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Value-Based Performance Measures for Hanford Tank Waste Remediation System (TWRS) Program

R. L. Keeney D. von Winterfeldt

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Prepared for the U.S. Department of Energy
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1. Introduction

The Tank Waste Remediation Systems (TWRS) Program is responsible for the safe storage, retrieval, treatment, and preparation for disposal of high-level waste currently stored in underground storage tanks at the Hanford site in Richland. The TWRS program has adopted a logical approach to decision making that is based on systems engineering and decision analysis (Westinghouse Hanford Company, 1995). This approach involves the explicit consideration of stakeholder values and an evaluation of the TWRS alternatives in terms of these values. Such evaluations need to be consistent across decisions. Thus, an effort was undertaken to develop a consistent, quantitiable set of measures that can be used by TWRS to assess alternatives against the stakeholder values. The measures developed also met two additional requirements: 1) the number of measure should be relatively small; and 2) performance with respect to the measures should be relatively easy to estimate.

Hanford stakeholders have a wide range of values and concerns, including short term health and safety of the public and workers, compliance issues, long term environmental impacts, and land use considerations. Some of these are related to the ultimate achievement of the Hanford clean-up (ends objectives), some to the means by which this cleanup can be achieved (means objectives), and some to the process by which decisions about the cleanup are made (process objectives). For instance, an important stakeholder ends objective is to protect public and worker health and safety. This can be achieved by many means, including, for example, an early stabilization of the tank

wastes which would reduce the time that some tanks may pose a risk to workers and the public. Decisions about early stabilization can be using decision processes that differ in terms of process objectives such as the public involvement, openness, and fairness.

These stakeholder values and concerns are usually expressed qualitatively as desired end states or preferred directions of the Hanford cleanup. It is not easy to relate these qualitative stakeholder values to the technical decisions facing managers and engineers of the TWRS Program. In general, engineering issues are related more closely to the means objectives than to process or ends objectives.

To facilitate technical evaluations of TWRS alternatives, it is therefore desirable to identify a comprehensive set of means objectives that logically relate to the process and ends objectives of the stakeholders. Since this set of means objectives are to be used in assessments of the performance of the TWRS alternatives, they are called *performance objectives*. To be manageable in the many evaluation tasks facing the TWRS Program, it is further desirable that the set of performance objectives is small and that they can be expressed in terms of measures that readily relate to the ongoing modeling and systems engineering activities. These measures will be referred to as *performance measures*.

Section 2 of this report summarizes the existing Hanford stakeholder values, logically relates them as means, ends and process objectives, and identifies a subset of the means objectives as performance objectives. Section 3 develops measures for the

performance and ends objectives. Section 4 logically relates performance measures to ends measures. Section 5 discusses the uses of the performance measures in TWRS decision making.

2. Existing Hanford Stakeholder Values

Armacost et al. (1994) conducted a review of nine documents that expressed the values and concerns of Hanford stakeholders. They also identified which of these values were expressed as process, means, and ends objectives. Two documents were considered especially important when identifying the stakeholder values: *The Future for Hanford: Uses and Clean Up* (The Hanford Future Site Uses Working Group, 1992) and *The Hanford Tank Waste Task Force Final Report* (Hanford Tank Waste Task Force, 1993). The reason for attaching special importance to these two documents was that they specifically addressed value issues, they involved representatives of many views, and they included public debate. The values reported in Armacost et al. and used here were taken verbatim from these and other reports. Table 1 shows the results of this review.

A network relating all the stakeholder objectives identified in Armacost et al. is shown in Figure 1. The arrows in the figure indicate what objectives influence what others. In general, better achievement of the process objectives contributes to better achievement of the means objectives, and better achievement of the means objectives contributes to better achievement of the ends objectives.

Table 1: TWRS ENDS, MEANS, AND PROCESS OBJECTIVES (from Armacost et al., 1994)

Ends Objectives

- Protect public/worker health and safety
- Protect the Columbia River
- Protect the environment
- Clean up to the level necessary to enable future use options to occur
- Capture economic development opportunities locally
- Protect rights of Native American Indians
- Ensure compliance
- Enhance technology development
- Reduce cost

Means Objectives

- Deal realistically and forcefully with groundwater contamination
- Clean up areas of high future use value
- 'Get on with the cleanup' to achieve substantive progress in a timely manner
- Transport waste safely and be prepared
- Do no harm during cleanup or with new development
- Improve waste management
- Use mature technologies

Process Objectives

- Involve the public in future decisions about Hanford
- Use a systems design approach that keeps endpoints in mind as intermediate decisions are made
- Establish management practices that ensure accountability, efficiency, and allocation of funds to high-priority items
- Enhance public acceptance
- Use open and fair processes
- Increase efficiency

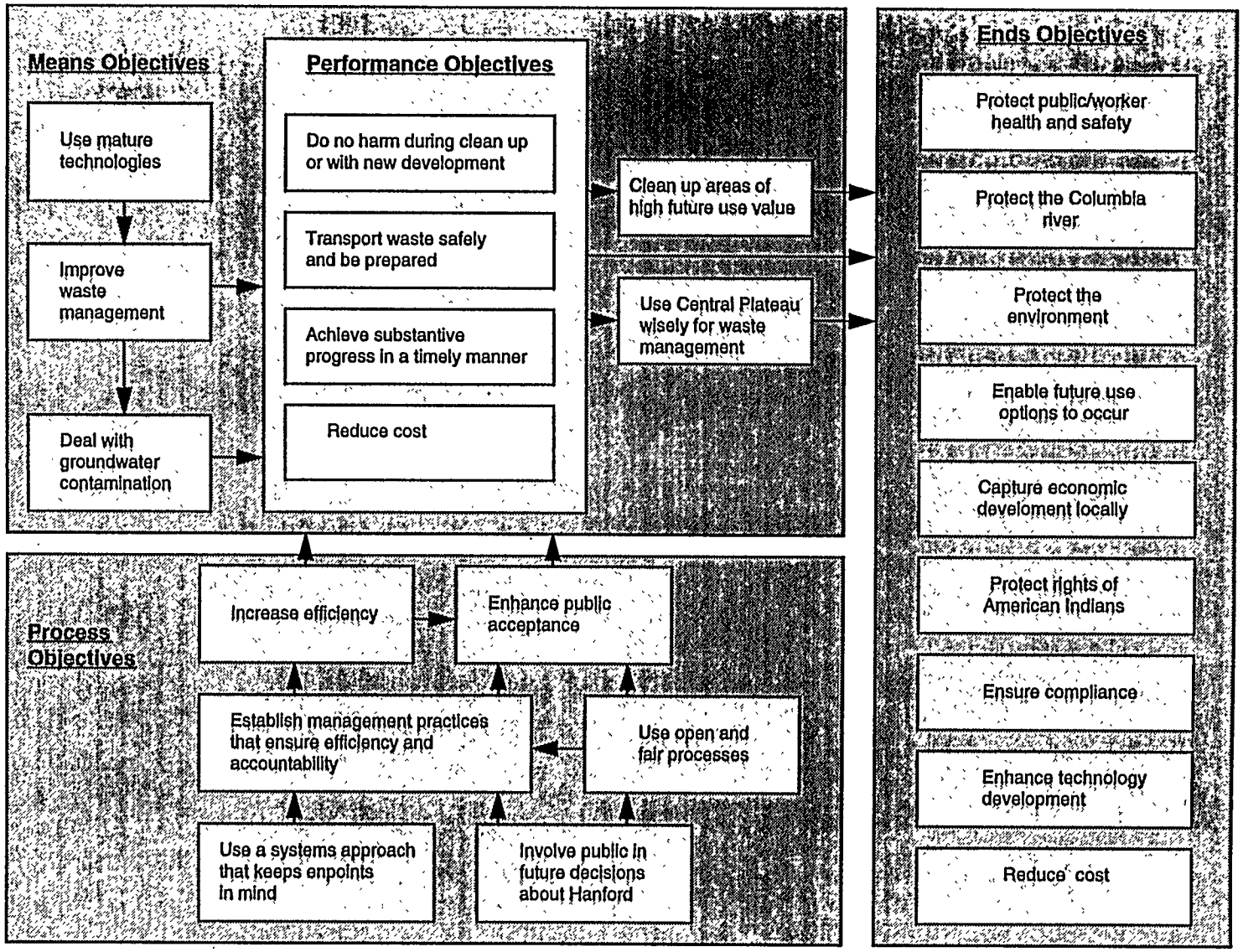

Figure 1: Process-Means-Ends Objectives for Hanford Decisions

The process objectives relate two main thoughts: that public involvement leads to more open and fair processes which in turn increase public acceptance; and that the use of a systems approach increases accountability and efficiency of management. The process objectives primarily apply to process alternatives (e. g., how decisions are made), not to the technical alternatives themselves.

Means objectives, on the other hand, relate quite closely to the evaluation of technological alternatives. For example, some technologies are more mature than others, which affects the likelihood of success in clean up, which in turn influences the degree to which waste management can be improved. Several of the means objectives relate very closely to technical measures of systems performance. They are highlighted in Figure 1 as performance objectives. This set of performance objectives covers the majority of implications on ends objectives resulting from TWRS decisions. The selected performance objectives are

1. Do no harm during clean up or with new development.
2. Transport waste safely and be prepared.
3. Achieve substantive progress in a timely manner.
4. Reduce cost.

The first performance objective "Do no harm during clean up or with new development" is related to short and long term environment, health and safety objectives. The second performance objective "Transport waste safely and be prepared" is related to accidents that may occur during the transportation of wastes and that may involve worker and public fatalities or injuries. The third performance objective "Achieve

substantive progress in a timely manner" is related primarily to two ends objectives: "Ensure compliance" and "Protect public/worker health and safety." Timely progress leads to compliance with schedules and milestones. Similarly, the earlier tank waste problems are solved, the earlier the short and medium term accident risks are reduced. "Reduce cost" is both a performance objective and an ends objective, since cost is important in and by itself and because it influences local economic development.

Ultimately, the stakeholders care about the ends objectives. When asked why an ends objective is important, the answer is typically that its achievement is important in and by itself. For example, protecting public and worker health and safety, protecting the Columbia River, and protecting the environment are ends objectives whose importance is self evident. Similarly, enabling future site use options to occur provides important flexibilities in the long term planning and management of the site. The idea behind the ends objective "Capture economic development locally" is to enhance economic opportunities at the local level. Protecting the rights of Native Americans is also an important ends in itself. Ensuring compliance might at first be considered a means to health, safety, and environment objectives. However, meeting laws and regulations and avoiding the negative consequences of violations of laws and regulations is increasingly becoming an important intrinsic concern at many sites. Enhancing technology development is technically a means to creating societal (ends) benefits with improved technologies. However, it is impossible to list all societal benefits of improved

technologies. For the purposes of decisions about Hanford, therefore, technology enhancement is considered an ends. Finally, the importance of the ends value "Reduce costs" is self evident.

3. Ends Measures and Performance Measures

Alternatives in TWRS decisions such as possible retrieval techniques or pre-treatment strategies need to be evaluated to determine how well they achieve the stakeholder objectives. For this purpose, it is useful to develop measures that specify, how each objective should be measured. In the following, measures will be specified for both the set of ends objectives and for the set of performance objectives. Subsequently, the logical relationships between these two sets of measures will be discussed.

The ends measures are shown in Table 2. They are well defined except for those related to ensuring compliance and enhancing technology development. For the compliance measure, weights have to be developed that indicate the relative importance of being consistent with different laws, regulations, agreements, and DOE orders. A measure for enhancing technology development needs to be constructed, for example, by developing a scale indicating different degrees of technology advancements.

The performance measures are shown in Table 3. The performance objective "Do no harm during clean up or with new development" has four measures indicating the possible health and safety risks due to tank clean up. Since there are only negligible

Table 2: ENDS OBJECTIVES AND MEASURES FOR TWRS DECISIONS

ENDS OBJECTIVES	ENDS MEASURES
Protect public/worker health and safety	Years of worker-life lost Years of worker sickness or injury serious enough to miss work Years of public-life lost Years of public sickness or injury serious enough to miss work
Protect the Columbia river	Number of incidents at which a discharge into the Columbia River exceeds clean water standards
Protect the environment	Acres of Hanford restricted because of groundwater contamination
Enable future use options	Acres of Hanford permanently allocated for waste disposal
Capture economic development locally	Number of workers forced to leave area Number of new (non Hanford cleanup) jobs created
Protect rights of the Native Americans	Acres of Hanford not available for Native American use Number of disturbed and/or inaccessible religious or archaeological sites
Ensure compliance	Weighted percent of compliance with laws, regulations, agreements and DOE orders
Enhance technology development	Technology innovation scale
Reduce cost	Total lifecycle cost of clean up (discounted dollars)

Table 3: PERFORMANCE OBJECTIVES AND MEASURES FOR TWRS DECISIONS

PERFORMANCE OBJECTIVES	PERFORMANCE MEASURES
Do no harm during cleanup or with new development	Worker exposure, normal operations (worker-rems) Worker exposure, accidents (worker-rems) Public exposure, accidents (public-rems) LLW left on site (volume in metric tons, waste form, curies)
Transport waste safely and be prepared	Amount of waste shipped offsite (metric tons)
Achieve substantive progress in a timely manner	Time to interim stabilization of tanks (yrs.)[1] Time to closure of tanks (yrs.)[1]
Reduce cost	Total lifecycle cost (constant year dollars) Largest annual cost (constant year dollars)

[1]Other dates may be more relevant for specific decision problems.

risks to the public from normal operations, the performance measure for normal operations risk is the worker exposure. This measure is focused on radiological exposures, measured in person-rems. If there are significant risks from non-radiological exposures, they should be added. Tank accidents can have both public and worker health effects. Since the major concern is with radiological exposure, the measures are expressed as worker and public person-rems. The fourth measure, low level waste (LLW) left on site, should capture the potential long term effects on human health and the environment. To indicate this, one needs to measure the volume of the low level waste left on site, the number of curies present in this volume, and the waste form (e. g., glass vs. grout).

The objective "Transport waste safely and be prepared" is measured by the amount of high-level waste shipped off site which is closely related to the risks of transportation to the public and to transportation workers. This measure could also be an indicator of the long term health and environmental impacts of high level waste disposal. However, while the technical alternatives clearly differ in the amount of the high level waste produced, they will be virtually indistinguishable in terms of the radionuclide content and therefore there will be little or no distinction in terms of long term health and environmental effects. Thus, the major discriminator remains the accident risk which is directly related to the high level waste volume and the number of shipments required for transportation.

The objective "Achieve substantive progress in a timely manner" has two measures: "Time to interim stabilization of tanks" and "Time to closure of tanks." These two

measures capture two major milestones in the TWRS Program. Measures related to other milestones can be added in specific decision contexts.

To measure cost, a cost profile of constant year dollars over the lifetime of the project needs to be developed. This information can then be collapsed to a single measure of total life cycle cost. In some cases, other aspects of the cost profile may need to be considered. For example, the largest annual cost may be an indicator of the difficulty of obtaining funding for this profile.

4. Relationships Between Performance and Ends Measures

As stated in the previous section, TWRS alternatives can be evaluated using either the performance measures or the end measures. In general, the use of performance measures is easier and more straightforward. For example, measuring or predicting volume, waste form and number of curies of LLW is much more straightforward than measuring or predicting the potential environmental and health effects that could occur in the distant future as a result of disposal of this LLW at Hanford. While performance measures are easier to use in technical evaluations, it is not always obvious how they relate to the stakeholders' values. For example, why should the stakeholders care about the waste form of the low level waste?

To clarify the meaning of the performance measures in terms of the stakeholders' values, it is useful to logically relate the performance measures to the ends measures. Figure 2 begins with TWRS alternatives and indicates the main implications of these

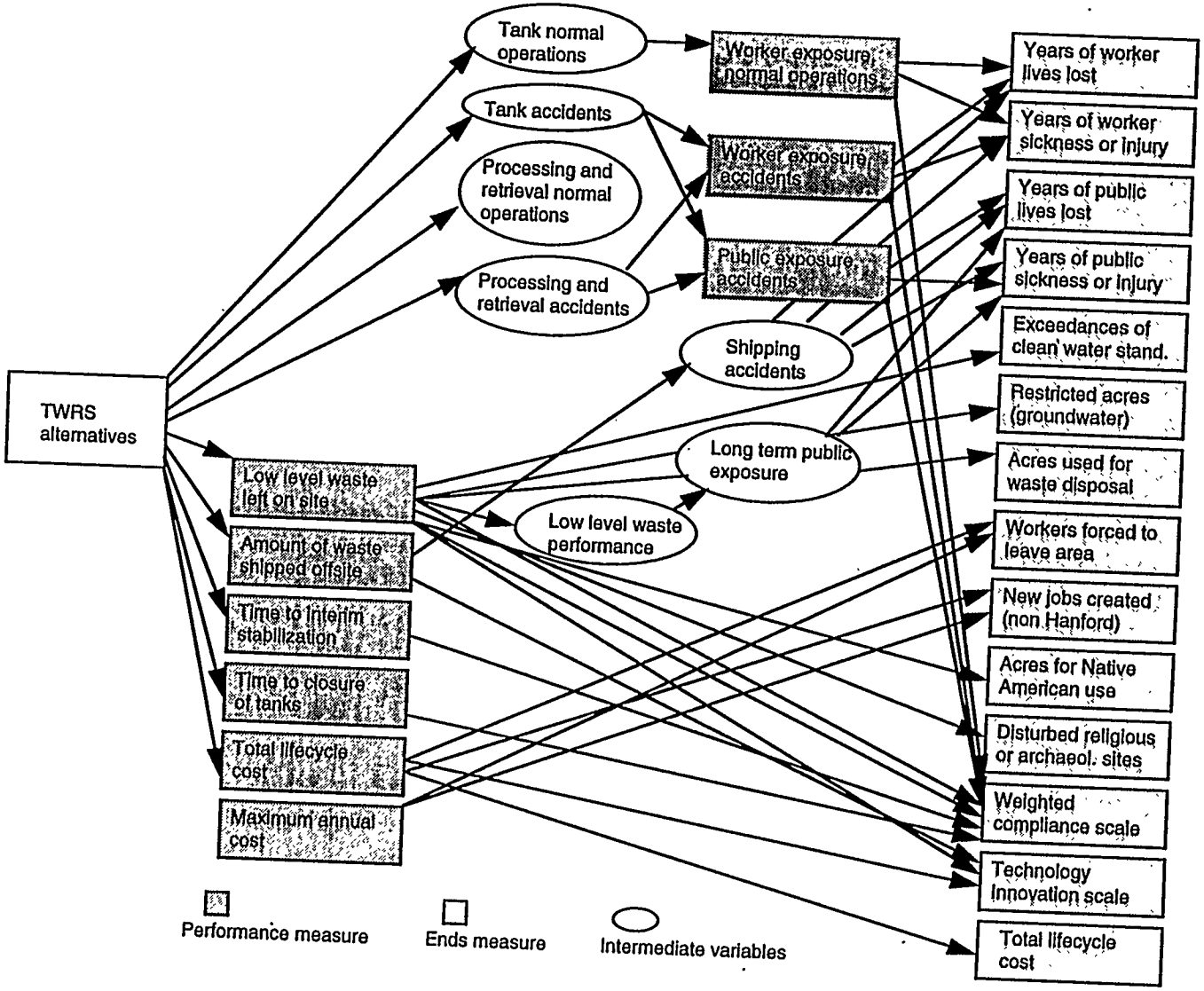

Figure 2: Relationships between Performance Measures and Ends Measures

alternatives on performance measures and ends measures. Any TWRS alternative generates a specific set of normal operations and some potential for accidents related to tanks, retrieval, processing and shipping of wastes. The performance measures characterizing worker and public radiological exposure are related through these normal operations and accidents.

A TWRS alternative also has implications for the amount of LLW left on site, which has implications for numerous ends measures. The primary relationship is between the amount of LLW left on site, the performance of the waste form, and long term public exposures leading to possible fatalities or illnesses. In addition, the amount of LLW left on site will have implications for groundwater restrictions, acres used for the disposal of LLW, acres available for Native American use of the site, disturbances of religious or archaeological sites, and compliance.

A TWRS alternative will determine the amount of waste shipped off site, the risks of shipping accidents, which in turn lead to public and worker fatalities and injuries.

A TWRS alternative will also define a schedule and the time it takes to achieve interim stabilization and closure of tanks. Earlier interim stabilization reduces the tank accident risks and improves compliance with milestones. Earlier closure of tanks improves compliance with milestones.

The cost of the TWRS alternative has implications for the number of workers forced to leave the area, the number of new jobs created, as well as the cost ends measure itself.

Figures 3a to 3i show the relationships between each performance measure and the ends measures.

5. Uses of the Performance Measures

Robershotte et al. (1995) defined a seven step methodology for TWRS decision making

1. Define Frame of Decision.
2. State Issues.
3. Develop a Set of Alternatives.
4. Formulate Decision Values.
5. Translate Decision Values into a Set of Measures.
6. Analyze and Evaluate Alternatives.
7. Make a Decision.

This report provides the information to complete steps 4 and 5 of this process. The main recommendation of this report is to use the performance objectives as a set of decision values (step 4) and to use the performance measures as the set of measures (step 5). The analysis and evaluation (step 6) should be done formally by measuring or predicting the achievement of each alternative on the performance measures. If this measurement or prediction involves uncertainties, these uncertainties should be characterized by probability distributions over the performance measures.

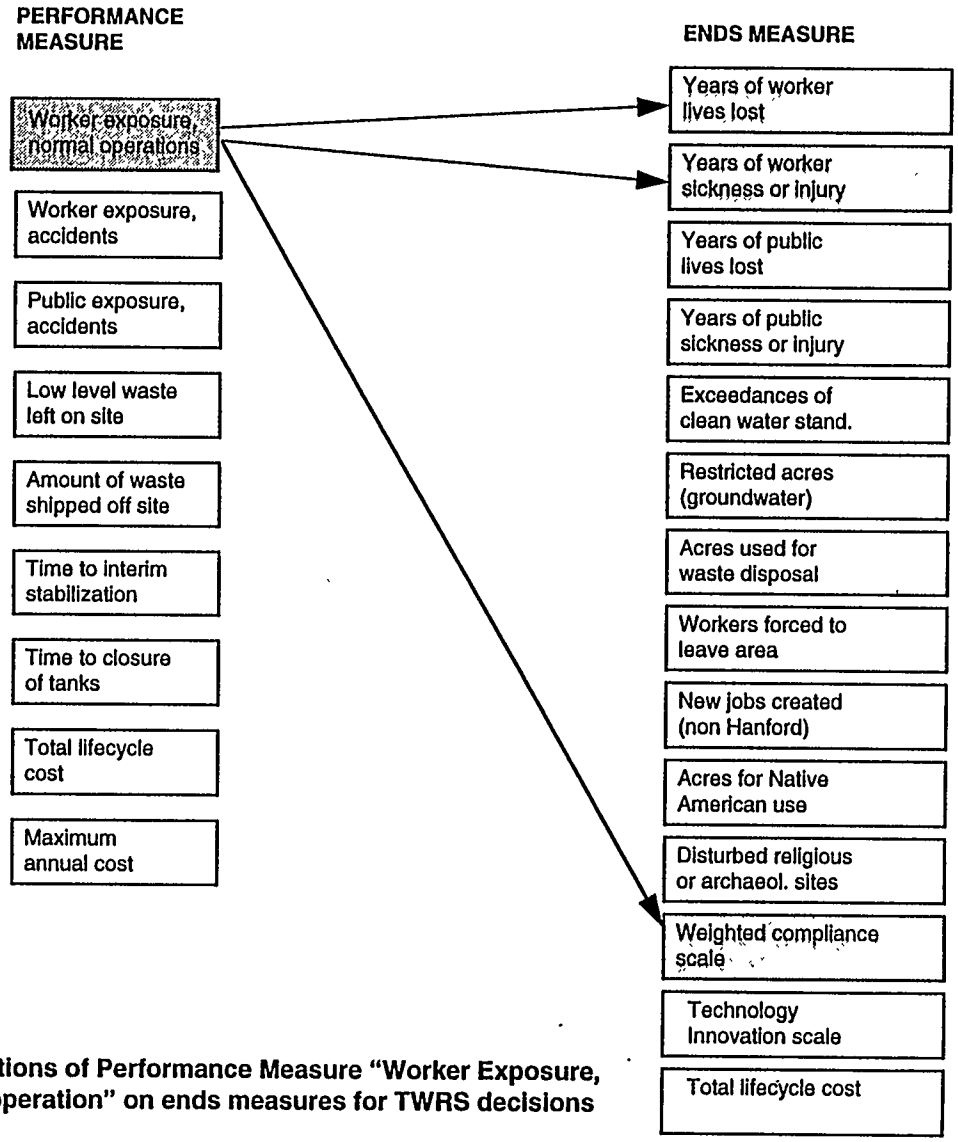

Figure 3a Implications of Performance Measure "Worker Exposure, normal operation" on ends measures for TWRS decisions

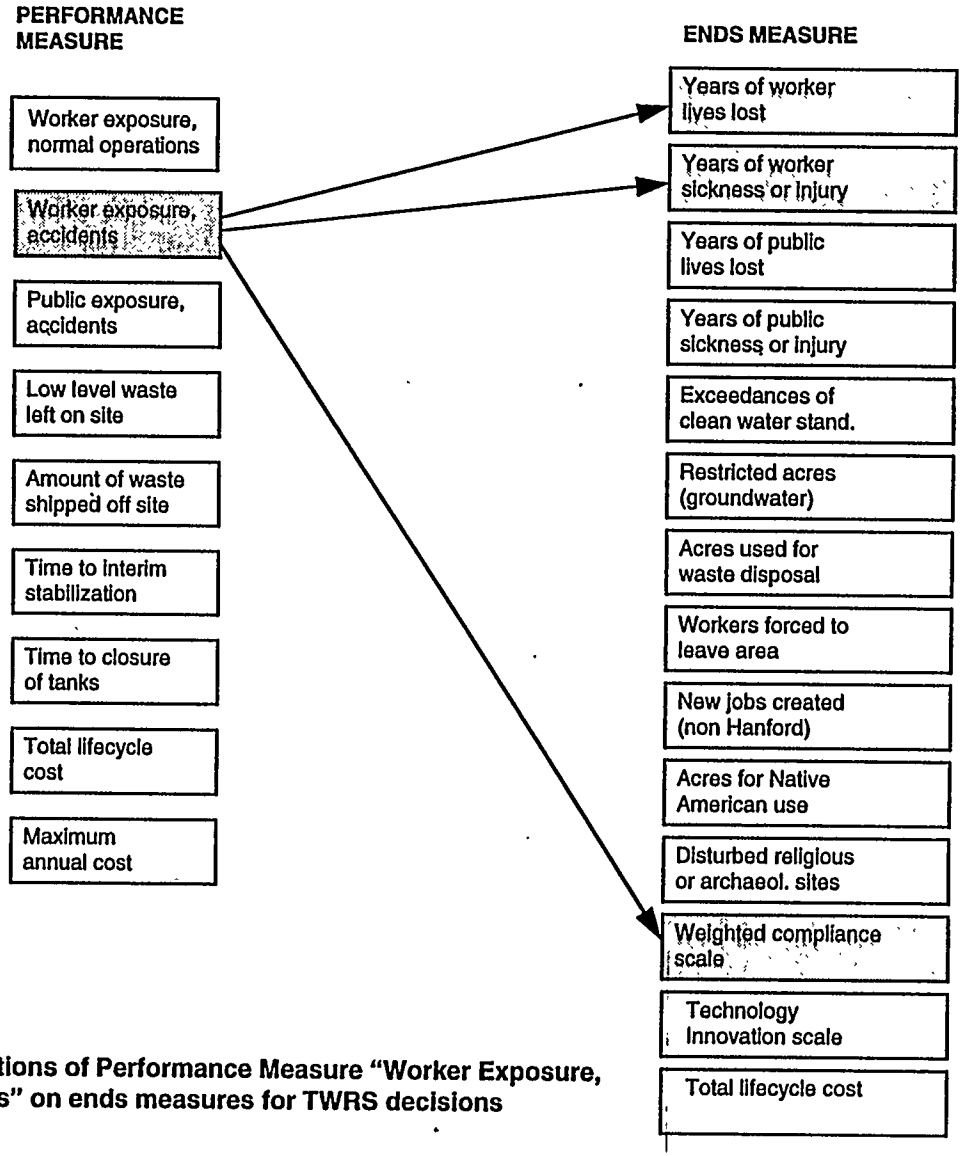

Figure 3b Implications of Performance Measure "Worker Exposure, accidents" on ends measures for TWRS decisions

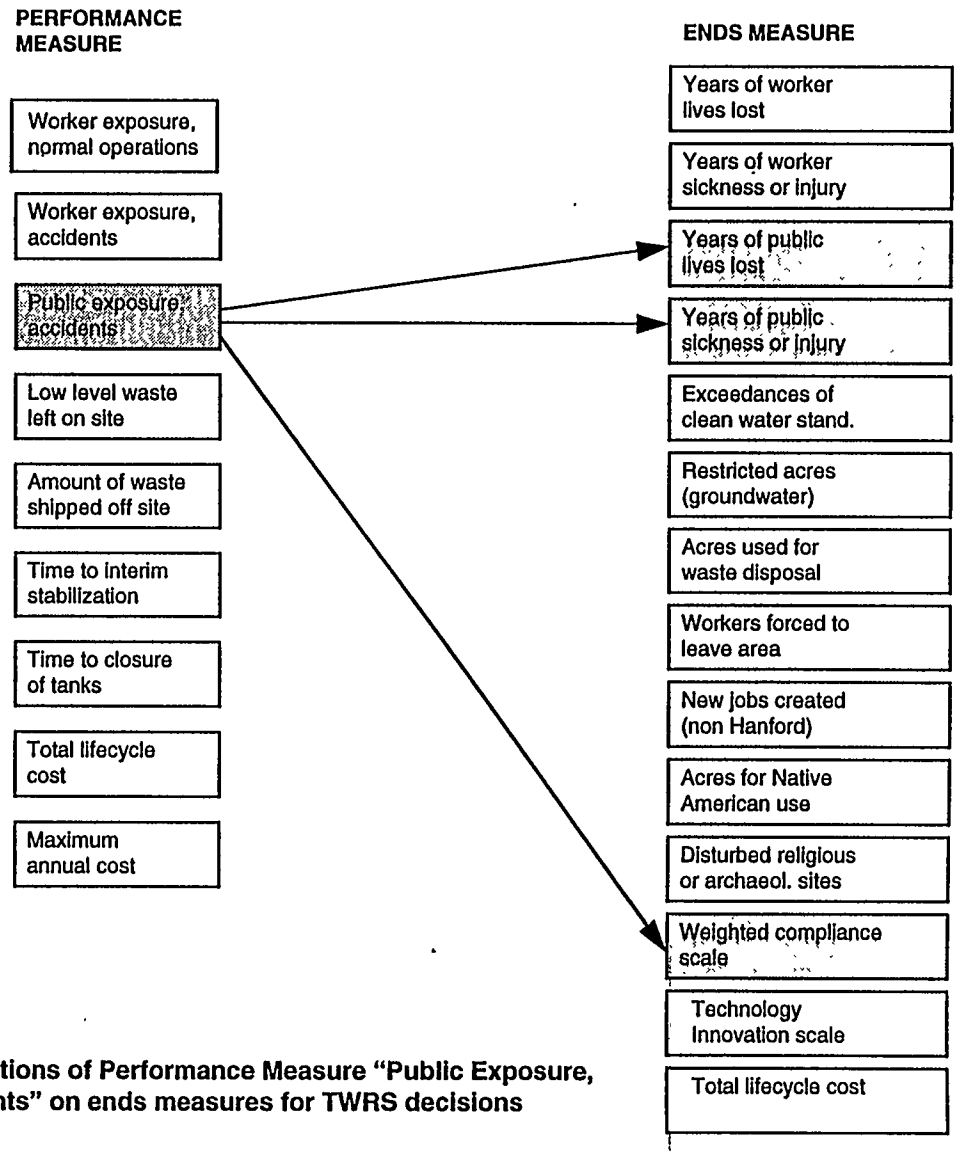

Figure 3c Implications of Performance Measure "Public Exposure, accidents" on ends measures for TWRS decisions

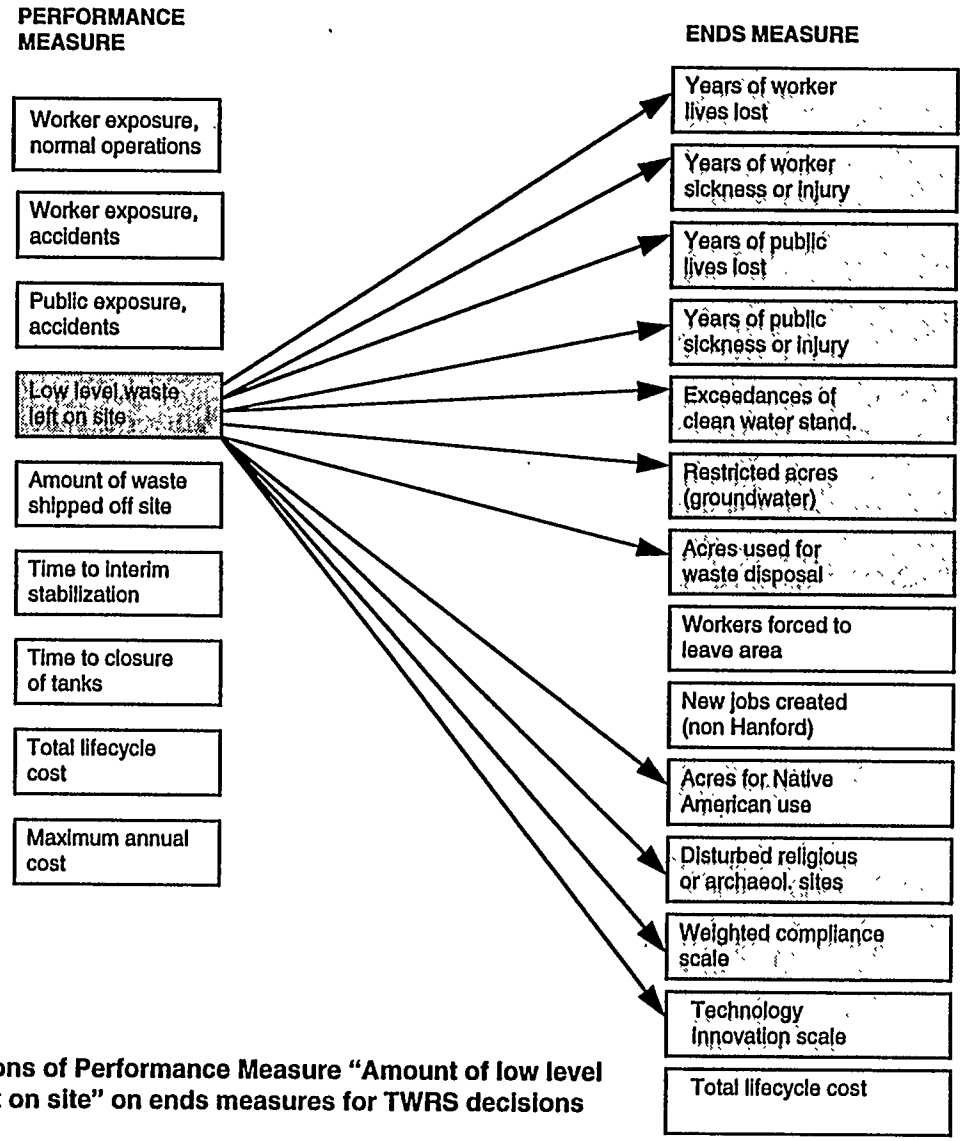

Figure 3d Implications of Performance Measure "Amount of low level waste left on site" on ends measures for TWRS decisions

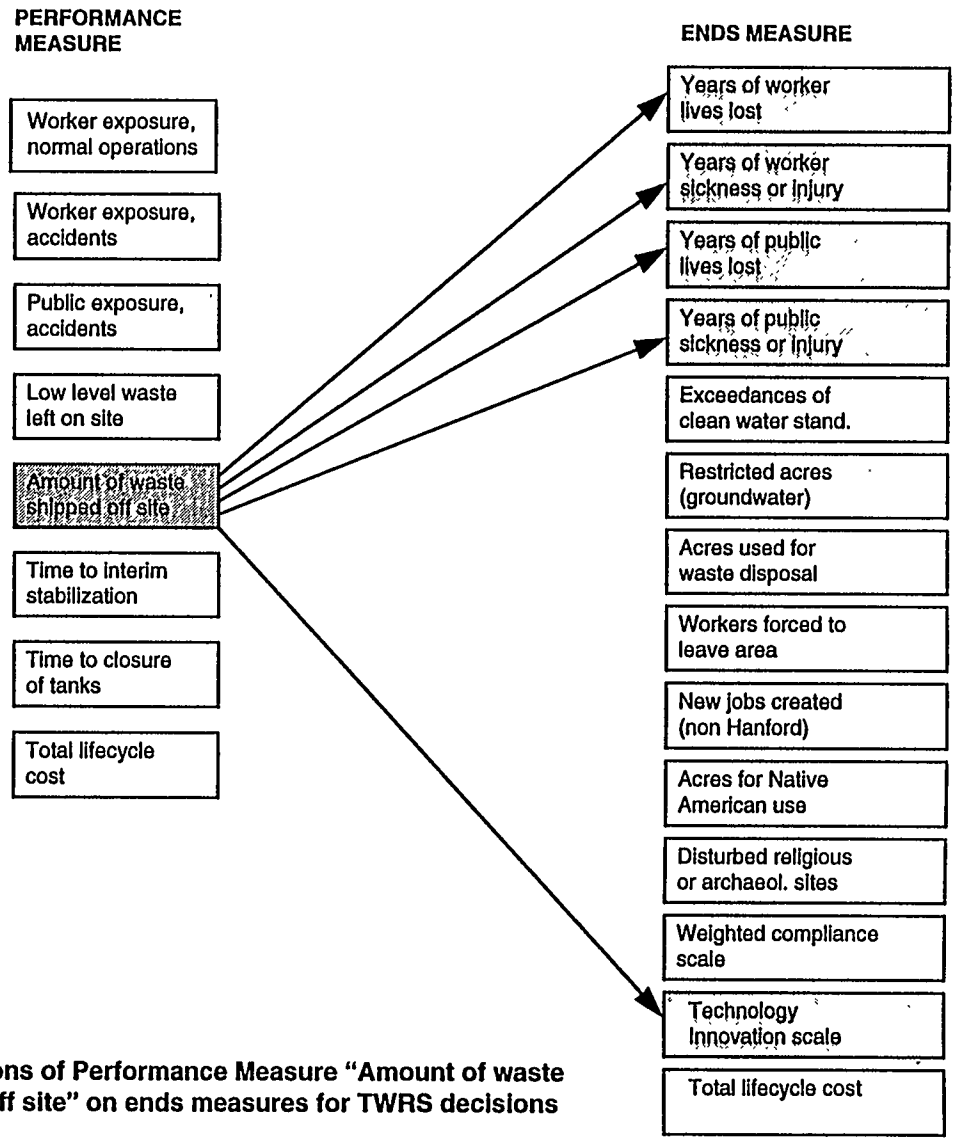

Figure 3e Implications of Performance Measure "Amount of waste shipped off site" on ends measures for TWRS decisions

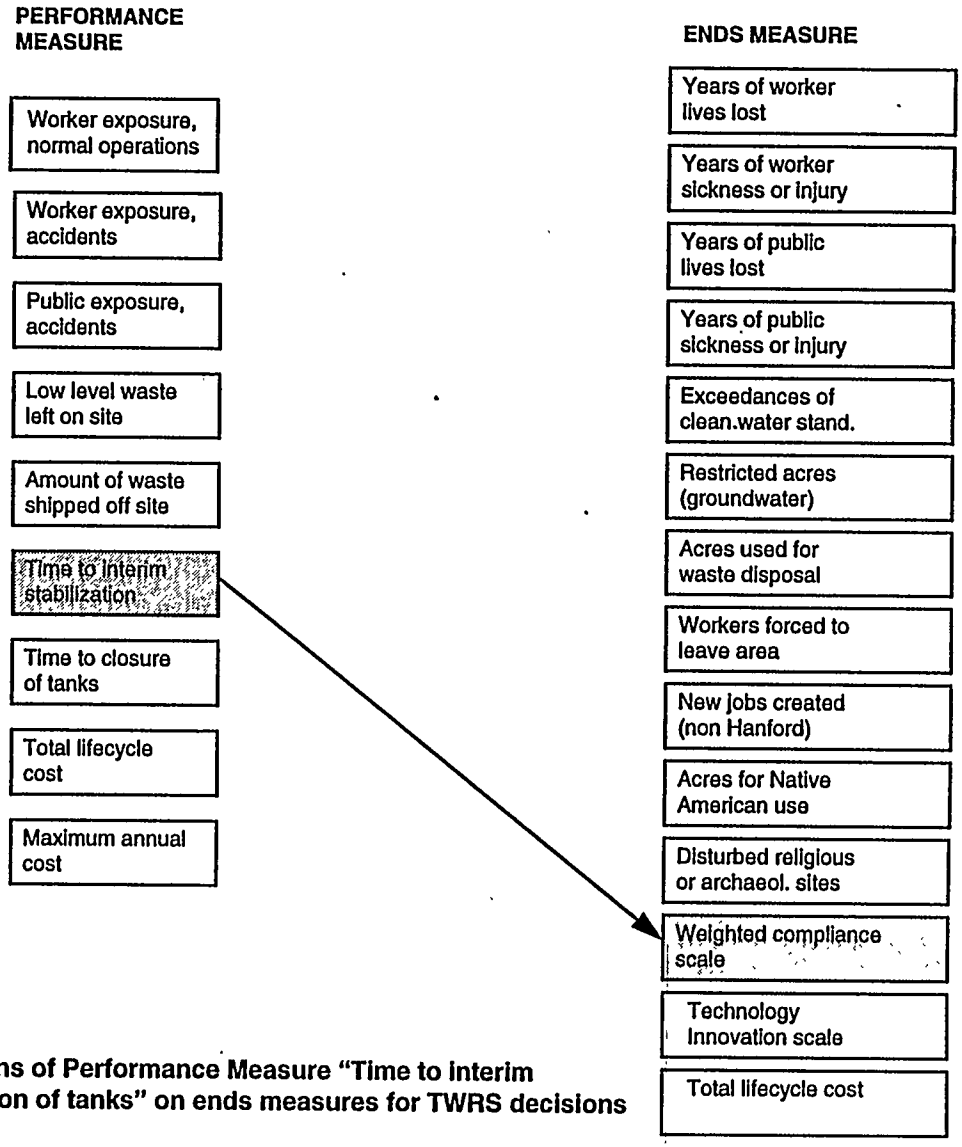

Figure 3f Implications of Performance Measure "Time to interim stabilization of tanks" on ends measures for TWRS decisions

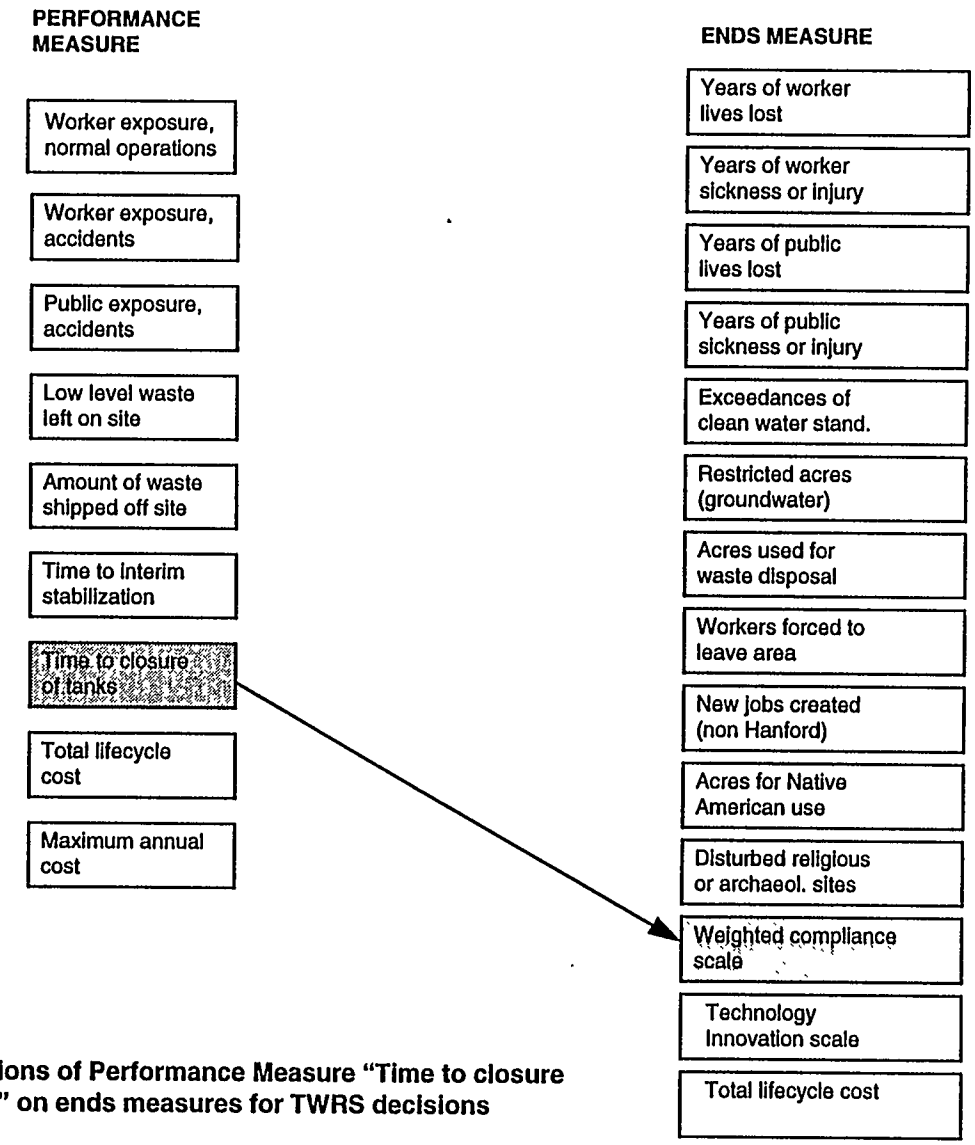

Figure 3g Implications of Performance Measure "Time to closure of tanks" on ends measures for TWRS decisions

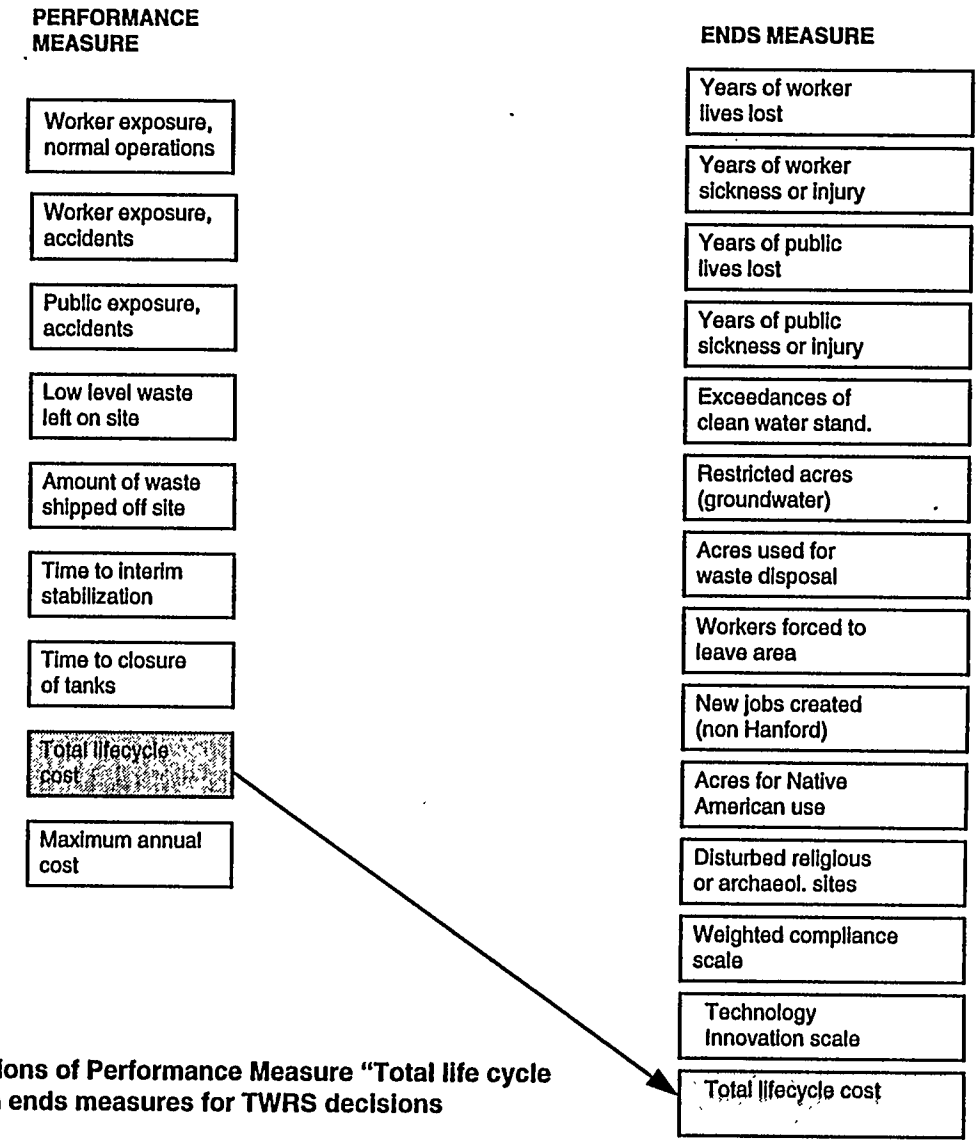

Figure 3h Implications of Performance Measure "Total life cycle cost" on ends measures for TWRS decisions

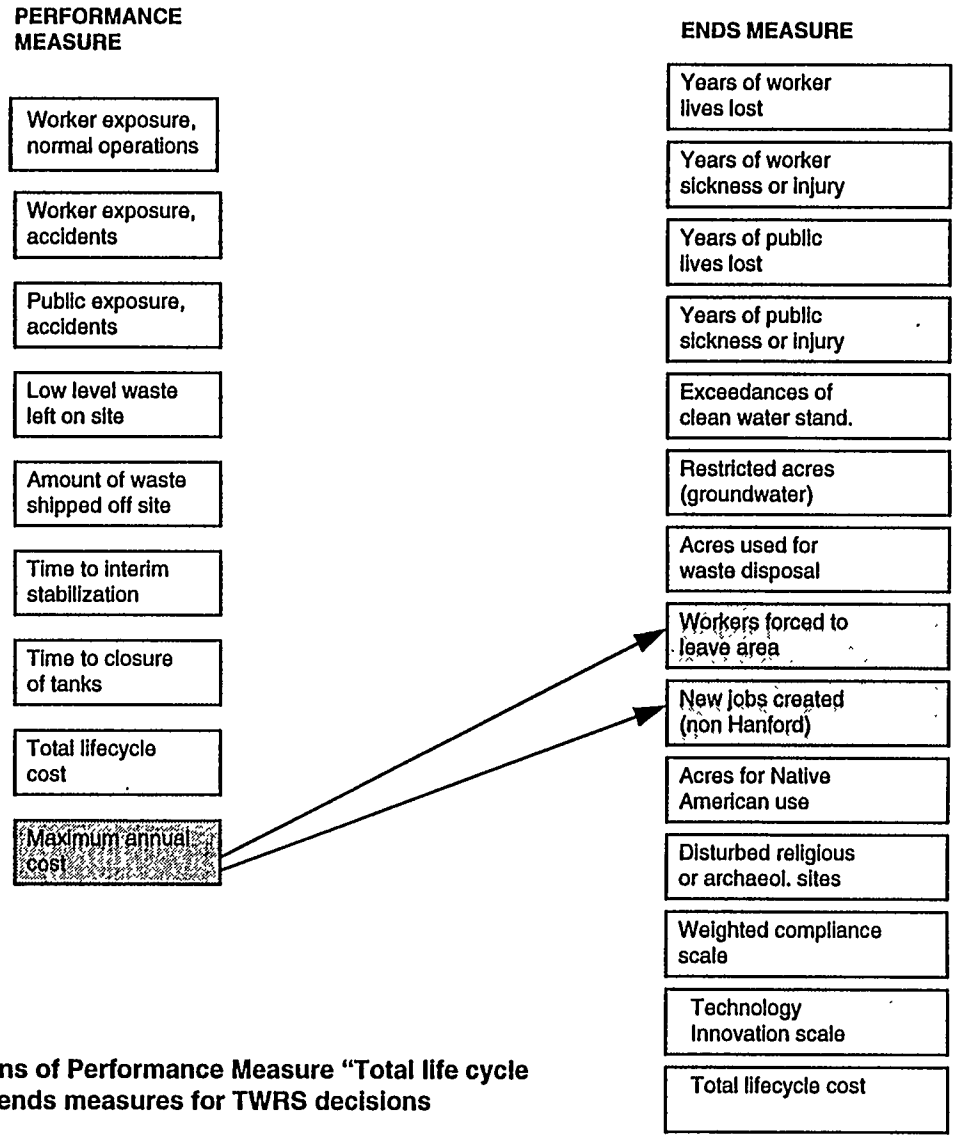

Figure 3i Implications of Performance Measure "Total life cycle cost" on ends measures for TWRS decisions

Additional values and measures can be used in a given decision context to analyze and evaluate alternatives. Whenever such additional values and measures are used, they should be explicitly related to either the existing performance measures or to the ends measures described above.

In practice, a team involved in a specific TWRS decision would go through steps 1-3 of the decision methodology described in Robershotte et al. (1995). Subsequently, the team members would examine which of the performance measures are likely to discriminate among the alternatives. For example, in almost all decisions, worker radiological dose and lifecycle cost will differ among the alternatives. Worker radiological exposure from accidents and public exposure from accidents, as well as the two schedule measures will also discriminators in many decisions. Differentiation among alternatives in terms of LLW left on site and HLW volume would occur only in major decisions.

Having identified the performance measures that are relevant for the decision problem at hand, the next task is to consider whether there are any other values or concerns that may be relevant, but that are not captured by the performance measures. To explore these additional values and concerns it will be useful to review the means-ends network in Figure 1. In addition, it may be useful to list the distinguishing characteristics of the alternatives.

Once any additional values are identified, measures need to be developed for them. In general, it is preferable to use natural measures, i.e. those that have a well defined numerical meaning. If this is impossible, measures may need to be constructed using

words and qualitative descriptions (for a discussion, see Armacost et al., 1994). These measures have to be logically related to the existing stakeholder values and/or the performance measures in order to assure that they are relevant for evaluating the alternatives.

Selection of the performance measures and definition of additional measures sets the stage for step 6 of the decision making methodology. In it, estimates are developed, either as points or as probability distributions, of how well the alternatives perform on the performance measures. In some cases, this information may be sufficient to clarify and support a decision. In other cases further aggregation of the information across the performance measures may be needed. For example, a decision maker may be interested in assessing the cost-effectiveness of the alternatives in terms of the overall risk reduction they achieve. In this case the performance measures related to risk (public and worker exposure, low level waste left on site, and amount of waste shipped off site) would need to be aggregated into a single risk measures. This aggregation requires that the decision makers assign weights to the measures. A subsequent report will address this issue of weighting and aggregation and illustrate the use of weights in TWRS decisions.

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