A Literature Review and Compilation of Nuclear Waste Management System Attributes for Use in Multi-Objective System Evaluations - 16618

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ABSTRACT

The purpose of this work was to compile a comprehensive initial set of potential nuclear waste management system attributes. This initial set of attributes is intended to serve as a starting point for additional consideration by system analysts and planners to facilitate the development of a waste management system multi-objective evaluation framework based on the principles and methodology of multi-attribute utility analysis. The compilation is primarily based on a review of reports issued by the Canadian Nuclear Waste Management Organization (NWMO) and the Blue Ribbon Commission on America's Nuclear Future (BRC), but also an extensive review of the available literature for similar and past efforts as well.

Numerous system attributes found in different sources were combined into a single objectives-oriented hierarchical structure. This study provides a discussion of the data sources and the descriptions of the hierarchical structure. A particular focus of this study was on collecting and compiling inputs from past studies that involved the participation of various external stakeholders. However, while the important role of stakeholder input in a country's waste management decision process is recognized in the referenced sources, there are only a limited number of in-depth studies of the stakeholders' differing perspectives.

Compiling a comprehensive hierarchical listing of attributes is a complex task since stakeholders have multiple and often conflicting interests. The BRC worked for two years (January 2010 to January 2012) to "ensure it has heard from as many points of view as possible." The Canadian NWMO study took four years and ample resources, involving national and regional stakeholders' dialogs, internet-based dialogs, information and discussion sessions, open houses, workshops, roundtables, public attitude research, website, and topic reports. The current compilation effort benefited from the distillation of these many varied inputs conducted by the previous studies.

The initial set of attributes is intended to provide a starting point for considering potential objectives for evaluating nuclear waste management system options. It is envisioned that this initial set will evolve and be revised as new and additional input is received from stakeholders on various attributes and their relative importance.

INTRODUCTION

The major purpose of this work was to develop an initial set of potential nuclear waste management system attributes in a format that can be easily used by the Waste Management System Multi-Objective Evaluation Framework (MOEF). MOEF, shown schematically in Fig. 1, is a set of capabilities, methods, processes, and tools that provide a means to evaluate alternative scenarios and system architectures where there are multiple conflicting objectives and differing stakeholder perspectives on a situation.

Originally conceived as a decision support tool, the MOEF is based on rigorous decision analysis methods and techniques [1, 2, 3]. These are theoretically sound and proven approaches that provide structure to complex comparative analysis problems and produce insight and understanding of tradeoffs from multiple perspectives. The MOEF is particularly well suited for breaking down complex and difficult trade-study problems into manageable and insightful pieces. It is ideally suited for integrating diverse types of information, including the results from system analysis models, cost and benefit studies, empirical data, and expert judgment, into clear and well-defined measures of merit for the alternatives being considered. Furthermore, developing an insightful understanding of how current alternatives perform with respect to stakeholder priorities often leads to the creation of new alternatives that better satisfy priority objectives.

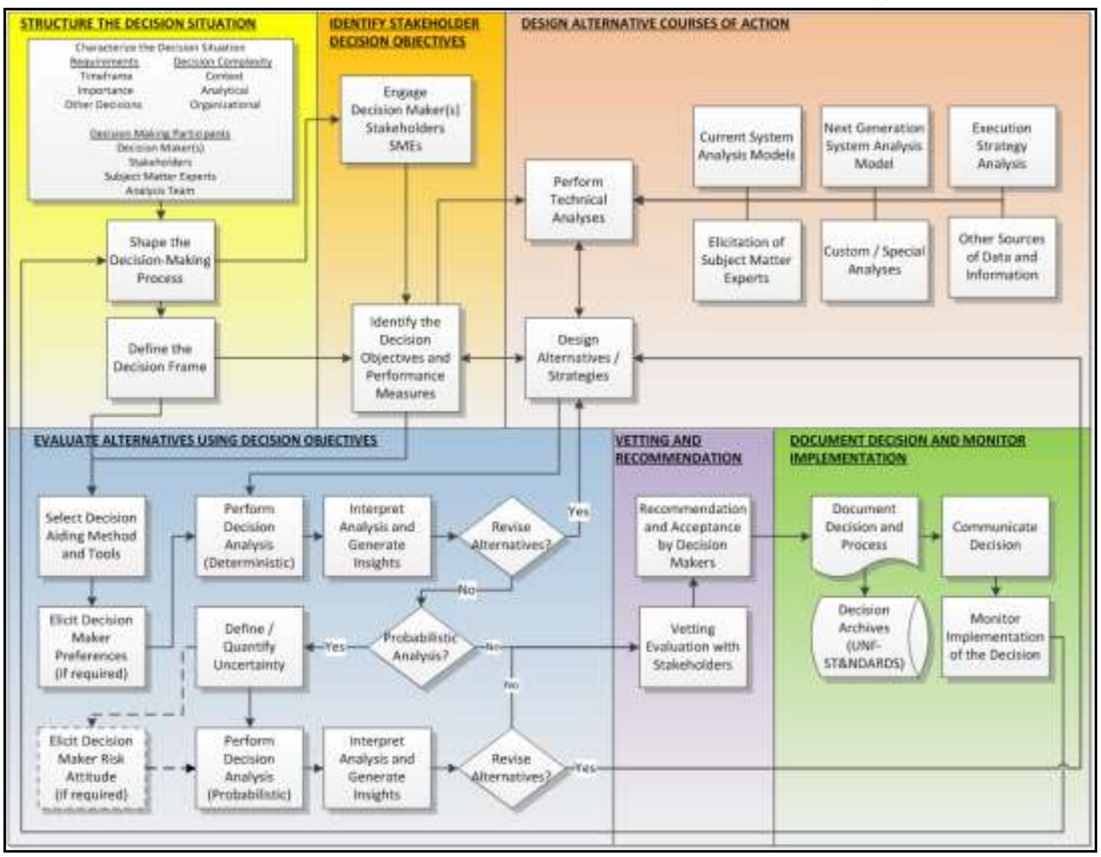

Fig. 1. Multi-Objective Evaluation Framework.

There are three important principles at the core of the MOEF: (1) that stakeholders prefer an outcome that maximizes what they value; (2) that different stakeholders value different things; and (3) that consensus outcomes must balance, or trade-off, the different values held within and among stakeholder groups.

The goal of a multi-objective evaluation is to identify an alternative that creates the greatest value for the stakeholders who will be affected by the choice of some policy or action. The level of value created by an alternative is measured by the performance of the alternative with respect to the objectives that are important to the stakeholder. Performance measures are used to quantify the degree to which an alternative satisfies stakeholders' objectives.

As depicted by the boxes in Fig. 2, the Multi-Objective Evaluation Framework incorporates five fundamental elements to arrive at a composite model of our knowledge and values. Stakeholders express their interests and desired outcome from a situation as a set of objectives that they hope to be achieved. Objectives are generally stated in terms of system attributes that a particular stakeholder prefers to maximize or minimize, such as minimizing cost, minimizing adverse health impacts, or maximizing regional economic benefit. The performance of an alternative with respect to the objectives is quantified by appropriate performance measures, all of which have different physical units – dollars, years, expected fatalities, expected heavy-lift drops, system flexibility, and so on. An objective may be measured by one or more performance measures. Because it is not possible to aggregate measures as dollars, years, and other units in a meaningful way, a method is needed to convert the various performance measures into common units. The common unit used for multi-objective evaluation is "value".

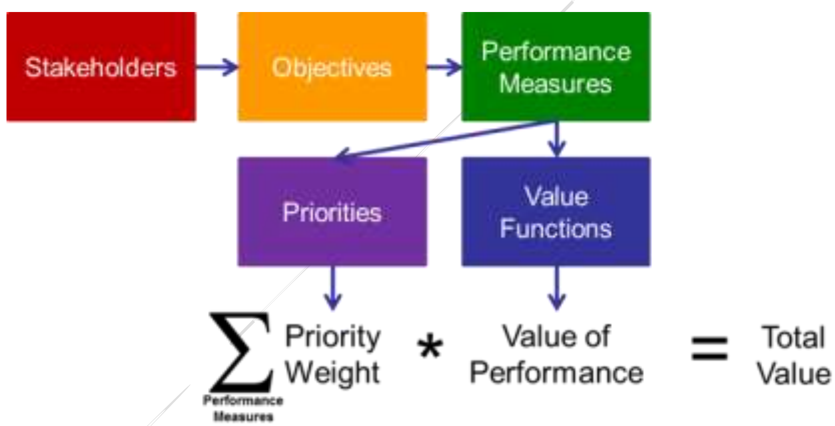

Fig. 2. Fundamental Elements of Multi-Objective Evaluation.

In economic theory, value is defined as the importance, worth, or usefulness of something to someone relative to satisfying their objective. Thus, the value received by a stakeholder from an alternative with respect to any objective depends on its level of performance, i.e., high performance with respect to what the stakeholder values provides more value to the stakeholder than low performance. Value functions translate performance with respect to each measure into a normalized relative value that a stakeholder receives from that level of performance. The relative value derived from performance with respect to the objectives is then weighted based on the stakeholder's priorities to account for variation in the importance of the measures toward the creation of aggregate value, and the significance of the scale range of the measures toward differentiating between alternatives.

The product of priority weight and performance level value is summed over the performance measures to arrive at the total value of an alternative as assessed by a stakeholder relative to their objectives. This multi-objective value model is shown in simplified form at the bottom of Fig. 2 and in mathematical form in Eq. 1:

$$V(x) = \sum_{i=1}^{n} w_i v_i(x_i) \qquad \text{(Eq. 1)}$$

where,

$V(x)$	is the total (aggregate) value of an alternative;
i = 1 to n	is the number of performance measures;
x_i	is the level of performance on the i^{th} performance measure;
$v_i(x_i)$	is the single performance measure value function for performance level of x_i ; and
w_i	is the priority weight of the i^{th} performance measure, also called the swing weight.

In a complex system, such as a waste management system, the number of performance measures can be very large. As a result, collecting the inputs for Eq. 1 (stakeholders' performance measures and the priority weights) can become a challenging task. The starting point proposed in this study is to learn from historical work in this area by compiling available information and combining it into a single objectives-oriented hierarchical structure.

APPROACH

Stakeholders include individuals and groups who will influence or be influenced by future policy and technical decisions. The starting point for constructing a nuclear waste management multi-objective evaluation model is to gain insight into and understanding of the many stakeholders' objectives. The initial set of attributes representing these objectives is intended to provide a reference basis for considering potential objectives for evaluating nuclear waste management system options. It is envisioned that this initial set will evolve and be revised as new and additional input is received from stakeholders on various attributes and their relative priority.

Compiling a comprehensive hierarchical listing of attributes is a complex task since stakeholders have multiple and often conflicting interests. The Blue Ribbon Commission on America's Nuclear Future (BRC) [4] worked for two years (January 2010 to January 2012) to "ensure it has heard from as many points of view as possible." The Canadian Nuclear Waste Management Organization (NWMO) [5] study took four years and ample resources, involving national and regional stakeholders' dialogs, internet-based dialogs, information and discussion sessions, open houses, workshops, roundtables, public attitude research, website, and topic reports.

The current compilation effort benefited from the distillation of many varied inputs conducted by the previous studies. The major goal of this compilation was to develop a framework that provides easy access to the pertinent information. The framework has to be capable of:

- providing sufficient detail regarding each objective and measure;
- describing the factors that were considered in developing objectives and measures; and
- offering a convenient way of displaying and manipulating hierarchical structures.

Microsoft Visio was found to be a useful tool to help meet the above requirements. Visio allows for building large and complex diagrams, which is essential for visualizing hierarchical structures. It offers convenient tools for revising and manipulating diagram building blocks and their connections; provides several options for adding detailed information to any point on the diagram, and is capable of generating summary reports.

The major elements of Visio diagrams are shapes, which are diagram building blocks. Shapes can be assigned shape-specific properties. A new stencil entitled "Decision Framework" was created to accommodate the master shapes specific to the hierarchical structures to be developed. Each master shape was assigned the shape-specific properties. The examples are shown in Figures 3 and 4. The property sets defined for each shape provide the way to include additional information for each specific objective and measure defined in the hierarchical structure.

The information associated with each objective (measure) can be either viewed in the shape property window or summarized in a table (Excel file) generated using Visio report capability. Additional information, when available, is provided either in a callout shape connected to the objective (measure) shape or via "Off-Page Reference" shape. The second method was used for displaying large amounts of information, such as an influence diagram (a graphical way of showing the factors affecting the parameter of interest and connections between them).

Fig. 3. Properties of the Objective Master Shape.

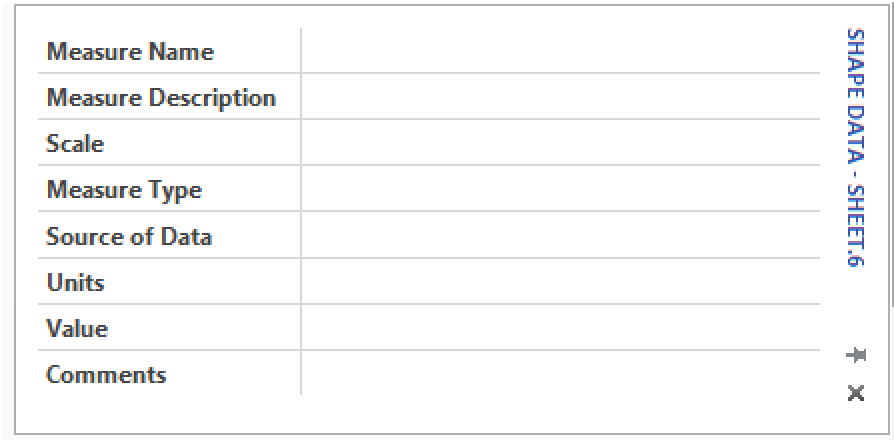

Fig. 4. Properties of the Measure Master Shape.

The objectives and measures were organized into a single hierarchical structure. “Off-Page Reference” was used for navigating between the different levels of the hierarchical structure. The number of levels under each highest-level objective represents the amount of detail considered in previous analyses. An attempt was made to go to the “deepest” lowermost level and to retain as many details as possible.

An iterative process was employed to construct a single hierarchical structure. This is because the previous studies were different with regard to the problems considered and level of detail supplied. The following sections provide a discussion of the data sources and the descriptions of the hierarchical structure.

DISCUSSION OF DATA SOURCES

A particular focus of this study was on collecting and compiling inputs from past studies that involved the participation of various external stakeholders. However, while the important role of stakeholder input in a country’s waste management decision process is recognized in the referenced sources, there are only a limited number of in-depth studies of the stakeholders’ differing perspectives.

The following sources provided major input for this analysis:

- BRC report “*What We’ve Heard*” [4];
- Canadian NWMO report “*Choosing a Way Forward: The Future Management of Canada's Used Nuclear Fuel”* [5]; and
- Westinghouse Technology Services report *“Phase 1 Study of Metallic Cask Systems for Spent Fuel Management from Reactor to Repository”* [6, 7].

The summary description of these sources is provided below. Also discussed below is the TRW System Architecture Panel Meeting Final Report [8]. This report was prepared for the U.S. Department of Energy Office of Civilian Radioactive Waste Management (OCRWM) in 1994. The Panel Meeting was conducted to begin eliciting the concerns and value judgements of stakeholders and it provided useful information regarding attributes that could be used to evaluate waste management system.

BRC Report "What We've Heard"

The BRC conducted its studies from January 2010 to January 2012. The BRC has investigated a wide range of issues including reactor and fuel cycle technologies, transport and storage, options for waste disposal, institutional arrangements for managing spent nuclear fuel1 and high-level wastes, handling of the Nuclear Waste Fund (NWF) and changes to the legal framework governing nuclear waste management in the United States.

Among the other tasks, the BRC and its subcommittees collected comments from hundreds of individuals and organizations on a wide range of issues. This was done through formal hearings, site visits, and written letters and comments submitted through the BRC web site. It was the BRC's perception that the loss of public trust "stems at least in part from a feeling among many groups that they have not been heard, that their concerns have not been taken seriously, and that they have been shut out of past decision-making processes." [4, page 3]

The BRC also held five public meetings in different regions of the country to hear feedback on its draft report. A wide variety of organizations, interest groups, and individuals provided input to the BRC at these meetings and through the submission of written materials. The public comments were summarized in the BRC report entitled "What We've Heard". [4]

NWMO Report "Choosing a Way Forward: The Future Management of Canada's Used Nuclear Fuel"

At the beginning of its work the NWMO conducted over 250 conversations about expectations with individuals and organizations to learn what they expected from this study and how they wanted to see it conducted. The approach was designed to "ensure that not only the best scientific and technical knowledge was brought to the study, but also that the values and objectives of citizens were identified and understood, and formed the road map for both the study and recommendation" [5, page 59].

The Canadians were asked to list the values and objectives against which a radioactive waste management approach should be assessed. The information was collected via nation-wide surveys, focus groups, issue-focused workshops and roundtables, e-dialogues and deliberative surveys, and public information and discussion sessions.

In addition, the public attitude research was conducted with a representative cross-section of Canadians, including 14 focus groups and a nation-wide telephone survey involving 2,600 Canadians. Special attention was devoted to conducting aboriginal dialog.

To assist in communication, approximately 70 peer reviewed papers on a number of radioactive waste management issues were prepared by the specialists in that field.

During the four years of study, approximately 50,000 people visited the project web site. More than 18,000 people have contributed, including more than 500 specialists in natural and social sciences and technical disciplines related to the management of used nuclear fuel.

Westinghouse Technology Services Report "Phase 1 Study of Metallic Cask Systems for Spent Fuel Management from Reactor to Repository"

In addition to examining the BRC and NWMO reports, a Westinghouse study [6] was also examined which was quite specific in terms of systems evaluated (metal cask systems), yet fairly broad in terms of covering the back-end of the nuclear fuel cycle. The study evaluated various metal cask systems for their suitability for onsite spent fuel storage, transportation, offsite storage at a surface storage facility, and a disposal in a geologic repository. Even though the study was conducted a long time ago (1984), it is still valuable because it considered all aspects of spent nuclear fuel management from reactor discharge through disposal in a geologic repository, including an interim storage facility. The study was led by Dr. Ralph Keeney, a recognized expert in the field of the multi-attribute decision analysis methodology [1, 3].

The study method was to use a Peer Advisory Group that represented many diverse interested parties whose acceptance was necessary for successful implementation of any radioactive waste management approach. The study asked the panel the following question: "What issues/criteria must be addressed in designing metal cask systems to handle all aspects of spent nuclear fuel management from reactor storage through final disposal in a geologic repository?"

As a result of the panel discussions, the suggestions on value criteria were obtained from each group. The suggestions from the different panels were used to generate a preliminary hierarchy of the value criteria. Of specific interest to this analysis was the public interest panel that included individuals in environmental groups, consumer groups, and universities. The value criteria developed by this panel were reported in Appendix G of Volume III of their study report [7].

TRW Report "System Architecture Panel Meeting Final Report"

The U.S. Department of Energy (DOE) Office of Civilian Radioactive Waste Management (OCRWM) sponsored a System Architecture Panel Meeting back in late 1993 and early 1994 to begin involving program stakeholders in activities related to their System Architecture Study (SAS). A Panel consisting of six program stakeholders and six OCRWM employees were invited to participate and two meetings were held. Approximately 10 panelists attended each of the meetings which were open to the public to observe. The Final Report [8] documented the outcomes of two meetings held with panel participates. The panel was presented with 13 alternative architectures of the waste management system. The panel identified and evaluated the attributes and measures that reflected their issues and concerns regarding the system architecture.

The hierarchical structure developed by the panel consisted of 25 attributes, some of which are similar to more recent studies and/or which can be viewed as a sub-set of the attributes found in these studies. The important attributes included: costs, radiation exposure, traffic accidents, first removal of waste from the reactor sites and first waste emplacement, generational equity, cultural resources management, and new/changed land use.

This effort to use a value framework process was constructive in that everyone (panelists, sponsor, and observers) gained insight about the differing perspectives of others. It also had some limitations due to the following factors:

- Very small panel size ($\leq$ 10 participating panel members) and turnover in attendance between meetings;
- Short duration of operations (a few days in panel meetings).
- Different levels of familiarity and knowledge about the waste management system architecture study and value framework process by various panelists.

Nonetheless, a few interesting observations can be derived from this study. First, the panelists encountered difficulties with quantifying some issues numerically and making tradeoff decisions. They expressed discomfort with the ranking of "allowable" attributes using a method that forces an attribute to be quantified, particularly as a prerequisite for its consideration. They also subsequently declined to participate in a third phase of the process pertaining to the pairwise comparisons exercise, noting that making tradeoff decisions between the attributes is subjective and that the value framework process attempts to make subjective decisions two-dimensional. Thus two lessons learned were to eliminate the requirement to quantify issues and to allow subjective decisions to be made.

Some additional suggestions/lessons learned made based on this study include:

- Communicate a simple and clear purpose of the meeting and relate it to the overall stakeholder involvement plan.
- Establish consistent ground rules and boundaries for evaluating the system architectures.
- Prepare panelists in advance and use an independent facilitator who is a communications professional.

HIERARCHICAL STRUCTURE DESCRIPTION

The top objective of the hierarchical structure was entitled "Public Acceptance of Spent Nuclear Fuel (SNF) and High Level Radioactive Waste (HLRW) Management Options". The IAEA guidebook [9] defines reaching the public acceptance as achievement of a "buy-in" from the affected communities and the public at large requiring the resolution of social and ethical issues, as much as scientific and technical ones."

The following high-level attributes (listed in an arbitrary order) were identified based on the review of the major literature sources described above:

- Transportation impacts; flexibility and adaptability;
- Adequate institution in place;
- Technical approach;
- Economic viability;
- Future generations;
- Stewardship;
- Transparency, accountability, and knowledge;
- Fairness and justice;

- Security;
- Environmental impacts;
- Health and safety; and
- Impacts on community

Each high-level attribute has an associated hierarchical structure containing the lower-levels attributes. As it was discussed earlier, the hierarchical structures were developed to provide a starting point for and assistance with the further development of the stakeholders' objectives and measures. When the new attributes are identified, they can be easily incorporated into the existing framework. Any attribute can be revised with regard to its properties and connections with the other attributes.

Most attributes in the hierarchical structure represent objectives. The measures were only defined for the cost related attributes. This reflects the fact that the available studies did not obtain this level of detail from the stakeholders. They derived the stakeholders' values, but they did not define the measures of fulfillment of these values. This would take even greater effort because agreement about the value does not necessarily imply agreement about the means of how to measure the fulfillment.

The names of some attributes are similar. However, these attribute are not redundant as they have different meaning with regard to their higher-level attributes. For example, one of the objectives under "Fairness and Justice" is "Liability and Compensation". One of the objectives under "Community Well Being" and subsequent "Psychological Concerns" is "Assurance and Compensation". The latter is the assurance of an adequate compensation system that concerns the public's psychological beliefs. The actual existence of an adequate compensation system is the issue under the fairness category.

The "Adequate Institution in Place" and "Future Generations" are two attributes with large hierarchical structures. The following second-level attributes under the "Adequate Institution in Place" address the credibility of an organization responsible for the waste management program:

- Trust and credibility;
- Continuity and short-term and long-term commitments;
- Responsibly manage nuclear fuel cycle;
- Technical excellence;
- Effectively manage transportation program;
- Flexibility with regard to the regulatory and major political changes;
- Freedom from political influence;
- Resilience;
- Ability of government to fulfill contractual obligation regarding accepting waste;
- Involvement of different governmental agencies;
- Accountability;
- Ability to effectively manage a controversial and complex project;
- Ability to make progress toward disposal solution; and
- Removing fuel from the shutdown sites.

The following second-level attributes under the “Future Generations” address the inter-generational concerns:

- Impacts on future generations - genetic (mutation) and cancer;
- Responsibility to our and future generations;
- Funds are in place to accommodate any future action;
- Fully understand the nature of challenge;
- Assess full range of options;
- Necessary studies, procedures and protocols are in place;
- Placing future generations at risk from safety or financial perspectives;
- Respect for future generations - human beings; other species, and biosphere;
- Sustainability across generations; and
- Knowledge transfer about long-term management of spent nuclear fuel.

Note that the second-level attributes listed above have multiple layers of lower-level attributes that provide more specific details regarding the nature of the concern.

Large hierarchical structures were also derived for “Technical Approach”, “Transparency, Accountability and Knowledge”, and “Transportation Impacts” attributes. The hierarchical structure for the “Transparency, Accountability and Knowledge” attribute is shown in Figure 5 for illustration purposes.

The total number of attributes currently included into the hierarchical structure is 132. Providing a description of each attribute was not the purpose of this paper because this work is in its initial stage. Rather the intent was to demonstrate the capability of this approach to support the development of the MOEF.

CONCLUSIONS

This literature review and hierarchal attribute structure provides a comprehensive starting point for further consideration by system analysts and planners to develop stakeholder objectives for a waste management system multi-objective evaluation framework based on the principles and methodology of multi-attribute utility analysis. The complex hierarchal structure of attributes is documented in a Microsoft Visio format that is well-suited for building large and complex diagrams and offers convenient tools for revising and manipulating diagram building blocks and their connection; provides several options for adding detailed information to any point on the diagram, and is capable of generating summary reports.

This work will be used as guidance, based on previous efforts to define stakeholder objectives and values, in the development of the MOEF. Although the attributes and measures will eventually need to be refined and revised using direct elicitation techniques to be aligned with actual perspectives of these stakeholders, early recognition, awareness, and exploration of anticipated stakeholder objectives will serve to inform policy options and system analysis scenarios.

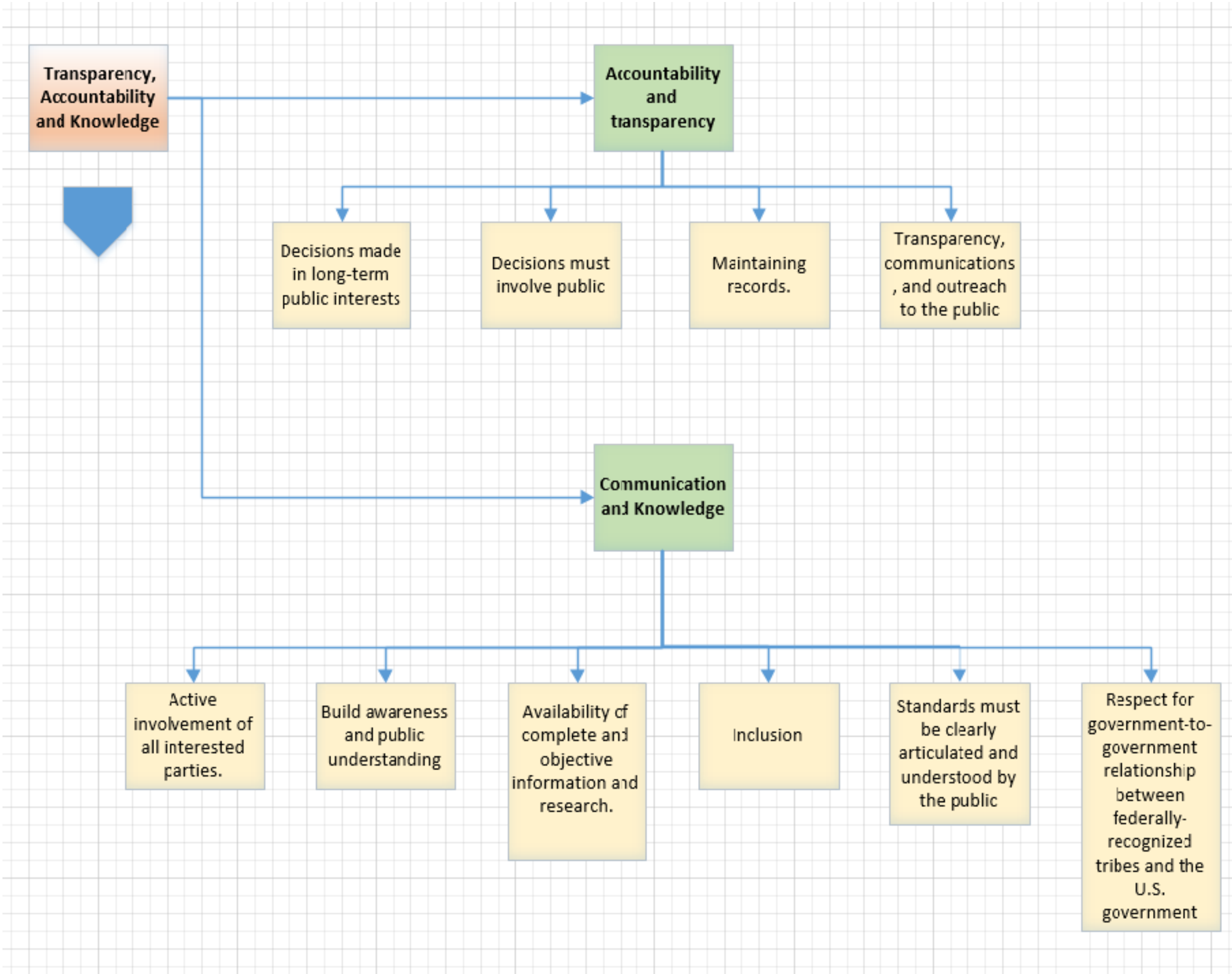

Fig. 5. Transparency, Accountability, and Knowledge Attribute Hierarchical Structure.

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