A Hybrid Approach to the Use of Safety Functions with Features, Events, and Processes (FEPs) in Performance Assessment-17524

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ABSTRACT

The use of Features, Events, and Processes (FEPs) is a well-established approach for improving the traceability and transparency of a performance assessment. The intent of the use of FEPs is to identify conditions that may occur in the future that may affect the ability of the disposal system to perform successfully.

While FEP analyses have been widely used, they have also been identified to have a number of drawbacks. In particular, as a bottom-up approach, they seek to identify all conditions of concern, without necessarily focusing on the key issues. As a result, they have in some cases led to large amounts of effort, but without a commensurate improvement in the traceability of the performance assessment.

These issues with FEP-based analyses have led to a more recent emphasis in the literature on the use of an alternative approach to identifying conditions that need to be included in the performance assessment. Increasingly, the literature on performance assessment emphasizes the use of safety functions as either a replacement for FEP analyses or as an augmentation of FEP analyses. A safety function is a feature of the system that provides a specific function that is relevant to the performance (or safety) of the facility. The set of these safety functions presents a high-level summary of the strategy by which the performance of the disposal system is assured. In addition to providing a technical approach to development of scenarios, the use of safety functions is beneficial in emphasizing the overall safety strategy with stakeholders.

In this paper, a hybrid approach is discussed that blends the beneficial elements of both safety function approaches and FEP approaches. In this hybrid approach, FEPs are used in a more targeted manner than in traditional FEPs methodologies. In the hybrid approach, FEPs are identified that may affect the ability of the safety function to provide assurance of performance in the future. That is, FEPs are identified that may degrade or modify the performance of the safety function in some way. For instance, performance of an engineered cover system may be influenced by a wide variety of FEPs that would change the rate of water movement through it. These FEPs might include (for example) mechanical changes to the cover soil, changes in the vegetation on top of the cover, climate changes that lead to different precipitation patterns on top of the cover, loss of institutional control leading to onsite irrigation, and so on. Since all of these FEPs influence the system in a similar manner (i.e., changes in water flow through the cover), sensitivity

analyses that vary this safety function represent an aggregated view of the potential negative effects of a suite of FEPs. In this way the performance assessment can be organized to evaluate a large number of FEPs with fewer sensitivity cases and scenarios.

The purpose of this paper is to describe the hybrid safety function-FEP analysis approach, and to describe how it has been used to provide a logical structure to the selection of key analyses needed to demonstrate regulatory compliance.

INTRODUCTION

The structure of uncertainty or importance analyses [1,2] in performance assessments[1] have long been considered to take the form shown in Fig. 1. Alternative scenarios are used to represent future uncertainties: potential future states or evolutions of the system. Conceptual model uncertainties are represented by alternative conceptual models, which explore the behavior of the system for different assumptions regarding the physical and chemical behavior of features of the system. Parameter uncertainties are represented by exploring ranges of input values. The effect of these uncertainties on performance assessment results may be propagated through the assessment using probabilistic methods, deterministic methods, or some combination of these approaches [2].

In specific regulations, scenarios are combined probabilistically to produce a single, aggregated calculation of a probability-weighted performance measure [see, e.g., 3]. More generally, The International Commission of Radiation protection (ICRP) has noted that while an aggregated risk-oriented approach, or a disaggregated dose approach, or a combination of both can be used to achieve a similar level of protection, a disaggregated approach is preferred for decision-making [4]. In Fig. 1, a disaggregated approach would mean that alternative scenarios and models are carried through the analysis independently, and are not aggregated using probabilities into a single performance measure. As a practical matter, both US and many international regulations for near-surface disposal specify a dose constraint for protection of members of the public, and for regulations of this kind a disaggregated approach is often used for comparison to such regulations. The significance of this is that in a disaggregated treatment of uncertainties, in which the scenarios and models are not weighted by probabilities, the suite of scenarios and models shown in Fig. 1 are not differentiated. Consequently, calculations intended to represent their consequences need not be differentiated, and an adequate treatment of future and model uncertainties can be thought of as a suite

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[1] The terms performance assessment and safety assessment are used interchangeably in this paper. Literature in the USA uses the term performance assessment whereas European and international literature uses safety assessment.

of calculation cases intended to represent the conditions of concern in the performance assessment.

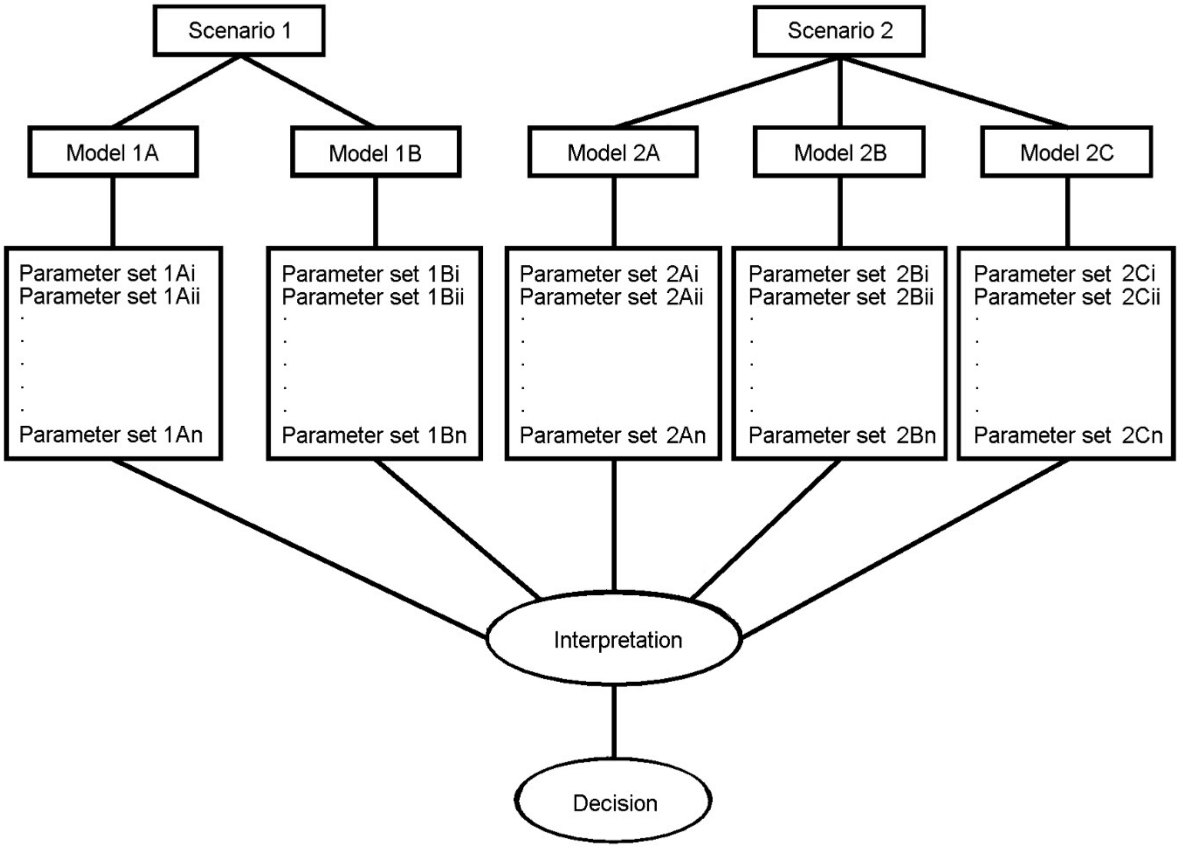

Fig. 1. Structure of Uncertainty or Importance Analysis [after 2].

Experience has shown that the defensibility of a performance assessment is largely based on the defensibility and completeness of the treatment of scenario and conceptual model uncertainties. For this reason, significant international effort has been directed over many years to develop formal and traceable methods to justify scenario and model development [5 – 13]. A key feature of most of these methods is the use of Features, Events, and Processes (FEPs). The use of FEPs within scenario and model generation and justification is primarily an approach for improving the defensibility and traceability of a performance assessment analysis. It is viewed as particularly important for assessments in which the assessment must be communicated to others that were not involved in the original assessment process, as is the norm in a regulatory setting.

Until recently, the formal use of FEPs was the primary approach to the development and justification of scenarios and models in performance assessment. In general, the process of using FEPs has consisted of four steps: (1) identifying a comprehensive list of features, events, and processes (FEPs), (2) screening the comprehensive list to a manageable number, (3) describing the relationships between the features, events, and processes, and (4) arranging them into calculation cases, or scenarios, for the performance assessment. Differences between published FEP evaluation approaches are comprised of differences between methods for one of these steps, or different ordering of the steps. For instance, the original scenario development procedure developed by Cranwell et al. [5] only calls for screening the full scenarios, whereas later scenario development approaches emphasize screening at the FEP level [6] or screening both FEPs and full scenarios [7]. Despite the differences in approaches and ordering, the concepts of these four steps are the same for all FEP-based scenario development procedures.

Considerable international effort has been expended to develop comprehensive FEP lists for geological (deep) disposal systems. There is only one approach that has been used for this step: collection and elicitation of expert opinion. Excellent summaries of the comprehensive FEP lists for geological disposal have been provided by Chapman et al. [8] and by Guzowski and Newman [9]. Chapman et al. [8] suggest that a comprehensive list of FEPs for a geological disposal system in Sweden was comprised of over 1200 entries [10]. The current incarnation of the comprehensive FEP list for geological disposal facilities is the Nuclear Energy Agency (NEA) FEP list [11] as amended [12].

Work on formal scenario development for near-surface disposal is more recent and based heavily on the prior geological disposal literature. IAEA [13] published the first comprehensive set of FEPs for near-surface disposal based on the results of the ISAM coordinated research program. This FEP list was an adaptation of a geological disposal comprehensive FEP list for near-surface conditions [13], and was audited against previously developed site-specific FEP lists for near-surface disposal (e.g. [14]), providing a good degree of confidence that the list was substantially complete and reliable.

As a result of these developments, FEP approaches have been used increasingly for near-surface disposal performance assessments (e.g., [15,16]), leading to increased practical experience in applying them in real licensing situations. These experiences have led to the identification of a number of drawbacks to FEP approaches. In particular, as a bottom up approach, they seek to identify all conditions of concern, without necessarily focusing on the key issues. As a result, they have in some cases led to large amounts of effort, but without a commensurate improvement in the traceability of the performance assessment. In addition, even after many years of use, there remain no standard approach for documenting the process of justifying scenarios and particularly models from a screened FEP list. As a result of these issues with FEP-based analyses, in recent years there has been increasing attention given to safety function approaches in structuring performance assessments. These approaches are reviewed in the next section.

Introduction to Safety Functions

The drawbacks to the FEP process have led to a more recent emphasis in the literature on the use of an alternative approach to identifying conditions that need to be included in the performance assessment. Increasingly, the literature on performance assessment emphasizes the use of safety functions as either a replacement for FEP analyses or as an augmentation of FEP analyses [e.g. 16 - 18]. A safety function is a feature of the system that provides a specific function that is relevant to the performance (or safety) of the facility. The set of these safety functions present a high-level summary of the *safety strategy* by which the performance of the disposal system is assured. In addition to providing a technical approach to development of scenarios, the use of safety functions is beneficial in emphasizing the overall safety strategy with stakeholders.

Increasingly, performance assessments include both FEP evaluations as a bottom-up approach and safety functions as a top-down approach to identifying conditions that need to be evaluated in the PA [16,19]. In this hybrid approach, FEPs are used in a more targeted manner than the traditional FEPs concept. In the hybrid approach, FEPs are identified that may affect the ability of the safety function to provide assurance of performance in the future, as shown in Fig. 2. That is, FEPs are identified that may degrade or modify the performance of the safety function in some way. For instance, performance of the engineered system may be influenced by a wide variety of FEPs that would change the rate of water movement through it. These FEPs might include (for example) mechanical changes to the silo associated with degradation processes, seismic degradation of the concrete, inadequate quality control, and so on. Since all of these FEPs influence the system in a similar manner (i.e. changes in water flow through the system), sensitivity analyses that vary this safety function represent an aggregated view of the potential negative effects of a suite of FEPs. In this way, the performance assessment can be organized to evaluate a large number of disruptive FEPs with relatively few analysis cases.

This hybrid approach identifies a suite of analysis cases that evaluate both alternative scenarios and alternative conceptual models, as shown in Fig. 1. The analysis cases are directly focused on potential conditions of concern for the safety of the facility, regardless of the type of uncertainty from which they originate (i.e. scenario or model uncertainty). Specifying analysis cases in this way does not address parameter uncertainties associated with the implementation of those analysis cases. For parameter uncertainties, the usual approaches to parameter uncertainty apply, as shown above in Fig 1., and either deterministic and probabilistic approaches may be appropriate [2].

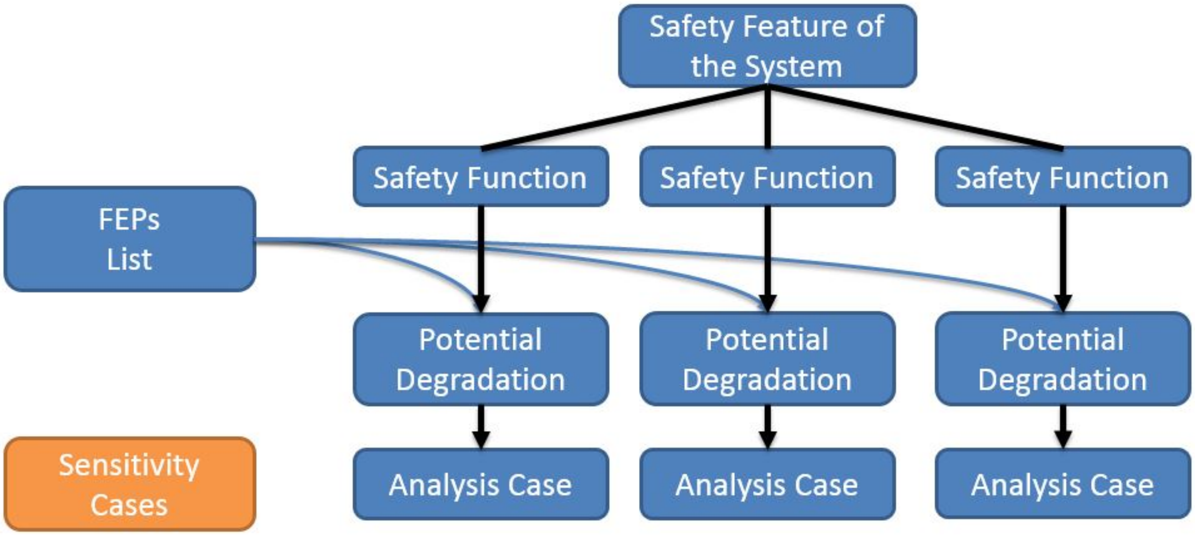

Fig. 1. Hybrid approach to the use of safety functions and FEPs for identifying analysis cases of concern.

This hybrid approach de-emphasizes the importance of FEPs, and leads to a streamlined approach to identifying a credible set of alternative analysis cases that support the performance assessment. These analysis cases may be thought of as representing either alternative scenarios or alternative conceptual models.

APPLICATION OF THE HYBRID APPROACH

A performance assessment of Waste Management Area C (WMA C) located at the U.S. Department of Energy's (DOE) Hanford Site in southeastern Washington has been conducted [20]. The location of WMA C is shown in Fig. 3. WMA C comprises twelve 100-series tanks and four 200-series tanks (see Fig. 4). The 100 series tanks are 23 m (75 ft) in diameter, have a 5-m (15-ft) operating depth, and an operating capacity of 2,006,000 L (530,000 gal) each. The 200-series tanks are 6 m (20 ft) in diameter with a 7.32-m (24-ft) operating depth and an operating capacity of 208,000 L (55,000 gal) each. To support the transfer and storage of waste within WMA C SSTs, there is a complex waste transfer system of pipelines (transfer lines), diversion boxes, vaults, valve pits, and other miscellaneous structures. These miscellaneous features of the tank farm are referred to in this document by the general term "ancillary equipment and components."

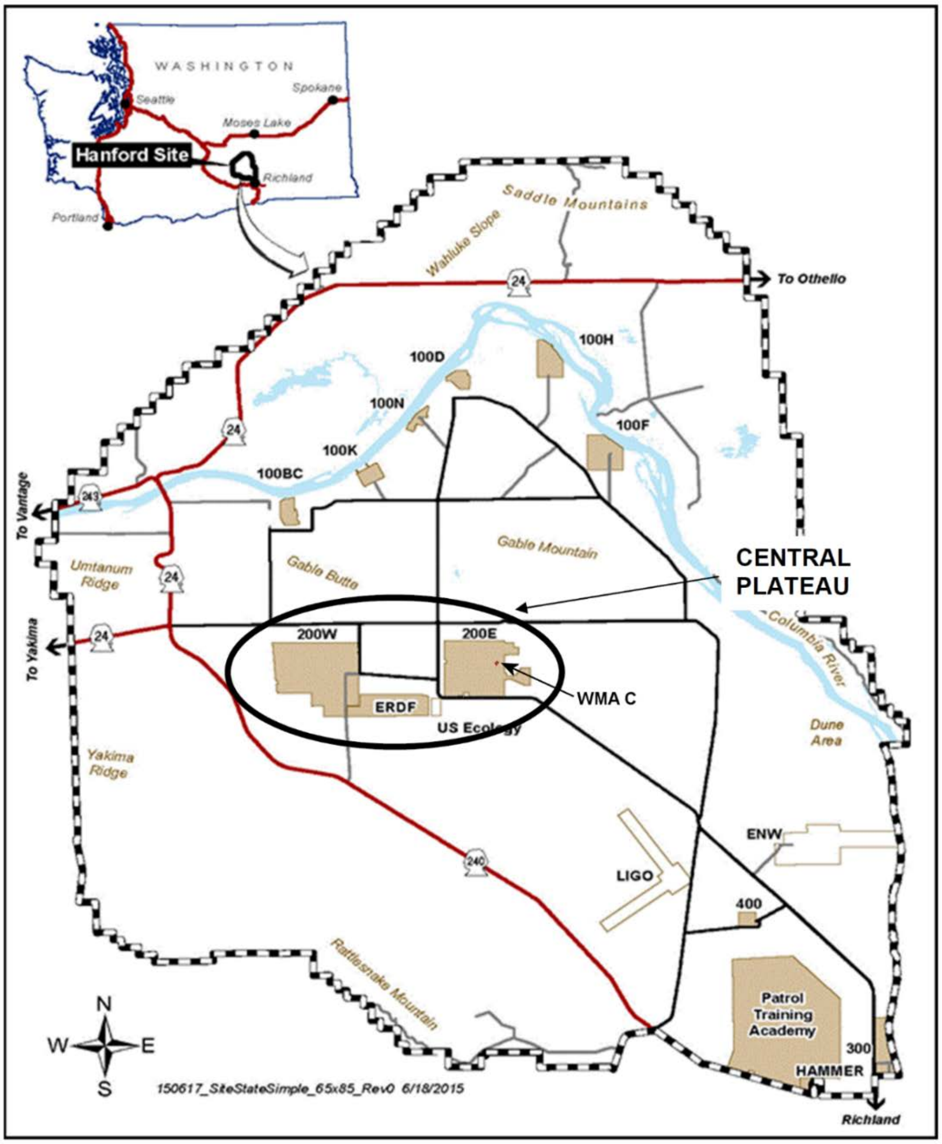

Fig. 3. Location of WMA C at the Hanford Site, Washington State, USA.

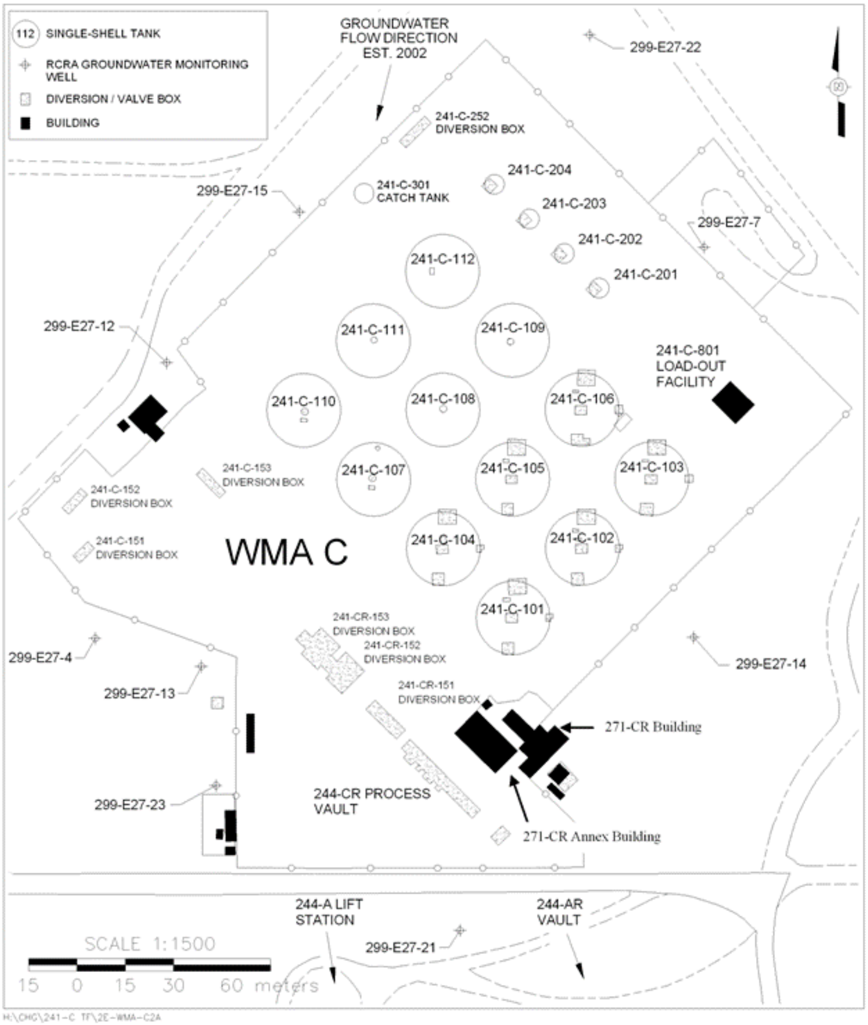

Fig. 4. Plan view of WMA C showing the locations of the tanks and key features of the ancillary equipment.

The plan for closure of WMA C is to remove as much of the wastes as technically and economically practicable, filling the tanks and key parts of the ancillary equipment with grout, addition of a modified RCRA C cover, and closure as a landfill. The WMA C performance assessment [20] evaluates the impacts on humans and the environment of radionuclides in residual wastes left in tanks and ancillary equipment and facilities in their assumed closed configuration.

As part of the performance assessment, the hybrid approach to the use of safety functions and FEPs was applied to identify a suite of analysis cases to be evaluated in the performance assessment. The safety functions were identified by examining each key feature of WMA C as a disposal system, and identifying how that feature contributes to the performance of the system, as defined by controlling doses calculated in the performance assessment. A schematic representation of the safety functions is shown in Fig. 5.

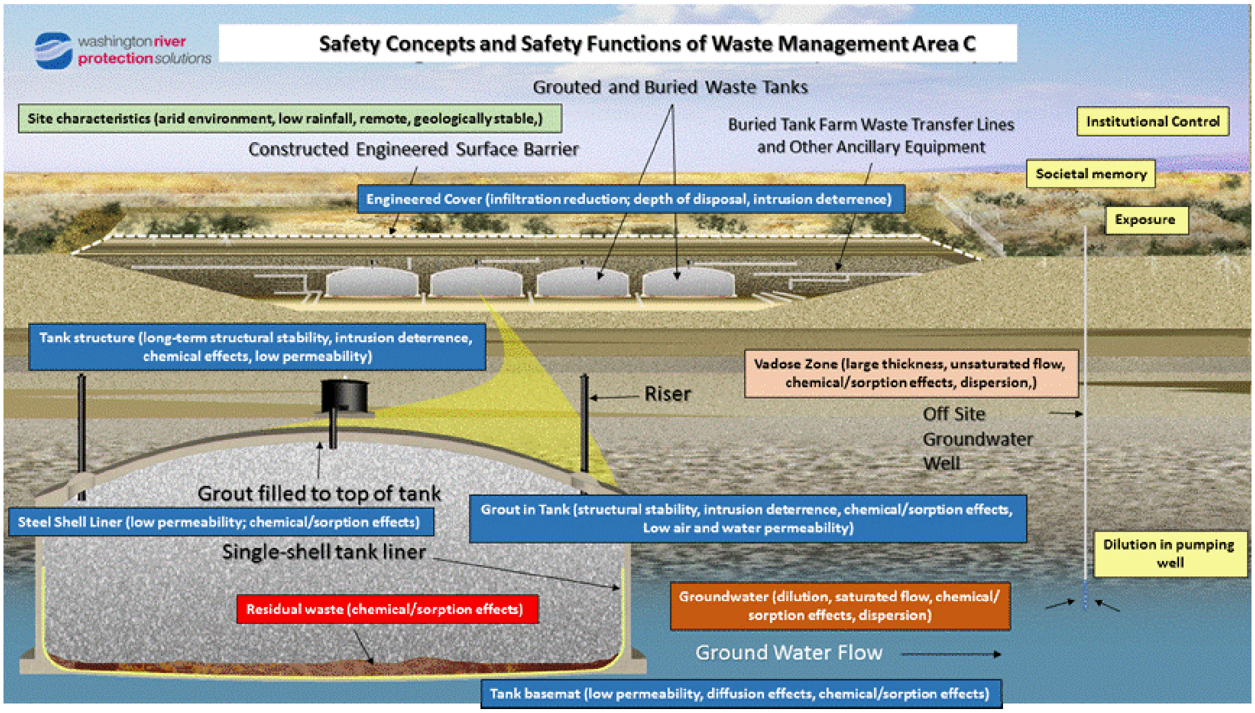

Fig. 5. Schematic representation of the safety functions for WMA C.

The safety functions were cross-referenced with an international FEP list for near-surface disposal of radioactive waste facilities [13]. Specifically, each FEP was examined by a group of subject-matter experts to determine if it applied to a safety function, and more specifically if it had the potential to degrade the performance of the safety function in some way. FEPs that have the potential to result in degraded performance of a safety ufnction have been termed “potentially deleterious FEPs.” The set of safety functions and associated potentially deleterious FEPs is presented in Table I.

Table I. Safety Functions and Potentially Deleterious FEPs identified for the WMA C performance assessment. The numerical designators for the FEPs are from [13].

Designation		Description	Potentially Deleterious FEPs (See Ref. 13 for definition).
I1	Institutional Control	By Order 435.1, we assume that control of the site will be retained for 100 years. A strong potential exists that the US government will retain	

Designation		Description	Potentially Deleterious FEPs (See Ref. 13 for definition).
		control of the site for a much more extended time. DOE O458.1 requires that plans for management and disposal of wastes provide for institutional controls and long-term stewardship. DOE Policy 454.1 identifies how that stewardship is to be carried out.	
I2	Societal memory	Societal memory is represented by records, deed restrictions, and other passive controls that would warn someone that additional care should be taken in the area. For a member of the public to come onsite to experience exposures to contamination from WMA C, records that the Hanford site existed would need to be forgotten or ignored. DOE O458.1 requires record keeping that would lessen the likelihood of this occurrence. DOE Policy 454.1 identifies how that stewardship is to be carried out.	
I3	Exposure	By Order 435.1, we assume a postclosure well is established 100 m down-gradient at the point of highest exposure. It is highly unlikely that this situation will occur.	
S1	Site characteristics	WMA C is a semi-arid site with low precipitation. The Central plateau is remote from members of the public, with a substantial buffer area under DOE control. The vadose zone is thick, with long travel times in the vadose zone.	
EB1	RCRA Cover (infiltration reduction)	The final design cover has not yet been established, but is believed to be able to produce very low initial flow rates. Over some period of time this function may deteriorate, with the rate of deterioration associated with a variety of processes.	1.1.08 1.1.12 1.2.04 1.2.07 2.3.08 2.3.12 2.3.13

Designation		Description	Potentially Deleterious FEPs (See Ref. 13 for definition).
EB2	Cover	Limitation of types of potential inadvertent human intrusion by depth of disposal.	
EB3	Steel Shell (permeability)	The function of the carbon steel shell to limit flow through the tank is not currently explicitly accounted for in the performance assessment. The shell is part of the overall assessment of low flow through the tank for long periods of time. Its potential eventual failure is considered as part of the generic barrier failure cases. DIF4 explores what happens if the tank behaves *better* than expected, and retains integrity for thousands of years, allowing ingrowth of progeny before releases commence.	
EB4	Steel Shell (chemical)	The carbon steel shell will corrode over a period of time, leaving behind corrosion products of (primarily) iron oxides. These corrosion products are highly sorptive and tend to produce reducing conditions that are highly advantageous for limiting solubilities of key radionuclides, particularly Tc.	
EB5	Tank structure (structural)	The dome and walls provides structural support preventing subsidence of the closed facility.	
EB6	Tank structure (intrusion)	The tank structure provides a barrier to intrusion.	
EB7	Tank structure (chemical)	The concrete of the tank acts to condition the chemistry of the waste residuals, with sorption characteristic of high pH environments.	
EB8	Tank structure (permeability)	The concrete of the tank structure is substantially intact and provides a barrier to flow into the tank.	1.2.03
EB9	Grout in tank (permeability)	The grout acts to limit water flow through the facility, making releases dominated by diffusion from the waste.	1.1.08 1.2.03

Designation		Description	Potentially Deleterious FEPs (See Ref. 13 for definition).
EB10	Grout in Tank (chemical)	The grout acts to condition the chemistry of the waste residuals, with sorption characteristic of high pH environments.	
EB11	Grout in tank (structural)	The grout provides structural support preventing subsidence of the closed facility.	
EB12	Grout (intrusion)	The structural strength of the grout provides a barrier to intrusion.	
EB13	Tank Base Mat (permeability)	The tank pad, if intact, will provide a flow-limiting	2.1.05
EB14	Tank Base Mat (chemical)	The concrete pad is anticipated to continue to provide a high pH environment, with associated sorption, for an extended time in the future.	
EB15	Pipelines (permeability)	The pipelines, if intact, provide a delay to releases of waste in ancillary equipment	
AP1	Grout (air pathway)	Limitation of releases to air owing to low air permeability and long pathway to the surface.	
WF1	Residual Waste (chemical)	The residual waste is recalcitrant by nature, providing limitations to the amount and rate of release of contamination from it upon contact with water.	2.1.1
VZ1	Vadose zone thickness	The vadose zone is thick with slow rates of water flow, leading to long delay times in the vadose zone	1.1.01 2.2.12
VZ2	Sorption on vadose zone soils	Vadose zone soils sorb some of the contaminants of potential concern, delaying their arrival at the water table. A number of key contaminants are not believed to sorb significantly.	1.4.07 2.2.08 3.2.03
VZ3	Dispersion in vadose zone	Spreading of contaminants in the vadose zone, dispersing them and decreasing concentrations.	2.2.12
SZ1	Water flow in saturated zone	Advective flow in the saturated zone leading to dilution of the contaminants.	1.3.01 1.3.02 1.3.03

Designation		Description	Potentially Deleterious FEPs (See Ref. 13 for definition).
			1.3.07 2.3.03
SZ2	Sorption on saturated zone soils	Saturated zone soils sorb some of the contaminants of potential concern, delaying their arrival at the point of compliance. A number of key contaminants are not believed to sorb significantly.	
SZ3	Dispersion in saturated zone	Spreading of the plume in the saturated zone, adding dilution to the contaminant plume and lowering concentrations.	
SZ4	Dilution in well	Dilution caused by pumping a groundwater well to the surface where it is useable and accessible by a member of the public.	

An analysis case was defined in which the safety functions evolve in an expected manner without unusual behavior or unanticipated disruption: this is termed the “base case.” In addition, a set of analysis cases have been conducted that show the effects when the safety functions are degraded compared to their expected behavior as defined in the base case. For each safety function for which a potentially deleterious FEP was identified, a corresponding analysis case was identified. Where no potentially deleterious FEP is identified, no alternative analyses of the safety function is needed.

The definition of the analysis case depends on the degree to which the potentially deleterious FEP may affect the safety function. One can establish an analysis case that assumes the complete removal of a safety function. Such analyses are commonly known as “one-off” or “barrier neutralization” analyses. For instance, to examine the importance of the safety functions associated with the vadose zone, an analysis case can be established in which leachate from the facility is put directly in the saturated zone, effectively assuming that the vadose zone does not exist. Such analyses provide useful information on the relative importance of the safety function, but must not be confused as a credible projection of system performance. To establish more reasonable analysis cases, the specific interaction of the potentially deleterious FEP on the safety function is examined. For instance, the safety function associated with reduced flow through the cover may be negatively affected by vegetative progression to less favorable plant species. The specific effect of this FEP must be examined to determine how that affects the flow through the cover, which then allows an analysis case to be estavlished that represents that effect.

The specific safety functions examined in this way relate to the various physical components of the disposal system that included model evaluations of groundwater impacts with the following:

- Higher than expected infiltration rates; these may be the result of a number of potentially deleterious FEPs, ranging from unexpectedly poor performance of the cover, through changes in land use with irrigation on top of the facility
- Changes in the effectiveness of the tanks and infill grout to act as barriers, by assuming that the hydraulic conductivity of the tanks increases at times earlier than expected
- Changes in the leachability of the residual wastes, by assuming that the material would dissolve instantly and completely upon contact with water
- Bounding inventories for unretrieved tanks
- Alternative conceptualizations of the stratigraphy of the vadose zone
- Alternative assumptions about dilution in the aquifer.

These analysis cases represent the uncertainties in conceptual models and future evolution of the closed WMA C. As discussed in Ref [20], the performance assessment showed acceptable performance for all combinations of degraded performance of safety functions, giving a high degree of confidence that the closed WMA C will comply with regulatory performance objectives.

SUMMARY AND CONCLUSIONS

A hybrid approach to the use of safety functions and FEPs has been described in this paper, and its application has been demonstrated in an application to WMA C at the Hanford site. This approach has demonstrated the ability to streamline the FEP process, to provide a credible path to identifying alternative analysis cases for inclusion in the performance assessment. By structuring the performance assessment in this way, the analysis specifically addresses concerns related to the performance of the facility. This approach therefore focuses the performance assessment on key issues in a way that prior FEP-based approaches did not necessarily do.

The link between safety functions and FEPs occurs primarily through the identification of potentially deleterious FEPs, which may cause degraded performance of the safety function and poorer performance of the disposal system. By evaluating the specific interaction of the FEP with a safety function, the magnitude of the potential disruption can be established, leading to a credible analysis case to address the key uncertainty introduced by a particular FEP.

The application of the hybrid approach to WMA C has shown its utility in providing a specific definition of the “base case” of the analysis, in identifying how the key features of the disposal system will contribute to the performance of the facility, and in focusing the analysis on key technical issues that could result in degraded performance compared to the base case.

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