[62]. This approach:

- Emphasizes continuous learning, both technical and societal
- Includes scientific and managerial re-evaluations and reactions to new knowledge
- Is responsive to stakeholder input
- Is designed to continually improve the project while retaining the option of reversibility.

Adaptive staging is characterized by:

- systematic learning
- flexibility
- reversibility
- transparency
- integrity
- audibility
- responsiveness

The adaptive staging approach divides the development of a geologic repository into stages that are separated by explicit "decision points". A decision point is a process involving analyses, review and evaluations as well as the consequent decisions for future actions. A decision point is intended to guide the implementers in identifying program improvement with respect to, for instance, costs, environmental impacts, safety and schedule[63].
Under adaptive staging, the repository implementers, at each decision point would:

1. systematically gather, evaluate, and analyze knowledge gathered at this point from previous stages.
2. take into account all relevant options for the next stage
3. evaluate and update the assessment of the safety of the repository system
4. make the finding transparent and publicly available.
5. engage in dialogue with the stakeholder at this stage
6. decide on the next stage based on the above mentioned set of actions.

5.2.9 Radiological Safety Regulations

Each country with a nuclear program sets its own radiation safety limits for public and worker exposures to ionizing radiation, both from chronic and acute exposures. However, there are several international organizations that provide safety analysis and guidelines. The most prominent of these is the ICRP (International Commission on Radiological Protection). The ICRP provides the theoretical and operational basis for virtually all domestic radiation safety regulations in Canada. However, it is the CNSC that actually issues and enforces the regulations on behalf of Canadian workers and the public.

Radiological Safety for Nuclear Industry Workers in Canada

In Canada, health and safety in the workplace is a provincial responsibility. In Ontario, the Ministry of Labour is responsible for administering the Occupational Health and Safety Act, (OHSA). Section 25(2) of the OHSA lists the general duties of an employer including:
"An employer shall:

- acquaint a worker or a person in authority over a worker with any hazard in the work and in the handling, storage, use, disposal and transport of any article, device, equipment or a biological, chemical or physical agent.
- take every precaution reasonable in the circumstances for the protection of a worker."

These general duties imply that the employer must identify hazards and take reasonable precautions to protect workers. In most cases, this is achieved through the development and implementation of a health and safety policy and corresponding safety management system.

The OHSA has several regulations relating to various industrial sectors and safety issues. For example, if a nuclear waste repository were built in Ontario, the regulations under the OHSA that would likely apply at some point in the life cycle of the facility include:

- Reg. 213 *Construction Projects*
- Reg. 851 *Industrial Establishments*, and
- Reg. 854 *Mines and Mining Plants*

Radiation Protection and Dose Limits

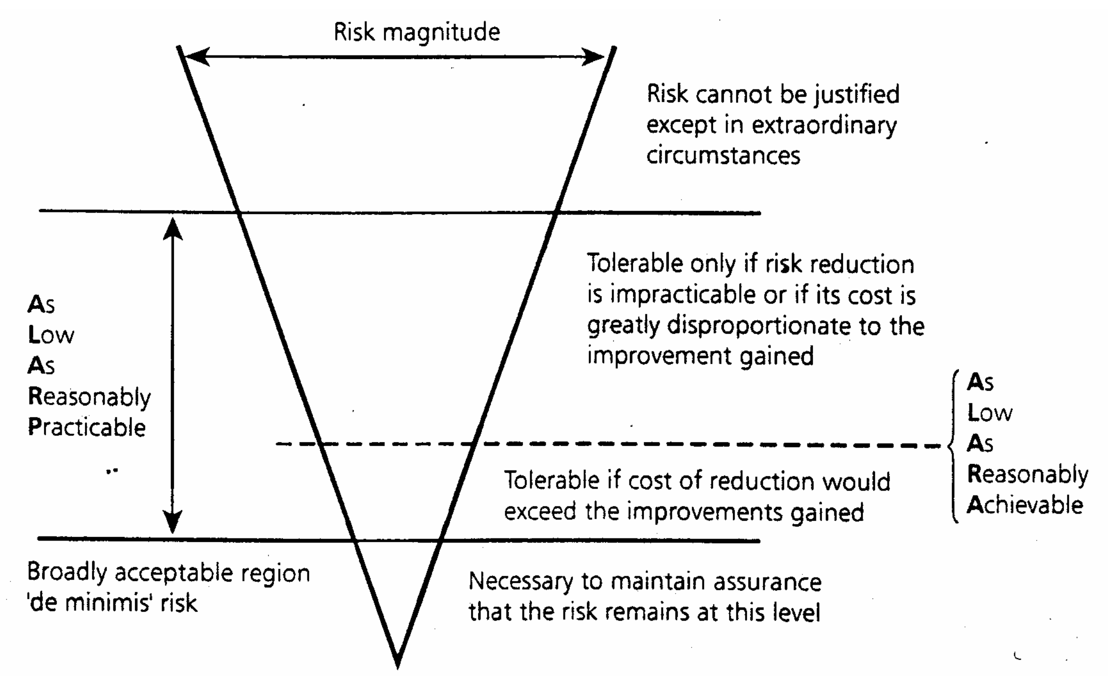
There were attempts to define radiation protection practices and limits to dose, even before the formation of the various national radiation protection societies and groups that were established in the 1920s. These groups had little definitive data on which to base their deliberations, and only in the last few decades has there been sufficient definition of high doses and related injuries to be able to establish reasonably supported dose limits for occupational exposures.
Following this, there were recommendations made concerning much lower general public dose limits from industrial radiation exposures. The risks are no different, but as the public is not monitored, as are radiation workers, and receives no monetary reward for tolerating any exposure, its limits were set lower. The intent was that by implementing a dose limit at some level well below that associated with somatic radiation injuries, that not only would early radiation injuries be entirely avoided by controlling doses, but that the risks of long-term effects would be minimized to some acceptable degree of risk. By assuming that there is no threshold for injury, despite the absence of adverse health data at low doses and thus absence of scientific justification for increasing protection, the temptation has been to push dose limits ever lower. These whole body dose limits, as currently recommended by ICRP-60[64], are 100 mSv in five years for occupational exposures (or an average of 20 mSv in each year), and 1 mSv a year for public exposures from industry. The occupational dose limit was further limited by stipulating that no worker should exceed 50 mSv of dose in one year of the five.

In practice, a typical radiation dose to those who work with radiation averages about 2 mSv per year, with a few individuals that may approach their dose limit. Such limits are rarely exceeded other than under exceptional and usually approved circumstances, as the regulatory penalties for accidental over-exposure are severe. Also, typical radiation doses to the public from nuclear power facilities - the only industry that measures and assesses its radiation effects upon the local population and the environment – are generally no more than about 2 microsieverts per year to local residents, with a world average individual dose from this source estimated to be less than 0.2 microsieverts per year.

The ALARA and ALARP Concept

Figure 5.2 illustrates the relationship between risk magnitude and the tolerability of risk. The diagram shows three distinct levels of tolerance, depending on the size of the risk. (For a detailed explanation of this diagram and risk tolerance, see Section 3.3.4. The As Low As Reasonably Achievable (ALARA) concept states that the risk is tolerable only if the cost reduction would exceed the improvements associated with any proposed risk controls.

Figure 5.2: The ALARP and ALARA Concepts



Despite the establishment of dose limits and adherence to them, there is a general paradigm which governs all radiation work, and that is the assumption that all radiation is potentially harmful and should be avoided if possible, and minimized if not. Applying ALARA (keeping doses As Low As Reasonably Achievable) is inherent in the LNT (linear no threshold) hypothesis. The ALARA principal applies to the safety procedures in all Canadian nuclear facilities and would also apply to whatever facility was ultimately built to deal with high level waste. The ALARP (As Low As Reasonable Practicable) Concept is a natural addendum to the ALARA level, in that it establishes a range of practicality, and specifically considers the costs relating to the improvement gained.

Dose and the Safety Case

When building the safety case (refer to Section 5.2.10) for a proposed disposal facility concept, the ultimate dose to the public (and workers) is the overriding limitation. No member of the public (critical group) exposed to residual radiation from the facility can have an exposure greater than 1.0 millisievert per year. This is from all industrial sources, not just the disposal facility.

Although the application of the ALARA principal will have to wait until the actual design phase commences, in other similar circumstances, a target of (for example) 10% of the actual limit (or in some cases 1%) are applied. This is done in order to assure ample margin for error and oversight in the various pathway models developed to calculate exposure and dose to the public. The actual selection of the ALARA target is developed after comparing the net societal benefit arising from the activity with the risks of calculated exposure and dose.

Radiological Assessments

IN SITU STORAGE

The assessment tools that apply to in-situ storage are essentially the same risk-based dose estimation mechanisms that are applied by nuclear regulators in all countries with nuclear programs. These are dominated by radionuclide release and exposure dose limits to the general population (critical group) and to radiation workers who accumulate occupational dose as a result of waste management operational activities.

In Canada, these dose criteria and limits are imposed by the federally mandated Canadian Nuclear Safety Commission (CNSC), and would not be much different from that applied to the dry storage facilities that presently exist at operating CANDU nuclear stations. Accordingly, the assessment tools would be essentially the same as those used to license these operating facilities, but likely applied over a longer time frame.

CENTRAL STORAGE

The basic concept of storage at one central location (surface or near surface) would differ little from the in-situ storage option from the standpoint of scenario assessment and biosphere modeling. However, the differences would relate to the risks and doses associated with additional transportation and handling. This arises from transportation from the site of origin to the central site and then eventually to the site of ultimate treatment and/or disposal. Transportation risk assessment has already been dealt with elsewhere in this report.

The risk based licensing and safety requirements applied in such a case would be an extension of the ones applied to in-situ. The assessment tools would be the same ones applied for licensing existing surface storage facilities and for which there are ample precedents in any country implementing a shorter-term spent fuel storage program.

ACTION LEVELS AND THE SAFETY CASE

One significant difference in the safety case for both in-situ and central storage (as opposed to deep geological disposal) is that operations staffers are actively involved with the radioactive materials management process over a longer time frame. This means that greater occupational radiation exposures are going to be a key issue in the safety case for the regulator (CSNC in Canada) regardless of location.

When applying the principles of ALARA at an operational facility the regulator will usually ask for a definition of an 'action level' which is somewhere above the ALARA limit and which would trigger some management response to ensure that any unplanned radiation dose excursions (above ALARA) remain temporary. The NEA and the CNSC are both putting more emphasis on action levels as part of the licensing process.

The performance assessment tools for such facilities would have to model the normal and off-normal occurrences to ensure that ALARA limits were met 'on average' and that action level triggers were appropriate and sufficient to ensure timely management response to design basis off-normal events or excursions.

5.2.10 Outline of the Safety Case

One of the mechanisms that is most prevalent among the various national programs in irradiated fuel management is the safety case for the assessment and acceptance of a particular storage or disposal concept. In each jurisdiction, the regulations may be prescriptive or they may allow the proponent to perform the analysis that confirms the acceptance. However, there is always a public dose standard and limit that must be met in order for it to be 'safe' with respect to the potential for long-term radiation dose to the public.

In Canada, the CNSC requires that no member of the public in the defined critical group be exposed to a dose of greater than 1.0 mSv/annum (refer to Section 5.2.9, "Radiological Safety"). The safety case must indicate, via a comprehensive and multi-level (defence in depth) safety assessment, that this level will not be exceeded for the entire period that the irradiated fuel is decaying to ambient levels. In order to provide confidence that this will be the case, the assessment must have sufficient margin for error and uncertainty that even in the worst case of acute events such as seismic activity or human intrusion, this dose level will not be exceeded.

Defining the Safety Case

The NEA (Nuclear Energy Agency), an organization under the auspices of the OECD, is in the process of defining the elements of the safety case in a generic fashion for the various national authorities who will likely apply it to their particular acceptance process. The following is a summary of the safety case description, outline and application as described by the NEA in a soon-to-be-released report.

Radioactive waste is associated with all phases of the nuclear fuel cycle and with the use of radioactive materials in industrial, medical, military and research applications. All such waste must be managed safely. The most hazardous and long-lived waste, such as spent nuclear fuel and waste from fuel reprocessing, must be contained and isolated from humans and the environment for many thousands of years.

Engineered geological disposal is the currently favoured radioactive waste management end-point providing security and safety in a manner that does not require monitoring, maintenance and institutional controls[65]. Engineered geological disposal is known to be technically feasible[66]; and it is also accepted from an international legal perspective[67]. A collective opinion of the NEA is that it is acceptable from an ethical and environmental viewpoint[68], but this is not the same as the Canadian experience with the Seaborn panel, which shows that it is necessary to complete, and then go beyond, the safety case. Disposal of long-lived radioactive waste in engineered facilities, or repositories, located deep underground in suitable geological formations which are closed and sealed following waste emplacement, is thus being widely investigated world wide in order to protect humans and the environment both now and in the future.

A repository will only be licensed for construction, operation and closure if it can be shown to be safe. A repository is said to be safe, from a technical point of view, if it meets the relevant safety standards, such as are internationally recommended or specified by the responsible national regulator. The task of analyzing the performance of a repository and showing, with an appropriate degree of confidence, that it will remain safe over a prolonged period, beyond the time when active control of the facility can be guaranteed, is termed post-closure safety assessment.

The task of post-closure safety assessment involves developing an understanding of how, and under what circumstances, radionuclides might be released from the repository, how likely such releases are, and the radiological consequences of such releases to humans and the environment. Importantly, it is necessary to understand how the geological characteristics of the site and the design function to prevent, lower the likelihood of, or attenuate such releases. This in turn involves collating data, developing models and performing analyses related to safety. In addition, in recent years, the scope of the safety assessments has broadened to include the collation of a broad range of evidence and arguments that complement and support the reliability of the results of quantitative analyses[69].

Safety assessments are performed periodically throughout repository planning, construction, operation, and prior to closure. These are used to develop and progressively update a safety case, which is a formal compilation of evidence, analyses and arguments that quantify and substantiate a claim that the repository is safe. The safety case may be seen as analogous, in some respects, to a legal case, in which multiple lines of evidence are produced, and for which the quality of each line of evidence must be evaluated to allow a judgment to be reached on the adequacy of the case to support a positive outcome of the decision at hand. The safety case becomes more comprehensive and rigorous as a result of work carried out, experience gained and information obtained throughout a project, including any pre-closure monitoring phase.

Safety assessment is the process of systematically analysing the ability of the design to provide the safety functions and meet technical requirements and evaluating the potential radiological hazards.

The safety case is an integration of arguments and evidence that describe, quantify and substantiate the safety, and the level of confidence in the safety, of the geological disposal facility.

From IAEA Safety Standard for Geological Disposal, 2003.

A license to construct, operate or close a repository will only be granted if due consideration has been given not only to post-closure safety but also to potential impacts and risks during the operation of the repository and prior to its closure. These include:

- the security of the waste against unauthorised interference or recovery,
- the safety of workers both during normal operations and in the event of accidents,
- the protection of the public from potential radiological exposures, e.g. due to accidents at the facility, and
- the radiological protection of the wider environment in which repository is located.

In addition, the conventional (non-radiological) environmental, social and economic impacts of the development, operation and closure of the facility will have been assessed and, in most countries, will presented in an Environmental Impact Assessment (EIA) as a necessary step to gaining planning approval. These pre-closure and non-radiological assessments are not within the scope of the present document.

The following summary presents some general considerations and is not intended to be prescriptive. This is because, although the presentation of a safety case is a legal requirement for certain decisions in most countries, the form of this legal requirement can vary considerably and the form of the safety case and its presentation must be adjusted accordingly.

Nature and purpose of the Safety Case

A post-closure safety case is a synthesis of evidence, analyses and arguments that quantify and substantiate a claim that the repository will be safe after closure and beyond the time when active control of the facility can be guaranteed. Safety assessments are performed periodically throughout repository planning, construction, operation, and prior to closure, and are used to develop and progressively update the safety case. The safety case, which becomes more comprehensive and rigorous as a programme progresses, is key input to decision making at several steps in the repository planning and implementation process.

A detailed safety case, presented in the form of a structured set of documents, is typically required at major decision points in repository planning and implementation, including decisions that require the granting of licenses. A license to operate, close, and in most cases even to begin construction of a facility, will be granted only if the developer has produced a safety case that is accepted by the regulator as demonstrating compliance with applicable standards and requirements, and key safety procedures and targets specified in the safety case are shown to be followed or met. Lesser efforts at technical and safety evaluations may be adequate to support minor decisions such as internal planning and decision-making by the developer. Crucially, the discipline of preparing a safety case, and presenting the case for scientific and technical review, regulatory review or wider non-technical reviews, ensures that post-closure safety is explicitly and visibly considered at each project stage.

Developing a post-closure safety case is a challenging task that differs in some key respects from the task of demonstrating pre-closure safety, as well as the safety of other types of nuclear facilities. These differences relate to the limited possibilities for monitoring and corrective actions after closure, and to uncertainties, particularly those arising from the long time over which post-closure safety is assessed.

Elements for documenting the Safety Case

Elements that contribute to the safety case include:

(i) The safety strategy

The safety strategy is the high-level approach adopted for achieving safe disposal, and includes a management strategy, a siting and design strategy and an assessment strategy. All national programs aim at management strategies that accord with good management and engineering principles and practice. This includes maintaining sufficient flexibility within a step-wise planning and implementation process to cope with unexpected site features or technical difficulties and uncertainties that may be encountered, as well as to take advantage of advances in scientific understanding and engineering techniques. The siting and design strategy is generally based on principles that favour robustness and predictability, including the use of the multi-barrier concept. The assessment strategy must ensure that safety assessments capture, describe and analyse uncertainties that are relevant to safety, and investigate their effects.

(ii) The assessment basis

The assessment basis is the collection of information and analysis tools for safety assessment. This includes an overall description of the disposal system (the system concept), the scientific and technical data and understanding relevant to the assessment of system safety, and the assessment methods, models, computer codes and databases for analysing system performance. The quality and reliability of a safety assessment depends on the quality and reliability of the assessment basis. Discussion of the assessment basis includes the presentation of evidence and arguments to support the quality and reliability of its components.

(iii) Multiple lines of evidence, the analyses and arguments

Most national regulations give safety criteria in terms of dose and / or risk, and the evaluation of these indicators, using either mathematical analyses or more qualitative arguments, for a range of evolution scenarios, appears prominently in all safety cases that are intended for regulatory review. Robustness of the safety case is, however, favoured by the use of multiple lines of evidence and different styles of argument, so that it can tolerate shortcomings in any single argument. Complementary types of evidence and argument in support of a case for safety include general evidence for the strength of geological disposal as a waste management option, evidence for the intrinsic quality of the site and design, safety indicators complementary to dose and risk, and arguments for the adequacy of the strategy to manage uncertainties and open questions.

(iv) Synthesis of evidence, arguments and analyses

In general, a safety case will conclude that is there is adequate confidence in the possibility of achieving a safe repository to justify a positive decision to proceed to the next stage of planning or implementation. This is a statement of confidence on the part of the author of the safety case - typically the developer - based on the analyses and arguments developed and the evidence gathered. The audience of the safety case must decide whether it believes the reasoning that is presented is adequate, and whether it shares the confidence of the safety case author. To this end, a synthesis of the available evidence, arguments and analyses is made. This should highlight the grounds on which the author of the safety case has come to a judgment that the planning and development of the disposal system should continue.

General considerations when presenting the Safety Case

Some general considerations when presenting the safety case include:

(i) Purpose and context

The adequacy of the evidence, the analyses and arguments relevant to post-closure safety has to be judged in the context of the stage reached within a programme and forthcoming decisions that must be taken. The planning and implementation process should therefore be described, including the responsibilities of different organisations within the decision-making process.

(ii) Concerns and requirements of the intended audience

The emphasis placed on particular lines of argument and analyses and other aspects of the style of presentation must take account of the interests, concerns and level of technical knowledge of the intended audience. This may include the regulator, political decision makers or the public, as well as technical specialists within the implementing organisation itself. Multiple levels of documentation may thus be required. For all audiences and in versions of the safety case at all technical levels, the presentation must be based on a sound scientific and engineering foundation and the R&D work that has actually been done. Flexibility needs to be maintained to respond to the requests of the intended audience. Over-simplifications leading to over-confident statements of safety must be avoided.

(iii) Other considerations

Finally, a number of other considerations must be taken into account in preparing the safety case and to promote its credibility. These include:

- Transparency – a safety case should be presented in ways that are both transparent and understandable to the intended audience;
- Traceability – especially for more technical audiences, it must be possible to trace all key assumptions, data and their basis, either through the main documents or supporting records;
- Openness – with respect to current uncertainties, open questions and the limits of predictability of disposal system should be discussed.
- Peer reviews – both internal and external peer review is a valuable tool for enhancing confidence in a safety case on the part of its author, and also the wider scientific and technical community.

The Nuclear Energy Agency (NEA)[70] formally defines a transparent safety report as “a report that is written in such a way that its readers can gain a clear picture, to their satisfaction, of what has been done, what the results are, and why the results are as they are." Traceability is defined by NEA as "an unambiguous and complete record of the decisions and assumptions made and of the models and data used in arriving at a given set of results." Traceability exists when there is an unbroken chain linking the result of an assessment with models, assumptions, expert opinions, and data used in the formulation of the result.[71] Mohanty and Sagar provide a useful working definition of transparency and traceability as "those attributes of a presentation that promote understanding at all levels of detail and allow the reader to reproduce the results or verify their authenticity and scientific accuracy."[72]

5.3 Environment Assessment Methods

Under the leadership of Blair Seaborn, an Environmental Assessment Panel on Nuclear Fuel Waste Management was set up and reported in February 1998. Many of the technical and environmental issues presented are still current. The deep geological repository was the approach that was reviewed in depth, by the Seaborn panel.

5.3.1 Site Selection

The process of selecting a site for a facility for long-term storage or disposal of radioactive waste could follow an approach based on:

- screening of potential sites on the basis of pre-established technical and other criteria
- an approach based on volunteerism by local communities, or even
- a process involving a combination of these[73]

Regardless of the site selection approach, and the possible community participation, the siting process will generally be organized in the following four stages[74]:

1. Concept and planning

The main objective of this stage is to develop the overall strategy for the siting process which comprises:

- Development of a conceptual disposal or storage concept
- A description and consequence of activities, including the interaction of the siting process with other elements of the repository development process such as the development of generic disposal or storage concepts
- Overall performance criteria for the repository or storage facility including screening guidelines for potential host environment
- Recommendations for site characterization and the process of data collection, taking account of any guidelines for the site selection process established by the regulatory authorities
- Cost estimates for the major components of site selection.

2. Area survey stage

The main objective of this stage is to identify a number of potential repository or storage facility sites, selected following the plan developed in the previous stage and in accordance with any regulatory guidance on site selection.

3. Site characterization stage

This phase of site selection is distinguished by the collection of site-specific geological, hydrological and other environmental data, as well as on the results of research work on the performance of the engineered elements of a repository at that location. Because this phase involves site-specific geological investigations it is envisaged that only a small number of potential sites would be characterised in detail.

The availability of site specific data will enable preliminary assessments of the performance of potential sites, including environmental impact, to be made, taking account of properties of the waste to be emplaced in the repository and the proposed disposal method for that particular environment. These assessments should address both radiological and non-radiological impacts, including an analysis of social and economic factors.

4. Site confirmation stage

Site confirmation will normally involve detailed site investigations undertaken underground, with the aim of confirming that the assumptions made in developing the preliminary performance and environmental impact assessment for that site are likely to be valid.

Data obtained during site confirmation activities will enable a more comprehensive assessment of the potential radiological impact from a facility to be undertaken. The non-radiological environmental impact will also be assessed in more detail and more information provided on the measures that might be taken to reduce potential harmful effects on the environment from the development.

The "Technical" Siting Approach

It is a strictly technical perspective where the decision making power lies with the proponent[75].

The application of this approach follows seven sequential stages:

1. goal identification
2. project characterization
3. selection of site specific evaluation criteria
4. area and site screening
5. site assessment and selection
6. final detailed design
7. site decision

The advantages of the technical approach are:

1. the approach has a technical merit
2. the approach can reduce the number of sites based on environmental data
3. the approach is based on optimal requirements necessary for safe operation.

The disadvantages of the approach are:

1. the approach provides an imposed decision

2. the approach needs a public education process in order to demonstrate the environmental and technical merits of the decision, and public opposition may still continue.

The "Voluntary" Siting Approach

This approach has been endorsed by the Environmental Assessment Panel as the best approach to select a nuclear fuel waste management facility in Canada[76].

The application of this approach follows the seven sequential stages:

1. set up general environmental and safety criteria
2. introduce broad public consultation
3. invite communities to participate
4. consult with interested communities
5. initiate a community referendum on whether or not to accept the facility
6. select the site

The advantages of this approach are:

1. the approach can overcome the social and political constraints
2. the site selection decision will have public (community) support

The disadvantages of the approach are:

1. the approach focuses on the social and political rather than engineering and technical aspects
2. the communities can withdraw from the project at any time (this could be considered an advantage to the community)
3. if no community volunteers, there is no decision.

5.3.2 Environmental Impacts

The environmental impacts criteria can be classified as:

1. Impacts during construction, operation, monitoring, and closure of confirmation
2. Short-term and long term impacts
3. Local and regional impacts
    - Visual impact
    - Noise during operation
    - Use of natural resources (land, terrestrial materials and/or water)
    - Transport and traffic
4. Radiological and non radiological impacts
    - Soil contamination
    - Groundwater contamination
    - Surface water contamination
    - Impacts on flora and fauna

Environmental Impact Assessment

EIA is a process that examines the environmental consequences of development actions in advance. EIA is also a document that should describe and compare different alternatives. The zero-alternative, which describes the situation providing that nothing changes in the future, should be included in the comparison. An EIA should take into consideration direct and indirect effects on:

- People, flora and fauna
- Land, water, air, climate and landscape
- Material assets and cultural heritage
- Interaction between the above mentioned factors

The assessment of how a project relates to environmentally sustainable development should be performed in a holistic perspective. Therefore, environmental, health-related, social and economic aspects should be considered.

Strategic Environmental Assessment (SEA) is a relatively new tool and has not yet been widely applied in practice. Therefore, there is no determined defined method for how a SEA should be applied. While EIAs are made for specific projects, SEA is used for programmes, policies and plans that are loosely structured and that are continuously reformed. A SEA has more diverse angles of approach than an EIA and the work takes place on an all embracing level. A project EIA, for example, deals first with the question how a project or an activity shall be worked out, while a SEA questions if various projects are suitable to carry through and if so where they are to be located.

According to Sida 1998[77] the SEA should include:

- A description and analysis of the environmental situation in the sector/region in question
- A description and analysis of environmental work in the sector, including legislation and environmental regulations.
- Other relevant information on the institutional situation.
- An analysis of the combined effects of different activities/measures in the sector/programme.
- Proposals for capacity building measures for environmentally sustainable development in the sector/programme.

EIA Processes in Relation to Disposal of Spent Nuclear Fuel

EIA is a planning tool that is generally regarded as an integral component of sound decision making. As a planning tool it has both an information gathering and decision making component which provides the decision maker with an objective basis for granting or denying approval for a proposed development.

In the global EIA literature, special attention has always been given to public participation and consultation in numerous projects and reports.

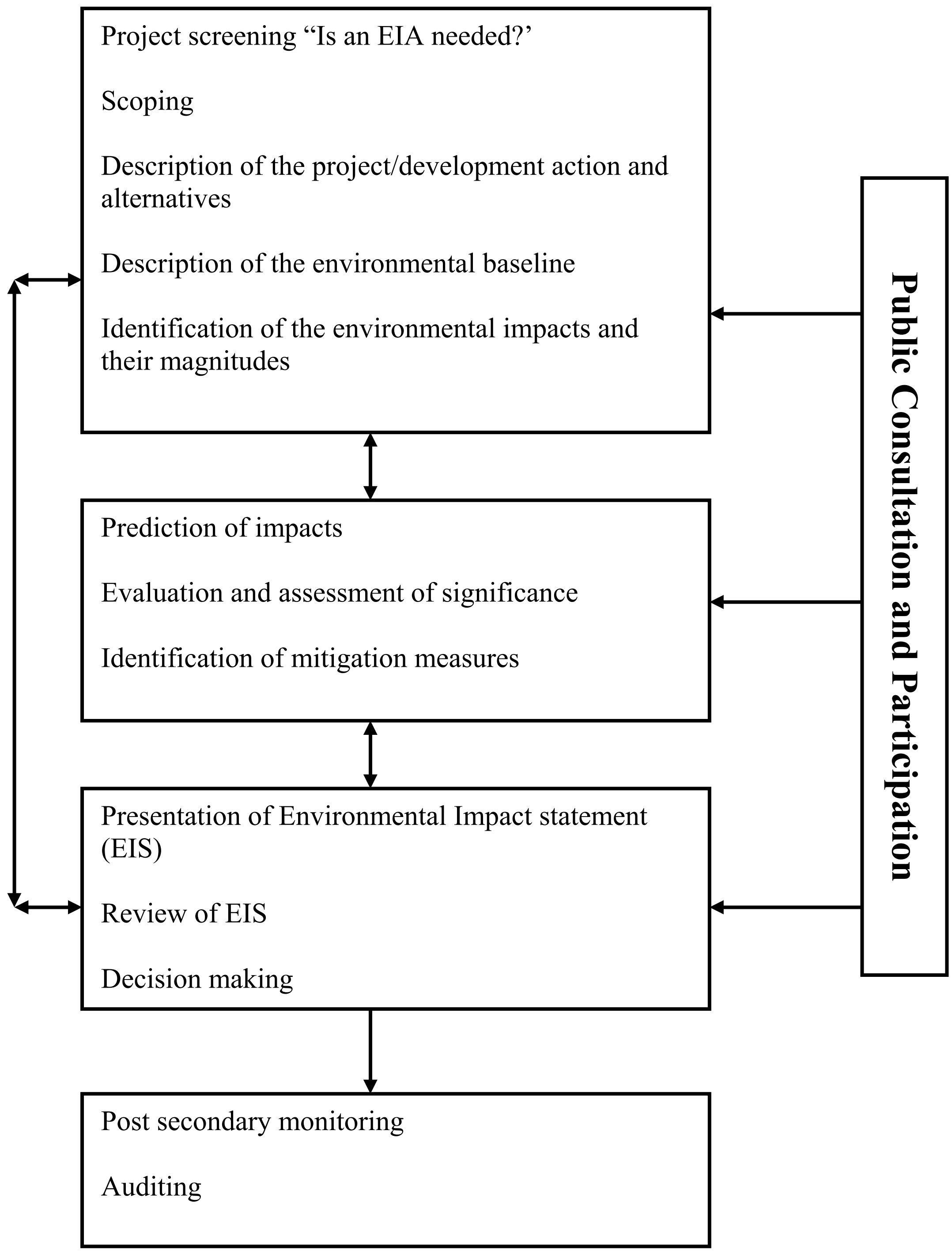
“EIA is a process for identifying the likely consequences for the biogeophysical environment and for man’s health and welfare of implementing particular activities and for conveying this information, at a stage when it can materially affect the decision, to those responsible for sanctioning the proposal" [78].

EIA roles can be summarized as[79]:

- An analytical technique to support instrumental rationality when there are uncertainties, conflict and risk associated with the decision
- Environmental protection as well as democratic stimulant
- A tool for public involvement to promote dialogue between the stakeholders and the general public
- A method to provide an input to the political and administrative decision process.

EIA is becoming not only an analytical tool but also a planning public participation process. As a result of 30 years of implementing EIA across the world, a number of well-defined steps have evolved in order to promote the best EIA practice. Figure 5.3 presents the steps in the EIA process according to Glasson et al. 1999[80].

Figure 5.3: Steps in the EIA Process.



Public Consultation: The objective is to ensure the quality, comprehensive and effectiveness of the EIA, and that the public's views are taken into consideration in the decision making.

Project Screening: The purpose of this step is to narrow the application of EIA to the projects that might have significant impacts.

Scoping: The purpose of this step is to identify at an early stage the crucial and significant issues that should be examined in greater detail.

Description of the Project/Development Action and Alternatives: This step includes a clarification of the purpose and rationale of the project and an understanding of its various characteristics such as stages of development, processes and location. It also seeks the consideration of other alternatives to ensure that the project proponent has considered other feasible approaches such as alternative locations, processes, operating conditions etc.

Description of the Environmental Baseline: The environmental baseline should include the establishment of both the present and future state of the environment, in the absent of the project.

Identification of the Environmental Impacts: This brings together the previous steps with the aim of ensuring that all potentially significant environmental impacts are identified and taken into account in the process.

Prediction of Impacts: This step seeks to identify the magnitude and other dimensions of the identified changes in the environment with the project, by comparison with the situation without the project.

Evaluation and Assessment of Significance: The purpose of this step is to assess the relative significance of the predicted impacts to allow the focus on the main adverse impacts.

Identification of Mitigation Measures: This step introduces the measures to avoid, reduce, remedy or compensate for any significant adverse impacts.

Post Secondary Monitoring: This step involves the recording of outcomes associated with development impacts, after a decision to proceed. Monitoring can contribute to effective project management.

Auditing: After monitoring auditing should take place. This can involve comparing actual outcomes with the predicted and can be used to assess the quality of predictions and the effectiveness of mitigation. It is a vital step in the EIA learning process.

Environmental Impact Assessment Methodologies

A number of methodologies have been developed for environmental impact assessment. Most of these methods are subjective and might not strongly quantify the impact of the project on the environment. However, the development of new computer-based modelling techniques might provide a bridge for the existing gaps[81].

Ad hoc approach

This is the oldest approach to EIA. This method was described as the crudest for it suggests impact on broad areas, and neglects any specific and secondary effects.

Checklist matrix

It is an updated version of the ad hoc approach that associates impact areas with a list of environmental parameters. The checklist usually contains a listing of possible impact areas. Generally, elements of the environment are listed on the left hand side of the matrix and checkmarks are placed in the cells. The checklist method is widely used because it ensures that a prescribed and comprehensive list of environmental and impact areas are considered in the assessment process. However the matrix is very large, very subjective, and provides little guidance that can aid in the decision making process.

Leopold matrix method

The method uses a matrix format to relate project actions and environmental impacts. The system is an open-cell matrix containing 100 project actions along the horizontal axis and 88 environmental components along the vertical axis. One of the drawbacks of this method is that it generally does not include secondary impacts. Its main strength is as a checklist that incorporates qualitative information on cause-and-effect relationships. It is also useful for communicating results.

Combinative matrix

The combinative method was developed by Shopley and Fuggle in 1984. It is an extension of the Leopold matrix. In this technique both numeric and non-numeric indicators represent impact characteristics. The main strength of this method is that it assesses potential impacts in terms of their importance, probability of occurrence, time of occurrence, duration and whether a negative or positive impact. It also seeks to identify whether there are plans for remedial measures and assesses the potential risks associated with specific development projects. This method is more sophisticated than the Checklist and Leopold methods because it establishes cause and effect relationships and also addresses issues of higher order impacts.

Peterson's matrix

The Peterson's matrix is a mathematical matrix method where algebraic operations can be performed. The approach has been criticized for its reliance on extensive mathematical operations and for the subjective inputs of the matrix.

Battelle environmental evaluation system (BEES)

BEES was designed to assess impacts of water resource developments, water quality management plans, highways, and nuclear power plants. This method is identified as one of the most quantitative methods. In this system, 78 measurable environmental parameters are divided into four major categories of ecology, environmental pollution, aesthetics, and human interest. One of the drawbacks of this system is that the approach does not link impacts to affected parties or to dominant issues. Its summary format is designed for the specialist and may sometimes require explanation.

Overlays

Overlays is the only explicit spatial technique used in EIA. It was developed by McHarg in 1969[82].The approach has been employed by Krauskopf and Bunde (1972)[83] for selecting highway corridors, by Nehman et al. (1973)[84] for evaluating development options in coastal areas, and in several other areas. The study is usually sub-divided into convenient geographical units, based on uniformly-spaced grid points, topographic features or differing land uses. A computer may be programmed to perform the tasks of aggregating the predicted impacts for each geographic subdivision and of searching for the areas least affected. The overlay approach can accommodate both quantitative and qualitative data. It is recommended for large regional developments and corridor selection problems, provided that the assessor views his analysis with at least a modest degree of scepticism. This technique has been criticized for its inability to reflect secondary or higher order environmental impacts.

Network approach

The network approach links the project and its impacts in an easily understandable format. This method explicitly recognises that environmental systems consist of a complex web of interrelationships. This approach has been identified as one of the best approaches for assessing higher-order impacts, though in reality it is very difficult to go beyond third order impacts. The main drawback of this approach is that the quantification of impacts is still subjective.

Computer aided EIA

A number of computer aided EIA methods have been developed in recent years. These basically link the multi-tasking software in a user friendly manner to produce an overall assessment system.

Geographic Information System (GIS)

In recent years, Geographic Information System (GIS) has emerged as a very effective spatial analysis and presentation tool, enabling the identification of the impacted zones by using the overlay techniques. The use of remotely sensed data within the EIA process is also valuable during the stages of screening, scoping, baseline inventory, and monitoring. Through the use of the GIS map layers; the decision makers and the public can develop an assessment of the environmental situation surrounding the project. GIS visualization can play a vital role during the phases of impact inventory and analysis, mitigation and monitoring. According to Lein (1998)[85],GIS provides a platform that enables the analytical manipulation of data that blends human rights, knowledge, and experience with data analysis. As a predictive instrument, GIS includes time series analysis, surface analysis, and environmental modelling[86,87].

5.3.3 Environment and Sustainability

Strategic Environmental Assessment (SEA)

SEA is a systematic process to address environmental considerations and consequences of a proposed policy or project. The main purpose of SEA is to integrate environmental and sustainability factors into the decision making process.

The objectives of using SEA are to:

1. Incorporate sustainability and environmental considerations into all levels of decision making.
2. Serve as an early warning mechanism to address environmental issues and impacts that are best dealt with regionally rather than on project to project basis.
3. Establish an appropriate context for project EIA by ensuring prior questions of need, justification and alternatives are subject to environmental scrutiny at the appropriate policy, plan and/or program level.

SEA can be used to either operate as a part of integrated process or a separate approach, and can incorporate factors such as social, health, or focus only on biophysical ones.

Methods for Impact Identification in SEA [88]

SEA is a new tool. There is no determined defined method for how SEA should be applied. However, the assessor may have a number of techniques that he may use for gathering and synthesizing information. These methods include:

- Literature search:
  - State of knowledge: search to identify the linkage between policy actions and environmental impacts.
  - Case comparison: compare examples from other jurisdictions or similar actions in other countries
- Expert Judgment:
  - Survey
  - Workshops
- Analytical Methods:
  - Scenario development: examples best versus worst case scenario of risks and impacts.
  - Model mapping
  - Checklists
  - Indicators
- Consultative Tools:
  - Interviews with experts and political leaders
  - Selective consultation with key interest groups or communities
  - Policy dialogue such as roundtable and multi-stakeholders process to clarify issues.

For impact analysis, the assessor could use any of these well known methods:

- Extended use of identification methods: It has been proven possible to sufficiently quantify environmental indicators using the above mentioned methods.
- Use of matrices: Grid diagrams can be used to cross-reference actions with environmental impact.
- Computer modelling
- Geographic Information Systems (GIS)
- Cost effectiveness analysis (CEA)
- Cost-benefit analysis (CBA)
- Multi criteria analysis (MCA)

Comparison of EIA and SEA [89]

Most practitioners view SEA as a decision-aiding rather than a decision-making process like EIA. Table 5.3 compares EIA and SEA. In the Canadian Environmental Assessment Act (CEAA), both are utilized.

Table 5.3: Comparison of EIA and SEA

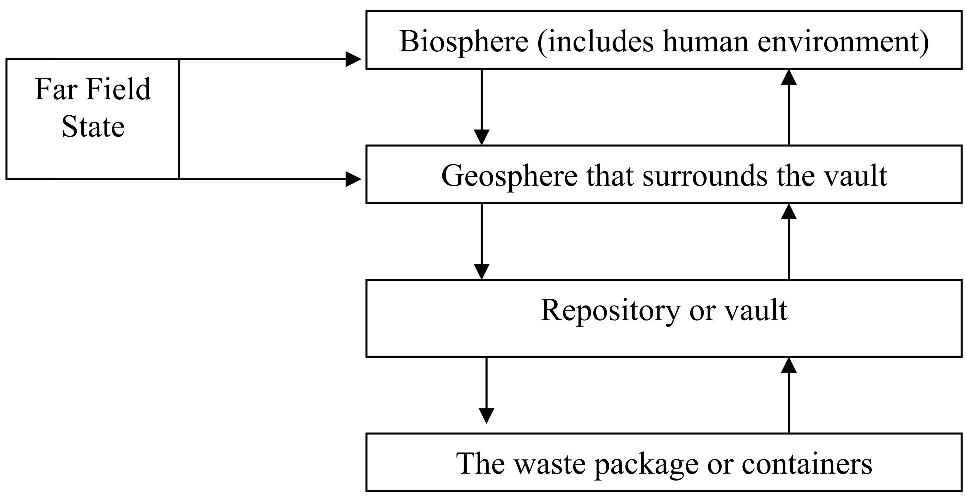
EIA	SEA
Is reactive to a development proposal	Is pro-active and informs development proposals
Assesses the effect of a proposed development on the environment	Assesses the effect of a policy, plan or programme on the environment
Addresses a specific project	Addresses specific areas, regions or sectors of development
Has a well defined beginning and end	Is a continuing process that provides information at the right time
Assesses direct impacts	Assesses cumulative impacts
Concentrates on the mitigation of impacts	Concentrates on maintaining a selected level of environmental quality
Has a narrow perspective	Has a wide perspective
Has a high level of details	Has a low level of details
Focuses on project-specific	Creates a framework against impacts and benefits that can be measured

5.3.4 Biosphere and Geosphere Modelling and Assessment

Biosphere and geosphere modelling are important elements of technical assessment because the time scales of concern are very long. Long-term behaviours of natural systems are used as analogues in behaviours of geological repositories, because natural geological systems have existed for long times and their present characteristics are susceptible to measurement. The engineered systems that will be proposed for geological repositories will be robust in that large safety factors are built in, and there is some degree of redundancy. The longevity of these engineered barriers is intended to be tested through modelling. In the next element of modelling to assess/design a robust system, the characteristics of the geosphere are considered. Although there are long-term uncertainties, the range of potential future behaviours is known with sufficient confidence to allow decision making based on societal concern for future generations. With the assumption of the double protection of the engineered plus geological barriers, transport into the biosphere is modelled, again over an extended period. Both the biosphere and the geosphere are considered to be the "far field". Only the host rock in the immediate vicinity of the waste package is considered to be the "near field".

The following diagram illustrates the subcomponents of the system model for nuclear waste management. This model is applicable to the three management approaches being considered by NWMO. The biosphere and geosphere, as part of the far field subsystem in this model, can evolve and change with time. Climate change and anthropogenic activities are two influences that have the potential to change the state of the far field.

Figure 5.4: The waste system flow diagram[90,91]



Biosphere Modelling

To predict the radiological impact of nuclear waste management, it is necessary to be able to analyse and quantify the behaviour of radionuclides in the biosphere. Mathematical models are often used for estimation of environmental transport of radionuclides and for assessing the resulting exposures, doses, and risks that may occur or may have occurred.

Biosphere modeling in the context of extended storage or disposal of irradiated fuel is built upon extensive national and international experience in surface and subsurface pathway analysis used in environmental assessments and the calculation of derived release limits for nuclear facility licenses. Recent developments in this area are described in [IAEA, 2002][92]. The recognized standard for this in Canada is CSA N288.1 [CSA, 2003][93]. (This standard does not cover all aspects relevant for subsurface waste disposal facilities, as explicitly noted in the document). Nevertheless, this code would be relevant to the assessment of surface (or near-surface) extended storage of used fuel. Computer codes have been developed and validated to implement this standard, in particular the IMPACT code which has been used in recent utility submissions to the CNSC [Lush, 2004][94].

Although not directly relevant to the extended storage or deep geological disposal of used fuel, work in the IAEA ASAM (Previously ISAM) project aims to apply safety assessment methodology to near-surface waste disposal facilities [IAEA,2004].[95] This group is expected to publish results as a TECDOC during 2004.

By far the greatest effort in developing assessment models for used fuel disposal has focussed on deep geological repositories, and that is the focus of the work described in the remainder of this section and in Appendix IV.

Biosphere Modelling and Assessment (BIOMASS) Methodology

Biosphere Modelling and Assessment Methodology (BIOMASS) provides a procedure for the development of assessment biospheres. An assessment biosphere is defined as a mathematical representation of biospheres that are used in total system performance assessment of radioactive waste disposal. BIOMASS provides a systematic approach, with supplementary documentation as an aid to decision making, including decisions on how to address biosphere change[96,97].

Geosphere Modelling

A critical aspect of the assessment of nuclear disposal systems is the modelling of the behaviour of the system through time. Predictions of performance are best achieved by using mathematical models that represent the system. New and sophisticated computer simulation models have been developed for modelling the geosphere[98].

The MOTIF (Model Of Transport In Fractured/porous media) model

The three-dimensional finite-element code MOTIF has been used extensively for the simulation of geosphere and vault processes[99].

The SWIFT (Sandia Waste-Isolation Flow and Transport) model

This three-dimensional model is based on the finite-difference method and is fully transient with steady-state options. The model is documented in Ward et al (1984)[100].

FRAC3DVS

This model is a numerical algorithm for the solution of three-dimensional variability-saturated groundwater flow and solute transport in discretely-fractured media[101].

Requirements Specifications for the model

According to Sykes 2003, " an important step in the development of a model that is part of the performance or safety assessment package is the development of the Requirements Specifications for the model". The objectives of the Requirements Specifications are to[102]:

- Present the equations to be solved, the input and output requirements, and the structure of the model.
- Quantify or define the components of the model.

The process to define the Requirements Specifications consists of the following steps:

1. Analyze the siting, design and licensing requirements to identify the factors that influence the model.
2. Define all the processes to be modeled
3. Define the general model requirements
4. Develop and detailed model requirement specifications

5.4 Economic Assessment Methods

This section outlines various decision-support techniques that are based primarily on cost valuation of the impacts of options.

5.4.1 Cost assessment methods for a nuclear waste repository

EPRI Methodology

The methodology of the Electric Power Research Institute (EPRI) was developed to analyse the cost of nuclear power facilities, and has since been adapted to analyse the cost of a radioactive waste repository. This methodology is capable of computing the factors of uncertainty assigned to each of the three major stages in the implementation of a repository, construction, operation and closure, and each is dealt with as a separate project[103].

In this methodology, the cost analysis must include a judgment on the quality of the data on which it is based. For this purpose, two types of contingency margins were identified.

1. The margins for project contingencies reflect the risks involved in the implementation of the industrial project. These contingencies are divided into four margins:

i. 30 to 50 % known as ‘simplified’ estimate
ii. 15 to 30 % known as ‘preliminary’ estimate
iii. 10 to 20 % known as ‘detailed’ estimate
iv. 5 to 10 % known as the final estimate

2. The margins for technological contingencies reflect the level of knowledge of the technologies used. They are divided into four margins:

i. At least 40 % for entirely new technology “no data for comparison exists”
ii. 30 to 70 % for technologies with some data for comparison
iii. 20 to 35 % for technologies that have been tested at a limited scale
iv. 5 to 20 % for technologies that have been applied at a full scale

5.4.2 Socio-economic analysis

There are different methods that can be used for socio-economic analysis. The most commonly used methods are the Cost Effectiveness-Analysis (CEA) and Cost Benefit Analysis (CBA), as well as some forms of multi-criteria analysis (MCA)[104].

Cost-Effectiveness Analysis (CEA)

This method is usually applied where the objective of the project cannot be valued. Cost effectiveness analysis can be used to assess the least-cost way of achieving the objective. The aim of this method is to develop a ratio that indicates the costs of achieving a per unit change in a specified physical outcome.

There are two different approaches that can be applied when using CEA:

1. Determining the least-cost option
2. In this approach, the CEA can deal with a simple comparison or a complicated analysis of alternative strategies with several risk reduction options. The first step in this approach is to set the targets or goals and then directing the CEA to find the least cost deduction strategy.
3. Comparative assessment of options
4. This approach is used when risk reduction options are not pre-specified. CEA would involve calculation of the implicit economic value that would have to be placed on a level of risk reduction for an action to be justified.

Cost-Benefit Analysis (CBA)

Cost-benefit analysis seeks to value the expected impacts of an option in monetary terms. These valuations are based on a well-developed economic theory of valuation based on willingness-to-pay or to accept. This theory can act as a guide to how it should be achieved, and as a referee in disputes about valuation.

In practice, it is impossible to value all costs and benefits and presented in dollar terms. There are always items that are either impossible to value or not economic to do so. If the most important costs and benefits can be valued, the unvalued items can be listed and included in the decision process.

The advantages of the CBA tool for guiding public decision making:

- it considers the gains and losses to all members of the society affected by the decision.
- it values impacts in a simple familiar scale ($), thus showing that implementing an option has a value when comparing to doing nothing.
- the money values used to weight the relative importance of the different impacts are based on the public’s preferences using established methods of measurement.

The limitations of the CBA tool:

- does not take into account the interactions between different impacts.
- cannot quantify all of the impacts.
- relevant data may not be available or too expensive to collect.

- it may not be possible to present some impacts in terms where people are able to make reliable trade-offs against money

5.4.3 Macroeconomic impacts

CEA and CBA are generally focused on the target sectors. They are considered as "partial equilibrium analysis" in that they assume all other sectors will remain unaffected. In cases where other sectors should be considered for socio-economic analysis or macroeconomics impacts, the use of "general equilibrium analyses" is required. The most commonly used models for macroeconomic assessment are the input-output and the computational general equilibrium models.

The use of macroeconomic modelling techniques produces different levels of information on the impacts of risk reduction option than does the implementation of "partial equilibrium analysis" (CEA and CBA). Therefore, integrating the input-output or the computational general equilibrium models with a "partial equilibrium analysis" model is necessary to provide the decision maker with an indication of whether or not the benefits of the proposed project will outweigh the costs[105].

Input-output models

This model addresses not only the economic linkages but also economic-environment and economic-employment linkages. Input-output models provide a systematic description in matrix form of the interdependencies that exist between different sectors in the economy. An input-output matrix can be used to examine how changes in the total output of a sector are likely to impact on the demand for inputs from other sectors.

The input-output models can be used to[106]:

- project the magnitude on the impact without giving an indication as to the change in net costs or benefits.
- assess both the direct and indirect effects of controlling flows of residuals from economic activities.
- quantify direct and indirect employment effect.
- compare two distinct states of the economy; i.e. pre-policy intervention versus post-policy intervention.

Some limitations of these models are:

- They are time consuming
- Prices are not taken into account which might prohibit the model from determining how demand for one sector's output will respond to changes in price
- Using fixed coefficients for inputs will not allow flexibility
- Economic-employment models may neglect several relevant channels of indirect unemployment.

General Equilibrium Models

Computational general equilibrium models are capable of quantifying direct and indirect effects of environmental policies on economic structure and product mix, economic growth, the allocation of resources and the distribution of income. These models are also capable of dealing with longer planning horizons.

The limitations of these models:

- They are too abstract
- They are time consuming, and some tailored models are used to reduce the number of elasticity-related parameters that should be estimated.
- The models assume that the labour market is in equilibrium, i.e. no unemployment

5.4.4 Methodology for economic analyses of spent fuel storage

Nagano (2003) proposed to categorize the analytical methodology or tools for economic analysis of spent fuel storage into three categories[107]:

Engineering-economic cost calculation

Engineering estimates of cost items are gathered and summed up in terms of monetary unit per unit of service, i.e. tHM of fuel stored. Fixed assessment is employed for a specific storage facility project.

Strategic projection of spent fuel management system

For this category, all spent fuel arising, storage, reprocessing and disposal are simulated in a dynamic framework. Regional or national scale projection is conducted against a certain long-range time horizon.

Specific project financing assessment

In this category, private or public investment in a storage service project is assessed if it can be justified. This method may require fine tune-up against specific features of spent fuel.

6 Integration Methodologies for Assessment

Integration of all inputs will be the culmination of the information gathering and criteria identification phase for the NWMO assessment of waste management options. Of all the methodologies reviewed in this paper, the choice and implementation of the integration methodology is the most critical (Steps 5 and 6 of the assessment framework, Figure 3.1)

Questions concerning sustainable management of nuclear waste are characterised by conflicting and/or overlapping economic, environmental, societal, technical, and ethical objectives. It is difficult to arrive at a straightforward and unambiguous solution without the assistance of a decision tool that provides for integration and structuring of complex information. Multi-criteria decision tools have been found useful to support decision making under such conditions. Criteria can be assessed on both quantitative and qualitative scales. The Multi- Criteria Decision Analysis (MCDA) approach is intended as an aid to analysis and decision making of an expert assessment group. Software support is available and its use can be considered where the specifics of the analysis could be enhanced by it. A further aid to analysis is to use the weighting criteria for the specific MCDA to produce several different perspectives, e.g. an economic or an environmental emphasis.

Implementation of multi-criteria decision support tools is becoming more common. Two case studies that are directly applicable to radioactive waste and sustainability are presented in this section. These applications of multi-criteria decision making have illustrations of a performance matrix or evaluation framework. The evaluation framework, once designed, is a document that can be repeatedly utilized and adapted as needed.

6.1 Assessment and Integration Experience in Canada and Internationally

Other countries have gone through, or are going through the same process, the details of which are given in Appendix VII, on a country by country basis. The complex decision making required is, of necessity, an integrative process. Many of the elements of the generic assessment framework, Figure 3.1, would enter, implicitly, into the ultimate selection of the recommended spent fuel management approach.

Since the Canadian options include on site or central storage, the Canadian experience at Port Hope is highlighted in Appendix VII. The Port Hope storage, for a 500 year period, is progressing through the CEAA and licensing processes, but not as a Class I facility, as would be the case with the spent fuel storage or disposal. The technical and environmental aspects geological repositories were reviewed in depth by the Seaborn panel; much of the subsequent international work has continued to focus on geological repositories, and near surface storage has been used at Port Hope in Canada . The integrative processes now to be used by the NWMO will incorporate the social, ethical and stakeholder issues, and can utilize the extensive existing technical/environmental findings.

6.2 What is Multi Criteria Decision Analysis (MCDA)?

Multi-criteria decision analysis (MCDA) also known as MADA (multi-attribute decision analysis) is an approach or set of techniques that has a well established record of providing robust and effective support to decision makers working on a range of problems and under various circumstances. MCDA models have adequate theoretical foundation and an ability to overcome the limitations of unaided decision makers. MCDA models are simple and transparent and could be easily used as part of a process of consultation with stakeholders. The goal of the MCDA is to provide an overall ordering of options from the most preferred to the least preferred option. The purpose of the technique/approach is to serve as an aid for thinking and decision making, but not to make the decision. Fortunately, there is easy to use software that could assist in the technical aspects of the MCDA. This class of management approach is shown in the assessment framework (Figure 3.1) as an integration methodology. Appendix V presents four case studies using MCDA as a tool for evaluation.

6.3 Applying MCDA

The following are sequential detailed steps that should be followed when applying MCDA[108]. Appendix V presents the Nirex case study as an example of applying MCDA in nuclear waste management project.

1. Establish the decision context
    - Set up aims for the MCDA
    - Identify decision makers (and/or stakeholders)
    - Consider the context of the appraisal

2. Identify the options to be appraised

3. Identify objectives and criteria
    - Establish a hierarchy by organizing the criteria under high-level and low-level objectives.
    - The "overarching" factors are to be included with the criteria, and to be given a high value, such that this factor could over-ride a management approach that was counterproductive in this way.

4. "Scoring"

Assess the expected performance of each option against the criteria. Then assess the value associated with the consequences of each option for each criterion

- State the consequences of the options
- Score each option
- Check the consistency of the scores on each criteria

5. "Weighting"

Assign weights for each of the criterion to reflect their relative importance to the decision.

6. Combine the weights and scores for each option to derive an overall value.
   - Calculate overall weighted scores at each level in the hierarchy
   - Calculate overall weighted scores

7. Examine the results

8. Conduct a sensitivity analysis

Sensitivity analysis provides a means for examining the extent to which vagueness about the inputs or disagreements between stakeholders makes any difference to the final overall results. The steps to be followed are:

- Compare advantages and disadvantages of the selected options
- Create new possible options that could be better than the original ones
- Repeat the above steps until a 'requisite' model is obtained. A requisite[109] model is one that is adequate to resolve the issues at hand.

6.3.1 Selected MCDA Methods

In general, MCDA methods do not depend upon sophisticated computer packages. The main benefits of using computer software are the easy amendment to input data, and the attractive and informative presentation of outputs. Appendix VI lists some of the computer software on the market.

Multi-Attribute Utility Theory (MAUT)

MAUT is widely used in the US for economic, financial and actuarial problems. It is based on utility theory and it was one of the first methods able to deal with risky outcomes. Different case studies show that it is often used for decision making concerning environmental issues, such as water management, energy management, but it is not often used for broader sustainable development issues.

In the mid-1980s, MAUT was the basis of a U.S. Department of Energy (DOE) study[110] in which five sites for nuclear fuel disposal were ranked against the postclosure and preclosure technical siting guidelines. The objective was to determine which three sites were the most favourable for recommendation for site characterization. This formal decision analysis methodology was developed and customized by the DOE specifically to aid in decision-making in relationship to the siting guidelines. In addition to providing an appropriate logical framework, MAUT provided a means of separating factual information and judgments, and a means of presenting this information explicitly for peer review and public review.

As related in the DOE publication on the use of this decision-aiding methodology, the six basic steps, as applied to the evaluation of sites were:

1. Establish the objectives of repository siting and develop preclosure and postclosure performance measures for quantifying levels of performance with respect to these objectives
2. For the postclosure analysis, specify a set of scenarios that, should they occur, might affect the performance of the repository system as represented by the postclosure-performance measures.
3. For each scenario, estimate postclosure performance with respect to each postclosure-performance measure. Estimate preclosure performance and impacts with respect to each preclosure-performance measure
4. Assess the relative values of different levels of performance against each objective (i.e. assess a utility function over each performance measure) and assess value tradeoffs to integrate the achievement of different objectives into an overall utility function.
5. Using the overall utility function aggregate impacts to obtain a composite score indicating the relative desirability of each site.
6. Perform sensitivity analyses to determine which models, data, technical judgments, and value judgments seem most significant for drawing insights from the analysis.

Evamix

The Evamix approach is an MCDA method, which can take into account quantitative and qualitative data, thus allowing it to construct a mixed evaluation matrix[111].

Regime

This method belongs to the family of qualitative multi-criteria evaluations. In this method, qualitative and quantitative data can be used for criteria. The outcome analysis is easy to understand, communicate and discuss[112].

6.4 Weighting of Criteria

6.4.1 The Analytical Hierarchy Process (AHP)

The AHP is a method in which clusters of criteria and alternatives are compared a pair at a time to obtain relative weights. A ratio of relative importance is assigned to each paired comparison, usually according to a ratio scale[113]. AHP uses a value tree to define the problem.

The benefits of this method includes:

1. Due to its verbal or mathematical terminology, it can simplify the process of eliciting priorities.
2. It is a systematic methodology that forces stakeholders to make consistent judgments

Although it is a simple and effective method, it has a disadvantage. Since the method depends on relative rating, all alternatives are dependent on each other. Therefore adding a new option might cause great changes in the ranking order[114,115,116].

6.4.2 Simple Multi-Attribute Rating Technique (SMART)

SMART originates from the work done in Multi-Attribute Utility Theory (MAUT) by Ward Edwards in 1977. This method employs a structure evolved from decision trees, called a value tree.

When using SMART in decision-making, the decision problem is broken down into attributes, and single-attribute evaluations are constructed by means of value measurements. In a manner similar, but not identical to AHP, a value tree structure is created to assist in defining the problem[117].

6.4.3 Decision Support Software

Decision support software allows for graphically structuring the rules into a clear model and offers numerous functions to vary all values. Linkages to spreadsheet cells are available and suitable for integrating whole data ranges dynamically into the model. Appendix VI provides a summary of the available software.

7 Independent Validation

7.1 Value of Independent Validation

Using a management approach that incorporates the assessment framework involves expert input and assessment at each stage. At any stage of the process, the participating expert(s) could develop a biased view, and/or an incomplete examination of some key point could occur. Because the "insiders" would have a conflict of interest in reviewing their own work, the appropriate management approach is independent validation by a knowledgeable third party.

As there are many different specialized knowledge areas that combine within the assessment framework, it is always possible that some important factor has not been taken into account. Independent validation can serve to identify such gaps. Independent validation also enhances credibility because it is a means of providing a level playing field.

Some of the areas where independent validation would add value include the following:-

- Social acceptance
- Individual technical components of safety
- Transportation
- Compliance with the legal framework
- Health protection, short and long term
- Site selection criteria
- Applicability of specific models
- Environmental and ecological impact methodology
- Environmental performance indicators
- Cost-Benefit Analysis
- Implementation of Multi-Criteria Decision Analysis (MCDA)

Engagement of the public is built-in to the collaborative approach of NWMO. This will be an iterative process, (as shown in Figure 3.1), with the Canadian public, a third party to the NWMO, and therefore the equivalent of independent validation will *already* exist in the category of social acceptance. In a similar manner, risk assessment techniques are to be applied throughout the assessment process, so risk assessment is both specific and integrative. This, too, would be the equivalent of an independent validation.

Validation methodologies such as certification and accreditation are based on compliance with pre-existing regulations or standards, whereas verification is a methodology that can be said to be "customized" to the specific requirement.

7.2 Environmental Technology Verification (ETV) in Canada, US and Internationally

7.2.1 Environmental Technology Verification (ETV) in Canada

The Canadian government recognized in the mid-90s that to encourage the successful introduction and commercialization of new environmental technologies there was a need for a national third party independent performance verification process. Environmental technology verification (ETV) is based upon a generic protocol that defines the documentation of scientific credibility and statistical requirements for the experimental test data to ensure that technology performance claims were verified to a 95% confidence level.

The principal of "third party" involvement is integral to the ETV and established transparency and credibility to the process. The owner or promoter of the technology has little ability to influence the performance assessment.

The initial approach taken in introducing ETV was to create a client driven process that allowed the technology developed to define the performance claims that formed the basis of the verification. This is referred to as "Market ETV". All such verifications must be in compliance to any national or provincial regulatory standards. A more recent development is the situation in which the achievement of national performance standards, verified by ETV, is a requirement for marketing of the technology product.

7.2.2 ETV in the United States

The US EPA Environmental Technology Verification Program

The US EPA, in describing its ETV program[118] states the essential goals of the program as follows:

"EPA's Environmental Technology Verification (ETV) Program develops testing protocols and verifies the performance of innovative technologies that have the potential to improve protection of human health and the environment. ETV was created to accelerate the entrance of new environmental technologies into the domestic and international marketplace."

The US EPA verification program addresses *technology areas*, working with a group of individual vendors in the specified technology category, e.g. drinking water systems for small communities. EPA has a verification process for air pollution control technologies, emission reduction systems for metal finishing shops and industrial coating and environmental monitoring technologies. In each case, EPA experts create efficient and quality assured testing procedures that are then utilized by EPA on behalf of each vendor, following which the acquired data are comprehensively reviewed and subjected to statistical tests.

The US EPA process, like the Canadian approach, is based on the need to create a performance assessment method that utilizes independent third parties to generate credible and transparent information on which stakeholder decisions can be based.

7.2.3 UNEP/IETC Perspective on ETV

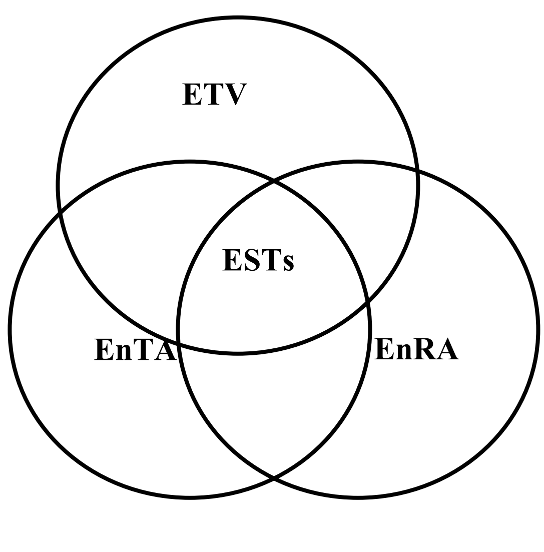
The United Nations Environmental Programme/International Environmental Technology Centre (UNEP/IETC) has determined that the lack of scientific approaches to produce independent, credible performance data is a major obstacle to the development and use of environmentally sound technology[119].

IETC uses two decision support tools: environmental technology assessment (EnTA) and environmental risk assessment (EnRA).

1. Environmental Technology Assessment (EnTA): is a broad concept approach that encompasses the process of assessing and understanding the possible impacts of the adoption, implementation and use of new technologies.
2. Environmental Risk Assessment (EnRA): is a systematic approach which attempts to predict the impacts of a certain action on human health and the environment.

Complementing EnRA and EnTA tools is environmental technology verification (ETV). ETV involves a third party verification of the environmental performance of a particular technology or process. The verification is based on established protocols and test methods which can be replicated, allowing a greater transparency and credibility of information provided to the decision makers and stakeholders. Figure 7.1 illustrates the integration between the UNEP support decision tools and ETV to facilitate the adoption and use of environmentally sound technologies (ESTs).

Figure 7.1: Integration of EnTA, ETV and EnRA[120]



IETC is integrating these three tools in order to facilitate the adoption and use of ESTs. Guidelines are being developed to address:

- Environmental releases and potentially adverse effects
- Environmental monitoring and management requirements
- Assessment and verification of technology performance

UNEP rationale is to improve the knowledge base and skills of administrations and decision makers in local authorities, institutions, and communities, regarding the adoption and use of ESTs.

7.3 Evaluation and Verification in the Assessment Framework

7.3.1 Safety Case

The definition of a safety case:
"A documented body of evidence that provides a convincing and valid argument that a system is adequately safe for a given application in a given environment" (Bishop and Bloomfield, Adelard, UK)[121]

Nuclear industry operators are accustomed to producing a series of Safety Cases for their installations and procedures, as these are required by applicable safety standards. Mandatory safety requirements for nuclear waste have been produced by IAEA in their Safety Standards Series[122], including a recent document on Geological Disposal of Radioactive Waste. These standards are developed through the Waste Safety Standards Committee (WASSC), utilizing specialists, and generating consensus opinions.

As described by Bishop and Bloomfield, the main elements of a safety case are:

- Claim
- Evidence
- Argument
- Inference

These apply to both systems and subsystems, and the point is made that "by using independent evidence (and possibly different styles of safety argument) the claim can be more robust, i.e. it can tolerate flaws in a single argument." This point is particularly valuable in the integrative context of the present work because independent work by several evaluators, in several technical, environmental and economic areas, can strengthen the whole. The production of the safety case is to be integrated with the design of the system. The safety case has a life cycle that extends beyond the stage of approval of a project into long term monitoring and audits, and finally to system updates and corrections. Application of safety case methodology in this way is a "design for assessment". Where a deliberate inclusion of the development of a safety case is not included at early stages, the identification of system and subsystem problems does not occur, and net result could be a significant direct and indirect cost to incorporate necessary attributes. An example is given of the Darlington Reactor Protection System, which, following development of the software for the protection of the system, required as much or more software assessment effort for the safety case. This cost overrun and delay could have been wholly or partially avoided by early inclusion of the safety case methodology.

7.3.2 Environmental Technology Verification

Environmental technology verification is just one example of an independent validation process that is founded on application of expert-developed protocols by verification experts that are third party to the claim being verified. Where there is quantitative test data available, it would be subject to pre-defined statistical testing. A further part of such verification is examination of the validity of the test procedures, the competence of the testing agencies and laboratories (where applicable) and the soundness and technical viability of the technology or process that is undergoing the verification. This type of verification is delivered under license from Environment Canada by ETV Canada Inc., and is considered a leading edge methodology. Similar processes (some of which are fully harmonized with the Canadian verification) are being undertaken in most developed countries, including the US, and are being considered/adapted for implementation in developing countries.

Other third party conformity assessments include auditing, certification, and accreditation. These, and also verification, are well described in a recent UNEP document on Environmentally Sound Technologies for Sustainable Development[123]

7.3.3 Special Expert Panels

Expert panels are perceived to have credibility in risk-based decision making[124], according to a paper by Leiss and Cairney. Both the qualifications of the experts and the process under which the expert panel is operated have an effect on the outcome. Expert panels can be utilized for policy input, technical assessment and methodological issues.

Even the ideal expert panel process can have a more credible and transparent outcome when it is supplemented by application of third party independent validation. It has been a characteristic of expert groups that the expert's own value systems, and their intuitive judgments can be shown to be flawed by not being inclusive of all facts and data[125]. Thus additional support for the expert panel process is another step toward credibility.

7.4 The Political Process

The political process is a qualitative, but, nevertheless, important reality. It provides further validation of decisions, based on identified interests of Canadian voter, the policy framework and the best interests of the nation as a whole. Intergovernmental discussions involving federal, provincial and municipal constituencies play an integrative role. Internationally, Canada must comply with its obligations as a participant in IAEA, and other agreements that the government has ratified.

Stakeholder involvement, an integral part of the NWMO process, can continue as the political process takes over the decision making on management of spent nuclear fuel. As noted in a recent article by Don Tapscott[126], "with the cheap and abundant communication tools now available, citizens can become involved in the governing process on an ongoing basis." The following digital tools could be used:

Real-time Moderated On-line Brainstorming

Officials responsible for policy and citizens would come together to identify new policy issues and needs

On-line Citizen Panels

Citizens serve as policy advisors, sing the Web to hear evidence, ask questions and deliberate.

Deliberative Polling

Citizens engage in small group discussions, supported by appropriate resources, and proceed in a collaborative and deliberative fashion. This could potentially lead to more informed public input on policy making.

Scenario Planning

Future policy needs are projected by politicians, bureaucrats and citizens, by assessing the potential impact of various scenarios.

Appendix I

Appendix I: Environmentally Sound Technology Performance Assessment (EST-PA)

The International Environmental Technology Centre (IETC) of the United Nations Environmental Programme (UNEP) is committed to a mandate based on Sustainable Development. Many of the worlds environmental problems are due to lack of understanding of the impact of human activity on the environment, and UNEP/IETC has developed new management methods and decision support tools to address, particularly for developing countries, the need to select and apply environmentally sound technologies (ESTs) to achieve sustainable development objectives.

Defining environmentally sound technologies in an absolute sense is difficult since the environmental performance of a technology depends upon its impacts on specific human populations and ecosystems, and the availability of supporting infrastructure and human resources for the management, monitoring and maintenance of the technology. The environmental soundness of technology is also influenced by temporal and geographical factors, to the extent that some technologies may be environmentally sound now but may be replaced in the future by even cleaner technologies. Likewise, what could be environmentally sound in one country or region might not be in another.

As stated in Agenda 21, ESTs in the context of pollution are process and product technologies that generate low or no waste, thus preventing pollution being generated. They also include end of pipe technologies for treatment of pollution after it has been generated. Furthermore, ESTs are not just individual technologies, but total systems that include know-how, procedures, goods and services, and equipment as well as organizational and managerial procedures. This implies that the human resources development and local capacity-building aspects of technology choices, including gender issues, must also be addressed when considering the identification, adoption and use of ESTs.

Sustainable development depends on broad-based knowledge and support, from a range of stakeholders, which implies and requires greater public participation in the selection of the technologies that will impact the environment. Factors such as economics and environmental impact must also be taken into account, together with the technology performance.

Chapter 34 of Agenda 21 defines ESTs as technologies which:

- protect the environment;
- are less polluting;
- use all resources in a more sustainable manner;
- recycle more of their wastes and products; and
- handle residual wastes in a more acceptable manner than the technologies for which they are substitutes.

ESTs are, therefore, technologies that have the potential for significantly improved environmental performance relative to other technologies.

ESTs are not just individual technologies. They can also be defined as total systems that include know-how, procedures, goods and services, and equipment, as well as, organizational and managerial procedures for promoting environmental sustainability. ESTs would also include the following characteristics:

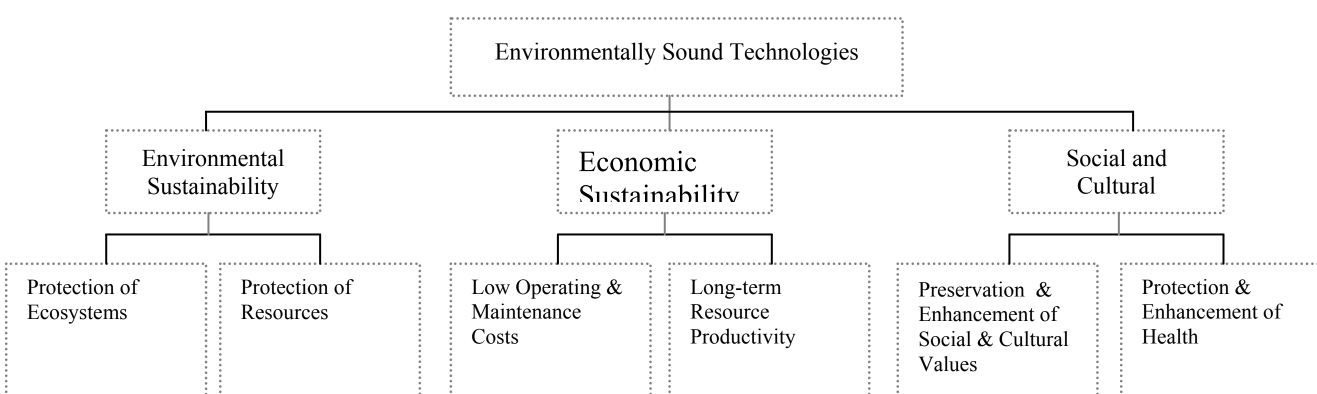
- captures the full life cycle flow of the material, energy and water in the production and consumption system;
- covers the full spectrum from basic technologies that are adjunct to the production and consumption system, to fully integrated technologies where the environmental technology is the production or consumption technology itself;
- includes closed system technologies (where the goals is zero waste and/or significant reductions in resource use), as well as environmental technologies that may result in emissions; and
- considers technology development within both the ecological and social context.

The adoption and use of ESTs must be underpinned by the concomitant development of more holistic environmental management strategies, taking into account the need for culturally appropriate, ecologically sustainable solutions. Transparency and accountability are fundamental prerequisites. Baselines, benchmarks, codes of practice and indicators of sustainable development are tools for assessing the performance of technological systems on a continuous basis and for modifying future strategies.

The problem to be addressed, especially in developing countries, is the inadequacy of information and decision support tools to quantify and qualify environmental technologies as meeting the requirements as "Sound". Methodologies must be used that address this "Performance Assessment" task and can take into account the broad range of technology options and the specific local requirements. Figure AI.1 illustrates for any environmental technology under evaluation some of the important characteristics that need to be taken into account.

Economic sustainability considers operating and maintenance costs as well as long-term productivity. Social and cultural sustainability considers health protection and the preservation of social and cultural values.

Figure AI.1: Characteristics of ESTs in Relation to Sustainability

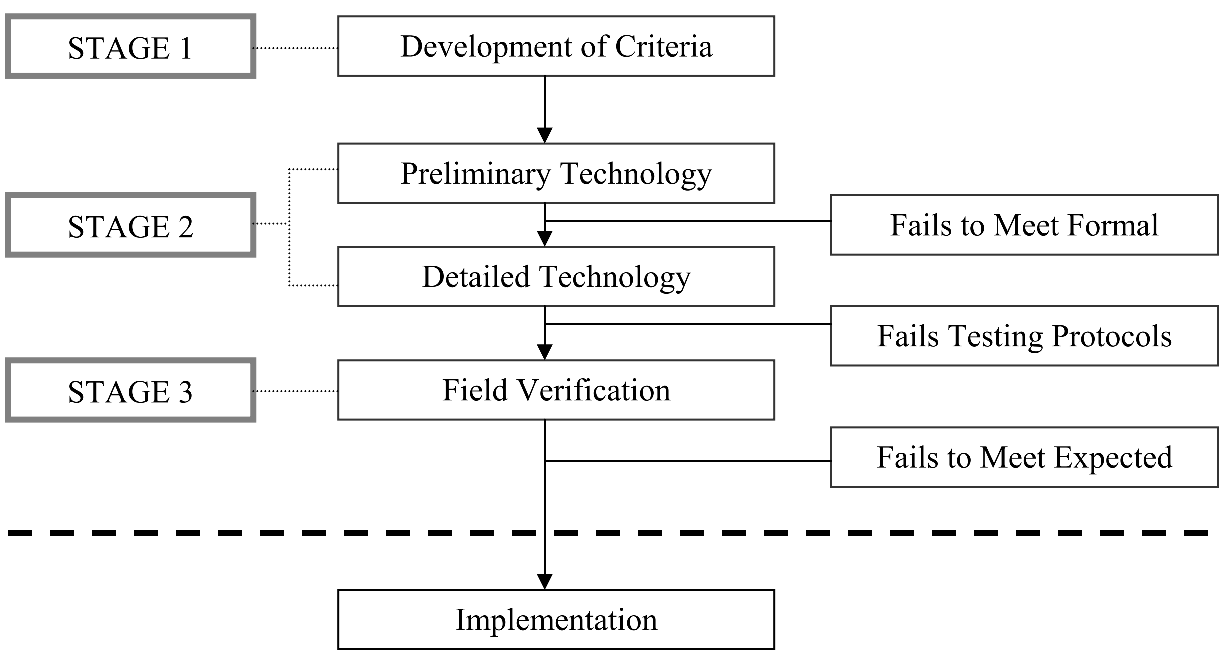


UNEP/IETC recognized a need for an assessment methodology that could be used by decision makers to make informed decisions on ESTs and developed the EST-.Performance Assessment (PA) approach to meet this need.

The purpose of EST-PA is to help evaluate the appropriateness and applicability of technologies using a comprehensive technology assessment and verification protocol. The EST-PA process can be used by local government and private sector organizations to perform technology assessment and verification leading to the identification and selection of appropriate environmentally sound technologies.

As shown in Figure AI.2, the entire EST-PA process consists of three stages: Stage 1 – Criteria Development; Stage 2 – Detailed Assessment; Stage 3 – Field Verification. EST-PA facilitates the assessment and evaluation of proposed environmentally sound technologies based upon internationally recognized technical protocols incorporating sound science and statistical analysis. The process can also be structured to take into account social and economic parameters specific to the needs of developing countries. In most cases, the EST-PA process endeavours to utilize local laboratory facilities and technology institutions for the provision of technical and organizational oversight. In addition, institutional capacity building and related training through the EST-PA process can be instrumental in strengthening local technology infrastructure.

Figure AI.2: The EST-PA Process



EST-PA utilizes a comprehensive assessment process based upon established criteria and recognized technical protocols. In meeting the basic objectives of the EST-PA process, the following activities are undertaken:

- Development of detailed criteria for screening, assessing and verifying environmentally sound technologies.
- Development of testing protocols based on criteria in order to validate the performance of technologies and identify possible changes that may enhance a given technology where appropriate.
- Organization of independent third-party verification of technology performance against established testing protocols.

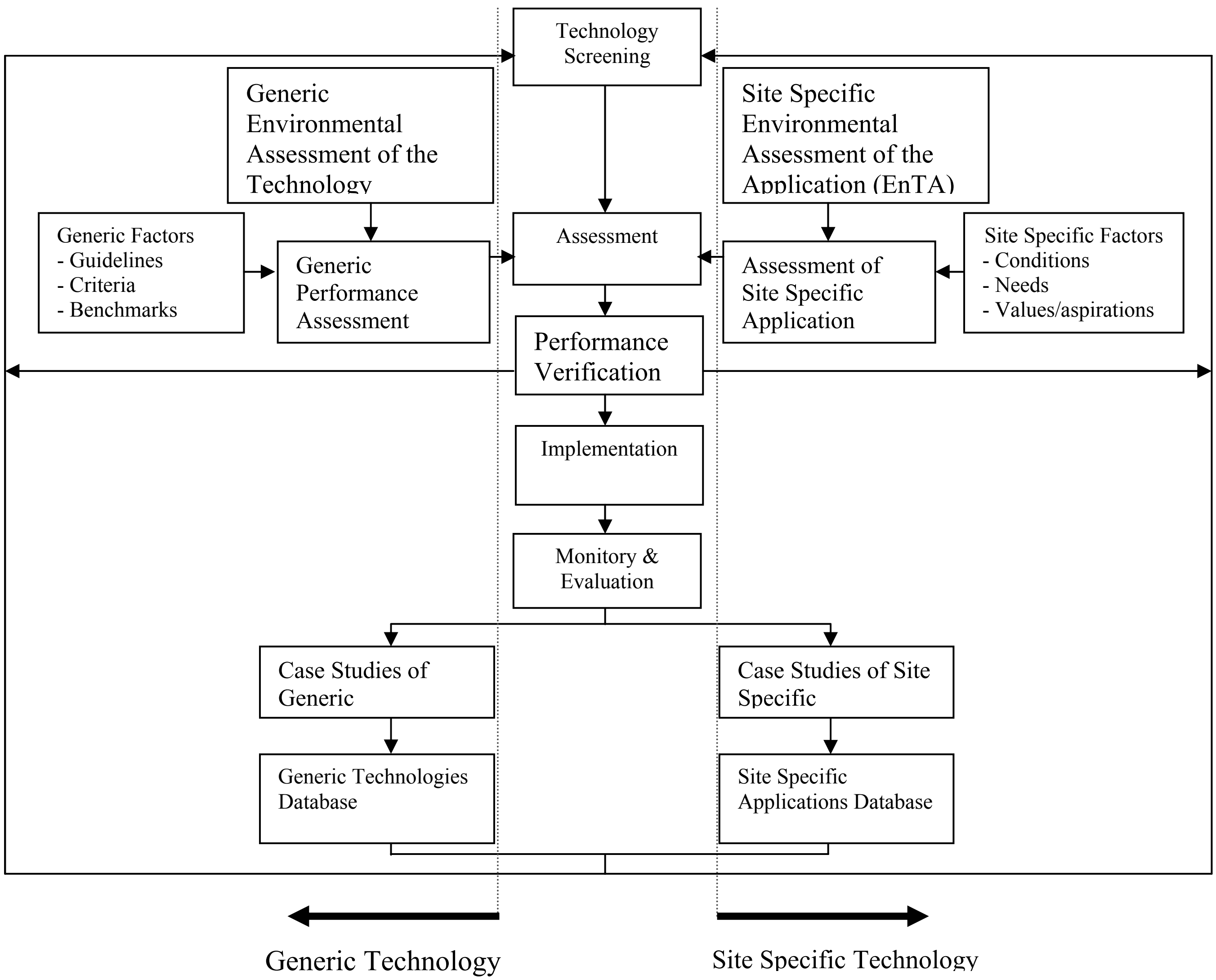
In most circumstances when environmental technology is being assessed for adoption, the performance assessment occurs at two levels.

The “Generic” assessment evaluates performance without any specific reference to the site where this technology will be located but rather looking at its general performance characteristics.

The “Site Specific” assessment addresses a complete range of factors that must be taken into account before installation and operation of the technology is permitted. This may include obtaining public and community support for the adoption and installation of the technology, and developing evidence and information of economic benefit, and environmental performance at the local level. An acceptable “Generic” performance assessment, is no guarantee of automatic local acceptance that would led to investment and installation.

In Canada, environmental technologies even if they are well established as good viable products for a particular problem and have many successful installations, must still obtain a Certificate of Approval (C of A) from the Provincial Government before they can be installed in a particular plant or location. If there is a strong community concern regarding the environmental problem being addressed through the selection of a specific technology solution, there may be a need to address such public concerns through direct involvement of the community.

Figure AI.3: Process for Evaluating Environmental Soundness of Technologies: Generic Technology Level vs. Site Specific Application Level*



**Applicable to production and consumption technologies, as well as, technologies designed explicitly for environmental enhancement, protection and remediation.*

Appendix II

Appendix II: Existing Models for Environmental Risk Decision-Making

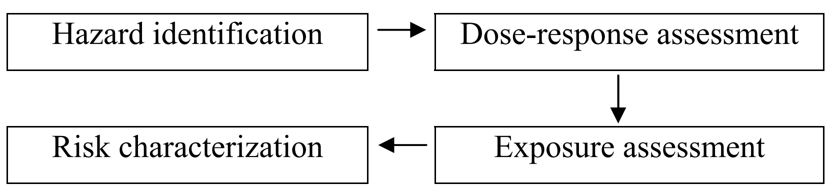
Ideal Model

This model is the ideal situation in which all possible information is known about a policy issue, including technical, social, ethical, and economic factors. This is rarely if ever the case and decisions have to be taken with imperfect and incomplete information. This model is included as a goal to develop methodologies that can help move closer to the ideal.

The [US] National Academy of Sciences "Red Book" Model

Cothern explains "This model starts by combining hazard identification with dose-response assessment and then combines this with the exposure assessment to yield a risk characterization" as shown in Figure AII.1.

Figure AII.1: The National Academy of Sciences "Red Book" Model



"The regulatory decisions that emerge from this analysis use inputs from analysis such as economics politics, and statutory and legal considerations as well as social factors." This is the classic model that assumes that risk assessment is based on science and is value free, and that values only enter the decision (policy) analysis afterwards at the risk management stage.

Although the tidiness and convenience of an approach that separates science and values is appealing, experience and research over the past 25 years has demonstrated the flaws in this thinking. Despite the evidence against it, many analysts and decision-makers continue to cling to the belief that the process of risk assessment can be kept impartial and value free. They do so at their peril and the news media and literature are filled with examples of the poor decisions and subsequent disastrous outcomes that result from this kind of flawed thinking. A decade after producing the Red Book model, the National Academy of Sciences proposed an alternate model that recognizes the value of pursuing tiered and/or iterative processes that provide opportunities for interactions between risk assessment and risk management processes. This model has, therefore, comparable elements with the assessment framework (Figure 3.1) used here.

Cost Benefit Analysis

Cost benefit analysis is one example of wider class of economic analysis methods which also includes cost-effectiveness analysis, risk-benefit analysis, and socio-economic impact analysis. This approach compares the benefits of a decision (such as preventing death or disease, reducing property damage, or preserving a resource) to the costs. Cothern points out that "any situation involves limited resources, and knowing how the costs and benefits compare is thought to be helpful. However, many of the benefits are difficult if not impossible to quantify, for example: the benefit of preserving a species, the aesthetic value of a forest, how valuable it is to be able to boat and swim in a river or lake. Also many comparisons are difficult: the relative benefit of averting sickness or death, averting a cancer case, or a case of birth or developmental defect. Almost all of the problem areas in cost-benefit analysis involve value judgments and thus this is an area that could be improved with the inclusion of value and ethical analysis."

A Framework Model

Brunk et al.[127] observed that risk assessment is an example of a "mandated" science, i.e., one which tries to fill the gap between theoretical or laboratory science to make reliable and defensible regulatory or management decisions. The distinction is that "pure" science is value free and mandated science is not. In the classical risk assessment model (e.g., see National Academy of Sciences "Red Book" model above) there are two stages: factual judgment (which is free of values); and evaluation (which is value laden). In the classic model, risk assessment can be value free even though it is dominated by human judgment in the face of uncertainty. The classical model does not acknowledge the role of value-based judgment. In reality, values can feed back between risk assessment and risk management without anyone realizing this. Brunk et al. dissect the Alachlor controversy (see case study below) as an example of the breakdown of the classical risk assessment model for decision-making. They assert that it was not a conflict between those who accept the verdict of the risk assessment and those who do not. It was also not a conflict between those who understand the objective risks and those who are guided by subjective perceptions. It was a political debate among different value frameworks, different ways of thinking about moral values, different concepts of society, different attitudes towards technology, and different ideas about risk taking.

The framework model suggested by Brunk et al. acknowledges the interconnections between the scientific and social policy elements. The components of the framework include:

- Attitude towards technology (positive or negative)
- Uncertainty (statistical, lack of knowledge, incomplete knowledge, methods to use)
- Risk taker or risk-adverse
- Causality (including confidence)
- Burden of proof, who has it and what are the criteria
- Rationality
- Voluntariness (John Stuart Mill's liberalism) or social order

The key point, as Brown[128] puts it, is that "sensitivity to the biases that are introduced by broad attitudes concerning rationality, technology and the liberal state should bring recognition by risk analysts that their activity is not, as they imagine, neutral and value-free".

CASE STUDY – Approval for Use of the Herbicide Alachlor

In 1969, Monsanto Corporation received approval from the Canadian government to sell its herbicide Alachlor in Canada. Central to the approval were numerous toxicological tests performed by a private firm, Industrial Bio-Test Laboratories (IBT). In 1976, regulatory authorities in both Canada and the United States found these tests and many others conducted by IBT to be fraudulent. This resulting in the unusual situation of a chemical being in widespread use without any evidence of its safety. The controversy in Canada developed as three different stakeholders (Health Canada, Monsanto, and a Review Board appointed by the court), starting with similar data, performed what they perceived to be objective, scientific assessments of the carcinogenic risk of Alachlor, only to arrive at three different answers. Monsanto's study showed it was safe. Health Protection Branch's 3-year study ended with the HPB denouncing Alachlor as "one of the most potent carcinogenic pesticides presently in use" and cancelling its registration. In its final decision, the Review Board contradicted HPB's decision and recommended that Alachlor be reregistered for legal sale in Canada. However, the Minister of Health chose not to heed this recommendation, for reasons that were not clearly documented. To this day, Alachlor is a prohibited substance in Canada. Yet Alachlor maintains its approval by the United States Environmental Protection Agency and according to EPA is "the second most widely used herbicide in the United States". Hatfield and Hipel use systems theory to illustrate how the value differences of the various parties were expressed as very different (but unstated) problem formulations. They conclude that "more explicit documentation and communication of problem formulations would have revealed the underlying causes of the controversy and perhaps saved significant time and expense"[129].

A Channel Model

This model encourages the consideration of all "channels", i.e., values or value-laden components of a problem, in order to reach the decision. Examples of channels are shown in Table AII.1.

Table AII.1: Examples of Channels.

Problem	**Values or Value-Laden Components**	**Solution or Decision**

Environmental Problem Requiring Solution
↳
	Objective, Hard or Quantitative
	• Quantitative Risk
	• Comparative Risk
	• Cost
	• Feasibility
	
	Subjective, Soft or Qualitative
	• Social
	    • Prejudice
	    • Equity
	    • Freedom
	    • Trust (scientist, government, media)
	    • Responsibility
	    • Blame
	• Quality of Life
	    • Job security
	    • Self image
	• Safety (error on the safe side)
	• Political (power)
	• Religious (e.g., stewardship)
	• Ethics (standards of moral values)
	• Psychological (feelings)
	    • Fear
	    • Embarrassment (ignorance)
	    • Guilt
	    • Helplessness
	    • Security
	• Life (prolong)
	• Judicial (let someone else decide)
		↴
		Decisions and Policies

According to Cothern, "all too often a decision concerning an individual environmental problem is made using only a few or even only one of the many elements shown above. In these cases, other horizontal channels depicted in the model above are known, but are ignored or overlaid with what the decision maker knowingly or unknowingly thinks are more important values."[130] There is no channel that is value-free.

An Overlay Model

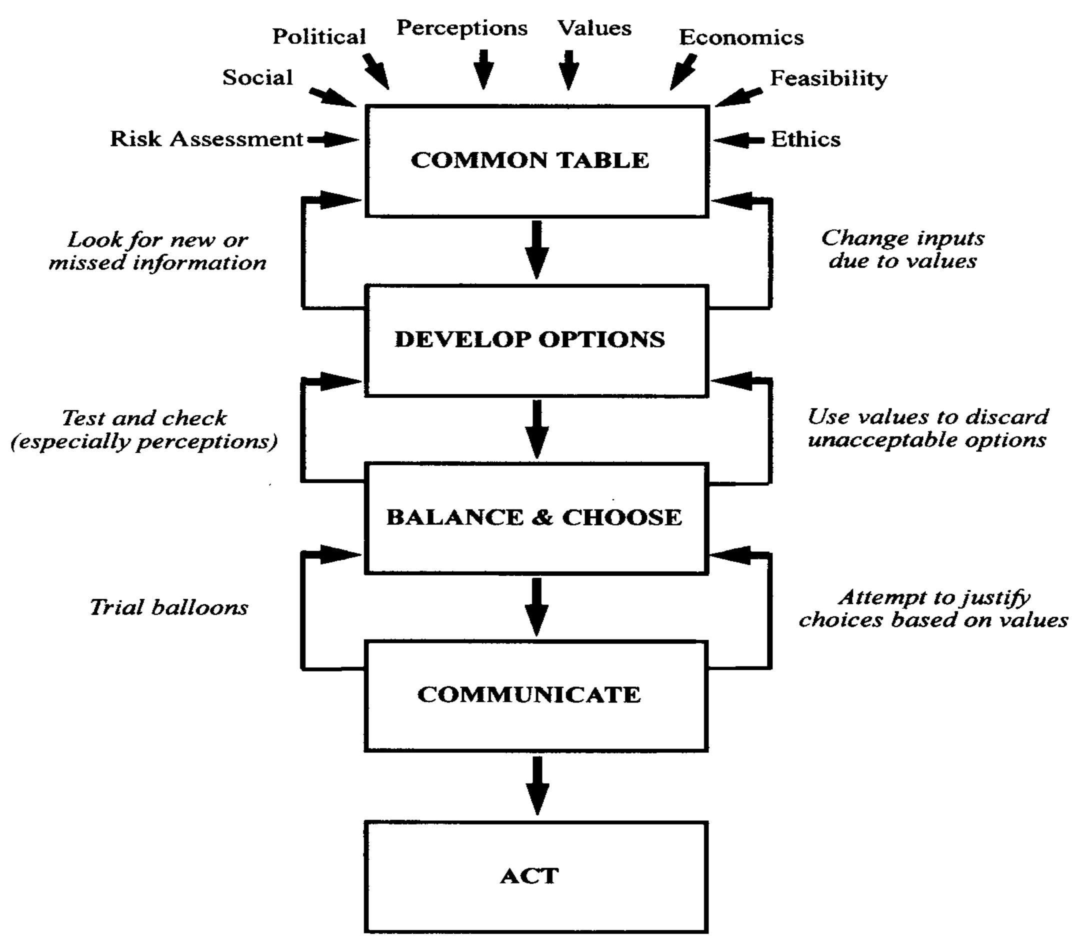
This model is a variation of the channel model in which the values are added as an overlay to the analysis. Cothern warns that "by adding the values at the end, one can easily lose sight of the critical features of a problem and focus almost completely on the value or ethic. An example of this approach is the use of the value of zero risk. … To overlay information concerning an environmental problem with a value such as zero risk prevents perspective, and this simple-minded approach prevents any understanding of the risks actually averted or the cost of doing so."

A Continuous Model

In this model, values, perceptions, and ethics enter the risk assessment and decision processes in several places and do so continuously. These elements are inserted by many different individuals in the form of assumptions or defaults at different places in the overall process. These individuals include scientists (e.g., physical, biological, social), economists, lawyers, politicians, regulators, engineers, managers, and many other professions. Few of these individuals are trained in the use of values and ethics. to address this NWMO an ethicist expertise should be integrated as a resource in the development and application of the comparative framework.

The model presented in Figure AII.2 is a single view or "snapshot" of a continuously changing process.

Figure AII.2: A Continuous Model



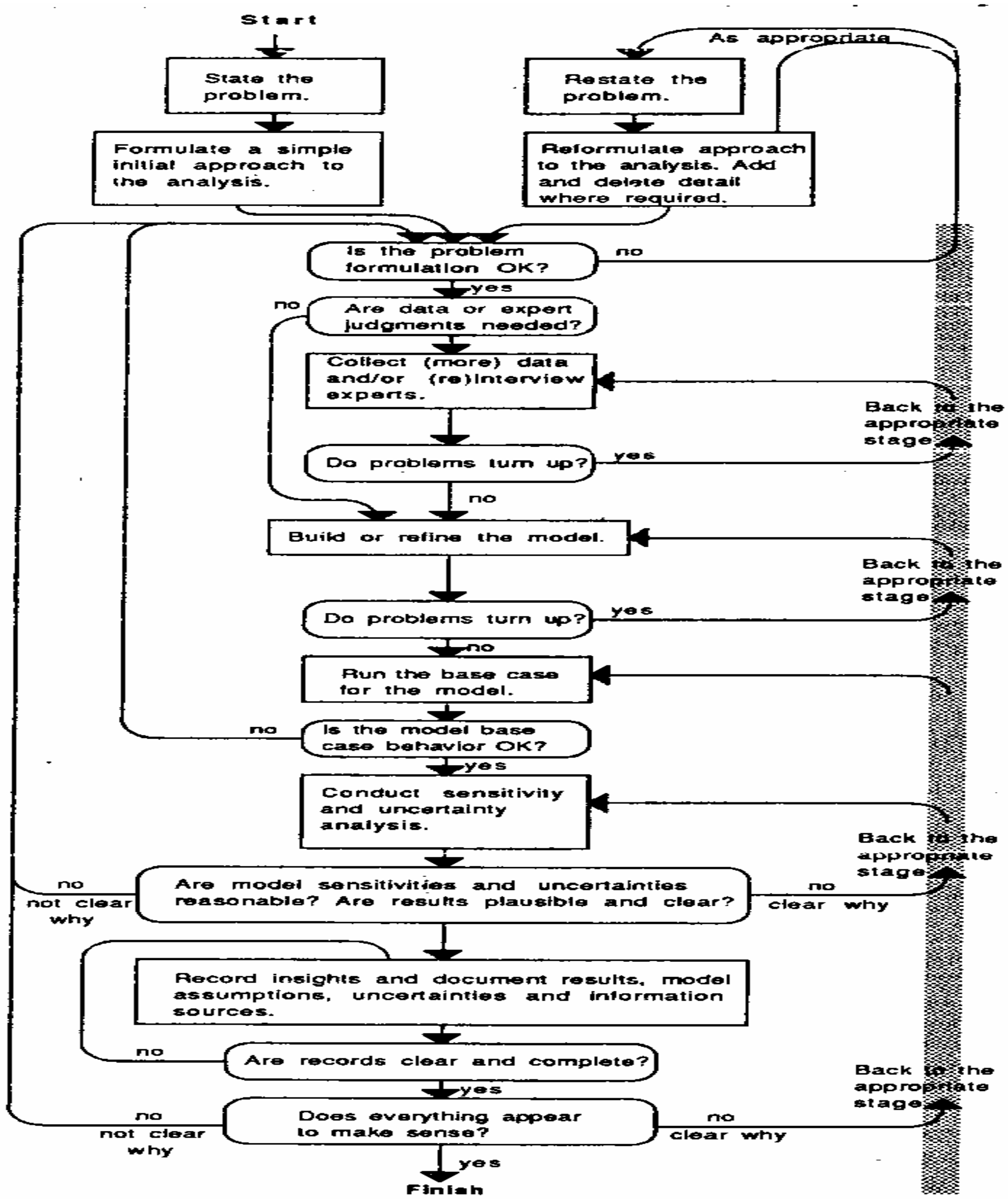
A Policy Analysis Model

Morgan and Henrion[131] propose a decision model that is designed to address uncertainty in quantitative risk and policy analysis. A key feature of the model is the heavy emphasis on iterative refinement (also proposed in this project). This reflects the view that policy decision analysis is a process of learning and discovery. Both the formulation of the policy questions and the structure of the problem are frequently refined or even re-defined. This model emphasizes input from experts, yet could easily be expanded to include input from stakeholders, including the public.

An important feature of this model is the inclusion of the base case. An understanding of the risks, costs and benefits associated with the current situation (or base case) can help to put the assessment of the proposed policy or management options into perspective. There is a maxim in risk management that states "not to decide is to decide". But how long should we wait for new research and what level of uncertainty is acceptable when making a decision? McColl et al. articulate the dilemma well.

> "Deferred decisions constitute implicit acceptance of the status quo, including the health risks and adverse outcomes that may result from the decision not to act. On the other hand, precipitate action may introduce new hazards as the result of substitution of an agent with known risks by another agent with uncharacterised, potentially greater risks. In the longer term, further research and analysis can undoubtedly reduce ignorance and uncertainty, but deferring crucial health protection decisions to a later point in time may lead to disaster. This dilemma is exemplified by the tragic outcomes of the HIV blood transfusion problem in Canada and elsewhere, the "Mad-Cow" disease outbreak in the United Kingdom, and the seemingly pervasive health problems associated with environmental contaminants – for example asbestos, heavy metals such as mercury and lead, or organochlorine compounds such as PCBs and dioxins."[132]

Figure AII.3: A Policy Analysis Model



Appendix III

Appendix III: Summary of Evident Practice in Public Consultation

Terminology and Concepts

To compare programs requires a common understanding of the terminology and concepts used. This can only be done at a "national" level, since terminology and concepts differ substantially from country to country. The most useful and detailed effort to define terminology was found in the UK documents cited [DEFRA 2001, DEFRA 2003]. Consequently, their concepts have been used as a framework. DEFRA 2001 refers to these as "Techniques for Engaging the Public", and subdivides them into two basic categories involving:

- Small numbers of people, intense deliberation
- Large numbers of people, less deliberation.

DEFRA's list of processes may also be logically categorized according to the sophistication and complexity and the stage of the process, viz:

1. Formulating strategies and approaches
2. Providing or collecting information
3. Educating and elucidating responses
4. Identifying areas of agreement and disagreement
5. Resolving differences and formulating positions
6. Involving the community in decision making

The EC RISCOM project[133] has also assessed the process. In their report, they distinguish between three forms of public communication followed by decision making based on the most inclusive form:

- Dialogue- communication between opposing parties
- Consultation- a "centrally controlled" opportunity to input
- Deliberation- involving "conditions of equality" amongst all
- Participation- decision making stemming from Deliberation.

Criteria for Successful Public Participation

Various agencies and jurisdictions have attempted to define the "criteria" for successful public consultation programs. The EC took an early lead with the "Aarhus Convention on Access to information, Public Participation, Decision Making and Access to Justice in Environmental Matters", which stemmed from the Rio Declaration and was signed in June 1998 as part of the "Environment for Europe" process [UNECE 2003].

The US National Research Council [NATREC 1996] defined "three compelling rationales for broad participation in risk decisions" as:

- Normative (consensual), i.e. involving the "consent of the governed"
- Substantive (inclusive), i.e. participation by "diverse groups and individuals"
- Instrumental (designed to decrease conflict and increase acceptance)

In this, NATREC emphasizes the "non-specialists should help design (broad participatory, deliberative) processes that allow for…weighting of social, ethical and political values that *cannot be addressed solely by analytic techniques*" (Italics added)

The US NRC also summarised experience with decision making and implementation of programs in this area with the subtitle "Learning While Doing and Keeping Options Open [NATREC 2001]. The message: traditional structured processes and "command and control" management fails when "coping with uncertainty, learning from and responding rapidly to errors and surprises, and progressively identifying promising new alternatives"

In their RISCOM paper, Hunt et al[134], define criteria for successful participation as:

- Instrumental - leading to a consensual decision, similar to the use above
- Procedural – regarding conduct of the process, e.g. inclusively, transparency
- Constitutive – enhancement of meanings, understandings between participants

They proceed (ibid, 5.3) to develop these three higher order criteria into several supporting statements which characterize each. These statements in themselves provide a useful "tool" for evaluating any public communication process.

Novel Approaches to Public Consultations

The following approaches are relatively new and are supported by limited experience.

The Internet

The Internet has developed over the last few years to become the leading means of communication. As a result, the use of Internet communication in public participation programs is still relatively untried. It allows for widespread inexpensive dissemination of large documents formerly only available to experts, rapid feedback and tabulation of responses, and special interactive communication approaches (e.g. via on-line chat rooms).

Oskarshamn Model

Swedish experiment in community-led assessment. Local political organization (councils) forms the basis. Regulators and proponents both participate actively. Full-time project leader and costs of all activities borne by the nuclear waste organization.

Team Syntegrity

An important developmental project in the area of stakeholder communications is the "RISCOM project. One experiment from this project concerns an approach called "Team Syntegrity". In this case, participants are invited to put together complete statements on the overall issues at hand called "aggregated statements of importance (ASI)" They then present these to the assembled participants who vote on them. The issues receiving a minimum number of votes are elaborated further in working groups and reviewed until a pre-determined number of "key" issues emerge.

Peer Preview

Method developed by NIREX [NIREX 2001] involving review of proposed research activities by stakeholders before the research is carried out.

Scenario Pyramids and Future Search Variations

These involve small groups engaged in envisaging the future in which the disposal facilities form a part of the reality. Refer to [NEA 2001] for a review and discussion of a range of novel, experimental techniques.

Appendix IV

Appendix IV: Repository Modelling- Concepts, Issues and Activities

1.0 Conceptual Modelling of the Repository – Model Elements

The purpose of individual element and integrated modelling efforts is ultimately to support the "Safety Case", the summary of carefully weighed evidence and argument presented to the regulator for licensing purposes. The concept of a "Safety Case" is shown schematically in Figure AIV.1 [NEA, 2003: to be published]

Examples of the types of evidence that can be used to support arguments for the robustness of the "safety case" for a geological repository are also found in NEA 2003[135] ("Box 5"). In summary, these arguments comprise the following types:

- Natural analogue arguments, stability of natural bentonite formations, Oklo reactor.
- Thermodynamic arguments, e.g. stability of copper in canister designs
- Kinetic arguments, e.g. corrosion rates of iron, steel
- Mass-balance arguments (i.e. limitations of reactions based on limited quantities of reactants)
- Natural isotope profiles in rocks, paleohydrogeological information in general.
- Extrapolation of short-term experiments
- Detailed modelling studies

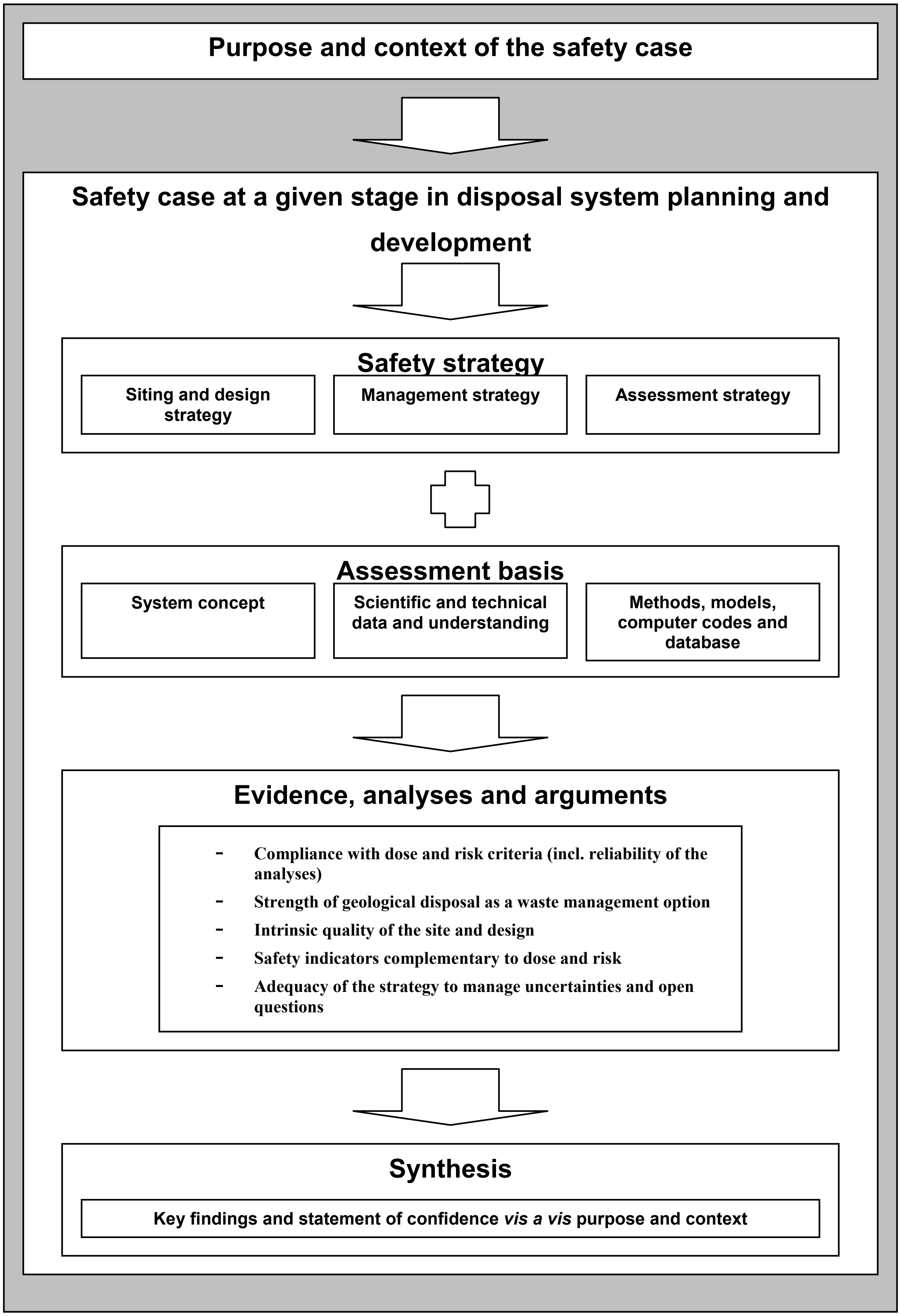
Efforts to integrate the many repository model elements have been ongoing for many years. The standards of assessment continue to rise as the tools available and experience with these methodologies expands around the world. Increases in performance and reductions in the cost of computational computer power is a significant driver for this process. Key "subsystems" to be modelled for a repository (working from the "inside" out) include[136]:

a) Fuel integrity and solubility
b) Packaging and backfill performance
c) Repository Design
d) Hydrogeology
e) Geochemistry
f) Geography (biosphere) & land-use
g) Climatology

2.0 Technical Issues with the Model Elements

The following items indicate the nature of issues which are currently under investigation in various national programs to improve not only the accuracy of prediction of behaviour of individual elements of deep repository models, but also to improve the design:

Figure A IV.1: Schematic Concept Illustrating the "Safety Case"



2.1 Fuel integrity and solubility

- fuel chemistry and interactions (including cladding) over long time
- fuel dissolution in the predicted repository backfill chemistry {e.g. King and Kolar, 2002]
- important nuclides: long-lived nuclides requiring greatest attention

2.2 Packaging and backfill performance

- Stress analysis of corrosion-resistant containers to identify initial failure points
- Corrosion prediction for the containers to estimate time to failure and subsequent failure progression
- Role of microbial agents (e.g. methylating bacteria)

The EC-lead "CROP" Project[137], organized by the EC in which Canada participates along with several EC members and the US, addresses a wide range of design, construction and performance modelling issues specifically related to the engineered barriers in the repository. As a multi-lateral forum, this project provides a means of reducing and quantifying the uncertainty associated with this element.

2.3 Repository Design

- Applicability of tunnel and mine structure stability
- tunnel and shaft seal effectiveness (prediction)
- Need to minimize excavation damage
- Predict thermomechanical effects in rock structures (faults, heat effects)
- Characterize the repository rock walls and predict local crack initiation and growth (Near-field design tools)
- Understand the risk and severity of tectonics and seismicity (the effects of future earthquakes)

Models to assess containers, backfill and vault performance have been reviewed by Sykes[138]. In this report, the author comparatively assesses four Canadian models (MT,INROC,BETRAC, and MOTIF), and three models (REPCON,COMP23 and STRENG) used for assessment of European vault concepts.Tabular comparison categories include:

- 3D vault domain including buffer, backfill, concrete, and the excavation damage zone
- Spatially varying media properties
- Transient fluid flow using sound science
- 3D, transient geosphere mode, spatially varying properties, fracture frequencies, and fluid densities dependent on temperature, brine density
- Convection, dispersion, radionuclide retardation and decay modelled by convection-dispersion equations is spatially and temporally varying

MOTIF emerges from this assessment as a superior modelling tool.

Hydrogeology

- flow in complex (and indeterminate) crack networks

- defining boundary conditions
- predicting infiltration rates, changes in pH and salinity
- flow-system evolution (see also under climatology)
- relevant natural “analogs” and their application (e.g. from paleo-)

Early efforts to model flow in the geosphere were generally lacking in their representation of a complex, non-uniform, 3D system over time. In particular they “ did not adequately account for uncertainties associated with spatial and temporal flow system variability” [139].

Subsequent work, such as that at University of Waterloo with FRAC3D, [Sudicky, 2003] is gaining acceptance as a means to address the complex issue of 3D fracture network modelling

Of particular interest in this area is a relatively new international initiative entitled “AMIGO - Approaches and Methods for Integrating Geologic Information in the Safety Case”, sponsored by the NEA.

2.4 Geochemistry

- development of reliable Kd values and predicting local applicability
- combining water flow in hydrogeological models with chemisorption

Prediction of the movement of radioactivity travelling along cracks in the rock under changing climatic conditions is addressed via “Reactive Transport Modelling”, which aims to understand the applicability of general physico-chemical models which predict the retardation through sorption (exchange reactions) with active surfaces, e.g. those provide by certain granular materials.

More sophisticated treatment of the chemi-sorption process than that afforded by “Kd”s appears warranted. One approach is to model the convective solute transport using a particle-tracking code[140]. It is expected that future efforts will aim to incorporate chemi-sorption into the fracture flow models, discussed above under hydrogeology, and the integrating models, such as SYVAC3, discussed later.

2.5 Geography (biosphere) & land-use

- changes in land use, location of receptors
- reference biota, current and future, impact on non-human biota
- prediction of intrusion scenario probabilities

In general, the surface modelling draws from established surface pathway analysis, such as that based on CSA N288 [CSA, 2003][92]. Recent reviews of biosphere parameters in this area have included reference biota [141] and transport of radio-iodine[142].

2.6 Climatology

- effects of major climatic changes, e.g. permafrost on surface elements
- glaciation effects on subsurface structures and flows

DECOVALEX (an international effort on thermo-hydro-mechanical modelling aspects) and MOTIF (a finite element code used in the Canadian Program [P25 of OPG 2003 An Report] are both being used to quantify the effects of climate change.

3 Integrating the Model Elements – Safety Assessment

Assessment of any overall modelling approach for a repository must address not only each of these elements independently, but consider the behaviour of the "coupled" elements either in terms of a set of agreed "scenarios", or by defining a set of parameters which permit characterization of the range of anticipated variability for each important aspect of the repository and the pathways to dose-receptors. A number of important issues have been noted in the literature concerning the robustness of such an overall modelling approach, in particular:

- All modelling approaches contain a significant degree of "expert judgment". It is important that these aspects be identified, communicated, and understood.
- The "couplings" note above can be expected to vary significantly in significance with location and over time.
- Efforts to devise all-inclusive analytical models have lead in the past to "large bushy fault trees and a lack of assurance that important chains of events have been adequately represented" [ibid, p73]. Hence the importance of well-communicated "expert judgment" noted in the first bullet.
- System boundaries and the interfaces between elements of the model are difficult to define, partly because these are not well defined in the physical world, and partly due to differences in model design and modelling technique amongst modelling specialists.
- Changes to the repository structure over time (or the occurrence of disruptive events) do not occur smoothly. Discontinuities and their (non-linear) impacts on model coupling pose an almost infinite array of possibilities.

A list of steps to be followed in the Performance Assessment of a repository system are listed in Section 5.2.2 [US NRC, 2001], although various experts and jurisdictions can be expected to vary this formula. The sequence in which various interactions occur can also significantly affect the outcomes. Indicative of the role of "professional judgment" in the application of integration models is whether the model elements are "fully coupled" or "sequential". For example [Sykes, 2001][143], fully coupling the vault and geosphere elements permits variables such as pressure, temperature, salinity and nuclide concentration to be continuous throughout the domain modelled. By using a sequential modelling approach, the requirements on the element model are simplified, intermediate results are available for inspection by the analyst, and computer efficiency is improved.

Early assessment of the integrated Swedish modelling efforts was performed by the NEA[144]. In reviewing the SITE-94 report on a hypothetical Swedish hard-rock repository, the reviewers noted specifically that the model was over-conservative in regards treatment of leakage from a failed container, but potentially non-conservative with respect to its use of a uniform, one-dimensional transport model for geospheric transport. This illustrates two important issues for overall site modelling: that it is important for the model to (a) including all significant model aspects and (b) make them as realistic as possible. It should be noted that subsequent Swedish models have addressed these points. The example also illustrated an important difficulty: as the model becomes more "realistic" it also becomes more complex, making simple intuitive grasp of the results more difficult, and that criticism of the overall modelling effort can rest on a single weak area (the chain is only as strong as…)

Additional overall benchmarking can be expected to build on comparison of the Swedish[145] with AECL [Goodwin et al 2002] and the OPG codes[146]. In the latter, the Swedish SR97 Safety Assessment case is evaluated using the Canadian codes RSM 1.0,DSM 1.0, SYVAC3-PR4, and the Swedish vault transport code NUCTRAN. Swedish comparisons with Canadian vault scenarios are particularly relevant due to similarities in design, rock-structures, surface geography and climate. To-date, comparisons have shown the Canadian analysis to be more conservative than the Swedish, since the Swedish codes contain additional interactions (matrix diffusion in the geosphere, bioturbation in the biospheric soil model) that tend to further slow radionuclide migration

A simplified model of the relationships of the various model elements used by the Canadian group (and the computer programs available to model the interactions) is shown in Figure AII.2. A the "heart" of this schema is the current reference Canadian safety assessment model for a deep geological repository, "SYVAC3-CC4[147]. Key elements outside this model are shown "coupled" to it.

Once an integrated model is available, it is also possible to eliminate some of the complexity associated with the almost limited combinations otherwise presenting. For example, the list of nuclides on which the modeller must focus can be reduced through consideration of their lives and chemical reactivity. (See "screened list", Figure AIV.2.)

Figure AIV.2: "Third Case Study" - Repository Modelling Scheme Proposed by OPG

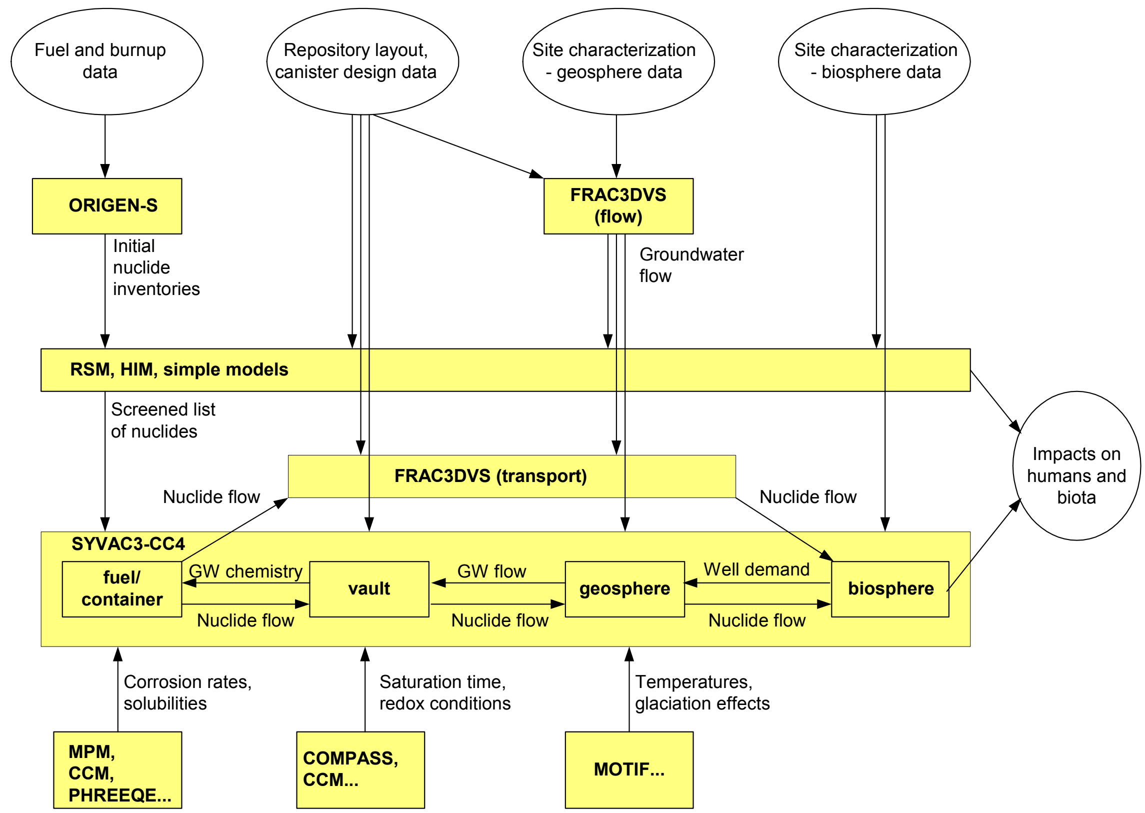


Figure AIV.2 is an illustration showing modelling approach used in the recent OPG "Third Case Study" scoping post-closure safety assessment exercise for a deep geologic repository concept. Note consistent use of data, interface between site characterization conceptual model and safety assessment model, and use of multiple-lines-of-reasoning including simple models, detailed models, and probabilistic system model

Approaches to uncertainty analysis of results from integrated modelling must include recognition of "variability" due to inhomogeneities in system elements, as well as "uncertainties" in the long term behaviour of the system element. In combining these, a "probability weighted" dose calculation can be obtained. This is the approach used by EPRI with their IMARC model[148].

4 Acceptance Standards – National and International Yardsticks

Although national regulatory bodies such as the CNSC have well-defined processes for licensing currently operational facilities, additional regulatory guidelines are likely to be applied in the scrutiny of models used for the licensing of a repository. In particular, the quality of the "safety case", and values of doses expected – individual and collective – over time may be expected to all play a part. Recent attention to non-human biota may result in the need to explicitly show the environmental acceptability of does to these.

In defining expectations for evaluating assessment analysis, NEA 2003 would require that:

- The approach be logical, clear and systematic
- The assessment be conducted within an auditable framework
- The approach be continually improved through an iterative process
- There is demonstrated effective, open communication process involving safety assessors and investigators
- Sensitivity analysis address all key uncertainties
- The scenarios are based on acceptable criteria for exclusion/inclusion of features, events and processes. Multiple "lines of argument" are used for this
- Mathematical models supported by sound science
- Computer codes fully calibrated and verified
- Demonstrated robustness and clear rules exist for the handling of uncertainties

Furthermore, SKB (The Swedish Nuclear Waste Management Company) [149] applies rules for differentiating between the "main scenario(s), "less probable scenarios", and "Residual Scenarios"

A caution on the use of integrating software models is provided by the IAEA [IAEA, 1994], in their discussion of "Safety Indicators" required for repository design:

- Assessed long term consequences can only be used as *indicators* of safety
- The long-term case can be most effectively made using a combination of several "safety indicators" such as risk, dose, env. Concentration, biospheric flux, recognizing that dose (and risk) are the fundamental indicators.
- Indicators are most valuable when supported from natural anologies.

5 The Path Forward – Expected (Needed!) Development

It is likely that the most successful method to apply comprehensive models and to achieve acceptance of them by the public, will lie in site-specific development of specific scenarios which will be varied around parameters linked to the range of physical change to be expected locally. These "scenarios" can then be communicated as a whole, depending on the reasonableness of the whole "picture" evoked by them. This places great importance on the public communication process as discussed in section 6.0. It should be noted that data pertaining to this effort will need to be obtained from detailed site-specific studies such as boreholes, which in themselves require careful public communication, as evidenced in other national programs (e.g. Sweden)

Continued efforts to develop integrated system modelling can be expected to focus on:

- Benchmarking involving further comparative work other national programs
- Improved interfacing of the software model elements, including means to ensure consistency of data/assumptions between elements.
- Sensitivity analysis features, permitting efficient and economical testing of hypotheses.

Although not an integral part of modelling per-se, means to visualize the results and communicate these to stakeholders are critical to the successful use of the integrating software; for example through “post processors” [150] to prepare visual representations of complex 3D effects.

Modelling related to Surface Storage

The integrated systems code IMPACT, tested in BIOMASS (see 5.3.4) as a fully transparent pathways model, is currently being used by Canadian[151] and international facilities. This system addresses releases from surface storage facilities and calculates derived release limits for CANDU reactors.

Appendix V

Appendix V: MCDA – Case Studies

The Nirex Case Study: Appraisal of sites for further investigation as potential repositories for radioactive waste

Nirex was established to build and operate an underground repository for radioactive waste in the UK. They selected twelve potential sites with no obvious best site among the twelve. In order to reduce the number of the sites for further investigation, Nirex decided to conduct an MCDA analysis.

Applying MCDA

Establish the context:
The aim of the MCDA was to recommend a short list of sites.
Limitation: The MCDA had to proceed with limited information
Solution: Sensitivity analysis played a crucial role in the analysis.

Identify the options:

A map was used to identify the sites.

Identify the objectives and criteria:

The group first identified the stakeholders: Nirex Board, Treasury, National Environment Groups, Regulatory Bodies, Local Residents, Politicians, Local Authorities, Scientific and Technical Community, and European neighbours.

The stakeholders group constructed a value tree. The higher-level objectives included:

1. minimising cost;
2. ensuring the robustness of the site;
3. maintaining a high level of safety; and
4. minimising impact on the environment.

These objectives were broken into sub-objectives and further to performance criteria. Thirty criteria were included in the model. The criteria involved are presented in Figure 7.1

Scoring:

Three methods were used for scoring:
1. Direct assessment: Preference scores were established directly for some criteria.
2. Rating: Rating models were constructed for some criteria.
3. Value function: Quantitative performance measures were constructed for some criteria ensuring that the more preferred performance measures were assigned higher scores.

Weighting:

The weights for all cost criteria were determined by the ranges of the costs on the fixed scales that were used on all those criteria.

The swing-weight method of assessing weights was used for the impacts criteria. The stakeholders were encouraged by the facilitator to assess the weights as appropriate to their current professional roles. Sensitivity tests were implemented to simulate different perspectives. Several consistency checks were carried out to help improve the weights' validity.

Derive an overall value:

First the stakeholders looked at the overall value results using the base case weights. Then they examined the overall results with different weighting systems intended to stimulate different perspectives.

Several weighting simulated systems were explored in this study, such as:

1. A national environmental view: no weight on cost and equal weight on safety, robustness and environment.
2. An economic view: a weight of 200 on costs, 40 on robustness, none on safety and 10 on environment.
3. A local community view: no weight on costs, 10 on robustness, 100 on impact split equally between safety and environment, and changes to 23 lower-level weights to reflect nuances in community concerns.

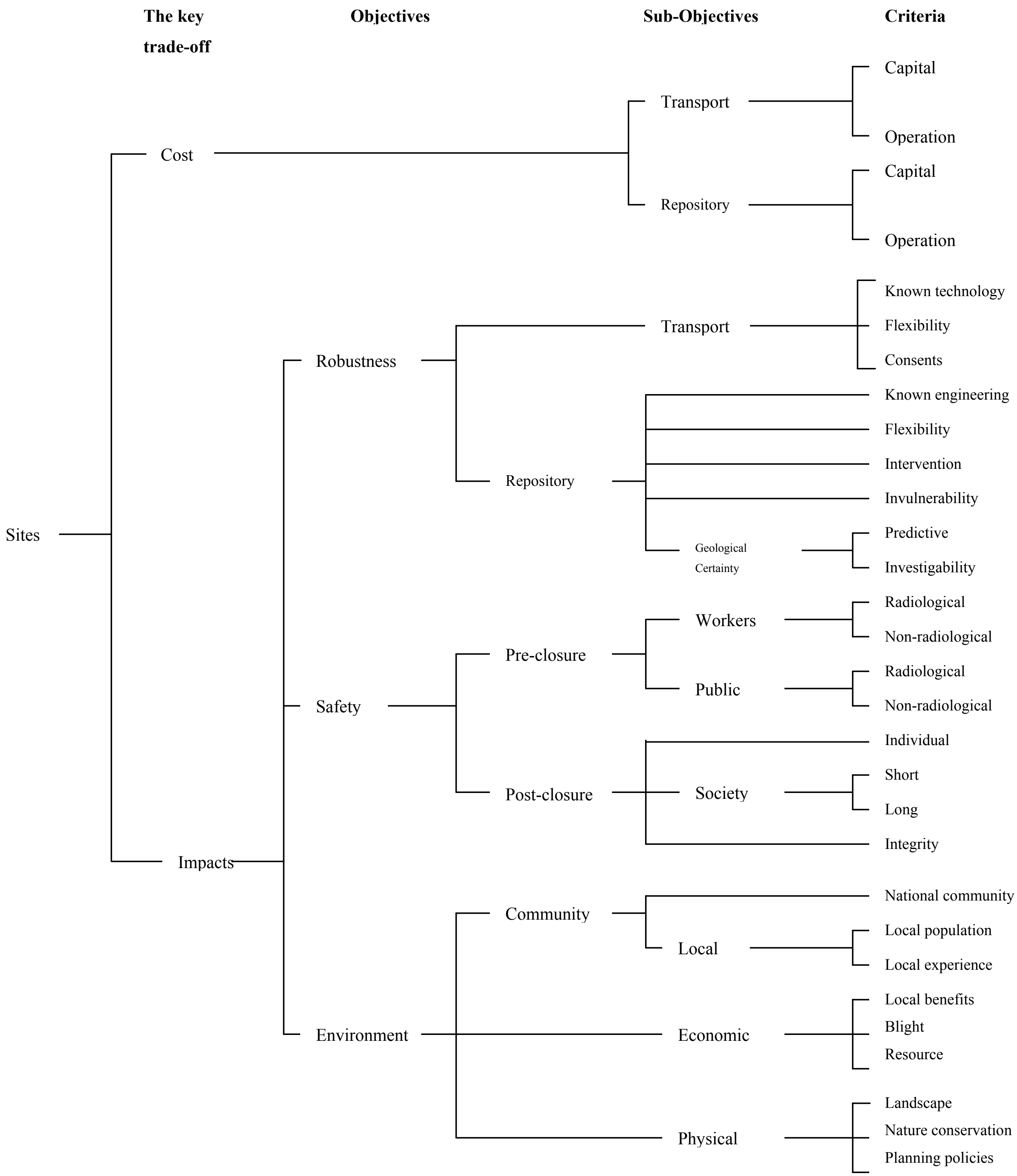
Examine results:

The stakeholders examined the sites on several plots of one node versus another, for example: Robustness versus costs, and impacts versus costs.

Conduct sensitivity analysis:

Sensitivity analysis is essential for MCDA to be useful in any public policy formulation. In this case study, sensitivity analyses on individual weights provided another way of examining the model. The use of the HIVIEW software also makes it possible to sort the sites and lists their relative advantages and disadvantages. The advantage of a site is defined as a high score on a heavily weighted criterion.

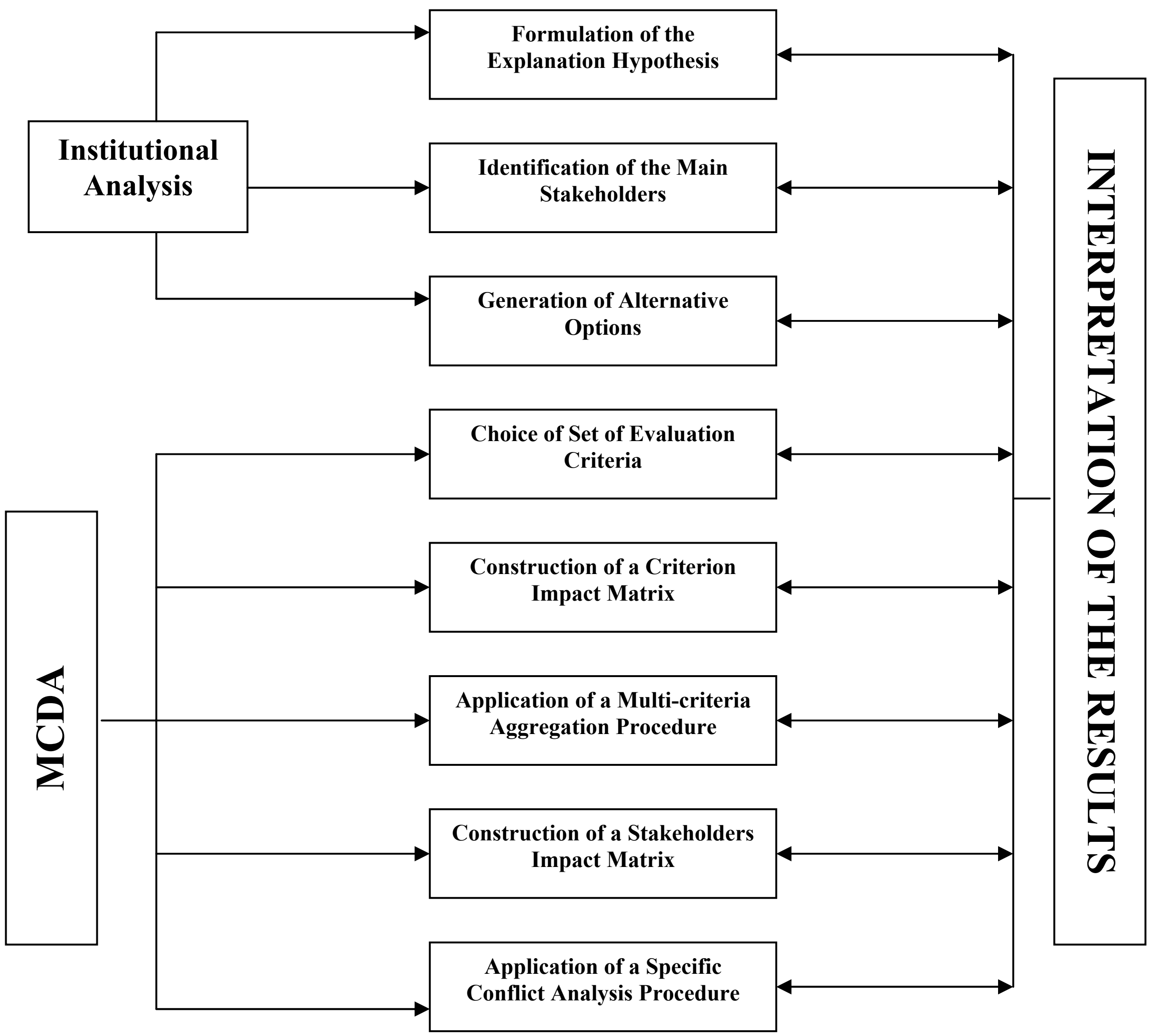
Figure AV.1: Hierarchical representation of objectives, sub-objectives and criteria for the Nirex case study (Adopted from DTLR)[152].



The VALSE Case Study

Valuation for Sustainable Environments known as VALSE[153] is a research project aimed at studying the integration between social processes and analytical methods for valuation of environmental amenities and natural capital for sustainability policy purposes. The VALSE study was based at the European Commission (EC) Joint Research Center (JRC) in Ispra, Italy. Multi-criteria evaluation tools combined with social inquiry methods, namely institutional analysis and social research methods, were deployed to address the problem of water scarcity in Troina, Sicily[154]. The MCDA method provided the means to structure the decision problem and all relevant information to initiate a dialogue with local stakeholders and achieve an effective negotiation platform about solutions. In this project, the MCDA was employed as the only decision tool. The key conceptual point of this method in the project was to structure information that did not only consist of 'expert inputs', but information that was also gathered through a social enquiry process. Figure AV.2 presents the scheme that was used during the evaluation process of the VALSE/Ispra project, and is another example of the application of integration methodology, as seen in Figure 3.1, assessment framework.

Figure AV.2: Scheme of the evaluation process[155]



Environmental Technology Verification Evaluation Framework

The Environment Technology Verification (ETV) Canada Program provides validation and independent verification of environmental technology performance claims. ETV provides the assurance that a vendor's claim(s) of performance for an environmental technology are valid, credible and supported by quality independent test data and information. ETV Canada employed the MCDA as a decision tool for two different programs, manure management and arsenic mitigation.

ETV- Arsenic Mitigation Phase 1- Case Study

Arsenic contamination of groundwater is a major public health concern in Bangladesh. The overall goal of the CIDA(Canadian International Development Agency) sponsored ETV-AM Program, Phase 1, was to address basic human needs in Bangladesh by providing safe drinking water at the point of use for people affected by arsenic contaminated groundwater. In an effort to mitigate the arsenic problem, a number of technologies[1] have been (or are being) developed. However, the ability of a particular technology to perform in Bangladesh had to be assessed and verified[2].

The ETV-AM Program is a part of the overall mitigation strategy developed by the Government of Bangladesh and stakeholders to address the arsenic crisis. The ETV-AM Program provides a framework for verifying the performance of arsenic removal technologies and assessing other factors such as waste characteristics, cycle duration, social acceptability and anticipated costs of technologies. ETV-AM is building capacity within the Government of Bangladesh to implement the verification and assessment program. Phase 1 has been completed; Phase 2 begins in February, 2004 and, in addition to CIDA, includes involvement of donor agencies such as UNICEF

Figure AV.3 provides an overview of the ETV-AM process. The key components of the Phase 1 ETV-AM Program were screening, laboratory testing, initial performance review, field testing, verification, social evaluation and fiscal evaluation.

Technology Screening: Candidate technologies pass through Screening in order to funded for further testing. The Screening Protocol provided a set of criteria for ranking technologies.

Laboratory Testing: The purpose of laboratory testing is to assess whether technology performance claims for removing arsenic were achieved under standardized conditions using

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[1] In the context of this program, "technology" means the equipment and process for treatment of arsenic contaminated water.

[2] Verification is an independent third party evaluation of a performance claim for a product or process, when operated under specified conditions. A technology that has its performance claim examined and confirmed by the verification procedure is said to be verified.

synthetic water matrices representative of water quality data for shallow well aquifers in Bangladesh.

Initial Performance Review: When laboratory testing was performed, data from laboratory testing would be used for the Initial Performance Review. If the verification organisation, following the procedure of verification protocol, determined that the laboratory data support the performance claim(s), the laboratory-based performance claim would be verified. Then, the technology would be eligible to proceed to field testing.

Field Testing: Technologies with insufficient or no data proceed to a field assessment based on the field testing protocol. It was mandatory that technologies proceeding to field testing had a Technology Specific Test Plan (TSTP), developed by the proponent, in association with the testing agency. The field testing protocol provided the rationale and framework for developing detailed field testing procedures to evaluate the efficacy of arsenic removal technologies under field conditions in Bangladesh. Wells for field testing were selected to represent a range of water quality factors known to influence arsenic removal. Five technologies, at 25 wells, underwent a field test in Phase 1.

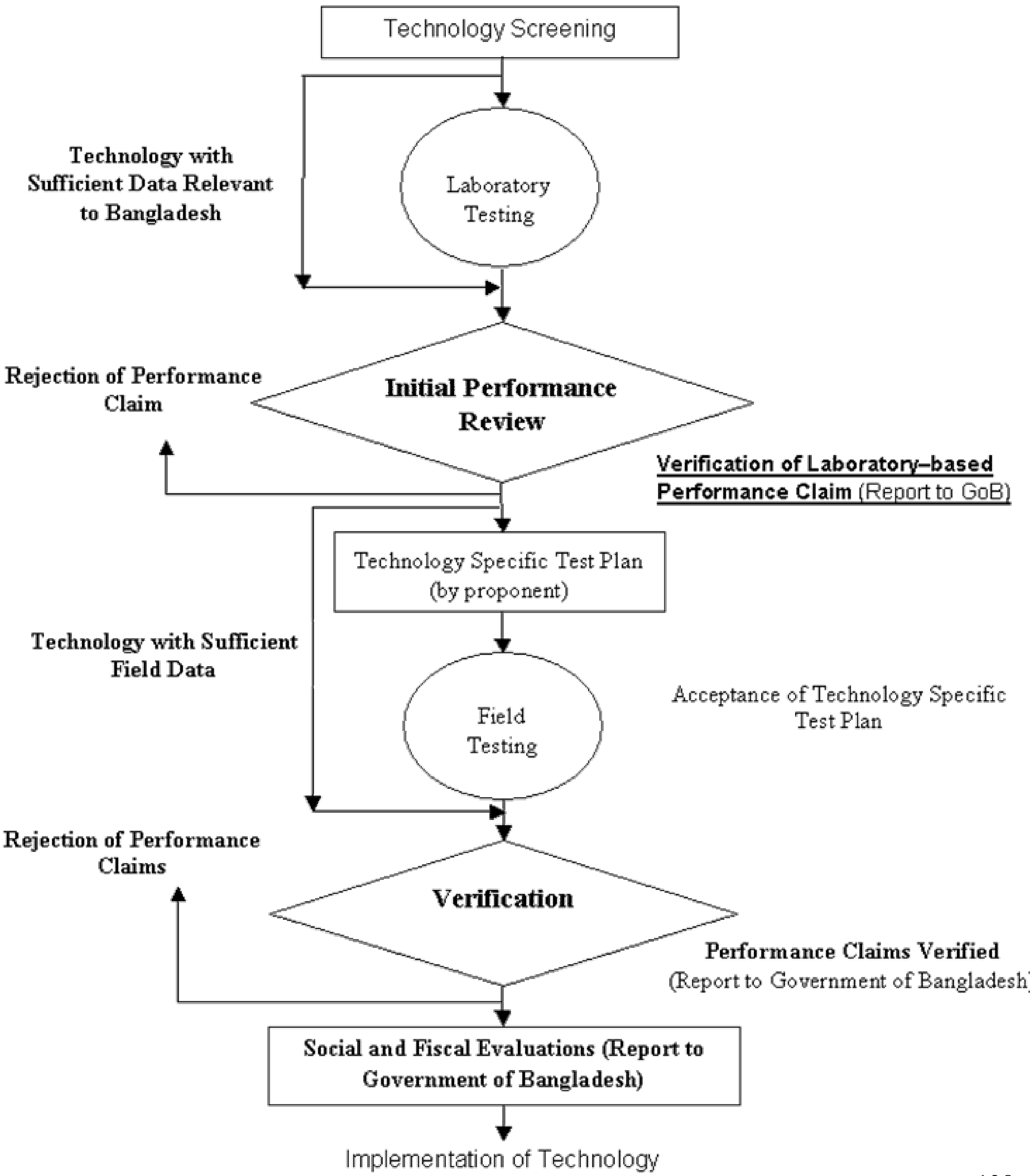
Verification: Data from field testing, Phase 1, were analysed by the Verification Organisation to ascertain quality of data and achievement of performance objectives. Performance data generated by a technology was applied only to the specific water matrix and operational conditions at the field testing site. This means that performance claims were verified for arsenic mitigation at an individual well. Since each technology was tested at multiple wells, a set of verification statements was made. Careful choice of wells allowed statements to be made regarding the impact of water quality parameters on technology performance. This information was used in determining the applicability of arsenic removal technologies under the different water quality conditions in Bangladesh.

Social Evaluation: Wells judged to be safe for water treatment using the technology will be used in a monitoring program as test wells for the social evaluation. The purpose of social evaluation was to assess the social acceptability of a technology. Indicators of acceptability reflected possible social, cultural and gender concerns, and enabled the identification of the technology's sociological strengths and weaknesses. Data will be collected through personal interviews with the main technology users (using a pre-designed interview form) and had provided the basis for making a statement regarding the social acceptability of a technology.

Fiscal Evaluation: The purpose of the fiscal evaluation is to provide an estimate of the true cost to the end user by determining all costs incurred during the expected life of a technology. The fiscal protocol is a standard process through which the direct and indirect costs of arsenic mitigation technologies were evaluated. The procedure requires consideration of capital costs (cost of acquisition), installation/start-up costs, operation and maintenance costs, and waste disposal costs associated with the technology. The dependence of the true cost of the technology on technical parameters such as arsenic concentration or other water quality parameters is also explored using the fiscal protocol.

Technologies with verified field performance claims, Phase 1, were recognized by the Government of Bangladesh as having provisional verification, and subsequently are undergoing a two year monitoring program. Provided the conditions of the two year program are met, the "provisional" character of the verification was removed. Long term commercial implementation would follow.

Figure AV.3: Overview of ETV-AM process.



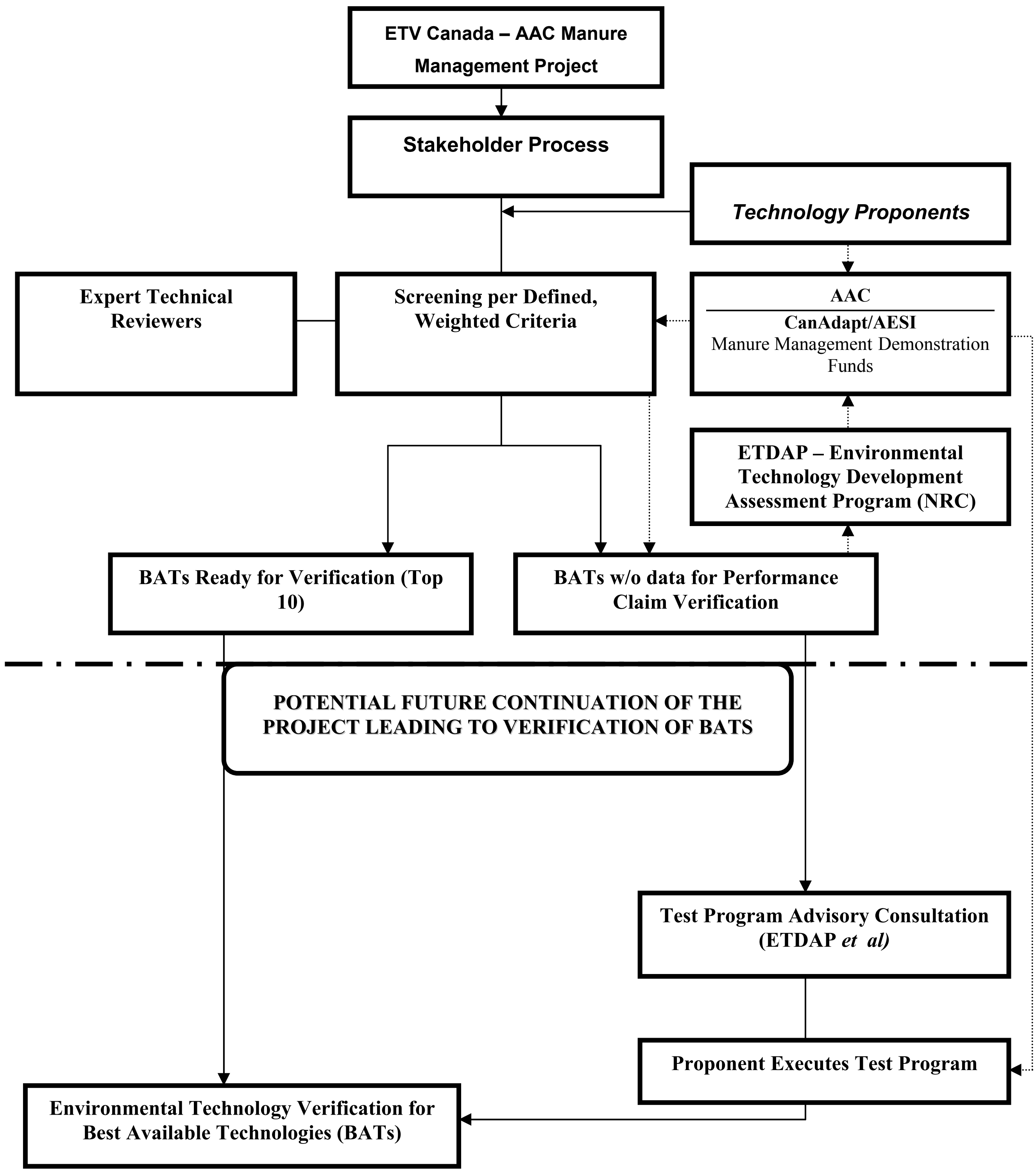
ETV - Manure Management – Case Study

A number of manure management technologies was proposed, and criteria for their selection was put forward from various sources, the most comprehensive to date being the 1998 evaluation report on liquid hog manure management and treatment technologies, produced by the Federation des producteurs de porcs du Quebec. In this work, the criteria from the Quebec report were used as the basis for development of a systematic methodology for evaluation. The technology proponent responded to a questionnaire containing a series of questions under headings such as environmental impacts, agronomic impacts, and so on. The answers were given a numerical "score". Scores were weighted according to the importance of the topic in overall manure management. The responses were combined systematically through a screening protocol. Lower scores indicated the Best Available Technologies (BATs) that were ready for performance verification through the environmental technology verification program of ETV Canada.

Figure AV.4 shows how the selection process operated. A stakeholder process (already in place) set up the system for evaluation. Technology proponents submitted proposed technologies, which were then subjected to the screening and evaluation process. The expert technical reviewer(s) used the screening process, with the weighted criteria and the screening protocol. As a mechanistic questionnaire cannot be expected to anticipate all characteristics and information that might come before a reviewer, the reviewer also was mandated to exercise best professional judgment, as required.

There were two streams of BATs. In the first group (the top ten from this solicitation), the technology proponent had demonstrated that there was sufficient data already available from testing that would support a performance claim for the technology. These technologies were therefore designated as ready for verification by ETV Canada. Proceeding with the verification process was part of a potential future continuation of this initiative undertaken by the vendor. A second group of technologies was shown by the screening protocol to be promising for application to manure management but had no data, or insufficient data, to support a performance claim. Therefore, the first step for this set of technologies was to design and execute further testing. In a potential future continuation of this project, ETV Canada provided guidance to the proponent through a test program advisory consultation. Following a successful execution of a test program, the technology was ready for consideration as a best available technology. The proponent then proceeded to environment technology verification.

Figure AV.4: Selection process for manure management technologies



Appendix VI

Appendix VI: Software Review for MCDA

HIVIEW

HIVIEW is a software program that has the capacity to solve large and complex MCDA problems. HIVIEW has many advantages. For example, it:

1. Produces a visually created value tree that can be easily edited.
2. Displays a variety of input and output graphs.
3. Compares the options by the importance of their weighted criteria.
4. Provides mechanisms for sensitivity analysis to test robustness
5. Allows export and import of input data to and from a spreadsheet for further modelling

MACBETH

This software program could be applied to determining criteria weights. A Multi-MACBETH software can provide MCDA modelling along with MACBETH scoring and weighting approach. This approach is useful in public-sector applications.

VISA

VISA is a window-based application for MCDA modelling. It is very similar to HIVIEW. It allows on-screen creation and editing of the value tree and provides input and output display possibilities.

Desysion Desktop

This software is a window application of the MCDA model. It places special emphasis on guiding decision makers through the whole of the overall process of decision making.

Logical Decision Package

This software program supports the implementation of a number of different MCDA support procedures, including Analytical Hierarchy Process (AHP) (Refer to Section 7.6.1 for more information on AHP).

HIPRE 3+

This package supports the AHP implementation. It is accessible and can be freely used over the Internet.

Geographic Information System (GIS)

GIS approaches use computer software, hardware and procedures to manipulate, analyze and present information that is tied to a spatial location. Since environmental management is concerned with spatially distributed phenomena, it has been recognized that GIS could be integrated with the MCDA for this purpose. GIS would also be suited to analysing transportation route and risk issues.

Criterium DecisionPlus 3.0

This is a decision management tool that can help in organizing, completing and communicating complex decision-making tasks. DecisionPlus runs as a Windows application and can assist in making and presenting a decision. It is capable of conducting thorough analysis using SMART and AHP methods. The program has been designed and developed by Philip Murphy, Andrew Solan and John Gibbon. It is a registered trademark of InfoHarvest, Inc[156].

DATA Professional 6

This program is originally aimed at the healthcare sector for which it provides special functions; it may be used for many more applications[157].

Expert Choice 2000

This program is built around the AHP. It has no modelling capabilities with decision trees or influence diagrams but concentrates exclusively on the criteria structure. It does not incorporate probability, however, risk and uncertainty are incorporated as criteria. Expert Choice has an excellent user interface and simple preference weighting tools. It is a good tool for group and multiple person interaction and public planning[158].

DecisionPro 4.0

This program has an extensive functionality and its own programming language. It also provides other features such as statistical analysis; linear optimization, financial mathematics and conditions that can be constructed as hierarchical tree structures with decision trees[159].

Appendix VII

Appendix VII.1: Highlights of Assessment Experience in Selected National Programs

This section will briefly review the key elements of those national programs deemed to have relevance to the Canadian circumstances. Specific emphasis will be placed on *public participation decision support models* since this was the element that caused the most difficulties and delays in the various national programs that were reviewed.

Given the wealth of detail associated with various radioactive waste management programmes internationally, the study focuses on particular sites and aspects of waste management programmes that provide the most useful lessons with respect to stakeholder dialogue and consultation.

Each sub-section will deal with one of the national programs and will begin with an overview of the basic concepts being implemented or considered closely followed by a bulleted summary of findings.

As part of the overall review being undertaken of Methodologies and Decision Support Tools for Assessing Spent Nuclear Fuel Management Options, the authors have undertaken an overview of public consultation strategies being applied in countries with an active nuclear industry, with emphasis on "what works and what doesn't work" and identifying promising, innovative approaches.

A wide sampling of the literature was attempted, although time and resource constraints meant this sample is far from exhaustive. Nevertheless its was possible to identify those programs which had had a relatively successful track record, or made recent strides in re-defining their public consultation programs, and to examine what was "different" about these.

Sweden

After an initial one-year cool down period at the originating nuclear power facility, spent nuclear fuel is sent to Sweden's Central Interim Storage Facility for Spent Nuclear Fuel, or CLAB, located in Oskarshamn in southern Sweden. During the first 30 years at CLAB, spent nuclear fuel cools in water in an underground rock cavern built to shield against radiation release. The facility will reach maximum capacity in 2004, so construction to enlarge it is under way.

Extensive research into deep geologic disposal has been in progress since the late 1970s. Following interim storage at CLAB, copper waste canisters of spent nuclear fuel will be shipped to a deep repository in granite bedrock. The canisters will be embedded in special clay called bentonite, which will swell and encase the canisters after groundwater fills the space between the rock and the clay.

Sweden is considering implementing its repository concept in stages. For instance, it may place 10 percent of its spent nuclear fuel waste into the repository, then wait for a number of years so that the emplaced waste can be monitored and evaluated.

A programme to site a deep repository for high-level radioactive waste and spent fuel was initiated by the Swedish Nuclear Waste Management Company (SKB) in 1992. It was envisaged that first-stage operation would begin in 2008. The concept suggested for disposal is abbreviated to KBS-3, and comprises a bedrock repository at a depth of approximately 500 m where spent fuel will be encapsulated in copper-steel canisters surrounded by layers of bentonite clay.

The Government gave broad approval to the initial proposed siting process but emphasised the importance of a well-defined and transparent programme that incorporated the following steps:

- publication of siting factors, covering safety, technology, land and environmental impact, and societal aspects;
- content and publication of countrywide siting studies;
- undertaking largely desk-based feasibility studies of between five and ten sites, followed by more intensive surface-based investigations at two or more sites;
- a final application for construction of a shaft and/or tunnel for detailed investigation at a preferred site.

The updated R&D program presented to the government by SKB in 1998 was reviewed by a large number of national organizations, including the Swedish Radiation Protection Institute (SSI) and the Swedish Nuclear Power Inspectorate (SKI). In April 1999, SKI delivered its recommendations to the government, following which the government stated, in January 2000, that the program fulfills the requirements contained in the Act on Nuclear Activities.

Feasibility studies have been conducted at eight sites chosen on the basis of municipalities volunteering to allow the study and subsequently being provided with up to Euro 250,000 per year from the waste funds for its own costs related to relevant activities. In addition, a National Co-ordinator was appointed by the Government in 1996 to promote information exchange and co-ordinate liaison between local authorities.

The first two feasibility studies were conducted for sites at Malå and Storuman, both situated in the far northern part of Sweden. Following completion of the studies, both the communities held a referendum and voted against continuing with the next step in the programme, namely site characterisation. An overview of the referenda timetables is provided in Table AVII.1 below.

Table AVII.1: An overview of referenda for Storuman and Malå.

Procedures	Storuman	Malå
Decision, overview study	June 1993	November 1993
Decision, referendum	February 1995	November 1993
Referendum	September 1995	September 1997
Interviews	November 1995	November 1997

Despite the absence of specific legislation governing siting in Sweden, SKB has agreed to respect the results of local referenda in municipalities. Any local veto, however, has no statutory force and the Swedish Government could override local objections and grant permission for further studies to be carried out. This did not happen with respect to Malå and Storuman and no further investigations have been undertaken at these localities. The Swedish National Council for Nuclear Waste (KASAM) has requested the Government to specify the circumstances in which local objections may be overridden.

Feasibility studies have now been undertaken at sites in six other municipalities, namely Nyköping (with the nuclear research centre at Studsvik), Östhammar (with the Forsmark nuclear site), Oskarshamn (with three reactors and encapsulation research laboratory), Hultsfred (neighbour to Oskarshamn), Tierp (neighbour to Östhammar) and Älvkarleby (in the same region as Östhammar and Tierp). Each of these communities had volunteered to take part in the process. SKB has recently proposed that surface-based characterisation activities, including deep drilling, should proceed at three of the sites (Oskarshamn, Östhammar and Tierp). If regulatory reviews are favourable, and the municipality and the government agree to the work, then drilling could commence as early as 2002.

Of the six municipalities, the consultation process at Oskarshamn provides the most useful example of community involvement in decision making. This process is referred to as the Oskarshamn Model and is described in more detail below.

The Oskarshamn Model

When Oskarshamn was identified as a possible site for the encapsulation plant, the municipality announced two prerequisites to its acceptance as a candidate site. The first was that the participation of the municipality in discussions and investigations was to be paid for from the Nuclear Waste Fund, and the second was that the key parties (SKB, SKI, SSI and the county) accepted the idea of an EIA Forum chaired by the Lt. Governor of Kalmer County. The municipality specifically chose EIA as the lead process for its involvement as the philosophy behind EIA, according to the municipality's understanding, provided the key elements of public involvement, i.e. openness, early involvement and identification of alternatives.

One of the first tasks of the EIA Forum was to set up a local reference group. The EIA Forum felt that the municipality council with 51 elected members should fulfil this function. Efforts were subsequently made to engage the local population through public meetings, seminars and local study organisations. Each of the neighbouring municipalities was also asked to identify a contact person. Six working groups were established to monitor the various aspects of the investigation. The elected representatives had full autonomy in terms of using external consultants and advisors when required.

The municipality was formally asked by SKB in 1995 whether they would accept a feasibility study for the siting of the deep repository. The municipality took one year to investigate the programme and engage as many stakeholders as possible in the decision-making process. To aid the discussion, two task groups were established by the municipality council, and were asked to report back to the full council with recommendations. One group consisted of the most experienced politicians in the council and the other group comprised the youngest members of each political party. Following positive feedback from both groups, the council voted to accept a feasibility study in October 1996 with certain conditions.

To monitor the feasibility study, six working groups were set up with different areas of focus. Each group comprises two council members, one civil servant, two local citizens and one external expert. Numerous meetings have been held with SKB and various consultants and scientists involved in the feasibility study, and all the minutes of these discussions are available on request or via the internet. The main questions and concerns raised by the working groups are forwarded to the EIA Forum for further discussion with representatives from SKB, SSI and SKI.

The structure of the EIA consultation process is presented in Table AVII.2, followed by a list of the key features of the Oskarshamn Model.

Table AVII.2: Structure of the EIA process.

Phases in the EIA process	Participants	Activities	Product
Phase 1 EIA Scoping Study	All stakeholders	Meeting with EIA Forum Meetings, hearings at local level	Advice on EIA document
Phase 2 Proponent's work	Proponent	Project work	Licence application
Continued EIA process	All stakeholders	Hearings, seminars	Understanding
Phase 3 Final phase of EIA = 1st phase of licensing	Regulator interacting with community	Review and decide followed by hearings	Improved licence application

Notes: Stakeholders would include the proponent, regulator, county, municipality and the public. The EIA Forum comprises a group of representatives for each stakeholder.

Key features of the Oskarshamn Model:

- Commitment to openness and participation;
- The EIA process as a framework for interaction and stakeholder involvement;
- The municipal council as reference group as a means of increasing knowledge of political decision makers;
- Local involvement through task groups and working groups;
- Regulator involvement;
- Participation by environmental groups;

- Transparency and challenging SKB.

SWEDEN SUMMARY

- Early application of the EC-funded "RISCOM" model elements, in particular "stretching" which required both SKB and the regulators to be exposed to a "demanding environment" in meetings and hearings.
- Information requirements to meet requests under the RISCOM "stretching" model greatly exceeded the plans/expectations of SKB
- "Oskershamn" model (see below), with municipal councils at focus rooted process in accepted political structure and Swedish life.
- Potential host municipalities formed their own assessment groups composed of politicians, local administrators, unions, trade, industry and environment.
- The Oskershamn page of the SKB website [SKB 2003] is characterised by a down-to-earth, even "folksy" tone ("And so autumn has rolled around again"), proceeds to describe recent in field work, an invitation to an "open house" and ends "Sincerely yours, Peter…"

Finland

In May 2001, Finland became the first country to approve plans for a geologic repository. The Finnish waste-disposal company Posiva Oy will research possible sites and plans to start building the repository in 2010. For more than twenty years, Finland has studied nuclear waste disposal in crystalline rock. Recommendation for the construction of a single, deep geologic repository for spent nuclear fuel disposal was the outcome of a study conducted by Posiva Oy.

Spent nuclear fuel is kept in temporary storage at Finland's reactor sites pending repository licensure. Spent nuclear fuel is cooled for one to three years in reactor pools, then shipped in transfer casks for additional pool storage at the same site.

The Finnish waste package design and clay buffer system is being developed in cooperation with the Swedish program, a good example of the type of international cooperation that is occurring in radioactive waste management. A Finnish repository would not begin operation until 2020.

Prior to the establishment of Posiva Oy, in 1983, TVO (Teollissuuden Voima Oy) identified 101 potential disposal sites and undertook a consultation process with the communities affected. By 1985, 5 potential volunteer sites remained. It was proposed that further detailed investigations were carried out at these sites. In 1992, following further safety and geological assessments, TVO announced that further investigations would only be carried out at Romuvaara in Kuhmo, Kivetty in Äanekoski and Eurajoki (near the Olkiluoto nuclear site). Interim reports on these sites were produced at the end of 1996. An additional site at Loviisa (host to an existing nuclear site) was added to the list in response to indications by the local community in Loviisa, that they too wished to be included.

In terms of Finland's Nuclear Energy Act, the first authorisation step towards a final repository of nuclear waste is the *Decision in Principle* (DiP). This requires the Government to consider whether the "construction project is in line with the overall good of society". In particular, the government should consider the need for the facility, the suitability of the proposed site, and its potential environmental impact. Legislation subsequently requires that the Radiation and Nuclear Safety Authority (STUK) should make a preliminary safety appraisal of the DiP. The proposed host municipality must state its acceptance or rejection for siting the facility. The decision has then to be endorsed by the Finnish Parliament. The application for the DiP also includes an Environmental Impact Assessment (EIA) report for the planned facility.

An EIA report to the Ministry if Trade and Industry (MTI) and a DiP application to the Government were submitted by Posiva Oy in May 1999. The EIA covered the four candidate sites and incorporated a number of consultation methodologies including open meetings, dissemination of printed materials and videos, an opinion survey, theme interviews, small group discussions and analyses of written feedback. The submission of the EIA was followed by a series of public hearings. During the hearing period, 15 authorities and public bodies, 5 civic organisations and communities, and 23 municipalities submitted their statements on the EIA report to the MTI. In November 1999, the Ministry gave its statement, which completed the EIA process

The authorities and municipalities were mainly positive and the EIA report was generally regarded as having been wide ranging and thorough. Of primary concern was the issue of social stigmatism - the potential deterioration in the self and external image of a municipality. This was particularly in relation to the inland sites (Romuvaara and Kivetty), where there are no existing power utilities and small-scale tourism and agriculture are regarded as important components of the local economy. The possible impact on health associated with the transport of spent fuel and potential transport accidents were also of concern.

Private individuals' and civic organisations' opinions on the EIA, as well as on the whole disposal project, were critical and opposing. Their viewpoints tended to focus on issues outside the scope of the EIA. There appeared to be some confusion regarding the purpose of the EIA, which was to assess the impacts of the programme rather than to identify a specific site.

Nevertheless, the MTI concluded that the EIA was sufficiently comprehensive and detailed and fulfilled the requirements set by the EIA legislation. The MTI did request however, that a construction licence application for the disposal facility, scheduled to be submitted by 2010 at the earliest, should include an updated EIA report.

Posiva Oy plans to construct an investigation shaft at the chosen site in 2003, and to apply for a construction permit in 2010. The first emplacement of spent fuel could not take place before 2020.

<u>FINLAND SUMMARY</u>

- Finland is generally acknowledged as having the most success in moving forward towards a solution.
- Highest level of community involvement and public confidence
- Balance between geological and social criteria appears to be a major factor [NATREC 2001]

- Following studies of a number of potential sites, two potential host sites which already have nuclear facilities were "selected" to go forward. (But note the cautious wording: "geological conditions were no less suitable than at others".)
- Competition broke out between the two sites vying to host the repository
- Website – POSIVA.OY – does not explicitly mention "methodologies" or use words like "stakeholder consultation" or "socio-economic impacts"
- Recent government decision demonstrates notion of "achievable goals" based on pre-established "pre-requisites". The government, noting municipality, and regulatory support has made a "policy decision" in support of siting the facility at Olkiluoto with the words, " the pre-requisites for the policy decision had been met". This is NOT a decision to construct, but just an endorsement that "makes it possible to concentrate research activities"

United Kingdom

The United Kingdom reprocesses its own spent nuclear fuel and also contracts to reprocess foreign spent nuclear fuel. Reprocessing facilities provide storage for reprocessed wastes for 50 years. High-level radioactive waste from reprocessing is vitrified, or converted into solid form, at a specially designed storage facility at Sellafield.

The United Kingdom's government is undertaking a review of its national policy on radioactive waste management. This involves taking a public consensus approach to the country's policies. As of 1999, it was agreed that the United Kingdom would store its radioactive wastes underground, and that research and development should continue, enhanced by cooperation with other nations. A phased approach to geological disposal is being considered. The date for repository construction is to be decided.

Although not formally a part of the Government consultation process, a "Consensus Conference" on radioactive waste management, held in London in May 1999, provided a further input. Consensus Conferences are a method of involving the public in the assessment of key issues of science and technology. Pioneered in Denmark, Consensus Conferences create a forum for a Citizen's Panel, made up of lay members of the public, to take part in an informed debate with expert witnesses of their choice.

The panel of fifteen citizens, recruited from throughout Britain, came together in London to debate the issue of radioactive waste management, following two weekends of intensive preparation. At the end of the Conference, the Panel produced a report on its views as to what are the key issues for circulation to the Government, media and other interested parties, thus opening up the debate in an area which is usually dominated by scientists and specialists.

The key issues/questions identified include:

1 What do you see as the primary advantages/disadvantages of deep disposal? What do you see as the primary advantages/disadvantages of shallow/surface storage?
2 What is the current/future policy with regard to companies other than BNFL who produce radioactive waste?
3 Currently, what research and development is there into nuclear waste treatment?

4 Would privatisation mean that an integrated approach to dealing with the problem of radioactive waste management would be more difficult? How can you guarantee that shareholders' profits will not become more important than preserving current safety standards?
5 What is the current/future policy with regard to informing the public about radioactive waste?
6 What benefits does the UK gain from importing spent fuel for reprocessing?
7 What is your opinion on the continuation of nuclear power? What are the financial, environmental and social costs?
8 Who supervises the military? How do we deal with decommissioned submarines? What research into "lost" waste is currently being undertaken (e.g. in the ocean, on Ministry of Defence land)?
9 What are your opinions on the current terminology used for the classification of radioactive waste?

The key conclusions of the Citizen's Panel were:

- Radioactive waste must be removed from the surface and stored underground, but must be monitored and retrievable. Cost cannot be an issue. We must leave options open for future solutions.
- A neutral body should be appointed to deal with waste management including site selection.
- Public awareness must be raised. Decision-making must be open and transparent.
- Research and development must be continued on a much larger scale.

<u>ENGLAND SUMMARY</u>

- Early NIREX experience very negative. Lead to wholesale "re-thinking" of public communication on Nuclear Waste.
- Recent efforts lead by DEFRA (Dept. of Environment, Food and Rural Affairs UK) include a two-day experts workshop to:
    - enunciate principles and
    - develop a range of program options and costs
    - define associated risks

- This workshop was itself novel in several ways:
    - Organization – experts worked by turn individually, in paired small groups and plenary sessions
    - Process – Search for adaptive models, qualitative and deliberative engagement and decision making processes vs quantitative.
    - Result compilation- observations are classified as "by Many+ Group", "Many", "Few + Group" and "Few"
    - Conclusions – a pre-determined "step-wise" process (e.g. the modelling references in the exercise) appeared too "linear" to many participants.
    - Self-assessment - the whole workshop was independently "Assessed" by a highly qualified expert in communications to ensure it was reported objectivity

- The program risks identified by this special experts workshop deserve special mention. For the "middle" program option defined by the participants, risks included :
    - Lack of inclusivity - limited funds forces emphasis on small groups. Does not engage wider community and potential host communities through a variety of media
    - Media risk – dependency on public media to "get the message out" risks failure due to lack of media interest, message distortion
    - Isolation - Insufficient link-up with existing government structures and activities
    - Insufficient link to implementation stage – potentially impacted communities may reject outcomes
    - Limited mandate – mission may be compromised by other nuclear activities outside its control

Internet cannot be used as a passive communication medium. R&D [Leeds 2001] shows users are sophisticated and will not accept "packaged" results. "Interactive" models must be developed for an interactive medium.

United States

Following the Nuclear Waste Policy Amendments Act (NWPAA) of 1987, the US siting programme for high-level waste and spent fuel has been centred on Yucca Mountain in the State of Nevada. A number of locations in various geological settings across the US had previously been under consideration, but the Amendments Act directed the DOE to examine *only* the Yucca Mountain site. The 1987 legislation was criticised by the State of Nevada as unfair, although the Act specified that if studies showed the site to be unsuitable then investigations would cease. The legislation also provides for a benefit package for Nevada of $10-20 million per year provided the State waives its right to object to the proposal, not surprisingly, this condition has not been accepted by the State.

Under US Law, the DOE takes title to the spent fuel from utilities prior to final disposal. For the interim, the DOE proposes to store the spent fuel at the surface in a centralised facility known as the Monitorable Retrievable Store (MRS). To enable the siting of the MRS, the 1987 NWPAA established the Independent Office of the Nuclear Waste Negotiator to try to find a willing host in exchange for certain benefits. However, although some progress was made with a number of Native American Tribes, the negotiation process was terminated without result.

The fundamental and acknowledged weakness in the US program (emphasized by EPRI research directions) is the need to transport high-level materials vast distances. The equipment for this does not yet exist, and there is no agreement between utilities and regulators on the test criteria (e.g. test to destruction?). The regulatory overlap (between federal, state and local jurisdictions) and public communication load is most onerous with the transportation issue.

Despite the assurances of the DOE that Yucca Mountain can never become a repository without reasonable assurance of its ability to contain and isolate the waste, the Nevada public remains sceptical. Much of this scepticism is based on previous experience where the government had assured stakeholders that there would be no adverse effects associated with weapons testing in the 1950s. Trust in the government was seriously undermined when people were exposed to radiation doses downwind of the atmospheric testing area. High-level nuclear waste disposal at Yucca Mountain is unlikely to pose the same threat, but the choice of a site with a history of radiation exposure does affect public opinion.

A “Viability Assessment” (VA) was published by the DOE in 1998. The purpose of the assessment was to provide Congress, the President, and the public with information on the progress of the Yucca Mountain Characterisation Project, as well as to identify critical issues that needed to be addressed before a decision is made by the Secretary of Energy on whether to recommend the Yucca Mountain site for a repository. The assessment comprised a collection of largely technical documents aimed at stakeholders with different levels of understanding.

The VA report identified the main advantages of the Yucca Mountain Site as being its previous use as a nuclear weapons testing area, and the desert environment (no significant water sources in proximity to the site). From a health and safety perspective the report predicted that maximum radiation exposure from the repository is expected to occur after about 300,000 years. People living approximately 20 km form the site at that time might receive additional radiation exposures equivalent to present-day background radiation.

Six months after the publication of the VA, an Environmental Impact Statement (EIS) was produced. The purpose of the EIS was to provide information on potential environmental impacts throughout the life cycle of the proposed repository at the Yucca Mountain site. As a baseline for comparison, the No-Action alternative was also considered in the EIS. Public input to the EIS included fifteen Public Scoping Meetings between August and October 1995. Of the issues identified, a number were addressed in the EIS, including aspects of the characterisation programme, construction, operating and monitoring, consistency with existing land-uses, effects of earthquakes and volcanism, health and safety, long term and cumulative impacts and possibility of sabotage.

Other issues raised were considered to be unrelated to the proposed action. These included general statements in support of or in opposition to a repository at Yucca Mountain, geological repositories in general and nuclear power; lack of confidence in the Yucca Mountain Program; perceived inequities and political aspects of the siting process; the constitutional basis for waste disposal in Nevada, perceived psychological costs and effects; risk perception and stigmatization; and legal issues involving Native American land claims and treaty rights.

The EIS did not identify significant adverse effects associated with the long-term performance of the site. Peak doses of 13 mSv per year over 10,000 years are predicted to a maximally exposed individual hypothetically located 5 km from the repository.
The cultural issues associated with the Native American Tribes in the Yucca Mountain region were identified as an “area of controversy”. The tribes consider the intrusive nature of the repository to be an adverse impact to all elements of the natural and physical environment. In addition, one Native American ethnic group (the Western Shoshone) continue to claim title to land at Yucca Mountain.

In the next year or so, it is possible that the site will be recommended by the DOE for approval by the President of the United States. However, the NWPAA provides the State of Nevada with veto powers over the President's decision. If exercised, however, the State veto can itself be overturned by a two-thirds majority vote of the US Congress.

If the site is approved, the DOE considers that a repository at Yucca Mountain could become operational by 2010. However, the siting issue, as indicated above, is as much a political issue as technical issue. A decision by the Federal Government to proceed with the repository at Yucca Mountain is likely to severely test the constitutional framework of the United States.

US SUMMARY

- Leading project (Yucca Mountain) has Presidential consent, but strong local opposition. Excellent lesson in risk associated with "linear", command-and-control processes.
- US process (like early UK experience) is identified as having been of the "Decide – announce – defend" affording "little scope for any re-characterisation of the issue or for concerns outside the instigator's frame of reference" [Hunt 2001]
- State of Nevada website [NEVADA 2003] provides a simple chronology demonstrating the failure of a process driven by "officialdom"
- DOE website (DOE 2003] provides an excellent example of user-friendly web-site design, allowing rapid access to overviews, process, key-contacts, and detailed technical documentation
- Industry websites (ANS, NEI) focus on providing well-packaged advocacy materials and "talking points" for those proponent agencies assuming the 'missionary' approach.

France

Spent nuclear fuel is kept for one year on site in specially constructed storage pools. Following storage, spent nuclear fuel is transported to the La Hague and Marcoule reprocessing plants and stored in pools for two to three years.

A research program to study high-level radioactive waste disposal began with legislation enacted in 1991. The French Waste Management Research Act of December 1991 authorized 15-year studies of three management options for high-level or long half-life radioactive waste. They included separation and/or transmutation, long-term storage, and geologic disposal. One site under consideration for deep geologic disposal in clay is currently being studied. The French are also searching for a granite site to research.

The 1991 Waste Act redirected the French deep site investigation process following the abandonment of an earlier high-level waste (HLW) programme which sought to identify promising disposal sites primarily by reference to geological considerations. This methodology resulted in strong opposition and, in 1990, a moratorium was declared on drilling activities by the Government. The 1991 law contains several provisions aimed at a more equitable siting process including a requirement that local officials and members of the public from the affected sites be consulted before any site investigations begin preliminary to Underground Research Laboratory (URL) construction.

The creation of URLs is a key requirement of the 1991 law. M. Christian Bataille was appointed as a mediator and specifically charged with leading public involvement prior to the selection of URL sites. His mediation mission had three objectives:

- information provision to the public,
- open dialogue, and
- decision facilitation.

The siting process for the URLs began in January 1993. By December of that year some 30 sites had volunteered for consideration. Ultimately, four potentially suitable sites were recommended by M. Bataille. Two were subsequently merged so that three locations were then under consideration:

- a clay geology in north-eastern France on the border of the Meuse and Haute Marne Departments (the Bure site);
- a clay geology beneath the Marcoule nuclear site in the south of the country in the Gard Department;
- and a granite geology in the Vienne Department in western France.

Surface-based investigations at these sites, including drilling between two and four boreholes and geophysical measurements, were completed in April 1996.

The Council of Ministers authorised the National Agency for the Management of Radioactive Waste (ANDRA) to submit requests for the installation and operation of URLs at each of the three sites in May 1996. Authorisation of the URLs was scheduled to have been completed in 1998, following review of the submissions by the Division of Nuclear Safety (DSIN) within the Ministry of Industry, and the Ministry of Research. The reviews were to take place in conjunction with public hearings and local consultation. The hearings at the sites ran from January to May 1997. The following December, the Government advised that investigations should continue at the Bure site and that further research should be undertaken towards identifying a suitable site in granite. A decree was issued in August 1999 allowing ANDRA to commence construction of the Bure URL, providing for the establishment of a Local Information Committee at Bure, and launching a consultation exercise to select a granite site.

The selection process for a granite site was initiated with a geological screening process that began in February 1999. This resulted in the identification of 180 plutons in the country and, by July 1999, this number was reduced to about 15 sites following consideration of hydrogeology. As a result of further screening, the number of potentially suitable sites was narrowed down to seven in February 2000. The next phase of the programme is divided into five stages and is being managed by a Granite Advisory Committee comprising two international experts, two government appointees, and four members recommended by the Academy of Sciences and approved by government. The stages are as follows:

1. seek consensus through consultation;
2. selection by government of a site or sites where the community wishes further consideration;

3. confirmation of geological suitability (by ANDRA); confirmation of safety factors by DSIN; and setting up of Local Information Committees made up of environmental groups, government officials, local community representatives, farm councils, professional associations, etc;
4. *enquetes publiques* (public enquiries) and endorsement by local authorities within a 10 km radius of a site.
5. decision by central government to authorise construction of a URL .

It was originally intended that the granite site selection process would be completed by 2003. However, the process is stalled at Stage 1, the objective of which is to seek consensus through consultation with the communities in proximity to geologically suitable sites identified during the Phase 1 screening exercise. A government delegation sent to consult with the affected communities was strongly opposed in all communities that were visited. The negative attitude of the community leaders could have resulted from a range of factors, including a ratcheting up of concern by NGO representatives from outside the communities, a perception that the government delegation was not sufficiently representative, and the nature of the screening phase with consultation coming too late in the process.

FRANCE SUMMARY

- Early efforts involving the French waste authority were quite successful. A nuclear waste act in 1991, identification of host sites (four in 1994) by a mediator went well.
- Support for the four sites was not well-founded or deeply rooted. Wine-growers in Cotes due Rhone lead to its withdrawal on fear of damage to the wine's reputation, and in Marcoule, grass-roots local opposition scuttled the initiative
- Subsequent perceptions of secrecy and high-handedness by the central authorities lead to its complete collapse.. The authorities decided to create a list of additional "qualifiable" sites and assigned three senior civil servants to role out the next phase of consultations. Unfortunately, they had to abandon their mission almost as soon as it began when the "secret" list of potential sites was published on the internet.
- ANDRA promotes its world-renowned research facilities for geological investigations with a unique tool: A virtual laboratory tour on CDROM! [ANDRA 2001

Czech Republic

The Czech Energy Board in Prague is responsible for the programme dealing with the management of spent fuel and wastes from Czech nuclear power plants. Research institutes, such as the Nuclear Research Institute (NRI) and universities participate in research supporting this programme.

The Czech Power Enterprise (EZ) has conducted several studies concerning spent fuel management in the Czech Republic. Alternatives include:

- interim storage followed by final disposal in the Czech Republic;
- re-processing in another country with return of the wastes to the Czech Republic, or
- final waste disposal in another country.

In 1993, development for a deep geological repository began, with the aim of producing at the end of five years, a plan for: a) a generic design for a repository in granitic rock and b) a generic plan for geological activities to be performed leading up to a siting consultation. Owing to the facility being the first site within the Czech Republic to be designed and organised under a democratic society, expectations are for a lengthy, complicated process. Procedures considering site selection have included technological development of engineered barriers, experimental data from selected test sites, natural analogue studies, and underground research laboratories for safety and performance assessments. The latter issue has included international collaboration with the Spanish Radioactive Waste Agency (ENRESA) and National Cooperative for the Disposal of Radioactive Waste (NAGRA, Switzerland). Results from the individual projects will be compiled for the use of the National Concept of Radioactive Management, a strategic document that will direct future activities. This document will be subject to EIA evaluation including a public hearing.

Following on from the 'Concept', the Radioactive Repository Authority (RAWRA) plans to initiate public discussion on the matter of national policy for radioactive waste management. Firstly, RAWRA plan to disseminate information to the media, politicians and technical experts. Secondly, they plan to hold discussions with students from technical, economic, sociological, environmental and legal University departments. RAWRA plan to invite the media to monitor the discussions. The final stage of public consultation will conduct public surveys within different social groups.

Czech radioactive waste management is based on the Atomic Law approved by Parliament in 1997. This law established RAWRA, the state organisation charged with the mission of assuring safe disposal of all radioactive waste, present and future. RAWRA took over the co-ordination of the development of a deep geological repository in 1998. Much of the development of a deep geological repository is contracted out to NRI who have extensive experience with repository development. Along with development of a national deep repository, RAWRA are also considering plans for long-term interim storage procedures, reprocessing, transmutation and the possibility of a European repository.

Public attitudes in the Czech republic have changed markedly over the last 10 years or more, from support in the early 1990's when people approved of the move away from 'dirty' coal-fired power stations, to anti-nuclear attitudes, emphasised by increasing pressure from near-by Austria, who are nuclear-free. In the period from 1993 to 1997 NRI conducted opinion polls with different social groups and began to aid the public relations arm of RAWRA. Following the Atomic Law, RAWRA have involved the public, including 4, out of 11, representatives from the public on the Board of members.

Belgium

Spent nuclear fuel is stored in reactor pools. High-level wastes are stored for 50 years at the country's central interim storage site at the Mol-Dessel nuclear power plant and research center north of Antwerp.

Belgium takes a multi-barrier approach to repository design. Storage casks will be made of steel over-laid with stainless steel. Current plans call for the repository to open between 2035 and 2080.

ONDRAF/NIRAS are investigating Boom Clay and Yper Clays for the disposal of high-level and long-lived intermediate-level waste. The Mol/Dessel nuclear zone is regarded as a methodological R & D site and the Doel nuclear zone as an alternative R&D site.

ONDRAF/NIRAS intends to publish a report (SAFIR 2) by the end of 2001, on research undertaken to date. This report will be subject to independent peer review. An accompanying strategic document will address potential approaches for stakeholder dialogue on high-level waste and long-lived intermediate-level waste in Belgium.

Initial plans involved publishing a list of potential sites and seeking municipalities to volunteer for local site studies. This failed totally.

<u>BELGIUM SUMMARY</u>

- Recent Successful launch of "partnerships" between the waste-management agency (ONDRAF/NIRAS) and potential host communities
- Universities involved in detailed "mapping" of social structure of potential hosts before actual assessment of proposal takes place. Input to design of the communications program and detailed socio-economic assessments

Additional National Programs of Note

<u>RUSSIA</u>

Investigations of potential geologic repository sites by a number of Russian institutions, including the Russian Academy of Sciences, are ongoing. Russia is currently investigating several regions as potential study sites. Four possible rock types are being considered for disposal: salt, granite, clay, and basalt. Disposal plans include using a multi-barrier approach.

Russia has a wide variety of geologic environments that contribute to the selection of suitable sites. It is likely that one will be chosen based on its proximity to a radioactive waste-producing facility. A repository operation date is to be decided.

<u>GERMANY</u>

Underground exploration of a salt dome at Gorleben began in 1986. The Gorleben site had been studied since 1979 as a potential permanent radioactive waste repository. After the 1999 parliamentary election, study of the Gorleben salt dome was temporarily stopped, pending further study of other types of geologic environments and to clarify conceptual and safety issues. A new site will be selected based on comparison with Gorleben, which may yet be an interim storage site. Steel canisters are being considered for radioactive waste containment.

SPAIN

The present policy for spent nuclear fuel and high-level radioactive waste management is continued interim storage followed by direct disposal into deep geologic formations. The 5th Radioactive Waste Management Plan, approved by the Spanish government in 1999, outlined that no decision on the final disposal of high-level radioactive waste be made up to 2010. Deep disposal study will continue, but new technologies, such as partitioning and transmutation, may also be considered. Intensified international collaboration is also stressed.
At-reactor storage lasts at least 10 years for all spent nuclear fuel. Interim storage of spent nuclear fuel consists of at-reactor wet and dry methods. Centralized storage is planned for implementation by 2010.

Non-specific conceptual repository designs have been developed for three candidate host rocks: clay, granite, and salt. The designs provide a basis for research and development, performance, and safety activities and the safety assessment studies of a multi-barrier repository system.

SWITZERLAND

For permanent high-level radioactive waste and long-lived low-level radioactive waste disposal, two host rock repository options are under consideration by the Swiss: a deep repository in crystalline rock and the Opalinus clay. Candidate sites for exploration should be recommended to the government by 2002. Although study of a site in the Opalinus clay began in 1999, construction of a repository is not foreseen until well into this century.

Spent nuclear fuel is stored for 1-10 years in water pools at Swiss reactors. An industry-owned organization, ZWILAG, built and operates Switzerland's centralized interim storage facility for spent nuclear fuel, high-level radioactive waste, conditioning low-level radioactive waste, and for incinerating wastes. Other interim storage facilities predating ZWILAG continue to operate in Switzerland

JAPAN

Spent nuclear fuel is stored at reactors in pools. High-level radioactive waste is converted to a solid form (vitrified) and stored on-site for 30-50 years for cooling. It will eventually be transported to a deep geologic disposal facility. At-reactor dry storage for spent nuclear fuel is currently being developed. Dry storage for high-level radioactive waste is also being developed at the Rokkasho-mura site.

In October 1998, Japan's Nuclear Cycle Development Institute (JNC) submitted a report to the Japanese government documenting Japan's radioactive waste disposal research and development activities since 1992. JNC's primary objective is to assess the technical reliability of geologic disposal in the country.

In October 2000, Japan established the Nuclear Waste Management Organization (NUMO) to implement geologic disposal in the country. Japan hopes to begin site selection and characterization, followed by infrastructure creation and site licensing. Construction of a repository in granite or sedimentary rock is planned for the 2030s.

CHINA

China is unique in that its repository plans are being developed concurrently with the early stages of nuclear power plant construction. Current plans call for conducting feasibility studies between 2010 and 2020, followed by site licensing. Repository operation will begin no earlier than 2040.

China carried out site screening from 1985-1986, concentrating on social, environmental, and geographical issues. The country is evaluating five potential repository sites, including its proposed underground research laboratory (URL) site in the Gobi Desert. This URL is planned to become operational around the year 2030. Field investigations are under way at the Beishan granite site in the Gansu province of the Gobi Desert in northwest China. The Gobi Desert is sparsely populated, has a low precipitation rate, a high evaporation rate, and a shallow water table.

Appendix AVII.2

Appendix AVII.2: Highlights of Assessment Experience in International Programs

Where Canada is a member state in international agreements such as the International Atomic Energy Agency (IAEA) and or is a member of an international organization such as the Organisation for Economic Cooperation and Development (OECD), adhering to the terms of these agreements becomes one of the overarching considerations. In addition, Canada is party to a number of international agreements on the transport of nuclear materials, including waste. The London Convention, on marine pollution, particularly, would have an effect on potential plans to transport nuclear waste by sea.

Secretariats of these organizations have significant resources for research and review on any topic pertinent to their contracting states or signatories interests. Thus, information gathering activities, per the generic assessment framework (Figure 3.1), can use, as a planned methodology, the services and research of IAEA and OECD.

International Atomic Energy Agency (IAEA)

The International Atomic Energy Agency is the intergovernmental organization established for cooperation in the scientific and technical use of nuclear technology for peaceful purposes. It is an autonomous organization, established under the United Nations in 1957, and headquartered in Vienna. Field liason and research centres have been established in various countries. IAEA has an office in Canada.

The June 16, 2003 statement of IAEA Director General Dr. Mohamed El Baradei to the Board of Governors states

> "The Agency's TC (Technical Co-operation) programme continues to be a principal mechanism for implementing the Agency's basic mission: "Atoms for Peace". Not only do we seek to ensure that nuclear materials and equipment are used peacefully and safely, but above all we are committed to expanding the contribution that nuclear technologies make to peace and development."

Key programs of the IAEA are handled by the Division of Nuclear Power, of which one subdivision is the Division of Nuclear Fuel Cycle and Waste Technology. IAEA is an intergovernmental organization, established for cooperation in the scientific and technical use of nuclear technology, including waste technology, and thus is categorized for the purposes of NWMO assessment as an available technical and economic information resource. Stakeholder participation, in this instance, becomes the participation of the contracting and signatory countries.

<u>Co-operative Activities between IAEA and Other Organizations</u>

There are cooperative activities with many of the member states and with international organizations in and outside the UN system, including OECD and European Union, and, specifically the following: - OECD Nuclear Energy Agency[160]; European Commission, Directorates General DG Environment dealing with Radioactive Waste Management Policy, and DG Research dealing with Radioactive Waste Management Research; Contact Expert Group for international cooperation in radioactive waste management with the Russian Federation (Est. 1996)

IAEA Guidance on Safety of Spent Nuclear Fuel Management

Nuclear waste handling methodology is inherently connected to safety. Sponsored by the IAEA, the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, entered into force with 15 Contracting States (including Canada) and 40 signatories. Some current safety issues and guidance provisions under review and development by the Agency include:

- Decommissioning and criteria for release from regulatory control
- Geological disposal of high level radioactive wastes
- Retrieval of wastes from underground repositories
- Disposal of radioactive waste in the oceans
- Radioactive residues from contaminated environments, such as uranium mining and processing sites

Technology available for nuclear waste processing is limited, and thus much of the technology that exists is to enable activities such as:

- Minimization of waste from uranium purification, enrichment and fuel fabrication[1]
- Chemical Durability and Performance Assessment of Spent Fuel and High Level Waste Forms under Simulated Repository Conditions[2]. It must be technically sound to store the waste over long periods and have it retain desired properties, especially if it may later be retrieved for reprocessing
- Recycle and reuse of materials from waste streams of nuclear fuel cycle facilities[3]. Little recycling is actually performed, in proportion to the total amount of this potentially valuable resource.

The output from an Agency (IAEA) symposium, Korea, 1999, "Technologies for the Management of Radioactive Waste from Nuclear Power Plants and Back End Nuclear Fuel Cycle Activities" was said to document that "proven technologies exist for managing radioactive wastes in ways that are safe, economical, and environmentally sound…" Experience exists with these technologies, in the Member States[4].

[1] This is the title of a technical document published by IAEA

[2] This is the title of a technical document published by IAEA

[3] This is the title of a technical document published by IAEA

[4] Nuclear Waste Bulletin, No. 14 – 2000 Edition, Nuclear Energy Agency, OECD

Appendix AVII.3

Appendix VII.3: The Port Hope EA Process for Low Level Wastes and Its Potential Relevance to Extended Storage of Used Nuclear Fuel

The long history of the efforts of various authorities to find an acceptable solution for the disposal of uranium processing wastes at Port Hope contains useful lessons for the planners of extended storage and disposal of used fuel.

Meadd [2003][161] assesses the federal government experience with Port Hope and observes that "experiences with managing low-level wastes can provide insight into the dynamics of public opposition toward waste management issues". She cautions that while repository siting in Europe has been more successful than in North America, "the comparison to the North American context can be awkward and difficult". Taking a first-principles approach, she defines three "framings" that the nuclear industry has successively applied in attempting to manage the public involvement process. These are:

1. Attributing resistance to the "limitations of the public" and thus to direct efforts at risk education
2. Attributing resistance to lack of public participation in the decision-making process and thereby addressing efforts to make the process more responsive and open to the public.
3. Recognizing that at the root of failures in risk-communication was a fundamental lack of trust between public groups and (government) decision makers.

The breakdown in "public trust" occurred at Port Hope, in the author's analysis, due to failure of the government bodies to act quickly, and by their making decisions that appeared to contradict advice taken in public fora (designating transportation routes opposed by local stake-holders), and the apparent wastefulness of proposed solutions (trucking waste to a host site in Northern Ontario, digging massive caverns under Lake Ontario). The reaction to transport of waste to a remote central site in the LLW case provides a strong caution with regards to centralized extended storage strategies for used fuel!

Recently, environmental assessment efforts for the disposition of the Port Hope (and Port Granby) wastes appear to have been put on a more productive track through the signing of a legal agreement between the federal government and the local municipalities in 2001, the creation of a Low Level Radioactive Waste Office and the alignment of efforts with CEAA processes. Project Description documents have been submitted and scope documents covering the proposed undertakings received for a "screening" EA. (NRCAN, 2002)[162]. Although Environmental Assessment reports have not yet been published by the proponents {LLRWMO, 2004][163], one important feature of the proposed facilities is known: the facility will employ structures with a proposed 500y design life! Successful completion of EA and licensing processes for the facility under a "screening" track EA would provide an important precedent for the options of extended reactor or centralized fuel storage. However, it is important to note that this project appears to differ significantly from any possible extended storage option for used fuel:

- the wastes involve very low-levels of radioactivity,

- neither the project documentation nor the scope documents addresses the outcome expected following the 500-year period (e.g. decommissioning or abandonment),
- although current on-site storage projects for used fuel at CANDU facilities follow a "screening" track, extended storage of the relatively large quantitites of fuel involved for periods of several hundred years could be expected to trigger a "comprehensive" study and formal public hearings

In summary, identification of local municipalities as the primary negotiating and decision-making bodies goes far in addressing the original concerns, and the establishment of "user-friendly" information centre and hot-line is a major step. However, the technical and EA-process parallel with extended storage of used fuel is limited.

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