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**Steven J. Piet**
**Dana L. Dettmers**
**Steven A. Eide**
**Patrick L. Gibson**
**Jeffrey C. Joe**
**Thomas A Kerr**
**Robert L. Nitschke**
**Kyle B. Oswald**
**John P. Reisenauer**

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Steven J. Piet, Dana L. Dettmers, Steven A. Eide, Patrick L. Gibson, Jeffrey C. Joe,
Thomas A. Kerr, Robert L. Nitschke, Kyle B. Oswald, John P. Reisenauer
*Idaho National Engineering and Environmental Laboratory (INEEL)*
*P.O. Box 1625 Mail Stop 3605*
*Idaho Falls, ID 83415-3605*
*pietsj@inel.gov*

Maxine E. Dakins
*University of Idaho at Idaho Falls*
*1776 Science Center Drive*
*Idaho Falls, ID 83402*
*medakins@if.uidaho.edu*

**Abstract—***The effects of closure decisions for used nuclear facilities can extend centuries into the future. Yet, the longevity of decisions made over the past half century has been poor. Our goal is an improved decision framework for decommissioning, stewardship, and waste management. This paper describes our overall framework. Companion papers describe the underlying philosophy of the* **KONVERGENCE** ***Model for Sustainable Decisions***[1] *and implications for a class of intractable decision problems.*[2] *Where* ***knowledge***, ***values***, *and* ***resources*** *converge (the K, V, and R in* KONVERGENCE*), you will find a sustainable decision – a decision that works over time. Our approach clarifies what is needed to make and keep decisions over relevant time periods. The process guides participants through establishing the real problem, understanding the universes of* ***knowledge, values, resources****, and generating alternatives. We explore three classes of alternatives – reusable (e.g. greenfield), closed (e.g. entombed structures), and adaptable. After testing for konvergence of alternatives among* ***knowledge, values, resources****, we offer suggestions to diagnose divergence, to reduce divergence by refining alternatives to address identified weaknesses, and to plan to keep* konvergence *over the life of the decision. We believe that decisions made via this method will better stand the test of time – because it will be either acceptable to keep them unchanged or possible to adapt them as* ***knowledge***, ***values***, *and* ***resources*** *change.*

## I. INTRODUCTION

The effects of closure decisions for used nuclear facilities and contaminated sites can extend centuries into the future. Yet, the longevity of decisions made over the past half century has been poor. Our goal is an improved participatory science-based decision framework for decommissioning-stewardship-waste management decisions. Here, "science" includes decision science, action science, sociology, psychology, political science, ethics, history, "hard" sciences, and many engineering disciplines. We want to make decisions more robust, transparent, and consistent by more *effective* stakeholder involvement, greater understanding of the consequences of the decisions, and recognition of what it will take to *keep* decisions once they are made.

This paper describes our framework, developed during the first half of a 3-year project. We offer these ideas to solicit feedback and continue progress. After reading this paper, we invite you to read our companion model and implications papers.[1,2] A draft guidebook is available from the lead author. In the second half of our project, we will further test the framework and further develop quantitative analysis tools. This is a research project and does not represent official positions of the Department of Energy or its contractors.

The classic *siting* approach is "decide-once" – single problem, fixed criteria, alternatives, then make a single decision to build or don't build. The "no action" alternative may be viable in such instances – do not build the hazardous facility. *Unsiting* of used nuclear facilities and sites poses different challenges, motivating changes to decision processes. The "no action" alternative is often untenable – the hazard is already there - and a "decide once" process can be unrealistic and costly.

The inadequacy of current approaches has been summarized: "Because uncertainty is inherent in many of these areas, and because DOE's preferred solutions – reliance on engineered barriers and institutional controls – are inherently failure prone, step-wise planning for DOE legacy sites must be *systematic*, *integrative*, *comprehensive*, and *iterative* in its execution through time, *adaptive* in the face of uncertainty, and *active* in the search for new and different solutions. Planning for long-term institutional management should commence while remediation is underway."[3]

## II. *K*ON*V*E*R*GENCE MODEL

Our framework is based on the need to establish and maintain *k*on*v*e*r*gence among the three universes of accessible ***knowledge***, ***values*** of those potentially affected, and available ***resources***. Each universe is represented by a circle in figure 1. We call this the ***K*ON*V*E*R*GENCE Model for Sustainable Decisions**.[1] Investigation of available data or to obtain new data defines ***knowledge***. Participation of stakeholders specifies ***values***. The availability of budgets, offsite disposal sites, environmental permits, etc. drives ***resources***. Acceptable alternatives are those in the *k*on*v*e*r*gence of ***knowledge***, ***values***, and ***resources***. The *K*ON*V*E*R*GENCE Model clarifies what can go wrong and ***why*** certain analyses need to be done.

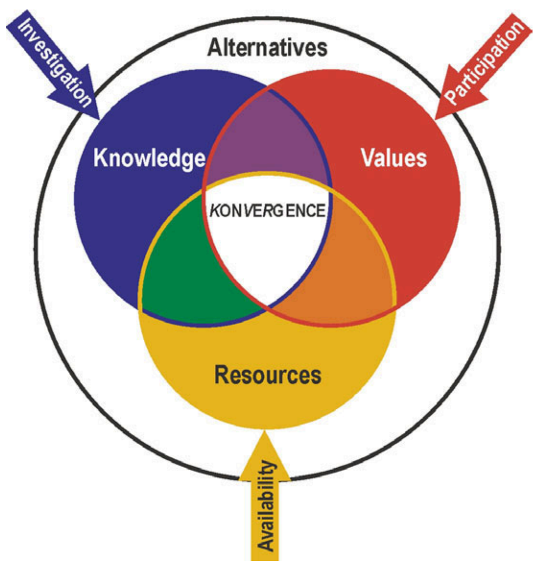


**Figure 1. *K*ON*V*E*R*GENCE Model for Sustainable Decisions[1]**

## III. ESTABLISH WHAT THE REAL PROBLEM IS

As in existing approaches, analyze the situation and identify the problem(s) to be solved. Many difficulties stem from a bad start and so we suggest enhancements:

- Analyze how decisions are related in time, space, functional, etc. Identify related decisions, rather than making simplifying assumptions that can artificially decouple related decisions.
- Analyze the appropriate decision level, e.g., should related decisions be considered together such as all cleanup decisions at a National Lab? If the decision level is too broad or high, the decision process can stall due to complexity. If the decision level is too narrow or low (such as focusing on one contaminated building ignoring surrounding hazards), decisions can be locally optimal but not optimal from a broader perspective, such as cases where there is a high degree of cleanup in a relatively dirty area.
- Decrease the odds of disruption by late-entry players[4] by actively inviting participation and probing their ***values***. This reduces the chances of having late-entry players and that any late-entry players that do arise are viewed as "saviors" rather than as "disruptors."
- Consider the decision environment[4]
    - Collaborative – participants trust the decision process and each other
    - Negotiable – participants may trust the decision process, but not necessarily each other
    - Polarized – those affected by the decision trust neither the decision process nor each other

  In our approach, the decision environment influences how to implement the decision process.

## IV. DISCOVER THE *VALUES* OF THOSE AFFECTED BY THE DECISION

Rather than jump to detailed objectives, e.g., cleanup a site to some risk limit, we start with broad ***values*** to maximize the chance for establishing a common ground and increasing collaboration, then work downward to principles, strategic objectives, tactical goals, and performance measures. Table 1 shows our generic hierarchy of 4 ***values*** and 20 principles (Table 1) - assembled from the literature, our analyses of decision difficulties, and test cases. They span process and result concerns. Users must decide what to add, change, or delete from our generic set. With the validated problem statement, these define what would constitute success.

Table I includes two **Precautionary Principles**. They advocate caution in differing ways. The first cautions against *taking actions* prematurely if the actions pose threat of irreversible harm. The second cautions against *not taking action* to protect against the threat of irreversible harm. Some cleanup problems can encompass risk of both types. Consider the case of a long-lived hazard that if left alone will eventually degrade, increase in risk, and become more difficult to cleanup. **Precautionary Principle 2** would argue to take cost-effective measures now! But, which measures?" **Precautionary Principle 1** would argue against taking an irreversible action that might not be wise from the long-term view. In such situations, how can we proceed? No action is dangerous; taking a wrong action is dangerous.[2] Below, we discuss the "adaptable" class of alternatives.

**Table I. Generic Values and Principles Relevant to Cleanup Decisions**

**Equality – the decisions are fair and just for current and future generations**

- **Trustee Principle** – "Every generation has obligations as trustee to protect the interests of future generations."[5]
- **Sustainability Principle** – "No generation should deprive future generations of the opportunity for a quality of life comparable to its own."[5]
- **Chain of Obligation Principle** – "Each generations' primary obligation is to provide for the needs of the living and succeeding generations."[5]
- **Precautionary Principle 1**– "Actions that pose a realistic threat of irreversible harm or catastrophic consequences should not be pursued unless there is some compelling countervailing need to benefit either current or future generations."[5]
- **Precautionary Principle 2** – "Where there are threats of serious or irreversible damage, scientific uncertainty shall not be used to postpone cost-effective measures to prevent environmental degradation."[6]

**Democracy – the decision-making process is open with participation by all**

- **Involvement Principle** – The process should incorporate meaningful community and stakeholder involvement in all phases of decision-making now and in the future.
- **Information Principle** – Complete, accurate, and useable information should be provided to both current and future peoples.
- **Invisible Man Principle –** The decision, the decision process, and supporting information must be transparent and understandable by interested parties now and in the future.
- **Poisoning of the Well Principle** – Don't poison the "well" for current and future decisions. The decision process should make future decisions involving related problems and key stakeholders easier not harder by improving the decision environment.
- **Tip of the Iceberg Principle** – Without granting veto power to individual participants, concerns must be noted, addressed to the extent possible, and the risk of proceeding in the face of strong concerns considered before proceeding.

**Truth – the decision should reflect the truth, the whole truth and nothing but the truth**

- **Uncertainty Principle –** There will be large uncertainties in the ***knowledge*** about the hazards, the facility and its environs especially their future behavior and performance. These uncertainties need to be acknowledged, documented and communicated with all involved.
- **Faber College Principle** – "Knowledge is good." To be able to make a sound decision, knowledge about the contaminated situation is essential. Research will be pursued if complete understanding is not possible. [*The name of this principle is our most obscure, from the movie Animal House.*]
- **Forest and the Trees Principle** – Understand the characteristics and context of the land and facilities near the site or facility in question. Actions that might make sense in one location may not make sense in another.
- **Price is Right or Fram Oil Filter Principle –** The stakeholders have a need and a right to know not only what the cleanup activity will cost but what the life cycle costs will be. [*From the Fram Oil Filter slogan, "Pay me now or pay me later."*]

**Reason – the decision should be real, practical, and meaningful**

- **What if You are Wrong Principle** – Decisions must withstand the test of time amid great uncertainty.
- **Paul Masson Principle** – No decision should be made before its time. [*From their slogan, "Sell no wine before its time."*]
- **Perry Mason Principle –** Decisions must comply with the intent of environmental regulations regardless of current language or interpretation, e.g., protective of human health and the environment.
- **Hippocratic Worker Principle** – Above all else, do no harm to the current worker especially when considering minimal hypothetical future risks.
- **Little Engine that Could Principle** – The decision should lead to actions that are achievable, not necessarily easy, but doable with existing ***resources***.
- **Snicker Principle** – The decision should be able to pass a snicker test by participants before implementation.

We believe that most decision difficulties arise from being perceived as violating one or more of these principles. For example, a common complaint is the lack of adherence to what we call the **Uncertainty Principle.**

We discourage prioritizing among values, principles, etc. at this point, especially if the decision environment is polarized. Maximize the chance for collaboration.

## V. GENERATE ALTERNATIVES

When identifying alternatives, establish the nature of hazards, degree of adaptability, responsibilities of those who would help implement, and relationships among decisions. Alternatives span ranges of adaptability and levels of residual on-site hazards (figure 2).

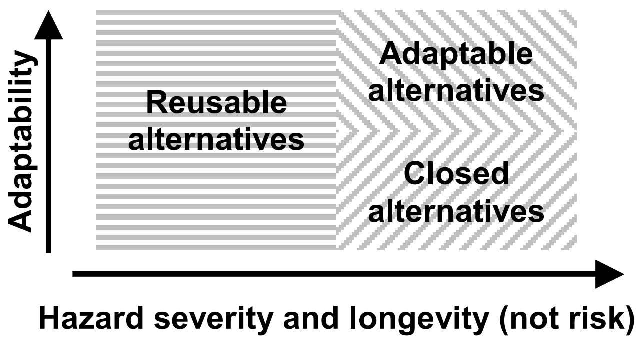


**Figure 2. Hazard-Adaptability Space for alternatives**

Three general areas of adaptability-hazard option space are as follows:

- **Reusable** - Relatively low hazard, variable adaptability - Facility can be released for other purposes, by other groups – with or without restrictions on use. If "any" use of the facility/land would lead to acceptable risk, the release is "unrestricted", e.g., greenfield. If some users would pose unacceptable risks, the release is "restricted", e.g., brownfield sites.
- **Adaptable** - Relatively high hazard, relatively high adaptability - Facility is kept in an adaptable state, thereby keeping future options open while keeping the risk from hazards acceptable to stakeholders for an extended period. Four examples are the concept of "assured storage" of low-level radioactive waste,[7] the C reactor at Hanford, temporary spent fuel storage at commercial power plants, and the suggestion for adaptive staged decisions at Yucca Mountain.[8]
- **Closed** - Relatively high hazard, relatively low adaptability - Facility is put into state with little adaptability, with little or no intention to revisit later unless severe unexpected things go wrong. So-called "entombed" facilities would be examples. Another is deep geological disposal after site closure.

Participants should brainstorm as creatively as possible, including the "no action" and greenfield alternatives. Often, the "no action" alternative will not be viable, but analysis of this alternative is required by the National Environmental Policy Act (NEPA) - if applicable to the decision in question. Also, the relative unattractiveness of "no action" provides motivation for the decision processes not to stall. The greenfield alternative is sometimes not viable, but should be studied because late entry participants and future generations will ask – why didn't you just clean it totally?

The adaptable class of alternatives is especially relevant to consider if there is a chance of polarization between those who advocate reusable and closed positions.[2] A true adaptable alternative provides for safely containing the hazard, while working to increase the chance for *k*on*v*e*r*gence of additional alternatives in the future.

Once participants generate a diverse list of alternatives, it is important to ensure that the description of alternatives are sufficiently complete to meaningfully evaluate and to identify key assumptions. The description must include the possible need for offsite waste disposition and any treatment of the hazards. This will generally increase the number of alternatives and variants. After considering offsite disposition and treatment possibilities, re-examine the list of people invited to participate. What might have been a decision with mostly local ramifications from *unsiting* a hazard may now have offsite ramifications.

The last part of generating alternatives is to get an anonymous initial assessment of how participants evaluate the alternatives with respect to ***knowledge***, ***values***, and ***resources***. Participants are asked to plot points (if certain) or circles/shapes (if uncertain) on the *k*on*v*e*r*gence diagram (figure 1). This gives an initial assessment of the degree of scatter and divergence. Scatter is the variance among participants for each alternative. Divergence is how far alternatives may be from *k*on*v*e*r*gence.

## VI. IDENTIFY AND REDUCE DIVERGENCE

Quantitative analyses are often expensive. Prematurely conducting detailed quantitative analyses can also give the impression that the decision owner has already selected among alternatives. Thus, it is appropriate to extract as much qualitative information as possible on participants' reactions to alternatives before proceeding to detailed analyses.

The objective is to create alternatives with low scatter and low divergence that are in *k*on*v*e*r*gence of ***knowledge***, ***values***, and ***resources***. We need to diagnosis what is causing scatter and divergence, as a prelude to narrowing the list, and refining alternatives. It is impossible to refine alternatives if we do not know why participants evaluate alternatives as they do.

Low scatter does not mean that people evaluate an alternative in exactly the same way – or are making the same key assumptions. Participants need not agree on the relative merits of many of the alternatives. However, having worked through ***values***, principles, and objectives and developed a range of alternatives, there should be sufficient common ground to allow fruitful discussion.

We hypothesize that the scatter of ***values*** evaluations may correlate with the decision environment. In a collaborative setting, participants have or are developing some sense of a shared set of ***values*** and should exhibit less scatter in ***values*** evaluations. In a polarized setting, distrust may have increased scatter not only in ***values*** evaluations but also ***knowledge*** and ***resources***.

Ask participants the following:

- Where does each alternative fit into ***knowledge***, ***resources***, and ***values*** – and why?
- What key assumptions are they making in that evaluation? (Later, gather more information to replace assumptions with ***knowledge*** to reduce uncertainties in evaluations.)
- What might change their evaluation, i.e., what weaknesses might be fixable?

In section V, the first test of *k*on*ver*gence was a scatter diagram. At this point, ask participants to give each alternative a score of 1 – 4 for each universe based on the definitions in Table II. Participants should note whether they are (a) highly certain, (b) somewhat uncertain, or (c) highly uncertain in each evaluation. Thus, a score of K-1a, V-1a, R-1a indicates the alternative, in the opinion of the evaluator, is well within the ***knowledge***, ***values*** and ***resources*** universes and the evaluator is highly certain of those ratings. We also ask participants to provide a brief text rationale for their evaluations, which are then analyzed.

Probe deeper into the causes of scatter if

- the decision environment is polarized,
- there is high scatter in ***values*** evaluations, or
- distrust has affected evaluations of ***knowledge*** and ***resources***.

If so, the discipline of "action science" is valuable. Space does not permit much discussion of the concepts or their application to decision making. To illustrate, note that we use mental models that reflect our world views. These can have significant impacts on decisions (Table III).

Circumstances that necessitate establishing an explicit networks of decisions at this point include:[2]

- Key relations among decisions, e.g., opening an offsite disposal site,
- Assumptions that cannot be validated now, or
- Adaptable alternatives.

Refine alternatives using the understanding gained in diagnostic analyses to improve alternatives. Alternatives that have inherent advantages but have weaknesses in some universes may warrant further attention to improve them. For example, Shrader-Frechette points out that some conflicts between inter- and intragenerational ethics can be reduced by refining alternatives to consider both perspectives.[9] Another example, if an alternative converges with ***knowledge*** but not ***values*** because of a lack of trust – perhaps reshape the alternative to include trust funds or stakeholder controlled mechanisms.

The final questions at this step are – (a) have we fixed alternatives' weaknesses by reshaping them? Those moving into or toward *k*on*ver*gence are retained; those remaining highly divergent are discarded and (b) is there an adequate diversity of alternatives still on the table? If so, continue to quantitative analyses. If not, generation of more alternatives or additional refinements to existing alternatives are needed.

**Table II. *K*ON*VER*GENCE Mapping Scales**

| Location in Each Universe | Knowledge of the solution | Values and Principles | Resources |
|---|---|---|---|
| (1) In the center of each universe | **Validated** – unquestioned (trusted) information and interpretation thereof | **Enthusiastic** – very consistent with participant's ***values***, they would be advocates | **Committed** – already available ("in hand"), e.g., trust funds, authorized budgets, operational waste disposal sites, existing workforce |
| (2) Tends to be inside universe | **Tentative** – significant evidence exists but questions persist on validity | **Acceptable** – on balance, consistent with the set of the participant's ***values*** but some aspects might be a bit troubling | **Proposed**, e.g., out-year proposed budgets, planned waste sites |
| (3) At the edge of each universe | **Speculative** – probably achievable given R&D investment or if trust in the source of ***knowledge*** increases | **Tolerable** – participant can "live" with the alternative but some aspects are clearly troubling | **Speculative -** could be made available, e.g., society likely has the ***resources*** but has not moved to use them. |
| (4) Clearly outside the universe | **Impractical -** the ***knowledge*** is unlikely to be obtainable in a time frame relevant to the problem | **Oppose** – on balance, inconsistent with participant's ***values*** | **Impractical –** necessary ***resources*** are unlikely to be available |

**Table III. Possible Mental Models Affecting Progress on a Decision**

| Universe | Mental model | Possible result |
|---|---|---|
| ***Knowledge*** | My ***knowledge*** is certain, yours isn't. | High scatter in ***knowledge*** evaluation. |
| | I cannot trust knowledge from "that" group, | |
| | Need to pool what we know | Modest scatter in ***knowledge*** evaluation. |
| ***Values*** | I do not respect the ***values*** from "that" group. | High scatter in ***values*** evaluation. |
| | We share significant ***values*** in common, e.g., the need to avoid stalemate so that corrective action becomes possible. | Search for common ***values***, decrease in ***values*** scatter. |
| | If you win, I lose. | Polarized decision environment, high scatter in ***values*** evaluation likely stalemate |
| | A win-win is possible. | Search for win-win alternatives, actively engage in trying to adjust or refine alternatives to make them acceptable to broader range of participants, shared ***values*** result and ***values*** scatter decreases. |
| | I don't trust them. | Withhold information; do not admit that "their" alternatives might be fixable. |
| | I might be able to trust them. | Cautiously share information, consider that "their" alternatives might have some merit. |
| ***Resource*** | Allocated ***resources*** are "cast in concrete" | Excessively pessimistic ***resources*** evaluation, high scatter in the ***resource*** evaluations. |
| | Endless pockets – more ***resources*** are always possible if I apply enough pressure. | Excessively optimistic ***resources*** evaluation, high scatter in the ***resource*** evaluations. |
| | Use of ***resources*** is limited, but the limits are not always clear. Find the most effective way to use resources among alternatives. | Balanced ***resources*** evaluations, modest ***resources*** evaluation scatter. |

## VII. ANALYZE REMAINING ALTERNATIVES

Detailed analyses, such as detailed engineering, cost estimates, and risk assessment, are expensive and time consuming. Only the most promising alternatives should be carried to this step. Most decisions do not fail because detailed analyses were inadequate. They may fail if the wrong alternatives were analyzed or some analyses were not done, e.g., not looking at longer-term costs, risk, and adaptability penalties from the initial decision.

Thus, part of our project is to extend the usefulness of two existing INEEL tools, the Environment, Safety, and Health Risk Analysis Program (ESHRAP)[10] for risk estimates and the Deactivation and Decommissioning (D&D) Life Cycle Map Model[11] for cost estimates**.**

The ESHRAP code allows two types of quantitative risk analyses – risk from performing environmental management activities and risks from wastes/materials. Risks to both workers and the public are calculated. Any type of contaminated facility or site can be considered. "Activities considered include storage, retrieval, characterization, packaging, various treatment processes (both in-situ and ex-situ), loading/unloading, transportation (onsite and offsite), disposal, decommissioning, and long-term stewardship activities."[10] The risk estimates include radiological and chemical exposure and standard industrial accidents. Risk to the public includes groundwater contamination, atmospheric dispersion, and various types of intrusion scenarios. This project is adding risk during decommissioning activities.

The goal of the D&D Life Cycle Map Model[11] is to provide an economical means to develop rough order of magnitude cost and waste volume projections. It is limited to decommissioning of contaminated facilities, whether the contamination is radiological or chemical, e.g., asbestos. Surveillance and maintenance costs escalate while waiting for dismantlement. The existing model only addresses one of the re-usable alternatives, full dismantlement. We have started to explore the cost of closed and adaptable alternatives relative to full dismantlement. Closure with hazards remaining in place (e.g. entombment) can cost from 7% to 50% of dismantlement based on our analysis of information in the following references.

- Piqua Nuclear Power Facility (50%)[12]
- Hanford Production Reactors (37%)[13]
- INEEL Waste Calcine Facility (7.7%)[14]
- INEEL Fuel Process Building (7.5%)[15]

We believe that there are two major factors controlling the ratio of dismantlement to entombment costs – complexity/type and condition. The more complex the facility, the more difficult to dismantle because of difficulty of sending workers inside to further decontaminate the facility. This raises the cost of dismantlement relative to filling with closure in place. The worse the condition of the facility, similarly the more difficult to dismantle; workers may even have to partially upgrade the facility, restore electrical services, etc. to safely clean it. Thus, letting the facility degrade while waiting to do something to it increases the financial motivation to select a closed alternative.

Putting the facility into long-term storage ("safe store") while maintaining adaptability costs only a few percent of full dismantlement costs.

- Hanford Production Reactors (3.1%)[13]
- INEEL Fuel Process Building (2.4%)[15]

Of course, there is some future cost to dismantle or close it. Our analysis of the data for the Hanford Production Reactors[13] suggests that the future deferred dismantlement cost in constant dollars would be about 94% of upfront dismantlement. There is some cost reduction because of putting it into safe store first.

We have also examined annual surveillance and maintenance (S&M) costs before and after decommissioning (Table IV). In the case of dismantlement, post-decommissioning S&M costs are zero. For closed and adaptable alternatives, however, post-decommissioning S&M costs must be factored into the decision.

**Table IV. Illustrative Estimates of Annual S&M Costs Relative to Full Dismantlement**

| | Before decommissioning | After decommissioning |
|---|---|---|
| Hanford Production Reactors[13] | 0.70%/yr | Adaptable: 0.14%/yr<br>Entombment: 0.41%/yr |
| INEEL Fuel Processing Building[15] | 2.1%/yr | Adaptable: 0.3%/yr |

We observe decision-makers struggling with the timeliness in making a decision or between stages of an adaptable alternative. Which problem is more urgent than the next? Attacking the highest risk first is one factor, but sometimes an initially lower risk, left unattended, can escalate unacceptably or lead to net higher costs.

Traditionally, risk is expressed as consequence times frequency. Consider for present purposes, risk (R) as hazard (H) divided by containment barrier effectiveness (B), $R = H/B$. Many hazards degrade with time, thereby decreasing risk without any other action being taken. Containment barriers also degrade with time, increasing risk of barrier failure, the risk of worker accidents during deferred decommissioning, the cost of surveillance and maintenance, and the cost of deferred decommissioning. In general, if the hazard is degrading slowly and the barrier is degrading quickly (or already seriously degraded), the risk is increasing and action is urgent. In contrast, if the hazards are decaying quickly (e.g.. short-lived radioactive isotopes) and the barrier is degrading slowly, risk is decreasing naturally and action is sometimes less urgent. In future work we will further explore such tradeoffs.

We note that sometimes people affected by a decision cannot agree on the **absolute** risk posed by an existing hazardous site. In such cases it may still be possible to agree on what conditions and actions lead to **relative** risk reduction.

We stress that risk and cost are only two of the factors necessary to make a sustainable decision, many other ones – for example ***values*** – are difficult or impossible to meaningfully quantify. We recognize that there is a tendency to focus decisions primarily on those factors that are quantifiable. In our daily lives, however, we include non-quantifiable factors in decisions. For example, do any of us only consider cost and risk in selecting our next automobile? Our framework is intended to preserve balance between quantifiable and qualitative factors.

## VIII. PLAN TO MAINTAIN *K*ON*V*E*R*GENCE

Management of *k*on*v*e*r*gence is required over the lifetime of any remaining hazard. Understanding how ***knowledge***, ***values***, and ***resources*** are changing with time is required to keep *k*on*v*e*r*gence – the situation should be managed so that either changes to decisions can be avoided or done in a controlled manner. There are only two strategies that are sustainable if the residual hazard will persist for long (decades and beyond) time periods. First, one can monitor the entire *k*on*v*e*r*gence and change the implemented solution as necessary to keep the solution in *k*on*v*e*r*gence. Second, one can attempt to actively manage parts of the three universes to increase the chance that the implemented solution remains in *k*on*v*e*r*gence.

A limited version of the first strategy is required in many environmental laws. For example, decisions under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) have 5-year reviews. However, the tendency is only to monitor changes in the ***knowledge*** universe, e.g., monitoring groundwater to detect containment barrier failure (after the failure has occurred!). We suggest creating a complete Early Warning System – monitoring changes in ***knowledge***, ***values***, and ***resources*** so that trends that might require a change to a decision are caught early enough that it is practical to make such a change.

The second strategy of managing the three universes also has limits. One cannot predetermine changes in ***knowledge***, but it is possible and appropriate in some circumstances to have an R&D program to attempt to increase ***knowledge***, which can reduce uncertainties. Managing ***values*** other than your own is problematical. However, one can attempt to earn increased trust by how the decision is implemented and maintained. Local communities cannot always force state and federal officials to supply ***resources***, but trust funds can be established to reduce uncertainties and fluctuations in some of the ***resource*** universe – as is required by the Nuclear Regulatory Commission for decommissioning funds for commercial power plans.

## IX. CONCLUSIONS

Decisions are sometimes made without considering the need to *keep* decisions acceptable over extended periods of time. Keeping decisions acceptable requires maintaining *k*on*v*ergence of ***knowledge***, ***values***, and ***resources*** – the ***K*ON*V*E*R*GENCE Model for Sustainable Decisions**.

Since we do not know how to make perfect decisions, we focus on how to make better ones. "Better" decisions means those that are coherent with available ***knowledge*** at the time, consistent with ***values*** of those potentially affected by the decision, and made in accordance with available ***resources***. We believe that such decisions will better stand the test of time – because it will be either (a) acceptable to keep them unchanged or (b) possible to adapt them as ***knowledge***, ***values***, and ***resources*** change.

Our framework may also provide an easier way to make decisions for problems that have proven to be difficult.[2] The resistance comes from one or more stakeholders (including regulators) because they either do not trust the person making the decision or view the consequences of being wrong as too high. In such cases, we must either reduce the consequences of being wrong (e.g. by implementing adaptable alternatives that can be changed later if need be) and/or by splitting a single decision into a network of decisions (e.g. earning trust).

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