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PROBABILISTIC SAFETY ASSESSMENT FOR HIGH-LEVEL WASTE TANKS AT HANFORD

by

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1. INTRODUCTION

Los Alamos National Laboratory has performed a comprehensive probabilistic safety assessment (PSA), including consideration of external events, for the 18 tank farms at the Hanford Tank Farm (HTF). This work was sponsored by the Department of Energy/Environmental Restoration and Waste Management Division (DOE/EM).

The Hanford tank farms are divided into east and west quadrants. The 18 tank farms are given one- or two-letter designations and contain either double-shell tanks (DSTs) or single-shell tanks (SSTs).

The DSTs consist of three concentric structures: (1) an outer, reinforced concrete tank designed to sustain induced loads from soil and seismicity, (2) a secondary, carbon-steel tank that lines the concrete tank and is designed to serve as a barrier to primary tank leaks, and (3) a free-standing carbon-steel primary tank that rests on an insulating concrete pad within the secondary tank. The primary tank contains the waste material; the secondary tank, which is 5 ft larger in diameter, encloses the primary tank to create a surrounding annular space. The annulus is ventilated and monitored constantly for evidence of primary tank leakage. Each of the 28 tanks has a capacity of 1.2 million gal. No leaks have occurred from the DSTs. The active induced-draft ventilation system for the DST farms has two completely separate subsystems: a primary tank ventilation system and an annulus ventilation system. Tanks are connected to the two subsystems by manifolds, which maintain a slightly negative pressure with the tanks and annulus. The ventilation subsystems have no redundancy; the ductwork is above ground in some cases and underground in others. The ductwork routes the ventilation air from the primary tank and annulus of each tank to the respective filter trains and exhaust fans.

SSTs are composed of a reinforced concrete enclosure with an inner steel liner on the bottom and sides. The 149 SSTs range in capacity from 55,000 to 1,000,000 gal. The tanks have a history of leaking into the surrounding soil. Most SSTs are vented through passive filter systems.

An earlier Los Alamos study focused only on the risks from Tank SY-101 (MacFarlane 1993). This tank, which periodically undergoes sudden releases ("burps") of a mixture of gases that includes hydrogen, nitrous oxide, ammonia, and nitrogen, was analyzed first because of public safety concerns associated with the potential release of the radioactive tank contents should this flammable gas mixture be ignited during one of the burps. The Tank SY-101 releases have been mitigated by the insertion of a large mixer pump into the tank to promote a slow, continuous release of the gases.

The HTF PSA involved three distinct tasks. First, the accident-sequence analysis identified the frequencies of those potential accidents whose consequences result in the release of tank material to the environment and quantified them. Second, radionuclide source terms for the airborne and liquid radioactive releases were determined. Finally, the consequences, as measured by onsite and offsite potential health effects and cleanup costs resulting from radionuclide release, were estimated, and overall risk curves were constructed. This PSA did not consider risk reductions from tank remediation activities (e.g., the Tank SY-101 mixer pump) or the risks from deliberate sabotage.

The accident-sequence identification task began with the construction of a master logic diagram (MLD) to identify the potential initiating events, which then were grouped into categories according to their effect on the tanks. These initiator groups included external events, such as earthquakes and airplane crashes, and internal events, such as gas releases ("burps") and liquid leaks.

Next, event-sequence diagrams, whose events represent physical phenomena, hardware responses, and emergency operator responses, were constructed for initiating-event groups. Accident sequences were defined for quantification by event trees developed for each initiator. The event trees were developed in such a way to allow dependencies between top events and initiators to be identified. Finally, the frequencies of accident sequences were determined by combining initiating-event frequency estimates with the branch-point probabilities, or split fractions, for the occurrence of each event on the event-tree paths. An important aspect of this process was quantification of the branch-point probabilities. This quantification used a combination of tank farm historical operating databases and occurrence reports, generic component/system failure data, and specific deterministic analyses for flammable-gas-releasing tanks. This effort involved considerable interaction with Westinghouse Hanford Company (WHC) tank farm operations personnel and analysts at Los Alamos and WHC who had performed other related safety analyses. The airborne source-term characterization task involved identifying factors that influence the magnitude and timing of a radionuclide release and defining release categories for accident-sequence grouping. Both deterministic and probabilistic analyses were necessary for modeling material release mechanisms for the various accident sequences, thereby providing estimates for the quantity of material and energy involved in each case. Core sample analyses of the contents of tanks were used to characterize the radionuclide composition of the source terms.

The consequence analysis provided estimates of radiological health risks for both co-located workers and offsite residents via the airborne pathway and for offsite residents only for the groundwater pathway. Because of the large worker population in relatively close proximity to the 200 West and 200 East areas, the airborne dose consequences to this group were estimated as well. The airborne-transport population doses were calculated with AP-RISK, a computer code recently developed at Los Alamos to calculate dose consequences and surface contamination resulting from waste tank accidents.

The discussion of the analysis is divided into four sections: defining the initiating events and their frequencies, accident sequence modeling and quantification, source terms, and consequence assessments. These areas are discussed in the following sections. Results and conclusions are provided in the last section.

2. INITIATING EVENTS

The first step in developing a risk model is to define a set of initiating events. For an accident sequence to occur, an event must first perturb the steady-state condition of a waste tank or its contents. Subsequent events may (or may not) result in a release of radionuclides or chemicals.

The primary objectives of the initiating event exercise are

- to provide a comprehensive list of initiating events and adequate assurance that all possible events are taken into account,
- to account for unique tank design and operational features,
- to provide a way to categorize events in all of the unique ways that the event may affect the entire tank population, and
- to group events that present similar threats to safety functions for quantification.

Candidate initiating events were identified for the HTF PSA using several different analytic approaches, including

- MLD development,
- hazard and operability (HAZOP) study analysis, and
- external events analysis

Applications of the MLD and HAZOP techniques to the HTF are described later. In addition to the information from the above analyses, new insights often are obtained from other PSA tasks that lead to identification of new initiating events or that alter the judgments made in finalizing the list. This is a highly iterative process and is difficult to predict. For example, the results of event-sequence quantification for one initiating event may be used to eliminate some others from the list. A review of operating experience often reveals new initiating events and becomes an important source of data and information.

2.1. Master Logic Diagram

The MLD is similar to a fault tree and provides a deductive approach for directly answering the question "How can a significant release of radioactivity, chemicals, or toxic gas occur?" The first page of the HTF MLD is shown in Fig. 1. A key objective of developing the MLD is to identify all possible types and sources of the hazardous materials and the pathways by which the top event can be satisfied down to a level of detail at which all important safety functions and barriers have been taken into account. When this is accomplished, specific causal events that can threaten a safety barrier or function can be listed. The question of completeness then is reduced to an assessment of the total frequency of all causal events that could produce any of the conditions shown on the MLD. It should be noted that it is not the objective of the MLD to delineate all possible accident scenarios that could result from the initiating event. For example, safety function failures could result in the failure of one or more fission product barriers. Such scenarios are not shown by the MLD but are addressed later in the accident-sequence model.

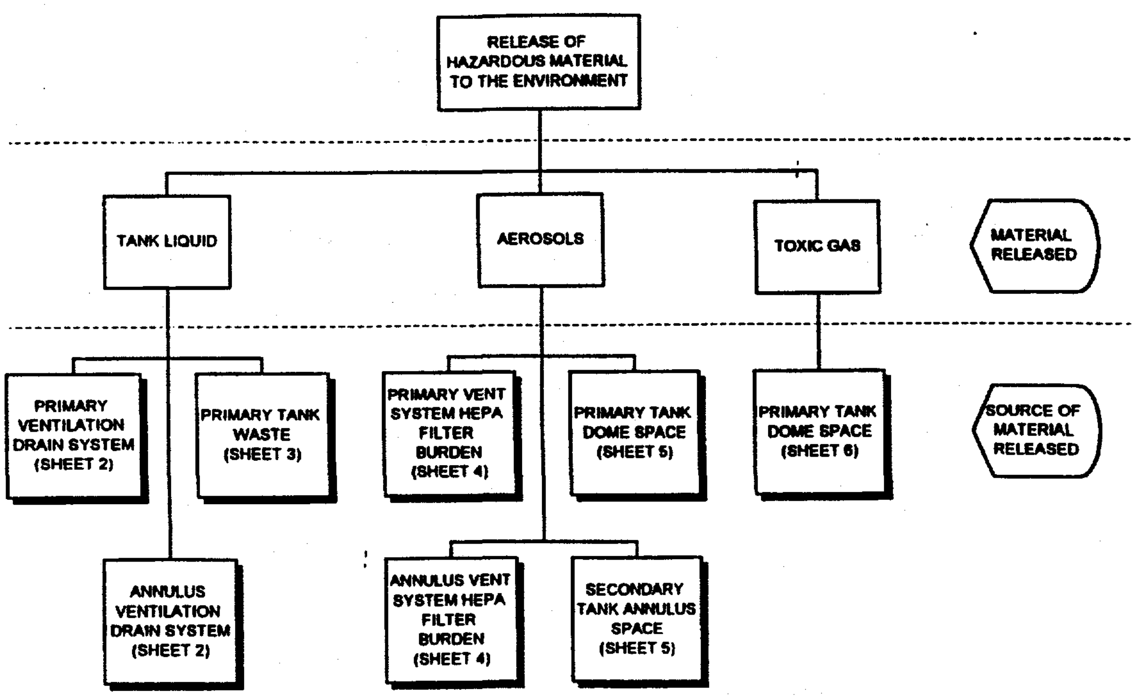

Fig. 1. Hanford Tank Farm Master Logic Diagram.

Many of the initiator events shown at the bottom of the MLD may be subdivided to reveal more specific causal events. Table 1 is a list of events that could threaten the safety barriers or functions shown at the bottom of the MLD. The events listed also are matrixed against the MLD initiator events to help identify common-cause initiators that can threaten multiple safety barriers or functions simultaneously. However, not all of the basic events shown on the HTF MLD qualify as initiators. For example, events such as "Flammable Gas Ignition" do not by themselves initiate the release and therefore are not true initiators, but they occur after to an initiator in an accident sequence. This and other subsequent events typically are found under an "AND" gate in the MLD (Fig. 1) and are shown for completeness by rounded rectangles, but they are not included in Table 1.

2.2. Initiating-Event Groups

The concept of grouping initiating events by similarity of expected response is common to most PSA models and helps to limit the number of event-sequence models to be developed. It is necessary and practical to analyze only those initiating events that are expected to make appreciable contributions to risk. Given knowledge of the approximate frequency of the initiating events and the relative effect of these events on the tanks, it is possible and desirable to group and screen initiating events to simplify the quantification of risk but without introducing large errors into the risk estimates.

The causal events listed in Table 1 are put into initiating-event groups in Table 2. Different causal events that affect the tanks in a similar way are grouped together. Where a causal event could be applied to multiple groups, the event was assigned to the more severe initiator group. This grouping results in a one-to-one correspondence between a causal event and an initiating-event group. However, care has been taken to keep common-cause initiators and initiators with special dependencies separate. The initiating-event groups listed in Table 2 are generally applicable to all storage tanks. However, because of differences in tank design, tank status, and waste characteristics, some of these general initiating-event groups have been subdivided to account for these differences. Evaluations of the susceptibility of individual tanks to each initiating-event group are discussed under the accident sequence modeling section.

3. ACCIDENT-SEQUENCE MODELING AND QUANTIFICATION

The HTF accident-sequence model serves two primary purposes: to document the PSA team's understanding of how radionuclide and/or toxic gas releases from the HTF facility could occur and to create a logic model describing the potential release scenarios that can be used to quantify the likelihood of releases. The general approach used to develop accident-sequence models is shown in Fig. 2 and is described in detail in the Tank SY-101 PSA report (MacFarlane 1993). For this analysis, the modeling approach from the Tank SY-101 analysis was expanded to address all 177 tanks.

Generic initiating-event groups that had the potential to lead to material releases from one or more tanks were identified in the initiating events section. The accident-sequence modeling process began by examining each generic initiator to identify any characteristics of the tanks or waste materials that could influence the assessment of the frequency of occurrence of the generic initiator for a particular tank or group of tanks. If segregation of the 177 tanks into subgroups or families was justified, then initiator frequencies were calculated for each of the types. This calculated frequency represents the total per year for the initiator occurring over all of the tanks belonging to the type. For example, if the frequency of a generic initiator was determined to be 1E-04 per tank per year and the event is equally applicable to all tanks, then the total type-initiator frequency for this analysis is 177 x 1E-04 or 1.8E-02 per year.

These segregated initiating-event types were used to develop accident sequences and quantify sequence likelihood. Event-sequence diagrams (ESDs) and event trees were developed for each initiator family. The ESDs document the subsequent system responses, phenomenological events, and mitigating actions that can occur in response to the initiator. The ESDs also specify the most

Table 1. Initiator Events

EXAMPLE CAUSAL EVENTS	MLD BASIC EVENTS**																
	Primary Tank Shell Breach	Secondary Tank Shell Breach	Tank Dome Failure	Annulus Vent Line Breach	Riser Breach	Primary Exhaust Vent Line Breach	Exhaust HEPA Filter Breach or Bypass	Vent. Drain Line Leak	Vent. Seal Pot Leak	Waste Transfer Event	Waste Transfer System Boundary Failure	Inadequate Primary Ventilation Flow	Inadequate Level Control	Criticality Event in Waste	Bound Flammable Gas Release	Flammable Gas Accumu-lation	Uncon-trolled Waste Heatup
Drilling Contact with Tank	X	X															
Excavation Contact with Tank	X	X	X		X												
Tank Thermal Stress	X																
Tank Liner Corrosion	X																
Vehicle Overloads Dome			X														
Load Dropped Over Tank			X	X	X	X											
Vehicle Impact w Above Ground Equip.				X	X	X	X	X	X								
Vent. Duct Corrosion				X													
Human Error, Equip. not restored after maint.				X	X	X	X	X	X		X	X					
Vent. Drain Line Corrosion								X	X								
Vent. Drain Line Freezing								X									
Excessive Moisture in Vent System							X										
Ventilation Exhaust Filter Blockage												X					
Ventilation Inlet Blockage												X					
Vent Fan Failure												X					
Loss of Power to Vent Fan												X					X
Loss of Air Supply to ALC's																	X
Dryout of Waste																	
Tank Inundated by Transfer Spill			X										X				
Tank Inundated by Raw Water Leak			X										X				
Tank Inundated by Heavy Precipitation			X										X				
New Waste Transfers From Other Facilities										X			X	X	X	X	X
Salt Well Transfers to Collector Tank										X				X	X		
Liquid Transfers to 242-A Evaporator										X			X	X	X	X	
Slurry Transfers from 242-A to DST Storage										X			X	X	X	X	X
Radiolysis of Water in Waste																X	
Bound Gas Release	X	X	X	X	X	X	X	X	X			X				X	
Lightning Strike on Tank												X					
Seismic Event	X	X	X	X	X	X	X	X	X		X	X					
Aircraft Crash	X	X	X	X	X	X	X	X	X		X	X					
Range Fire*												X					
High Wind & Dust Storm*				X		X						X					
Volcanism*												X					
Dam Break*			X										X				

Table 2. HTF Initiating-Event Groups

EXAMPLE CAUSAL EVENTS	HTF INITIATING EVENT GROUPS [a]												
	Tank Shell Breach	Tank Dome Failure	Riser or Vent Line Breach	Exhaust HEPA Filter Breach or Bypass	Vent. Drain System Leak	Waste Transfer Event	Inadequate Primary Ventilation Flow	Uncont. Waste Heatup	Flammable Gas Accumu-lation	Bound Gas Release	Water Intrusion to Tank	Seismic Events	Aircraft Crash
	TSB	DOMEF	RVB	FB	VDL	WT	LOTV	HEATUP	FGA	BURP	WI	SEIS	AC
Drilling Contact with Tank		X											
Excavation Contact with Tank		X											
Tank Thermal Stress	X												
Tank Liner Corrosion	X												
Vehicle Overloads Dome		X											
Load Dropped Over Tank		X											
Vehicle Impact w Above Ground Equip.			X										
Vent. Duct Corrosion			X										
Human Error, Equip. not restored after maint.			X										
Vent. Drain Line Corrosion					X								
Vent. Drain Line Freezing					X								
Excessive Moisture in Vent System				X									
Ventilation Exhaust Filter Blockage							X						
Ventilation Inlet Blockage							X						
Vent Fan Failure							X						
Loss of Power to Vent Fan							X						
Loss of Air Supply to ALC's								X					
Dryout of Waste								X					
Tank Inundated by Transfer Spill											X		
Tank Inundated by Raw Water Leak											X		
Tank Inundated by Heavy Precipitation											X		
New Waste Transfers From Other Facilities						X							
Salt Well Transfers to Collector Tank						X							
Liquid Transfers to 242-A Evaporator						X							
Slurry Transfers from 242-A to DST Storage						X							
Radiolysis of Water in Waste									X				
Bound Gas Release										X			
Lightening Strike on Tank							X						
Seismic Event												X	
Aircraft Crash													X

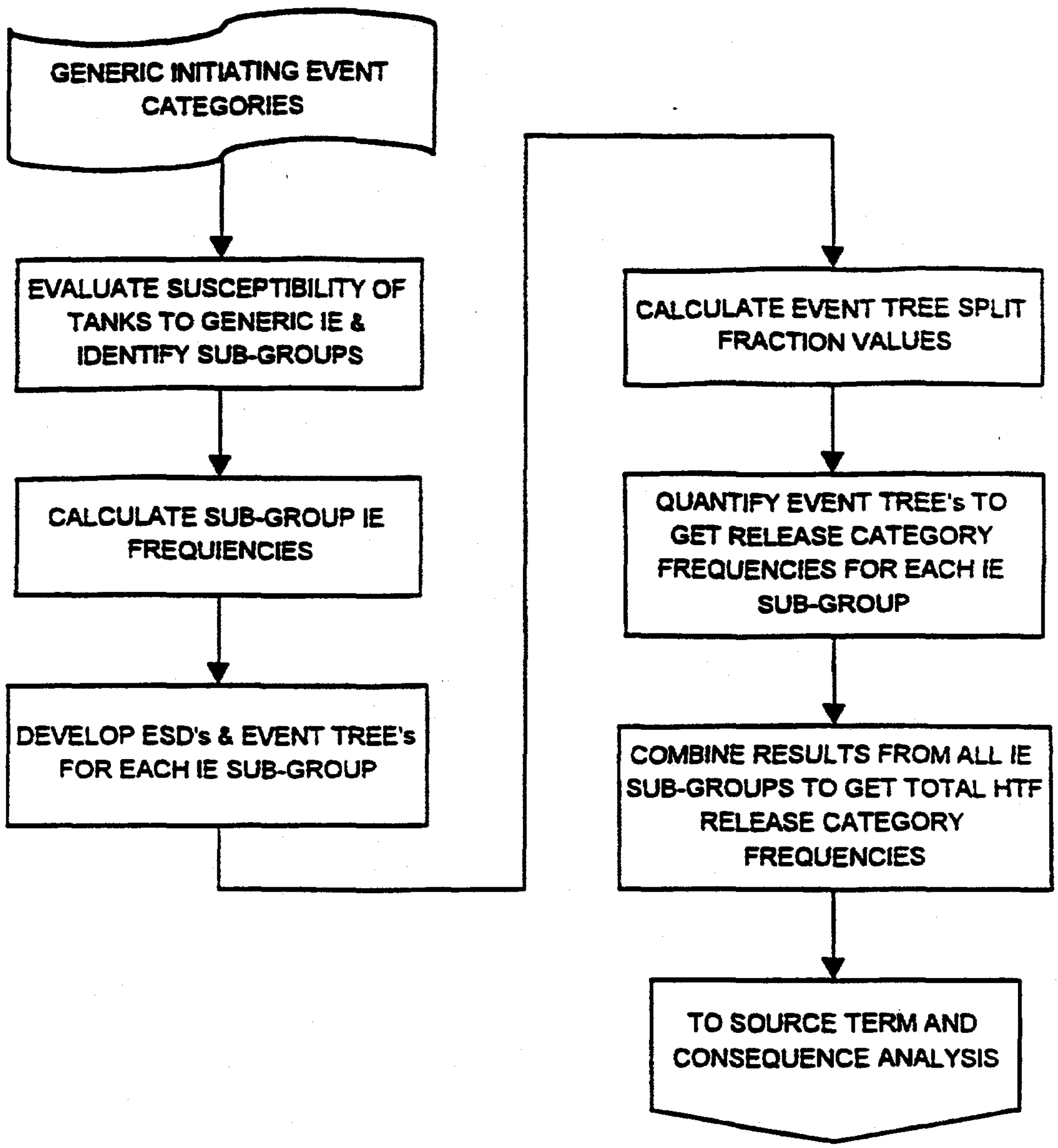

Fig. 2. Accident-sequence modeling steps.

Table 3. HTF PSA Release Categories

RELEASE PATHWAY		RADIONUCLIDE CONTENT	ENERGY OF RELEASE	RELEASE CATEGORY CODE
To Atmosphere	Unfiltered Release	Very Low	Low	BPL
	Unfiltered Release	Low (Aging Waste)	Low	BPH
	HEPA Breached	Low	Low	HEPAL
	HEPA Breached	High	Low (H_2 Burn)	HEPAH
	Dome Collapsed	High (101-SY Waste)	H_2 Burn	DCH
	Dome Collapsed	High (Wet Waste)	High (Aircrash & Fire)	DCVH
	Dome Collapsed	High (Dry, Inert Waste)	High (Aircrash & Fire)	DCVHI
	Dome Collapsed	High (Dry, FECN Waste)	High (Aircrash & Fire)	DCVHF
	Dome Collapsed	High (Organic Waste)	High (Aircrash & Fire)	DCVHO
To Ground	Subterranean Leak	Small	N/A	SLK
	Subterranean Leak	Large, SST	N/A	LLKSST
	Subterranean Leak	Large, DST	N/A	LLKDST
To Atmosphere and Ground	Surface Spill	Small	N/A	SSP
	Surface Spill	Large	N/A	LSP
	Spray Leak	Small	Low	SSPRY
	Spray Leak	Large	Low	LSPRY
	Dome Collapse + Subterranean Leak	High	Moderate (H_2 Burn)	DCLLK
	Dome Collapse + Subterranean Leak	High (C-103 Waste Only)	High (H_2 Burn & Fire)	DCHORG
	Dome Collapse + Subterranean Leak	4 Tanks	Low (Seismic Event)	DCL4
	Dome Collapse + Subterranean Leak	12 Tanks	Low (Seismic Event)	DCL12
	Dome Collapse + Subterranean Leak	45 Tanks	Low (Seismic Event)	DCL45
	Dome Collapse + Subterranean Leak	122 Tanks	Low (Seismic Event)	DCL122

appropriate release category describing the end state of each sequence. The release categories defined for the HTF PSA are presented in Table 3. A complete discussion of release category properties and the development of radionuclide source terms is presented in the source term. To quantify the accident-sequence frequencies for each initiator, event trees corresponding to the ESDs were developed and quantified. The results represent the total frequency per year of each release category for each initiator. Results from each initiator were summed to obtain the total release category frequencies over the entire tank farm.

3.1. Flammable Gas Accumulation

The major concerns associated with flammable gas accumulation (FGA) and a subsequent burn in the tank and/or ventilation system are damage to the components and concurrent release of radioactive materials to the environment. In addition to the burn-induced aerosol release from the dome space (including material entrained from the crust liquid waste), a fraction of the radioactivity trapped within the exhaust system can be released. In addition, if the dome collapses into the tank, the surface of the waste can become exposed to the atmosphere, permitting entrainment of materials from the surface. Leaks also can develop from tank failure, resulting in a liquid pathway for the release of radioactive materials to the environment.

The accident sequences of concern contain the following elements.

- Concentrations of combustible gases exceed the lower flammability limit (LFL) in the tank dome space and/or ventilation system.
- An ignition source within the tank or ventilation system ignites the flammable gas.

- Combustion of the gases produces a pressure and temperature transient that results in a pressurized release of gases and entrained material into the environment. These transients could result in pressures sufficiently high to fail the high-efficiency particulate air (HEPA) filters, ventilation system, and even the tank.

Twenty-four tanks are included on the Flammable Gas Watch List at the present time. Six of these tanks are DSTs (such as Tank SY-101), and the remaining eighteen are SSTs. All of the DSTs on the Flammable Gas Watch List are actively ventilated. The SSTs on the watch list were placed there primarily because they exhibited increases in waste level without the addition of liquids. The Flammable Gas Watch List was used as the initial screening criterion for tanks that might be subject to burns. However, all of the 177 tanks were examined for their burn potential. In addition, double-contained receiving tanks (DCRTs) have been identified as having the potential for the accumulation of hydrogen generated while the waste was held temporarily in these tanks. DCRTs are small holding tanks used for routing, sampling, and other operations in the course of on-site waste transfers.

In the waste tank environment, hydrogen is believed to be produced by three mechanisms: (1) radiolysis, (2) thermolysis, and (3) corrosion. Radiolysis and thermolysis are estimated to produce approximately equal amounts of hydrogen in Tank SY-101, and the contribution of corrosion is not negligible. Radiolysis and thermolysis occur in the liquid components of the tank waste. However, because gamma and beta radiation dominate the radiolysis component, the amount of hydrogen produced by radiolysis is assumed to depend on the total radiolytic power of the tank.

3.2. Initiating-Event Frequency for Double-Shell Tanks.

As mentioned above, the DSTs on the Flammable Gas Watch List are all actively ventilated. Continuous operation of the ventilation system maintains flammable gas concentrations at levels well below the LFL. It is assumed that ventilation system failures are repaired promptly, long before appreciable concentrations can build up. Therefore, only episodic releases are of concern for the DSTs. The greatly reduced magnitude of burps in DSTs other than Tank SY-101 clearly indicates that the events associated with this latter tank dominate the flammability concern with DSTs.

Before the mixing pump was installed, Tank SY-101 experienced a spontaneous release (burp) of slurry gas approximately every 100 days. In developing the initiating-event frequency for burps in Tank SY-101, only events occurring after March 1989 were considered because the practice of air lancing in this tank was terminated at this time. Based on these considerations, the mean frequency of Tank SY-101 burps (initiator BURP) was estimated to be approximately 3.5/yr. A more detailed analysis of the release history yielded the following attributes for a probability distribution for the frequency of burps in Tank SY-101.

5th Percentile:	2.64 events/yr
50th Percentile (Median):	3.44 events/yr
Mean:	3.51 events/yr
95th Percentile:	4.74 events/yr

A review of the level drop information for the other DSTs indicates mean frequencies of release events from approximately 2.0 events/yr to approximately 3.2 events/yr (Tank SY-103). However, because the magnitudes of the burps in tanks other than Tank SY-101 have been relatively small and flammable gas concentrations in the dome and ventilation system have been only fractions of the LFL, only Tank SY-101 was considered in this evaluation. That is, the frequency of burns resulting from burps in other DSTs is negligible compared with that for Tank SY-101.

3.3. Initiating-Event Frequency for Single-Shell Tanks

The frequency of passively vented SST failures because of burns was estimated probabilistically using two conservative assumptions.

- Each electrical spark from the level probe is capable of igniting the gas mixture when the LFL is exceeded. (The level probe is the only component inside the tank dome space that is deemed important as an ignition source in passively vented tanks.)

- Each ignition/burn is capable of causing catastrophic failure (dome collapse and shell failure) of the tank.

Adiabatic burns (but not complete combustion) at relatively low hydrogen concentrations produce a significant pressure rise in the tank. The presence of nitrous oxide (N_2O) as one of the oxidizers increases the magnitude of the pressure rise for the hydrogen concentrations of interest. The failure pressure of SSTs has been estimated to be only 11 psig. Thus, there is a high probability that burns at low concentrations will fail an SST. Because there are no probability distributions for either the tank pressure loads induced by burns or the load capacities of the tank (except for Tank SY-101, which is a DST), it was assumed conservatively that each ignition/burn would cause a tank failure. This assumption does not appear to have a dramatic effect on tank failure frequency because sensitivity calculations performed for several of the tanks indicate that the frequency of ignition/burns at an assumed LFL of 5% is not significantly different than that for an assumed LFL of 4%. The failure pressure for SSTs is relatively low compared with the failure pressure calculated for Tank SY-101 and the other DSTs.

The hydrogen gas released to the tank dome space by each of the three generation mechanisms (radiolysis, thermolysis, and corrosion) was represented by discrete distributions. The calculated values shown in Table 4 were assigned a probability weight of 0.4. In recognition of the perceived conservative assumption that all of the gas generated is released continuously to the dome space, a gas-release value equal to 50% of the table value was assigned a probability of 0.2. The final point in the three-point distribution accounted for the fact that there is some probability that the hydrogen release rate could be greater than the point estimates given in Table 4. This final point was assigned a value equal to 150% of the table value and was assigned a probability of 0.4.

3.4. Single-Shell Tank Leak Frequency

Initially, all tanks constructed at Hanford were SSTs. A total of 149 SSTs were built in various farms from 1944 to approximately 1964. A total of 68 SSTs are reported to be leakers in official Hanford records. Except for four tanks built in 1964, every group has tanks that developed leaks of various sizes, from a few hundred gallons to hundreds of thousands of gallons. When a leak is detected in any tank, efforts are made to minimize the continuing leak over the future years by removing the drainable liquid out of the tank. The time of detection of these leaks may not be precisely known because of the sparsity of leak detectors around the tanks and the difficulty in detecting leaks by observing changes in tank liquid level (1-in. level change in a 75-ft-diam tank = 2750 gal.). Historically, both methods have suggested leaks.

The Tank Farm Surveillance Report provides tank data on the years the tanks were built, the years they began to leak, the quantity of various liquid and solid wastes they contain, and other relevant information.

Recent data analysis performed by Steve Agnew of Los Alamos National Laboratory revealed that at least 12 of the 68 reported tank leaks were attributable to overfilling and/or transfer-line leaks. Also, reported leak dates were revised to reflect the actual time of the leak rather than the declared dates. Therefore, the leak data included in the Surveillance Report were modified in light of this new information.

Table 4. Burn Frequency for Passively Vented Tanks

Tank	Mean Burn Frequency (events/yr)	Release Category Assignment
Flammable Gas Watch List Tanks:		
AX-101	1.40E-04	DCLLK
AX-103	0.00E+00	DCLLK
S-102	1.96E-04	DCLLK
S-111	4.52E-05	DCLLK
S-112	1.76E-04	DCLLK
T-110	0.00E+00	DCLLK
U-103	4.70E-07	DCLLK
U-105	1.86E-04	DCLLK
U-108	0.00E+00	DCLLK
U-109	0.00E+00	DCLLK
High Organic Watch List Tanks:		
S-102**	1.96E-04	DCLLK
B-103	0.00E+00	DCLLK
C-103	1.55E-04	DCHORG
TX-105	0.00E+00	DCLLK
TX-118	0.00E+00	DCLLK
U-106	3.65E-07	DCLLK
U-107	9.70E-05	DCLLK
U-111	0.00E+00	DCLLK
Other:		
A-102	3.60E-05	DCLLK
B-101	1.74E-05	DCLLK
B-203	8.69E-05	DCLLK
B-204	8.38E-05	DCLLK
BY-106	8.40E-05	DCLLK
S-101	1.91E-05	DCLLK
S-108	2.62E-06	DCLLK
S-110	1.10E-05	DCLLK

Total Burn Frequency (events/yr) 1.34E-03

**Also on Flammable Gas Watch List

3.5. Possible Root Causes of Leaks

Two primary conclusions appear to be supportable from the above analysis of historical SST leak data. First, a dramatic change in SST leak frequency occurred when these tanks were removed from active service and has continued to the present. Second, the patterns and timing of the recorded failures indicate that common- cause mechanisms are the primary causes of tank leaks. Physical evidence of failure causes is not readily available; however, several hypotheses have been suggested during our investigations that may help explain the observed data. These are discussed in the following paragraphs.

Application of the mean SST leak frequency to the binomial distribution for the recorded 379 tank-years of DST experience produces a probability of 36% that no failures would have been observed in this period. Thus, applying the SST leak frequency directly to the DSTs would not be completely unreasonable. A lower estimate of future DST leak frequency could be obtained through Bayesian updating of the SST leak projections with DST experience. However, this was not done because it was judged that it could produce nonconservative results for future performance. Although no leak has been detected for a total of 379 tank-service years, it is likely that some wearout has occurred and the DSTs are operating in a somewhat degraded status. Also, independent of the issue of tank aging, it is believed that most mechanisms leading to leaks are cumulative. Therefore, the likelihood of primary-shell leakage is expected to increase with continued operation. Furthermore, the bulk of the SST tanks developed leaks after they were 20 yr old, and only three DST tanks are older than 20 yr. Therefore, the future leak frequency distribution developed for SSTs also applies to the primary shell of the DSTs.

3.6. Seismic Response Analysis

A seismic response assessment was performed on a double-walled waste storage tank, the associated equipment pits, the tank gas exhaust ductwork system, and the support facilities; an assessment also was performed for a single-walled waste storage tank. The assessment consisted of the following.

- **Seismic Hazard Analysis.** Determination of the frequency of various potential peak ground accelerations at the site.

- **Fragility Analysis.** Determination of the seismic-initiated peak ground acceleration at which plant structures and components are predicted to fail.

- **Accident-Sequence Model.** Development of a logic model that depicts the potential component failure scenarios considering possible combinations of associated equipment or structure failures.

- **Preliminary Quantification and Results.** Assembly of seismic hazards, fragilities, and models and the quantification of the frequency of causing sufficient damage to release hazardous materials, as well as identification of dominant contributors.

- **Final Quantification.** Calculation of the uncertainty in the damage and release frequency. The seismic uncertainty analysis was not performed in this study because the contribution to total risk from seismic events was negligible compared with non-seismic-initiated events.

3.7. Seismic Hazards

The Woodward-Clyde Consultants (WCC) study performed in April 1989 predicted peak ground acceleration frequencies at six Hanford sites. As in other contemporary probabilistic hazard studies, the WCC results were based on (1) the location and geometry of earthquake sources relative to the site, (2) the recurrence of earthquakes of various magnitudes on the sources up to the maximum magnitudes for each source, and (3) the attenuation of ground motions from the sources to Site 1. The source models and attenuation relationships that were developed earlier by WCC in the seismic hazard studies for the WNP-2 nuclear power plant, which is located in the region, and for the N Reactor studies performed earlier in 1987 were used in the WCC 1989 study. The uncertainty in the source models and attenuation relationships in these studies was embedded in the 1989 study.

The overall site plan indicates that the two sites (Sites 1 and N) are relatively close to each other. A comparison of the results for these two sites showed that there is a similarity in the annual probability of exceedance between the two sites. The hazard curves were extrapolated to an annual exceedance frequency of 1E-07. The upper bound at an acceleration of approximately 1.3 g is limited by the mean frequency of 1E-07/yr because values lower than this are of little interest in the tank farm risk assessment.

4.0. SUMMARY OF RADIOLOGICAL SOURCE TERMS

The airborne release and liquid release estimates, in terms of kilograms of material released, are summarized in Table 5 for each release category. Table 6 provides a snapshot of one measure of relative risk in terms of the quantity of material released to the atmosphere between the various release categories. The radiological consequences of these releases are presented in Chap. 6.

5. SOURCE TERMS

The mass and isotopic content of radioactive material released into the atmosphere and/or into the soil column is an important factor in determining consequences and risk. These releases, along with the timing of the release and the parameters that influence the dispersion of these materials in the environment (e.g., release height and the energy associated with airborne releases), are referred to as "source terms." Source terms were developed for each important release category. The airborne source terms, along with meteorological data and relevant demography, were input to atmospheric dispersion codes to determine the health effects associated with airborne releases. Liquid pathway source terms were input to codes that model ground transport and retention to determine long-term health effects resulting from releases into the ground. A similar approach was used for economic risk.

Table 5. Point Estimates of Risk Based on Total Airborne Releases

Release Category	Release Category Freq (1/yr)	Mean Value of Total Release (kg)	Mean Risk (kg/yr)
DCL122	2.26E-06	2.98E+05	6.74E-01
DCL45	5.93E-06	4.21E+04	2.50E-01
DCLLK	1.19E-03	8.95E+01	1.06E-01
LSP	1.57E-01	6.10E-01	9.58E-02
HEPAL	2.89E-01	2.20E-01	6.36E-02
DCH	6.98E-04	8.95E+01	6.24E-02
LSPRY	4.52E-04	6.98E+01	3.16E-02
SSP	1.81E+00	1.70E-02	3.08E-02
DCHORG	1.55E-04	1.79E+02	2.77E-02
DCL12	7.91E-06	3.04E+03	2.40E-02
HEPAH	5.07E-03	2.90E+00	1.47E-02
BPH	8.52E-03	1.40E+00	1.19E-02
SSPRY	8.59E-03	1.26E+00	1.08E-02
BPL	7.04E+00	1.11E-03	7.81E-03
DCL4	1.03E-05	5.29E+02	5.45E-03
DCVHI	2.09E-07	3.63E+02	7.59E-05
DCVHO	1.54E-08	4.09E+03	6.29E-05
DCVH	2.71E-07	1.78E+02	4.81E-05
DCVHF	4.93E-08	3.63E+02	1.79E-05
SLK	5.33E-01	0.00E+00	0.00E+00
LLKSST	5.59E-02	0.00E+00	0.00E+00
LLKDST	1.10E-02	0.00E+00	0.00E+00

Table 6. Total Quantities of Material Released to the Environment

Release	Airborne Releases (kg)														Liquid Release (kg)		
	Short-Term, Energetic Release				Short-Term, Ground-Level Release				Long-Term, Ground-Level Release								
	Low Value	Mean Value	High Value	Mean Release Duration	Low Value	Mean Value	High Value	Mean Release Duration	Low Value	Mean Value	High Value	Mean Release Duration	Low Value	Mean Value	High Value		
Category	(10th %)		(90th %)		(10th %)		(90th %)		(10th %)		(90th %)		(10th %)		(90th %)		
BPL	--	--	--	--	8.95E-05	1.11E-03	2.21E-03	8 h	--	--	--	--	--	--	--		
BPH	--	--	--	--	0.087	1.4	3.166	8 h	--	--	--	--	--	--	--		
HEPAL	--	--	--	--	0.03	0.22	0.48	10 min	--	--	--	--	--	--	--		
HEPAH	0.84	2.88	5.64	10 min	--	--	--	--	--	--	--	--	--	--	--		
DCH	3.39	10.83	19.73	10 min	3.39	14.06	29.34	8 h	4.8	64.6	156.2	2 d	--	--	--		
DCL4	--	--	--	--	10	59.84	131.52	8 h	30.48	469.52	1108	3 d	1.59E+05	1.06E+06	2.29E+06		
DCL12	--	--	--	--	30.12	179.64	394.56	8 h	197.64	2856.24	6714.24	6 d	1.39E+06	3.18E+06	5.34E+06		
DCL45	--	--	--	--	112.95	674.1	1479.6	8 h	3001.5	41450.4	97206.3	23 d	8.18E+06	1.20E+07	1.60E+07		
DCL122	--	--	--	--	306.22	1827.56	4011.36	8 h	21740.4	296479.52	696105.16	60 d	2.76E+07	3.32E+07	3.80E+07		
DCVH	26.87 (Cs Eh)	98.43(Cs Eh)	198.69 (Cs Eh)	30 min	3.4	14.06	29.48	8 h	1.42	64.98	158.65	2 d	--	--	--		
DCVHI	137.73 (Cs Eh)	283.77 (Cs Eh)	447.01 (Cs Eh)	30 min	3.4	14.06	29.45	8 h	1.42	64.96	158.35	2 d	--	--	--		
DCVHF	137.73 (Cs Eh)	283.77 (Cs Eh)	447.01 (Cs Eh)	30 min	3.4	14.06	29.45	8 h	1.42	64.96	158.35	2 d	--	--	--		
DCVHO	761.27 (Cs Eh)	4007.6 (Cs Eh)	8068.9 (Cs Eh)	30 min	3.4	13.99	29.34	8 h	3.51	64.38	154.5	2 d	--	--	--		
DCLLK	3.39	10.83	19.73	10 min	3.39	14.06	29.34	8 h	11.58	89.46	205.28	2 d	3.41E+04	9.51E+05	1.41E+06		
DCHORG	10.55(Cs Eh)	98.08(Cs Eh)	229.87(Cs Eh)	30 min	2.22	14.26	32	8 h	0.8	66.18	163.57	2 d	6.80E+05	7.55E+05	8.31E+05		
SSPRY	--	--	--	--	0.07	1.26	2.85	15 min	--	--	--	--	1.98E+01	9.82E+01	2.08E+02		
LSPRY	--	--	--	--	4.12	69.82	149.49	8 h	--	--	--	--	5.80E+02	5.46E+03	1.22E+04		
SLK	--	--	--	--	--	--	--	--	--	--	--	--	1.14E+04	3.42E+04	5.68E+04		
LLKSST	--	--	--	--	--	--	--	--	--	--	--	--	8.52E+04	2.04E+05	3.12E+05		
LLKDST	--	--	--	--	--	--	--	--	--	--	--	--	4.09E+05	1.11E+06	2.50E+06		
SSP	--	--	--	--	5.70E-03	0.02	0.03	8 hr	--	--	--	--	5.70E+02	1.70E+03	2.84E+03		
LSP	--	--	--	--	0.21	0.61	1.15	8 hr	--	--	--	--	2.07E+04	6.11E+04	1.15E+05		

Notes: *The total release of each radionuclide is equal to the product of the numbers listed in this table and the concentration (Ci/kg) of* radionuclide in the released material.
Amounts shown for Release Categories DCL4, DCL12, DCL45, and DCL122 are the totals for all tanks.
Cs Eh = Cesium enhanced

There is a basic difficulty in trying to combine the risks of population health consequences via the atmospheric and liquid pathways. Airborne releases typically involve transport times to receptors and exposure times to the passing cloud of minutes to hours. The population at risk and the exposure doses for various accident scenarios can be determined with reasonable accuracy based on dispersion modeling, current census data, and evacuation scenarios (if any). In contrast, the releases of liquids into the soil column can involve transport delay times to receptors of hundreds or even thousands of years. These delay times introduce substantial uncertainty in quantifying future health effects because they must be based on projections from current population distributions and lifestyles. In addition, there is considerable uncertainty involved with the current models for vadose zone and groundwater transport. This modeling is an essential element in the prediction of groundwater pathway health effects involving future generations.

Philosophical questions arise as well; e.g., how do you balance the importance of health effects thousands of years in the future against the priorities and concerns of today? The approach used here was to report the long-term doses and risks from the groundwater transport pathways separate from the doses and risks from the airborne transport pathway. Thus, , two sets of source terms were calculated for those release categories that involve both an airborne release and a liquid release into the soil column.

In addition to the frequency of the accident-sequence/release category (from the accident-sequence models section), it is important to know the location of the release to perform the consequence calculations described in the consequence assessment section. Because of the large number of tanks at the HTF and the impracticability of performing calculations for each individual tank, it was convenient to group the tanks by location for the source-term definition. As a result, four different source-term compositions were developed to be representative of the tanks in the NE, SE, SW, and NW quadrants of the 200 Area. The radiological source term for a given isotope in each quadrant is the product of the quantity of waste material released and the concentration (Ci/kg) of that isotope in that quadrant. This section describes the development of distributions for the quantities of material released to the environment. These distributions are appropriate for all tanks contributing to the particular release category. Details on the source term/dose modeling are shown in Fig. 3.

6. CONSEQUENCE ASSESSMENT

This section presents the basis for and the results of dose calculations for the source terms given in the previous chapter. For airborne releases, dose estimates were made for the onsite, co-located worker, and offsite populations. In most PSA consequence analyses, only the offsite population (general public) is considered, but because of the large number of workers in the 200 East and 200 West Areas close to the tank farms, it was necessary to consider workers in adjacent facilities as well.

The much longer term liquid pathway doses apply *only* to the offsite populations located along the Columbia River, downstream from the Hanford Site. As will be shown, potential exposures to liquid pathway releases are delayed in time for hundreds of years for some isotopes and thousands of years for others, so using the present population distribution is clearly questionable. Because there is no rational basis on which to predict that far into the future, no attempt was made to do so. It also was assumed that no water for human consumption would be drawn from on-site wells in close proximity to the tank farm locations. Although this assumption may be indefensible over the very long term (many centuries), it does provide a consistent basis for performing the liquid pathway consequence assessment.

The dose calculation procedures used here are similar to those used in the Tank SY-101 PSA. The principal difference is that there are four different sets of radionuclide source-term compositions, corresponding to the contents of tanks in the four quadrants of the 200 Area. Although the primary interest here is in the person-rem population doses and concomitant LCF health effects calculated by AP-RISK, we also have reported maximum individual doses calculated with AI-RISK at various distances.

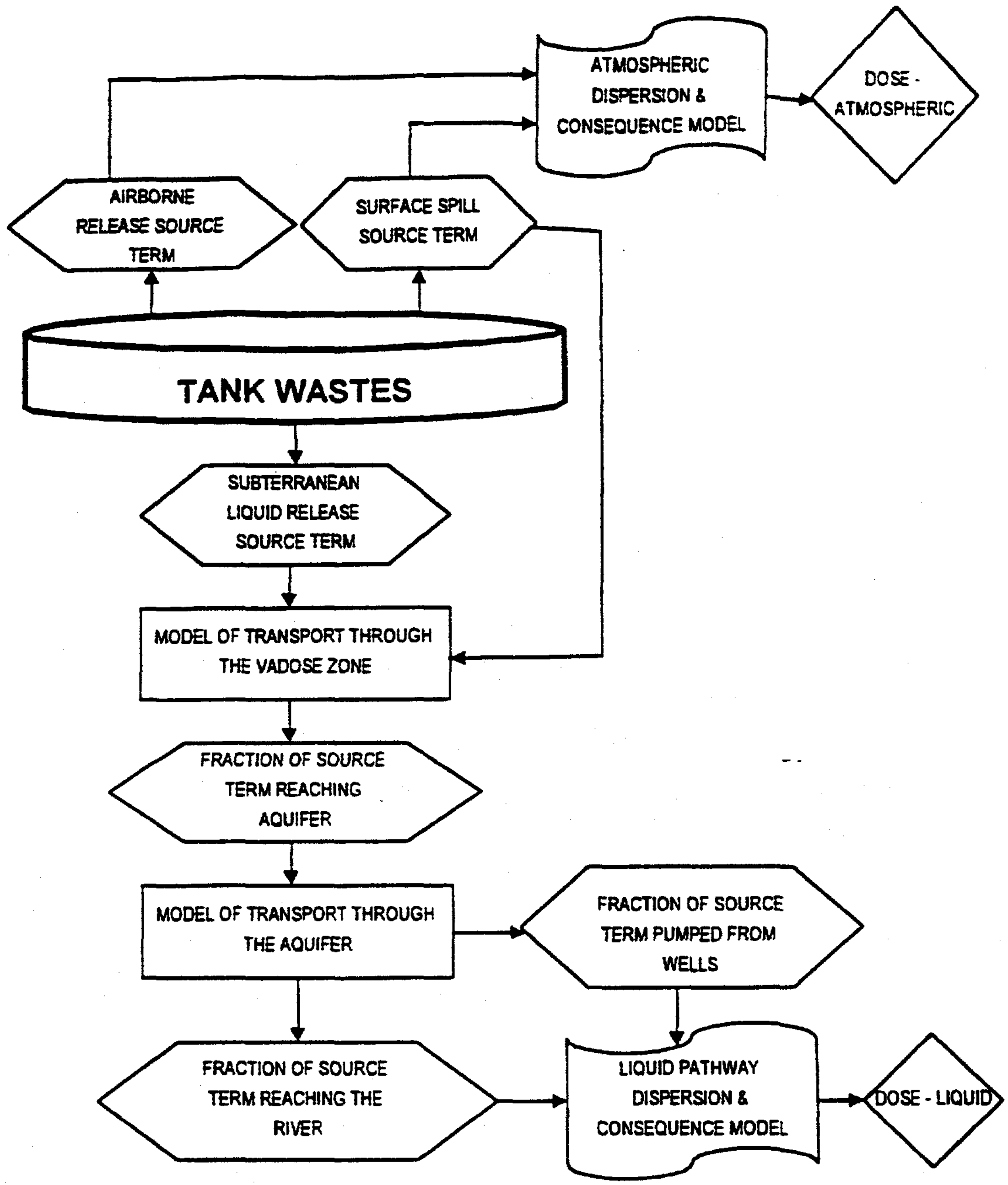

Fig. 3. HTF source term and consequence model assessment.

6.1. Atmospheric Dispersion and Dose Assessment Models

Two related computer codes, AI-RISK (Yuan 1992) and AP-RISK (Yuan 1993), were developed by Los Alamos to perform radiation risk calculations for individuals and for collective populations, respectively. The codes originally were developed to facilitate comprehensive analyses of health consequences, ground contamination, and cleanup associated with possible energetic chemical reactions in high-level waste tanks. Because tank farm accidents can release aerosols containing significant fractions of large particles, AI-RISK and AP-RISK have provisions for environmental transport and dosimetry models for all dispersible particle sizes. Both codes use a tilted Gaussian plume model that tracks the dispersion of particles in five separate size groups or bins. To estimate the range of potential doses to an individual, a cumulative probability distribution of dose values is constructed by using the joint-frequency meteorological data for the site.

Inhalation dose factors were calculated based on values of committed dose equivalent factor per unit intake given in ICRP-30 (ICRP-30 1979). Particle-size-dependent and solubility-class-dependent dose factors for various radionuclides (based on ICRP-30) were used to calculate the resulting effective dose equivalent (EDE). In addition to the acute accident dose, the codes calculate appropriate long-term offsite doses (50 yr) resulting from continuous ingestion of contaminated food and water. The codes also calculate the long-term occupational dose (50 yr) resulting from post-accident occupancy of a partially contaminated (assuming clean-up to a Protective Action Guideline (PAG) level of 5 rem over 50 yr) work place, the dose contributors being ground shine and the inhalation of resuspended particulate contamination. This dose contribution is based on user-specified site occupancy factors and post-accident cleanup criteria. Both codes also estimate the potential health effects from calculated doses based on ICRP-recommended models and methodology. They are presented as lifetime probabilities of (1) latent cancer mortality, (2) genetic effects, or (3) acute mortality, depending on the dose level.

6.2. Equivalent Release Quantities

As discussed in the source term section and shown in Table 6, airborne releases can be characterized by three time frames: short-term energetic (occurring in less than 2 h), short-term (occurring in less than 8 h), and long-term (occurring from 8 h to 60 days). In AP-RISK, the long-term releases are simulated by a series of short-term (2-h) releases over the appropriate time span for the particular scenario. This is implemented in the code by a Monte Carlo simulation in which the normalized 2-h dose vs probability curve, based on the meteorological data, is repeatedly sampled for the total release time to obtain the dose for the longer duration releases.

The long-term, ground-level releases were considered only in the evaluation of the offsite population doses because the onsite personnel would not be permitted to return if there was a release lasting for days.

6.3. Maximum Individual Doses

Although not directly used in the population dose consequence assessment, dose factors for individual onsite receptors at 100 m, 1 km, 5 km, 10 km, and 15 km are presented in Table 7 for reference purposes. They are the acute doses, received *during cloud passage* at the plume centerline, corresponding to a release quantity of 1 kg. To obtain the maximum individual doses corresponding to the various release quantities, it is only necessary to obtain the product of the appropriate release quantity (Table 6) and the dose factor (Table 7). Note that the factors for the elevated (fire) release should be used for categories DCVH, DCCVHI, DCVHF, DCVHO, and DCHORG and that the releases for the earthquake categories (DCL4, DCL12, DCL45, and DCL122) are for multiple tanks rather than a single tank. The major contributor to the dose factors listed in Table 7 is the transuranic isotopes via the inhalation pathway.

Table 7. Acute Individual Doses (1-kg Release)

Quadrant	Distance from Release Point (km)	Ground (rem)		Elevated, Fire (rem)	
NE		50%	95%	50%	95%
	0.1	1.35E-01	8.00E-01	2.15E-04	4.93E-03
	1	2.81E-03	2.81E-02	9.64E-05	1.30E-03
	5	2.44E-04	2.24E-03	1.38E-05	2.56E-04
	10	8.48E-05	8.19E-04	6.00E-06	1.15E-04
	15	4.94E-05	4.59E-04	3.72E-06	6.99E-05
SE					
	0.1	1.19E+00	7.07E+00	1.46E-03	3.59E-02
	1	2.49E-02	2.50E-01	5.48E-04	9.86E-03
	5	2.16E-03	2.00E-02	9.32E-05	1.99E-03
	10	7.51E-04	7.31E-03	4.36E-05	8.95E-04
	15	4.38E-04	4.06E-03	2.80E-05	5.46E-04
SW					
	0.1	3.66E-01	2.18E+00	5.26E-04	1.23E-02
	1	7.67E-03	7.72E-02	2.18E-04	3.32E-03
	5	6.67E-04	6.19E-03	3.32E-05	6.66E-04
	10	2.31E-04	2.26E-03	1.52E-05	3.00E-04
	15	1.35E-04	1.25E-03	9.52E-06	1.83E-04
NW					
	0.1	2.52E-02	1.50E-01	5.78E-05	1.23E-03
	1	5.26E-04	5.27E-03	2.92E-05	3.04E-04
	5	4.57E-05	4.21E-04	3.53E-06	5.98E-05
	10	1.59E-05	1.54E-04	1.49E-06	2.68E-05
	15	9.25E-06	8.52E-05	8.96E-07	1.63E-05

The highest individual doses result from the large earthquake (DCL122). None of the release categories would cause a prompt fatal dose at 100 m. Because all the co-located workers considered in the dose calculations are at distances greater than this and have the benefit of building shielding, no fatalities are expected in this group.

6.4. Exposure to Hazardous Chemicals

In addition to radionuclides, the tanks contain a number of chemicals that are potentially harmful to humans. If these chemicals are released through the vadose zone and the underground aquifer streams, they would ultimately reach and contaminate the Columbia River water. This release of the chemicals to the river could occur decades after the actual spill/release of the tank contents to the ground. The contaminated river water can lead to a toxicological dose if it exceeds the safe concentration levels and is consumed by surrounding human population. Accordingly, a scoping hazard analysis was performed to evaluate the potential hazards of the potential chemical exposure. The purpose of the scoping analysis was to determine and identify if there is a need to perform a detailed chemical dispersion analysis and hazard evaluation for the tank.

Hazardous chemical contamination of the Hanford Site groundwater and the Columbia River was examined comprehensively in the 1986 Hanford Environmental Impact Statement (EIS). This study evaluated the effects of potential leakage from all Hanford SSTs and found that hazardous chemical concentrations in the Columbia River remained well below Environmental Protection Agency (EPA) drinking water standards for all remediation scenarios under all site conditions. The EIS also showed that groundwater within the current site boundaries would, over time, show hazardous chemical concentrations well above EPA standards with no tank remediation.

Because large leaks from DSTs were not evaluated explicitly in the EIS, a scoping analysis of the potential for contamination of the Columbia River was performed for Tank SY-101. This analysis confirms that leaks from DSTs represent no threat to the Columbia River based on US EPA maximum contaminant levels for drinking water. Because site boundaries were assumed to remain as is for this evaluation (as discussed in the initiating events section), no further analysis of hazardous chemical risk was performed, and no health effects from hazardous chemical releases are included in the results reported here.

7. RESULTS AND CONCLUSIONS

The final results of the PSA performed for the HTF are the unconditional risk curves. Risk curves present the relationship between the frequency of occurrence of radionuclide release events and the level of damage sustained as a result of the release; they are presented as complementary cumulative distribution functions (CCDFs) for total health and economic consequences and for those release categories that contribute significantly to these risk indices. In addition, an uncertainty quantification was performed to generate risk bands (i.e., percentile curves) for the total unconditional health effects for both on-site and off-site receptors.

The health risk curve assembly process involved integrating the release category frequency distributions and the conditional risk curves corresponding to each release category. The release category frequency distributions were generated using the RISKMAN® personal computer software package. The mean value and 5th, 50th, and 95th percentiles of the release category distributions were used in the development of risk curves for health and economic consequences.

7.1. Health Risk Results

7.1.1. Airborne Releases. The consequences of airborne releases were quantified for two receptor populations, on site (i.e., co-located workers) and the off-site public. The risk curve assembly process outlined here is applicable to both population groups.

To facilitate the calculation of consequences, the release quantity distributions determined in the consequence assessment section for the various release categories were replaced with three-point discrete probability distributions. The quantities used for the discrete distributions were the 10th, mean, and 90th percentile of the more detailed distributions calculated in the consequence assessment section. The probability weights assigned to these three values were as follows.

Release Quantity	Probability Weight
10th Percentile	0.2
Mean	0.6
90th Percentile	0.2

The radioisotope concentration in a release was based on the location of the release within the tank farm. The site was divided into quadrants: northwest, northeast, southwest, and southeast. As described in Sec. 4, representative radioisotope concentrations and doses were generated for each quadrant. Table 8 shows the fraction of the release category frequency that results from tanks in each of the four quadrants.

Table 8. Percentage Contributions to Release Categories by Quadrant

Release Category	Frequency (per yr)	Per Cent Contribution by Quadrant			
		Northeast	Southeast	Southwest	Northwest
BPL	7.04E+0	5.83%	58.06%	30.28%	5.83%
SSP	1.81E+0	10.96%	48.91%	35.14%	4.98%
HEPAL	2.89E-1	0.00%	61.63%	38.37%	0.00%
SLK	5.34E-1	38.18%	12.68%	17.58%	31.55%
LSP	1.57E-1	13.92%	44.30%	35.44%	6.33%
LLKDST	1.09E-2	0.00%	89.29%	10.71%	0.00%
LLKSST	5.59E-2	19.64%	21.43%	39.29%	19.64%
SSPRY	8.59E-3	13.92%	44.30%	35.44%	6.33%
BPH	8.52E-3	0.00%	100.00%	0.00%	0.00%
HEPAH	5.07E-3	0.00%	0.00%	100.00%	0.00%
DCH	6.98E-4	0.00%	0.00%	100.00%	0.00%
LSPRY	4.52E-4	13.92%	44.30%	35.44%	6.33%
DCLLK	1.18E-3	23.02%	14.89%	62.09%	0.00%
DCL4	1.03E-5	26.85%	17.45%	28.86%	26.85%
DCL12	7.91E-6	26.85%	17.45%	28.86%	26.85%
DCL45	5.93E-6	26.85%	17.45%	28.86%	26.85%
DCHORG	1.55E-4	0.00%	100.00%	0.00%	0.00%
DCL122	2.26E-6	26.85%	17.45%	28.86%	26.85%
DCVH	2.71E-7	21.59%	35.23%	27.27%	15.91%
DCVHI	2.09E-7	13.24%	23.53%	30.88%	32.35%
DCVHF	4.93E-8	68.75%	18.75%	0.00%	12.50%
DCVHO	1.54E-8	20.00%	20.00%	20.00%	40.00%

Probability Weights for Release Category BPL Conditional Consequence Curves				
Release Quantity (probability)	**Tank Farm Quadrant (and Conditional Likelihood)**			
	NE (0.06)	**SE (0.58)**	**SW (0.30)**	**NW (0.06)**
10th percentile (0.2)	0.012	0.116	0.06	0.012
Mean (0.6)	0.036	0.348	0.18	0.036
90th percentile (0.2)	0.012	0.116	0.06	0.012

Possible releases of material from four locations (with unique release concentrations), with three possible release quantities at each location, led to the development of 12 conditional consequence curves for each release category. The probability weight associated with each of the 12 curves is a function of the probability weight of the release quantity and the conditional probability that the event occurred in the given quadrant. For example, the list below Table 8 shows the probability weights associated with each of the 12 conditional consequence curves developed for release category BPL.

Not all release categories had frequency distributed throughout all four quadrants of the tank farm. For example, the frequency of Release Category DCH comes entirely from BURP events occurring in Tank SY-101, which is located in the southwest quadrant. Therefore, conditional consequence curves for DCH were needed for the southwest quadrant only.

Calculation of a probability distribution for the exceedance frequency of a given damage (person-rem) level requires the merging of the 12 weighted conditional consequence curves and the release category frequency distribution for each release category. The distribution for the unconditional exceedance frequency per year of damage level x for Release Category A is calculated as a product of the frequency distribution for Release Category A and the conditional exceedance frequency distribution at damage level x. The conditional exceedance frequency distribution for damage level x is a 12-bin discrete distribution (one bin for each of the conditional consequence curves), where the bin probabilities correspond to the probability weight assigned to each curve. To generate the mean risk curve with uncertainty bands for Release Category A over all damage levels, probability distributions for the exceedance frequency must be calculated at a number of damage levels to sufficiently define the shape of the curve.

The CCDFs for total offsite and onsite risk were calculated by summing the appropriate probability distributions for exceedance frequencies at corresponding damage levels for all contributing release categories. The 5th, 50th, and 95th percentile curves and mean risk curves were calculated for total offsite and total onsite consequences. Figure 4 presents mean curves for total offsite consequences and for the seven most risk-significant release categories. Figure 5 shows the 5th, 50th, and 95th percentile total offsite consequence curves. Figure 6 presents mean curves for total onsite consequences and for the seven most risk-significant release categories. The 5th, 50th, and 95th percentile total offsite consequence curves are presented in Fig. 7.

7.1.2. Liquid Releases. The procedure described above for airborne releases also was used to develop health effect consequence curves for liquid releases. Because there are no onsite health effects associated with subterranean releases, results are presented for offsite consequences only. The mean risk was calculated for each release category involving a liquid release. Some of these release categories, such as DCLLK, cause an airborne release as well as a subterranean release. Risks as a result of the airborne component of these release categories were calculated. As shown, the radiation exposure risks posed by subterranean liquid releases are significantly lower than those for airborne releases. They also are delayed significantly in time compared with doses from airborne releases. Figure 8 presents mean curves for total offsite consequences as a result of subterranean releases and for the seven most risk-significant liquid release categories. The 5th, 50th, and 95th percentile total offsite consequence curves for liquid releases are presented in Fig. 9.

7.1.3. Accident Sequences Important to Health Risk. The mean total offsite health risk of 20.2 person-rem/yr can be divided into five general accident-sequence groups.

1. Structural failures of SSTs caused by seismic events contribute 52% of the total risk. These events are characterized as medium- to high-intensity, low-frequency seismic events that fail multiple SSTs simultaneously.

2. Accidents during waste transfer operations account for about 18% of the total risk. The conditional consequences of these scenarios are generally low, but their frequency of occurrence is relatively high.

3. Another 18% of the total is a result of flammable gas combustion events. These include the BURP event for Tank SY-101 and hydrogen combustion in the dome spaces of a number of SSTs as discussed in Sec. 4.2.1. These events are predicted to occur relatively infrequently, but their consequences can be severe.

4. Failures in ventilation systems contribute another 11% of the total risk. These events include loss of active ventilation, HEPA filter failures, and ventilation line breaches in active or passively ventilated tanks. These are relatively high-frequency events with minor consequences.

5. Risks from an aircraft crashing into one of the 177 tanks contribute less than 0.1 of 1% of the total risk of offsite health effects. Releases from these events have very high conditional consequences, but their frequency of occurrence is very, very low.

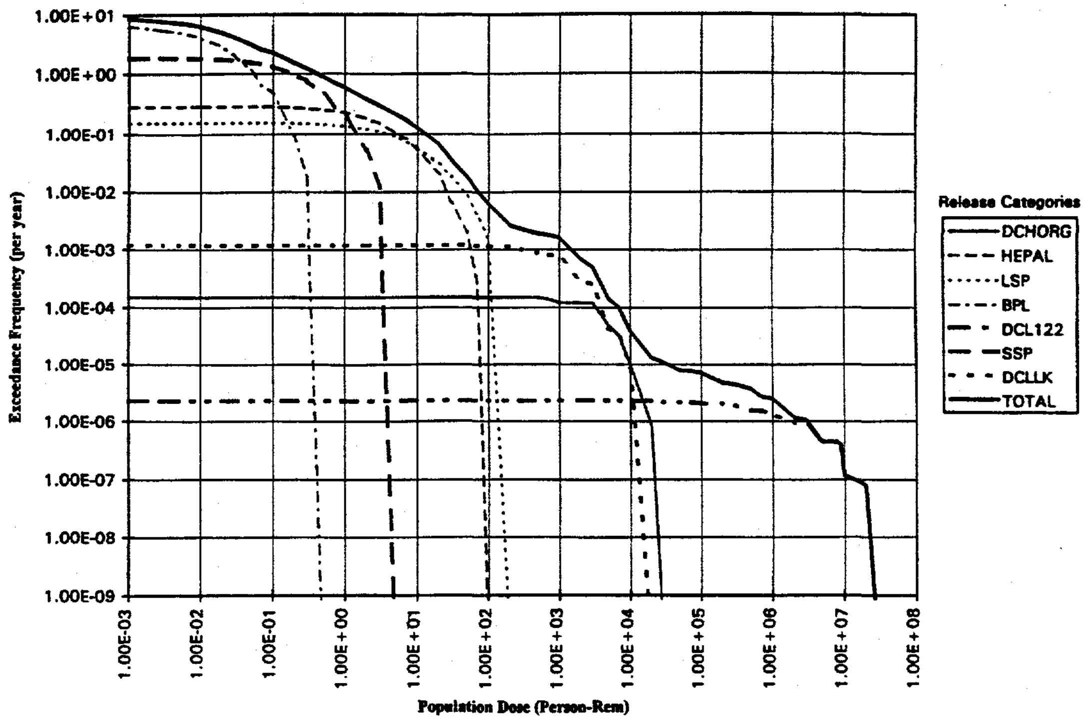

Fig. 4. Offsite total mean unconditional consequences.

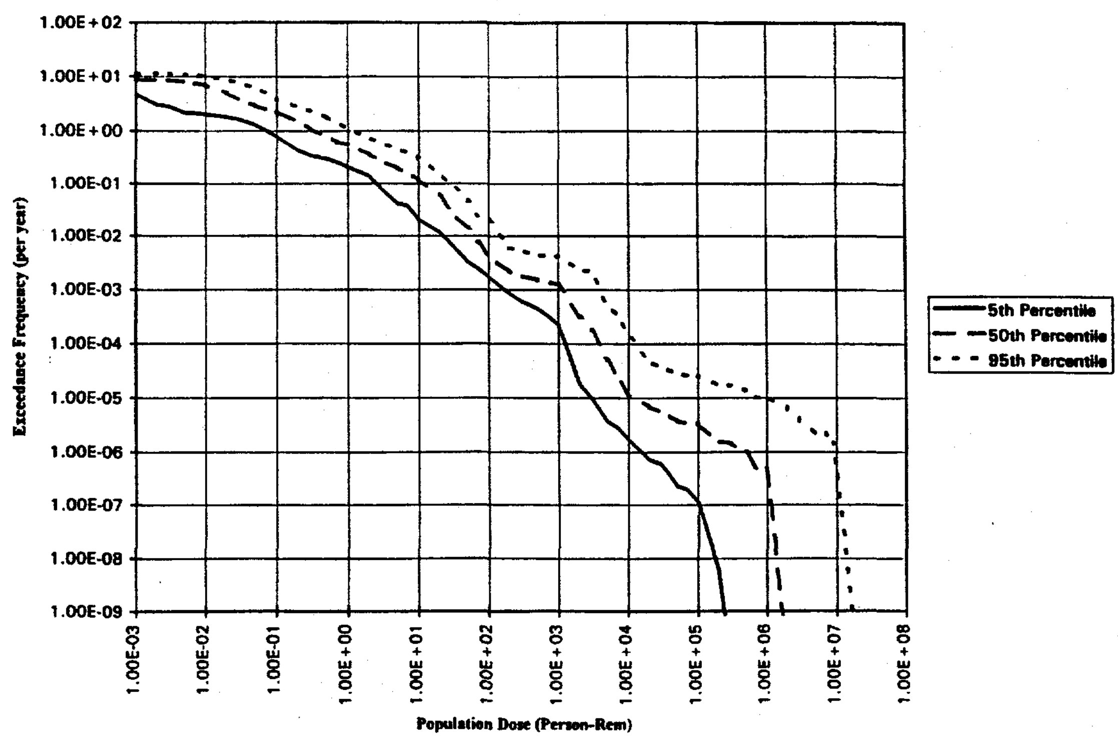

Fig. 5. Offsite total unconditional consequences.

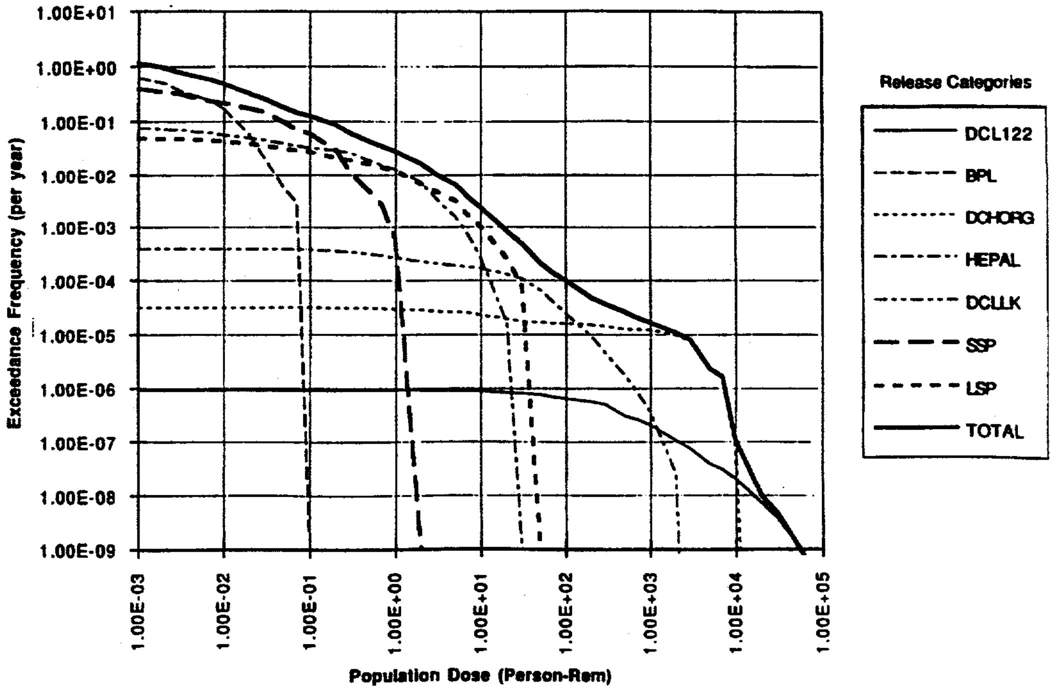

Fig. 6. Onsite total mean unconditional consequences.

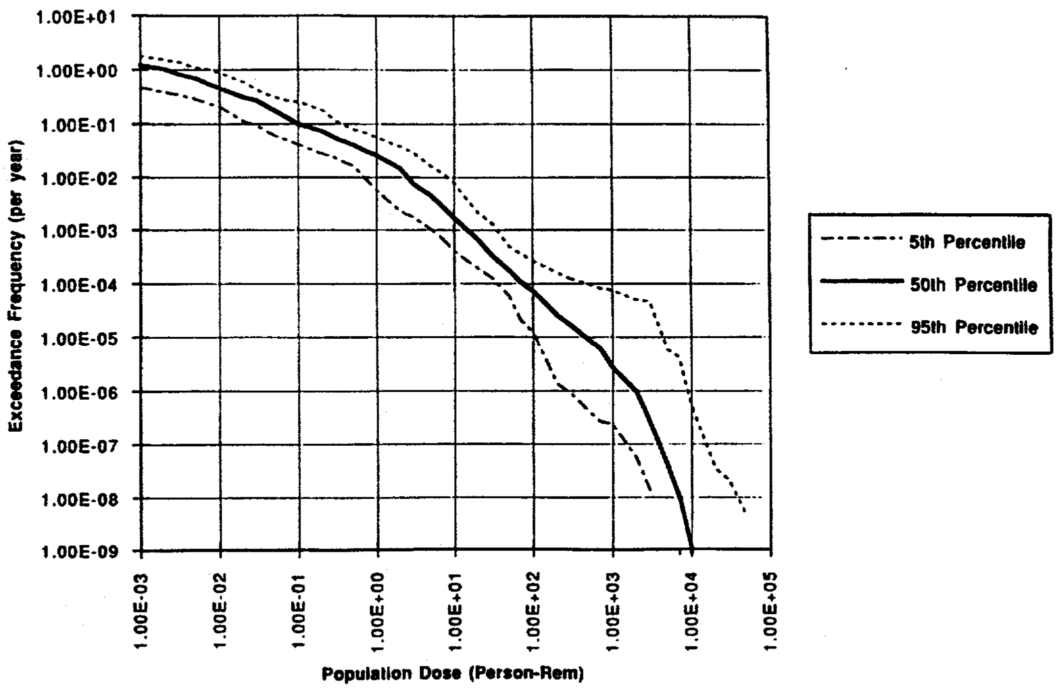

Fig. 7. Onsite total unconditional consequences.

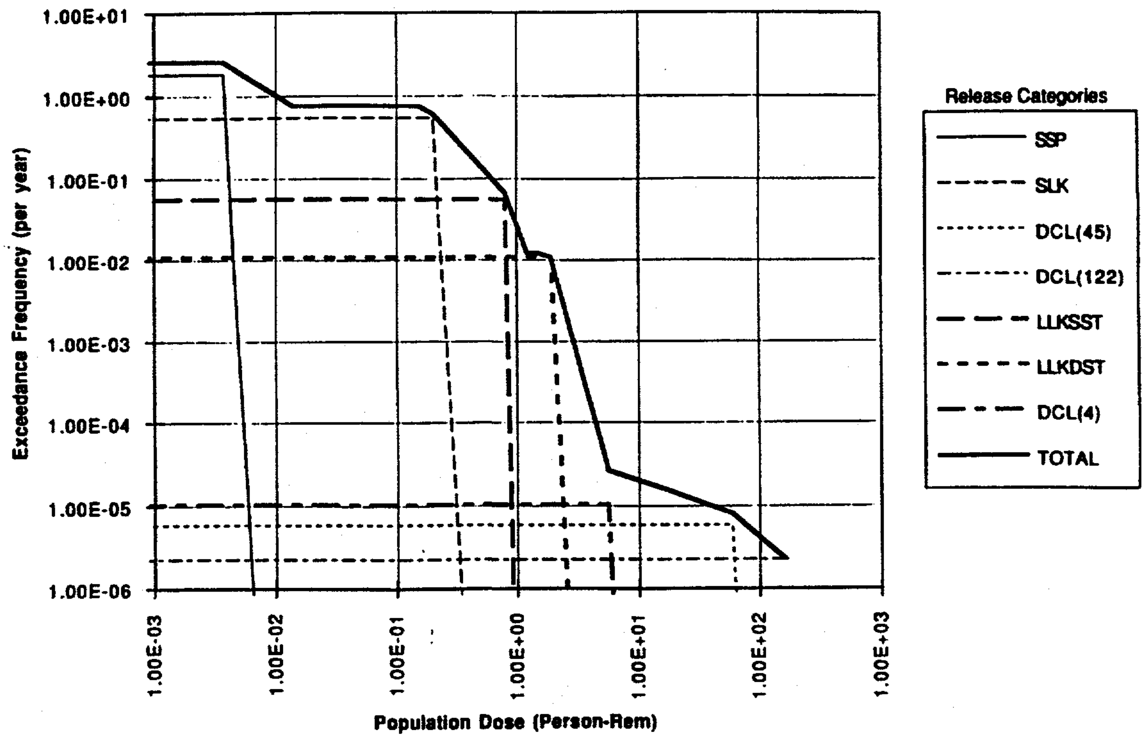

Fig. 8. Liquid total mean unconditional consequences.

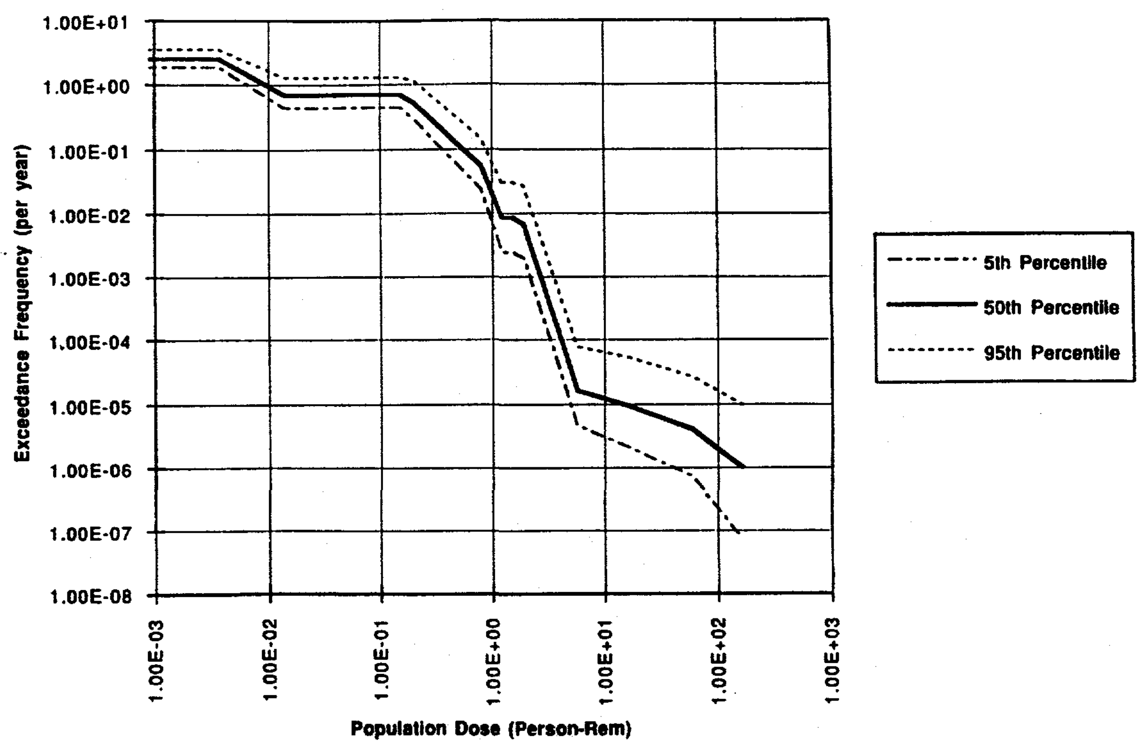

Fig. 9. Liquid total unconditional consequences.

Although the frequency of seismic events is very low, the involvement of multiple tanks and the potential for extended releases until recovery actions can be completed caused the calculated consequences to be sufficiently large to rank first for overall health risk. Two points are important to remember in comparing risks from low-frequency seismic events with higher frequency operational events. The frequency of large earthquakes is, by definition, difficult to predict. Also, the phenomena modeled in the source term analyses for these releases exhibit wide ranges of possible outcomes. Second, the damages postulated from radionuclide releases following a seismic event pale in comparison with the direct damage that would be caused by a large earthquake in the Hanford area.

7.1.4. Tank Importance Based on Health Risk. Based on the relative contributions of each tank to each release category, the mean release quantity for each release category, and the average radioisotope concentrations for each quadrant of the tank farm, the mean risk associated with each of the 177 high-level waste tanks can be calculated. Rankings of the most risk-significant tanks and groups of tanks contributing to off-site and on-site health effects are presented in this section.

Table 9 is a list of the 177 waste tanks sorted by mean off-site health consequences. Of the 177 waste tanks, only 35 tanks individually contribute more than 1% to the total offsite health risk. These 35 tanks constitute approximately 58% of the total risk. The leading tank relating to offsite risk (at 5.5% of the total) is Tank SY-101. The relatively high risk-rank results of Tank SY-101 are primarily because of the formation and periodic release of hydrogen gas (i.e., the BURP initiating event). Of the 1.12 person-rem/yr attributable to Tank SY-101, 1.03 (or 93%) is caused by the BURP initiating event. Operation of the mixing pump installed in Tank 101-SY in July 1993 appears to have precluded such BURP events. Without the BURP event, the mean annual risk for Tank SY-101 would drop to 0.107 person-rem/yr, and the tank ranking would drop to number 78 in the list.

The number two tank with respect to offsite risk is Tank C-103, contributing 4.8% of the total for offsite health effects. The dominant risk scenario for Tank C-103 is the generation of hydrogen gas in the waste, with the gas accumulating to a concentration greater than the LFL in the dome space and igniting. The hydrogen burn is assumed to ignite the floating organic layer known to exist in the tank. The tank is assumed to fail as a result of the hydrogen combustion. The release category and source terms for this scenario (DCHORG) account for the increase in the airborne release resulting from the pool fire. This scenario accounts for 0.669 of the 0.960 person-rem/yr consequences (70%) attributable to Tank C-103.

Tank AX-101 ranks third with respect to offsite risk with consequences of 0.875 person-rem/yr (4.3% of the total offsite consequences). As was the case with Tanks SY-101 and C-103, the dominant cause of releases from Tank AX-101 is the generation, accumulation, and ignition of hydrogen gas within the tank leading to a dome collapse. This scenario accounts for 67% of the risk associated with Tank AX-101.

SSTs A-102, S-102, U-105, and S-112 are listed in Table 9 as the fourth, fifth, sixth, and seventh tanks with respect to offsite health risks. These tanks, as a group, account for 8% of the total offsite health consequences. Hydrogen generation, accumulation, and ignition scenarios causing dome collapse are the leading contributors to offsite consequences for all four of these tanks, accounting for 61% of the consequences attributable to these four tanks. The remaining 166 tanks listed in Table 9 contribute 77% of the offsite health risk.

Summing the risk by tank type from Table 9 yields a total of 4.85 person-rem/yr for 28 DSTs and 15.4 person-rem/yr for 149 SSTs. Thus, even though the total risk from DSTs is about one-third of that for SSTs, the per-tank risk for a DST is about 70% higher than the risk from an SST. One of the reasons for this is that all of the DSTs are active tanks and, as such, are susceptible to releases that occur as a result of waste transfer activities, such as large and small spill and spray events. Only about one-third of the SSTs are active. Therefore, a disproportionate percentage of the risk associated with waste transfer accidents is included with the DSTs. Also, most of the DSTs are located in the southeast quadrant of the tank farm, where the average radioisotope concentrations and worker density used in the consequence assessment are the most severe from a dose standpoint.

8. INSIGHTS AND CONCLUSIONS

The results of this study are particular to the Hanford Site, and they should not be applied to other sites having waste tanks.

Health risks to co-located workers (on site) and the public (off site) from airborne releases in the Hanford high-level waste tanks are very low, about 0.014% and 0.027% of the exposure from background radiation for the average on-site co-located worker and the public, respectively.

The highest ranking class of accidents was found to be seismic events, contributing about half of the total mean value off-site risk. Although the frequency of these events is very low, the involvement of multiple tanks and the potential for extended releases until recovery actions can be completed caused the calculated consequences to be sufficiently large to rank first for overall health risk.

After seismic events, scenarios contributing to health risk are high-frequency, low-consequence events, especially the airborne component of surface spills during waste transfers. Although there may be conservatism in the modeling of transfer spill events, improvements in data and modeling would not be expected to change the scenarios' relative position as important risk contributors. This finding implies that the potential risks of sluicing operations should be examined carefully as part of the preparations for waste retrieval.

Flammable gas accumulation and ignition are important risk contributors, even with elimination of BURP events in Tank SY-101. The results of this analysis indicate that flammable gas accumulation and ignition in passively ventilated tanks is the most likely scenario capable of producing significant tank damage and a significant radionuclide release.

Risks from liquid pathway releases were shown to be significantly lower than those for airborne releases. This assessment was made assuming that the Hanford Site remains a restricted area. This means that only off-site consequences from the long-term transport of radionuclides to the Columbia River were evaluated. The conclusion that liquid pathway risks are very small is expected to remain valid for other site-use scenarios as long as the direct pumping and consumption of contaminated groundwater is prevented.

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