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Hanford Tank Vapor Assessment Report

October 30, 2014

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Hanford Tank Vapor Assessment Report

October 30, 2014

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LIST OF ACRONYMS AND ABBREVIATIONS

ACGIH	American Conference of Governmental Industrial Hygienists
ARP	Actinide Removal Process
CAM	Continuous Air Monitor
CDC	Centers for Disease Control and Prevention
CFD	Computational Fluid Dynamics
CHAT	Chemical Hazard Awareness Training
CIH	Certified Industrial Hygienist
COPC	Chemical of Potential Concern
CSP	Certified Safety Professional
CVST	Chemical Vapor Solutions Team
DABT	Diplomate of the American Board of Toxicology
DNFSB	Defense Nuclear Facilities Safety Board
DOD	Department of Defense
DOE	Department of Energy
DP	Differential Pressure
DR	Dose-Response
DRI	Direct-reading Instrument
DST	Double Shell Tank
EA	Exposure Assessment
EPA	Environmental Protection Agency
HAB	Hanford Advisory Board
HAMTC	Hanford Atomic Metal Trades Council
HEPA	High Efficiency Particulate Air
HLW	High-level Waste
HP	Health Physics
IH	Industrial Hygiene
ISMS	Integrated Environment, Safety, and Health Management System
LOI	Line(s) of Inquiry
MPH	Master in Public Health
NDMA	N-nitrosodimethylamine
NIH	National Institutes of Health
NIOSH	National Institute for Occupational Safety and Health
NRC	National Research Council
OEL	Occupational Exposure Limit
OEL-C	Occupational Exposure Limit-Ceiling
ORP	Office of River Protection

OSHA	Occupational Safety and Health Administration
OSTI	Office of Scientific and Technical Information
PE	Professional Engineer
PEL	Permissible Exposure Limit
PER	Problem Evaluation Request
PNNL	Pacific Northwest National Laboratory
PPE	Personal Protective Equipment
RCE	Re-usable Contaminated Equipment
RCH	Risk Characterization
RCO	Risk Communication
RCRA	Resource Conservation and Recovery Act
RM	Risk Management
RNS	Reactive Nitrogen Species
ROS	Reactive Oxygen Species
rVOC	Reactive Volatile Organic Compound
SC	Site Characterization
SCBA	Self-contained Breathing Apparatus
SEG	Similar Exposure Group
SOEN	Shift Office Event Notification
SRNL	Savannah River National Laboratory
SRNS	Savannah River Nuclear Solutions, LLC.
SST	Single Shell Tank
STEL	Short-term Exposure Limit
TAA	Technical Assessment Area
TLV	Threshold Limit Value
TVAT	Tank Vapor Assessment Team
TVIS	Tank Vapor Information Sheet
TWA	Time-weighted Average
TWINS	Tank Waste Inventory System
VCZ	Vapor Control Zone
VOC	Volatile Organic Compound
VRZ	Vapor Reduction Zone
WRPS	Washington River Protection Solutions, LLC.

1.0 EXECUTIVE SUMMARY

This report provides the results of the Hanford Tank Vapor Assessment led by the Savannah River National Laboratory and conducted by a panel of nationally recognized experts in the fields of occupational and environmental health, environmental engineering and science, toxicology, health physics, and industrial hygiene.

This report reflects the scientific and technical opinions of the Tank Vapor Assessment Team (TVAT) based on the TVAT's review of information provided by Washington River Protection Solutions (WRPS), interviews with numerous personnel who work at the site, and observations made during records reviews and site visits. The draft report underwent a factual accuracy review by WRPS and the Department of Energy's (DOE's) Office of River Protection (ORP), and the TVAT has incorporated corrections identified in that factual accuracy review into this report.

After reviewing its charter, the TVAT began the assessment by gathering and reviewing information concerning the health effects reported by employees with potential exposures to Hanford tank farm vapors. This review included evaluating monitoring data, from personal and field monitors, for chemicals thought to be present in the tank farm. The testimony and data provided to the TVAT indicated that the concentrations of chemicals reported as time-weighted averages were not consistent with the health-related symptoms reported. This led the TVAT to develop several plausible scenarios that could explain the relationship between potential exposures in the tank farm environment and the health effects reported by the Hanford tank farm workers.

The TVAT reasoned that if efforts to assay tank vapor emissions and tank farm worker exposures were unsuccessful, then three principal scenarios needed to be considered:

1. Tank vapor emissions and consequent exposures were not occurring.
2. Conditions other than tank vapor exposure were causing the symptoms.
3. The assay methods being employed were inadequate to characterize the tank vapor emissions and tank farm worker exposures.

After reviewing the information provided, conducting focus group meetings with various work groups including a large population of workers with reported exposures, and interpreting engineering data, the TVAT determined that the most likely scenario was that characterization methods (e.g., use of 8-hour time-weighted averages) were inadequate. The TVAT developed a hypothesis that vapors coming out of tanks in high concentration (bolus) plumes sporadically intersected with the breathing zones of workers, resulting in brief but intense exposures to some workers. The TVAT then sought additional data and information to support or refute the hypothesis. The hypothesis was substantiated by computer modeling, which indicated that under certain weather conditions, concentrations approaching 80% of the head space concentration could exist 10 feet downwind from the release point and potentially in workers' breathing zones.

To affirm further the likelihood of a causal linkage between tank vapor exposure and the adverse health effects reported by tank farm workers, the TVAT applied the principles of Hill's Criteria of Causation. Established by English epidemiologist Sir Austin Bradford Hill in 1965, Hill's Criteria of Causation comprise a group of minimal conditions necessary to provide adequate evidence of a causal relationship between an incident and a consequence. Based on the body of data and information the team has examined, analysis of the Hill's criteria strongly suggests a causal link between chemical vapor releases and subsequent health effects, particularly upper respiratory irritation, experienced by tank farm workers. (Appendix C summarizes the TVAT's "Application of the Principles of Hill's Criteria of Causation.")

This causal relationship, however, does not identify the mode or mechanism by which the exposures are generated. The TVAT has provided in this report its professional thoughts and a set of recommendations that presents a means by which the potential of exposure can be reduced in the near term and that defines steps to conclude definitively whether these transient exposures are or are not the primary cause of the reported health effects.

The TVAT conducted the assessment along lines of inquiry in six Technical Assessment Areas: Site Characterization, Exposure Assessment, Dose-Response Assessment, Risk Characterization, Risk Management, and Risk Communication. (See Attachment 2 for the TVAT's "Initial Lines of Inquiry.") Those Technical Assessment Areas align with the fundamental building blocks of risk assessment and risk management delineated by the National Research Council (NRC 2009).

It is notable that the Hanford Tank Vapor Assessment Team (TVAT) was given full access to data and personnel to assess any aspect of the tank vapor issue without influence from WRPS or the ORP. The TVAT's activities have been observed by members of DOE's Office of Enterprise Assessment (EA-32) and by members of the Radioactive Air Emissions Section of the Washington State Department of Health.

Arising from the Technical Assessment Areas was a number of technical issues. The TVAT provides in the report its observations regarding those technical issues. The TVAT makes over 40 recommendations for improvements to the program. These individual recommendations support ten overarching recommendations that reflect overall programmatic issues and incorporate themes identified across multiple Technical Assessment Areas. The TVAT's overarching recommendations (ORs) are:

- OR 1: Hanford site contractor and DOE management actively demonstrate commitment to improve the current program and ultimately resolve the vapor exposure concerns.
- OR 2: Implement measurable benchmarks to assure operational and cultural parity among chemical vapor, flammability, and radiological control programs.
- OR 3: Establish a program to sample proactively the head space of tanks to validate and enhance chemical characterization.
- OR 4: Accelerate development and implementation of a revised industrial hygiene exposure assessment strategy that is protective of worker health and establishes stakeholder confidence in the results for acute as well as chronic exposures.
- OR 5: Modify the medical case evaluation process and reporting procedures to recognize the appropriate uses and limitations of the available monitoring data and other potential exposure information when evaluations are made regarding tank chemical vapor exposures.
- OR 6: To reduce the impacts of bolus exposures, utilize real time personal detection and protective equipment technologies specifically designed to protect individual employees.
- OR 7: Accelerate implementation of tailored engineering technologies to detect and control vapor emissions and exposures experienced in the Hanford tank farms ("tank farm of the future").
- OR 8: Augment the Hanford tank farm industrial hygiene programs to further develop competencies to address the tank vapor exposure issues.
- OR 9: Effectively communicate vapor exposure issues and actions proactively with all stakeholders.
- OR 10: Investigate and pursue external research opportunities and partnerships to address data and technology gaps related to vapor exposure, effects, and mitigation.

The TVAT will continue its assessment for the next several weeks, during which time the TVAT expects to receive the implementation plan for review. The TVAT will provide its comments on the implementation plan in a separate communication.

2.0 INTRODUCTION

BACKGROUND

Hanford Tank Waste

The underground storage tanks on the United States Department of Energy's Hanford Site house 53 million gallons of concentrated radioactive and chemical waste that is the byproduct of the processing and "reprocessing" of nuclear materials for the US weapons programs. Seven major facilities and six flow sheets were used at the Hanford Site to process and reprocess plutonium, uranium, and fission products. Each of the processes used chemicals that added to the inventory of waste stored in the Hanford tanks.

The waste contained in the tanks is commonly referred to as being of three types: highly radioactive sludge and lower level radioactive supernate and saltcake. The high-level waste (HLW) sludges contain concentrations of both radionuclides and chemicals (bismuth, cadmium, chromium, iron, nickel, etc.) at very high levels. Used solvent and complexing agents from separations processes also were discharged to the tanks. Over time and as a result of chemical and radiolytic reactions, the organic moieties have degraded and produced many smaller organic and inorganic molecules.

The waste is stored in carbon-steel underground tanks. There are 177 in total, of which 149 are single shell tanks (SSTs) and 28 are double shell tanks (DSTs). The tanks are arranged in groups referred to as "tank farms." There are seven tank farms in the 200-West Area and 11 in the 200-East Area. The tank volumes range from 50,000 gallons to 1.3 million gallons. The DSTs are equipped with forced ventilation, while the SSTs are passively ventilated through breathing filters.

For many years, work at the tank farms mainly involved monitoring conditions within tanks to ensure corrosion control to preserve the integrity of the tanks and performing routine maintenance. Beginning in the 1970s and re-commencing in the late 1990s, free liquid and interstitial liquid was removed ("pumped") from the SSTs and transferred to the DSTs to limit the amount of free liquid in, and the potential for leakage from, the SSTs. Additionally, over the past several years, the tank farm contractor has been retrieving waste from C-Farm to empty the tanks to achieve eventual closure. The retrieved waste has been transferred to DSTs, with much of the sludge being transferred to AN Farm. As the tank farms necessarily transition from waste monitoring to waste retrieval, the waste is disturbed and "gases" contained within it are likely released.

Hanford Tank Vapors

Concerns about chemical vapor exposures on the Hanford tank farms are not new. The chemical vapor issue has been the subject of assessment efforts accompanied by issuance of formal reports and recommendations over more than 20 years, having originated in 1992 as the subject of a DOE Type B investigation [DOE 1992]. (See Appendix E, "Selected List of Previous Hanford Tank Vapor Assessments.") However, reports from workers of odors and noxious chemical vapors on the Hanford tank farms continue. During a short time span this past spring, more than two dozen tank farm workers received medical attention following exposures on the tank farms to vapors emanating from waste storage tanks or other sources. While most of those workers experienced short-term effects and rapidly returned to work, there is concern about potentially more severe short-term effects as well as potential long-term health effects. With the intent of finally resolving the issue or at least significantly mitigating the problem, Washington River Protection Solutions (WRPS) is re-examining the Hanford tank vapor issue. As part of that evaluation, WRPS has commissioned the Hanford Tank Vapor Assessment Team 2014 to take a broad look at the issue and offer independent analysis and recommendation.

Hanford Tank Vapors Assessment Team Objective

WRPS asked the Savannah River National Laboratory (SRNL) to assemble and lead the Hanford Tank Vapors Assessment Team (TVAT) 2014 to determine the adequacy of the established WRPS program and prevalent site practices to protect workers from adverse health effects of exposure to chemical vapors on the Hanford tank farms.

Hanford Tank Vapor Assessment Team Membership

SRNL assembled and is leading the independent technical review team to evaluate the chemical vapors and odors on the Hanford tank farms. In addition to the SRNL chairman, the team comprises eight individuals from industry, academia, and national chemical associations with nationally recognized expertise and experience in pertinent disciplines. A member of the local Hanford Atomic Metal Trades Council (HAMTC) also is a member of the TVAT to serve as liaison between HAMTC workers and the Assessment Team, ensuring that accurate and relevant information is brought from the job sites to the Assessment Team's meetings and that the Hanford workforce has access to and is aware of the activities of the Assessment Team. (See Attachment 1, "Team Member Qualifications.")

Technical Assessment Areas

Six TVAT sub-teams have evaluated six Technical Assessment Areas (TAAs) to understand, evaluate, and identify potential improvements to the established WRPS program and prevalent site practices. The TAAs have been evaluated both retrospectively (what has been done since previous Hanford tank-vapor assessments) and prospectively (what improvements are needed).

Lines of inquiry were developed to focus the assessment so as to support the overall objective of the review and to obtain complete and pertinent data to inform and underpin the conclusions of the assessment. (See Attachment 2 for the TVAT's "Initial Lines of Inquiry.")

Most TVAT members serve on two or more of the sub-teams both to leverage individual members' expertise and to promote sharing of information among the sub-teams so that overarching assessment observations and recommendations may ultimately be reached. The TAAs are

1. Site Characterization
Site characterization identifies the chemicals or groups of chemicals, their sources, and the pathways of exposure to workers on the tank farms (the sites).
2. Exposure Assessment
Exposure assessment establishes the extent to which exposures to hazards intersect with worker activities, that is, estimates how much of a particular chemical (or particular group of chemicals) workers have been or could have been exposed to during a specific time period as well as how many people have been exposed.
3. Dose-Response Assessment
Dose-response assessment identifies the relationship between the amount of exposure (dose) to a substance and the resulting changes in body function or health (response). This area includes considerations for developing appropriate exposure limits.
4. Risk Characterization
Health risk characterization uses toxicological data combined with information regarding the degree of exposure to predict a particular adverse response in a specific exposure population, such as a workforce.
5. Risk Management
Risk Management identifies and institutes effective ways to protect human health under identified conditions, including consideration of control and remediation methods.

6. Risk Communication

Risk communication promotes exchange of information among on-site and off-site stakeholders as to the likelihood and consequences of adverse events at a site and the steps being taken to manage the risks.

Methods of Inquiry

During two intensive five-day visits to the Hanford site, the TVAT performed the following activities to collect data and information about program definition and field practices. During those site visits, independent observers of the TVAT's activities included members of the DOE (Headquarters) Office of Worker Safety and Health Assessments and members of the Radioactive Air Emissions Section of the Washington State Department of Health.

1. Program Definition

- Studied documents, such as procedures and reports (prior to, during, and following visits)
- Met with and/or received briefings from leadership entities, including:
 - DOE Office of River Protection
 - President, Washington River Protection Solutions
 - Members of the Hanford Advisory Board (HAB)
 - President, Hanford Atomic Metal Trades Council
 - Defense Nuclear Facilities Safety Board (DNFSB) site representative
 - Hanford Challenge Executive Director
 - Washington State Governor's Policy Advisor
- Received programmatic briefings, including:
 - Chemical Vapor Solutions Team (internal improvement team)
 - WRPS Points of Contact in the six Tank Vapor Technical Assessment Areas

2. Field Practices

- Interviewed site personnel in focus groups and individually (Industrial Hygiene Technicians, Operators, Health Physics Technicians, Mechanics, Shift Supervisors, etc.) to provide workers opportunities to offer first-hand information, opinions, and experiences that may not have been documented.
 - 12 Focus Group discussions (~80 site personnel)
 - Worker who had requested interview through Deputy Attorney General (DAG)
 - Engineering about issues raised by worker who had requested interview through DAG
 - Industrial Hygiene technicians and IH program management
- Observe work
 - Toured affected tank farms
 - Observed field Industrial Hygiene sampling and event response to vapor exposure
 - Attended pre-job briefings and observed two Tank Farm jobs

Empirical Assessment

What are commonly called Hill's Criteria of Causation are the minimal conditions needed to establish a causal relationship between potential disease agents and human diseases. The criteria were originally presented by Sir Austin Bradford Hill (1897-1991), British Professor Emeritus of Medical Statistics of the University of London, as a way to determine the causal link between a specific factor and a disease. Hill's Criteria form the basis of modern epidemiological research and have been used in epidemiological science for sixty years. Hill's Criteria have been further adapted as a standard tool in modern chemical risk assessment.

Applying the principles of Hill's Criteria of Causation to aid in assessing the Hanford tank vapor exposure question, the TVAT finds that the weight of testimony and evidence strongly suggests that a causal link exists between chemical vapor releases from Hanford waste tanks and subsequent adverse health effects, particularly upper respiratory irritation, experienced by Hanford tank farm workers and that those adverse health effects are likely caused by acute, transitory exposures to relatively high concentrations of chemicals. (Appendix C summarizes the TVAT's "Application of the Principles of Hill's Criteria of Causation.")

Measurement and Control Strategy

The TVAT has recommended the implementation of the Occupational Exposure Limit-Ceiling (OEL-C) as an exposure control. Utilization of the American Conference of Governmental Industrial Hygienists' excursion rule allows for a rapid selection of limiting values for the 500 or so chemicals for which OELs have been established. Appendix H provides a primer on the effect that bolus event sampling time has on the measured concentration relative to the OEL for that given duration and the effect on sampling and analysis strategies. It is recognized that the OEL-C has a zero minute time element that from a measurement standpoint is impractical. Therefore, the TVAT has further recommended that the controls be placed at 10 % of this new OEL-C value. The safety factor allows for a pragmatic implementation of a time frame component that can be utilized in sampling and analysis methods to allow for sufficient volume of sample to be taken such that compliance with this exposure time frame is established. The TVAT recommends the time frame be short on the order of seconds to minutes but ultimate selection is determined by analytical capabilities. The TVAT has further recommended research to examine irritation exposure-response and how it can influence the selection of the control strategy.

TVAT Deliverables

1. Draft Report to WRPS by September 21
2. Report by October 30

Definition of Technical Terms

Due to the broad range of stakeholders (i.e., toxicologist, industrial hygienist, occupational medicine, analytical chemistry, engineering, management, workers, general public) who are involved in evaluating, responding, and communicating on these tank vapor issues, it is of critical importance that the technical nomenclature be clearly defined. (See Appendix J, "Glossary," for definitions of terms used in this assessment.)

3.0 OVERARCHING RECOMMENDATIONS

This chapter describes the key conclusions and overarching recommendations of the technical assessment conducted by the Hanford Tank Vapor Assessment Team (TVAT) 2014. Chapters following this one summarize the observations and recommendations regarding technical issues specific to the six Technical Assessment Areas investigated by the TVAT.

The TVAT arrives at the following key conclusions:

1. Applying the principles of Hill's Criteria of Causation to aid in assessing the Hanford tank vapor exposure question, the TVAT finds that the body of testimony and data examined by the team strongly suggests a causal link between chemical vapor releases from Hanford waste tanks and subsequent adverse health effects, particularly upper respiratory irritation, experienced by many Hanford tank farm workers. (Appendix C summarizes the TVAT's "Application of Principles of Hill's Criteria of Causation.")
2. The adverse health effects, e.g., upper respiratory irritation, are not representative of chronic exposures resulting from the current interpretation of personnel monitoring data (that is, eight-hour time-weighted averages) but are the result of transitory exposures to relatively high concentrations of chemicals. This is consistent with the descriptions of field experiences provided by many workers and with the engineering data associated with vapor releases.
3. An industrial hygiene (IH) program that emphasizes full-shift exposure measurement and compliance with standard occupational exposure limits cannot adequately address the complex and episodic nature of the Hanford tank vapor incidents. Significantly enhancing and integrating operational, management, and IH programs and processes, as described in the TVAT's recommendations, are needed to address the particular conditions on the Hanford tank farms.
4. The ongoing emission of tank vapors, which contain a mixture of toxic chemicals, is inconsistent with the provision of a safe and healthful workplace free from recognized hazards. Mitigating the emission of and worker exposure to tank vapors represents an extraordinary challenge that cannot easily be addressed through traditional approaches. Full commitment of the Hanford site and DOE leadership will be needed to address the vapor exposure issues. The formation of the TVAT is a sign of site management's degree of commitment.

The TVAT has identified ten overarching recommendations, implementation of which will significantly improve the safety and health management program as it pertains to Hanford tank vapors. The overarching recommendations reflect programmatic issues and incorporate themes identified across multiple Technical Assessment Areas. The following chapters include discussions of over forty supporting recommendations across the six Technical Assessment Areas arising from a number of identified technical issues. Appendix B provides a table cross-referencing the overarching and supporting recommendations; the table may be used as a guide to additional detail within this report about the recommendations and as a guide to potential actions that may be taken to implement the recommendations.

Washington River Protection Solutions (WRPS) management has committed to develop and carry out an implementation plan addressing this report. Effectively responding to this report not only requires specifying actions for expeditious execution of all TVAT recommendations but also requires clearly defining a process to monitor, document, and report progress and assure continuous improvement. Essential to that control process are a reporting schedule and a list of key stakeholders who will receive updates on progress. Built in to the process must be explicit mechanisms to assure continuity of programs through budget, leadership, and management changes.

The ten overarching major recommendations (OR) of the TVAT are described below.

OR 1: Hanford site contractor and DOE management actively demonstrate commitment to improve the current program and ultimately resolve the vapor exposure concerns.

Only management can institute the systemic change to address the vapor issue. Management must acknowledge the health risk associated with episodic releases of tank vapors. While the ability to measure and document

exposures may currently be inadequate, workers are nonetheless being affected by vapors on the tank farms. Acceptance of this observation should be communicated to all internal and external stakeholders. In addition, all levels of management must commit to continuously improving management of systems to assure that workers are not adversely impacted by tank vapors. To this end, WRPS, through the industrial hygiene function, should develop and conduct specialized training for management, starting with first-line supervisors, which expands the concepts addressed in the general Chemical Hazard Awareness Training (CHAT) and provides additional skills in risk communication. Management should develop and carry out an implementation plan effectively responding to the recommendations in this report as well as clearly defining a process to monitor, document, and report progress and assure continuous improvement.

OR 2: Implement measurable benchmarks to assure operational and cultural parity among chemical vapor, flammability, and radiological control programs.

In accordance with 10 CFR 851, *Worker Safety and Health Program*, WRPS is charged with providing a safe and healthful workplace: “With respect to a covered workplace for which a contractor is responsible, the contractor must: (1) Provide a place of employment that is free from recognized hazards that are causing or have the potential to cause death or serious physical harm to workers...” (Section 851.10(a)(1)).¹ Tank chemical vapor exposures are a recognized hazard on the Hanford tank farms and must receive operational and cultural emphases that are functionally equivalent to those proven to protect workers in the radiological and flammability control programs at Hanford. As required by 10 CFR 835, *Occupational Radiation Protection*, the importance of radiological control is fully embedded in all aspects of the operations of the Hanford site.² The IH program should achieve functional parity with the health physics (HP) radiation control program, adopting proven features of HP, including worker training requirements at all levels, locally tailored training for IH technicians and IH professional personnel, careful definition of how the IH department can support the operational mission, staffing adapted to that IH mission, continuing professional education and training that focus on unique challenges of Hanford tank farm operations, and full inclusion of chemical vapor considerations in work planning and conduct. It is clear from discussions with tank farm staff that HP technicians are accepted members of project work teams. Although The TVAT notes the existence of procedures that include involvement of IH technicians and IH professionals in operational aspects of the tank farms, these roles have not been well integrated, despite the operational and health impacts of the chemical exposure issues arising from tank farm operations.

OR 3: Establish a program to sample proactively the head space of tanks to validate and enhance chemical characterization.

The Hanford tank waste is a complex matrix of aqueous soluble and insoluble inorganic salts combined with an inventory of water and organic components that number into the thousands. These organic components are constantly undergoing radiolysis from the tank radioactivity plus thermal and chemical reactions with tank contents. Reliable prediction of tank head space composition has been a significant challenge. The then-Hanford tank farm contractor embarked on a program in the 1990s and performed then state-of-the-art effort to identify, correlate, and determine the fate of as many of the chemicals as possible. The TVAT recommends that these characterization efforts, inactive in recent times, be re-established. New, state-of-the-art techniques, including *in situ* measurements of reactive species and other compounds the prior methods would not have detected need to be thoroughly reviewed and applied in the characterization studies. See Chapter 4, “Site Characterization,” Technical Issue 1, and Chapter 5, “Exposure Assessment,” Technical Issue 2 for further details. Prioritize the characterization based on factors such as retrieval/transfer schedules, known organic loading, and prior high measurements of chemicals of potential concern (COPCs). Less comprehensive screening of appropriate index chemicals should be routinely conducted. Further, the program should not rely on stack or exhauster sampling results to understand the possible releases as these samples represent mixtures of tank contents exhausted through a mutual stack or exhauster that have been diluted during the process. The concentrations are not meaningfully

¹ http://www.ecfr.gov/cgi-bin/text-idx?tpl=/ecfrbrowse/Title10/10cfr851_main_02.tpl

² http://www.ecfr.gov/cgi-bin/text-idx?tpl=/ecfrbrowse/Title10/10cfr835_main_02.tpl

applied to a fugitive emission source from a single tank. There are many opportunities, such as corrosion sampling events, whereby tank head spaces can be accessed. Following the prioritization, sufficient samples should be obtained under quiescent and waste disturbing conditions to determine statistically the probable concentration ranges emitted for both routine and retrieval/transfer operations.

OR 4: Accelerate development and implementation of a revised IH exposure assessment strategy that is protective of worker health and establishes stakeholder confidence in the results for acute as well as chronic exposures.

The current program relies on the traditional approach of protecting the long-term health of the workforce by managing exposures to tank vapors against the occupational exposure limit. This traditional approach of relying primarily on an eight-hour time-weighted average is designed to protect only against long-term health effects that result from cumulative or ongoing exposures. Of the issues facing the current IH program, the one causing the vast majority of reported worker exposures requiring medical treatment comprise short-term and acute (bolus) exposures, which cause immediate symptoms in the workers and may or may not develop into medical signs of chemical exposure. The current program is not designed to detect and is incapable of detecting and quantifying this type of transient exposure event. Resolution of this issue is supported by a number of recommendations regarding changes to sampling strategies and adoption of different approaches to identifying transient emission sources, the exposures associated with these release points, and the proper assignment of acute occupational exposure limits (OELs). See Chapter 4, "Site Characterization" (Technical Issues 2 through 4), Chapter 5, "Exposure Assessment" (Technical Issues 1 through 3), and Chapter 7, "Risk Characterization" (Technical Issues 1 through 4). Implementation of these recommendations will lead to an advanced understanding of the acute dose-response potential or potency of vapors from the tank head space and other sources. It will give workers confidence that the problem is identified and understood and will provide an approach that addresses workers' experiences and concerns.

The TVAT has recommended the implementation of the Occupational Exposure Limit-Ceiling (OEL-C) as an exposure control. Utilization of the American Conference of Governmental Industrial Hygienists' excursion rule allows for a rapid selection of limiting values for the 500 or so chemicals for which OELs have been established. Appendix H provides a primer on the effect that bolus event sampling time has on the measured concentration relative to the OEL for that given duration and the effect on sampling and analysis strategies. It is recognized that the OEL-C has a zero minute time element that from a measurement standpoint is impractical. Therefore, the TVAT has further recommended that the controls be placed at 10 % of this new OEL-C value. The safety factor allows for a pragmatic implementation of a time frame component that can be utilized in sampling and analysis methods to allow for sufficient volume of sample to be taken such that compliance with this exposure time frame is established. The TVAT recommends the time frame be short on the order of seconds to minutes but ultimate selection is determined by analytical capabilities. The TVAT has further recommended research to examine irritation exposure-response and how it can influence the selection of the control strategy.

OR 5: Modify the medical case evaluation process and reporting procedures to recognize the appropriate uses and limitations of the available monitoring data and other potential exposure information when evaluations are made regarding tank chemical vapor exposures.

The TVAT was not charged with an assessment of medical programs or Worker's Compensation process. However, in the course of our assessment, the TVAT has learned that both these systems and the determination of work-relatedness rely heavily on exposure data provided by the industrial hygiene function and/or management regarding the extent to which workers were exposed to chemical vapors. These data are, for the most part, results associated with long term personal monitoring, after-the-fact grab samples, and readings from non-chemical-specific direct reading instruments and do not properly characterize the exposures experienced by a worker during a tank vapor incident. Using these industrial hygiene data alone in determining whether an acute transient exposure has occurred and reporting that "no exposure greater than 10% of the OEL" has been measured for the worker or his or her assigned similar exposure group is insufficient to communicate the limitations of the data and undermines the credibility of the industrial hygiene function and the systems the industrial hygiene data support.

Site and medical personnel evaluating whether a work-related illness/injury has occurred or whether a worker's compensation claim should be accepted or denied as a result of a tank farm vapor incident should rely upon relevant exposure information that recognizes the complex chemical mixture of tank vapors and the potential short-term, episodic nature of the vapor incidents. Relying primarily upon long-term monitoring, after-the-fact grab samples, or non-chemical-specific direct readings is inadequate. The information transfer protocol and review approaches need to be redesigned to assure industrial hygiene personnel are consulted before each evaluation so that the limitations and relevance of the available exposure data can be appropriately considered before Labor and Industry claims are denied and work-relatedness determinations are made. See Risk Management #8 for more details. A presumption of work-relatedness is consistent with Occupational Safety and Health Administration (OSHA) guidance.³ Previous medical determinations should be re-visited based on a more thorough understanding of the uses and limitations of the monitoring data.

OR 6: To reduce the impacts of bolus exposures, utilize real time personal detection and protective equipment technologies specifically designed to protect individual employees.

To supplement implementation of effective and reliable control technologies for tank vapor emissions, use direct-reading personal gas/vapor detection devices that provide early detection and clear alarm/warning when potentially hazardous conditions exist. Investigate commercially available and promote the development of technologies/devices that provide detection of appropriate constituents of tank vapor emissions that are implicated in odor detection and bolus exposure incidents. Additionally, workers in areas with potential bolus exposures should have readily available, escape-type respiratory protective equipment for donning when irritating conditions are encountered or personal detection monitors alarm. Chapter 5, "Exposure Assessment" (Technical Issue 1), provides additional information.

OR 7: Accelerate implementation of tailored engineering technologies to detect and control vapor emissions and exposures experienced in the Hanford tank farms ("tank farm of the future").

Through the avenue of the Chemical Vapor Solutions Team approach, WRPS is striving to implement the mandate from ORP to develop and implement detection and control technologies that will be effective in managing both acute and chronic exposures, thereby creating the "tank farm of the future." The TVAT endorses these efforts, as discussed further in the Risk Management chapter under Technical Issue RM 6, and the TVAT expressly recommends the following:

- Investigate and implement best available technologies to detect the presence of vapor plumes from fugitive sources as well as from vents and stacks. Include continuous surveillance by platform-mounted optical gas imaging cameras among the technologies to be evaluated. Also, investigate equipping this detection technology with an alarm or warning system.
- Continue to investigate control options for vents and stacks, as appropriate for each tank farm, including using exhausters (permanently or temporarily, as appropriate) for actively venting tanks that are presently passively vented, increasing stack heights, using air flow promoters on the stacks to enhance dispersion of the stack exhaust, relocating stacks away from the work areas ("stacks in the sticks"), and routing exhaust from the stacks to a control device. Resolve the efficacy of the three control technology alternatives identified in the 2004 Baker study (Baker 2004) as well as other promising technologies that may have been identified more recently. Recognize, however, that vent and stack controls alone will not entirely eliminate short-term vapor exposures. The active venting systems presently in use experience significant downtime, both planned and unplanned, during which stack controls are rendered ineffective; e.g., POR 003 Exhauster and POR 008 Exhauster had 20% and 55% runtime respectively in the 2nd quarter health report [Khabir 2014]. In addition, events such as opening cabinets in the tank farm, removing foam from above pit cover blocks, removing wrapping from reusable contaminated equipment (RCEs), and changing out filters will still pose potential for short-term releases, as will fugitive sources such as some valve pits and waste isolation disposal sites. Also, evaluate the use of large fans to sweep air across the tank farms (orchard fans) for effectiveness in dispersing episodic wafts or puffs, and evaluate the use of box fans at passive vents to enhance dispersion.

³ 29 CFR 1904, "Recording and Reporting Occupational Injuries and Illness" and 10 CFR 851.26, "Recordkeeping and Reporting"

- Investigate detection devices that are triggered by changes in the concentrations of selected chemical species in real time and that are equipped with an alarm system to warn personnel of an increased vapor concentration. Evaluate these alarming devices for use as ambient monitors in areas of known fugitive emissions and as in-line monitors for vent and stack emissions, and implement appropriate devices upon being demonstrated to be effective.

OR 8: Augment the Hanford tank farm IH programs to further develop competencies to address the tank vapor exposure issues.

The TVAT recognizes the enormity of the industrial hygiene challenge that the Hanford tank vapors represent. The TVAT believes that in its current state, the IH (professional and technician level) resources available are not sufficient to properly characterize and assess worker vapor exposure in the tank farms. The lack of IH participation, as compared to radiation control, in critical work activities, and the extreme delay in reporting formal monitoring results (backlogs have increased to 40 days) lead to the belief that management is not committed to understanding and controlling chemical hazards and that the recognition, evaluation, and control of chemical hazards are less important than for radiological hazards. The inadequate focus on the industrial hygiene function at the Department level does not appear to be unique to Hanford and tank vapor exposure. After examining DOE standards and implementation guidance, the TVAT has noticed a clear disparity between the amount of regulatory/management attention paid to radiological hazards compared to that paid to industrial hygiene and chemical hazards. DOE should increase their focus on chemical hazards such as those at the Hanford tank farms and develop more specific IH guidelines and regulatory requirements regarding the anticipation, recognition, evaluation, and control of chemical hazards, comparable to the focus and rigor currently given to radiological hazards.

The TVAT recommends that WRPS augment its current staff and its newly hired staff to support the enormity of the challenge. It is noted that the WRPS Safety and Health organization cumulatively has significant professional credentials. The TVAT notes this includes 15 Certified Safety Professionals (CSPs) and 11 Certified Industrial Hygienists (CIHs) and that numerous of these staff hold graduate degrees. In addition, the TVAT notes that WRPS has actively recruited recent hires who are dual-qualified as CSP and CIH. Despite these qualifications, the staff does not have a high degree of experience in addressing the direct issues involved nor is it currently equipped with a sufficient number of experienced CIHs to meet the challenges. The efforts of the current staff are commendable, and their dedication is not questioned. Augmentation would provide the needed mentoring of the less experienced staff and assist in developing implementation actions to many of the supporting recommendations in a timely manner to dramatically improve the current program and increase the value of the IH program to the workforce. In the near term, the TVAT recommends these actions to augment the Hanford tank farm IH programs to further develop competencies to address the tank vapor exposure issues:

- Increase the field presence of the professional IH staff with a proportion of time in the field commensurate with the hazards of the work in the field.
- Increase the knowledge level of newly hired IH professionals by placing them on shift to observe field work for a specific period prior to their qualification.
- Adopt a qualification program functionally equivalent to the radiological control program to enhance the value of the IH programs.

OR 9: Effectively communicate vapor exposure issues and actions proactively with all stakeholders.

WRPS provides general internal communications to workers on a regular basis and participates in a number of outside panels or councils that have been mostly responsive to questions and concerns relating to vapor incidents. The TVAT held conversations with many individuals in interviews and focus group meetings and also observed communication flow regarding vapor issues as part of pre-job briefings and team meetings. It is clear that WRPS is making efforts to engage with stakeholders and initiate additional communication about vapor issues. Nonetheless, the TVAT identified a significant need to re-build the communication program to better communicate the nature and application of the tank vapor risks. Communication gaps were identified at all levels. Examples included lack of clarity on the nature, application, and effectiveness of IH monitoring, lack of

communication about exposures among different operational activities in adjacent tank farm areas, lack of communication on disposition of suggestions and recommendations for improvement, and missed opportunities to communicate to key external parties. In a complex environment with multiple parties, significant uncertainties, and at least to some extent concerns about trust, clear communication (open, complete, and frequent) is essential.

WRPS should be more proactive and timely with internal and external communications about specific incidents, possible health impacts from tank vapor exposures, and efforts to minimize and control future vapor exposure incidents. Unsolicited, timely and detailed communications regarding vapor incidents, health risks, and the progress being made to reduce the frequency and magnitude of vapor events would help improve internal and external relationships and help establish a sense of trust that WRPS is working to reduce health risks associated with tank farm vapors and is committed to preserving the health and safety of its workers and the community. In addition, holding both internal and external stakeholder focus group meetings on a regular basis will help WRPS evaluate the effectiveness of its communications, encourage participation, and assure transparency across interested parties.

OR 10: Investigate and pursue external research opportunities and partnerships to address data and technology gaps related to vapor exposure, effects, and mitigation.

Tank farm vapor exposures issues are complex. There is a general appreciation among all levels of the organization at WRPS of the challenge of understanding all the issues and relevant strategies that may be needed to solve this problem. Ongoing limitations in source characterization, availability of suitable IH methods, understanding of biological effects of complex mixtures, transient exposures, and validation of engineering methods will result in ongoing unanswered questions and uncertainty. It is also recognized that the unique nature of the Hanford tank waste problem requires the development of novel strategies to evaluate the exposure, dose and response continuum effectively. In this regard, the DOE is well positioned to address this complex problem by utilizing the unique technologies and science that underpin the DOE National Laboratory System. The contribution of the National Laboratories is clearly evident by the substantial number of Pacific Northwest National Laboratory (PNNL) technical reports specifically addressing critical issues at the Hanford tank farms. It is recommended that WRPS in partnership with DOE, national laboratories, technology providers and University faculty subject-matter experts develop a research strategy and roadmap to address these critical questions. It is anticipated that both short- and long-term solutions will emerge to currently identified challenges and limitations. In addition, the resulting research findings will provide the technical and scientific strategies to address mixture exposures/toxicology and IH monitoring issues and should establish novel approaches for addressing these complex problems. These partnerships with the larger research community can address a broad range of research needs, including epidemiology studies, testing of real-time analytical vapor detection systems, computational modeling of plume dynamics, and modeling of the exposure, dosimetry and biological response in humans. Such research efforts could be extended to other key areas of uncertainty. It is anticipated that based on the scope of this research problem, many research funding agencies would have interest in and directly benefit from supporting these endeavors. Those agencies might include the National Institutes of Health (NIH), National Institute for Occupational Safety and Health (NIOSH), Centers for Disease Control and Prevention (CDC), Environmental Protection Agency (EPA), and Department of Defense (DOD) as well as the Department of Energy.

PATH FORWARD

WRPS will develop an implementation plan that addresses all the overarching and supporting recommendations in the TVAT's report and provide that implementation plan to the TVAT. The TVAT recognizes that closing the overarching and supporting recommendations will take commitment over several years. The TVAT expects the implementation plan to include actions to be taken in three phases – near term, intermediate, and longer term. (See Appendix D for “Examples of Remedial Actions.”) The TVAT will comment on the implementation plan in a separate communication.

4.0 SITE CHARACTERIZATION

INTRODUCTION

The site comprises the tank farms, transfer lines and associated equipment in the former Hanford Nuclear Reservation. Mixtures of radioactive and chemically toxic wastes are presently held in 177 underground tanks. Hanford waste tanks contain settled sludge, settled sludge with interstitial liquid and liquid supernatant, settled salt cake with interstitial liquid, or settled salt cake with interstitial liquid and a liquid supernatant. Five double shell tanks (DSTs) contain a settled salt cake with interstitial liquid, a liquid supernatant, and a floating crust containing salt cake with interstitial liquid and retained gas. The waste material is radioactive, continually generating heat, continually catalyzing both known and unknown chemical reactions in all layers, and continually generating gases and known and unknown chemical products that are continuously created and destroyed via chemical, thermal, radiocatalytic and radiolytic processes in all layers.

The tanks are constructed of vertical cylindrical shells with dome roofs, the top of the roof being on the order of seven to fifteen feet below grade. The majority of the tanks (149) have a single shell (SSTs), while a group of newer tanks (28) have double shells. There are typically concrete-lined pits above each tank (both SSTs and DSTs), with concrete blocks covering the pits. The topside of the cover blocks is typically at or up to a few feet above grade. Various appurtenances may extend from the tank up through the pit and the cover blocks, such as a riser for the vent stack or valve stems for operating valves located below grade. The head spaces of groups of two to eight tanks are connected by overflow piping.

A primary operation on site is to transfer waste material from the older SSTs to the newer DSTs. This process is referred to as retrieval. Retrieval has typically been limited to one tank at a time but is being expanded to two tanks at a time. While the retrieval of material from the SSTs for storage in the DSTs is due to known leakage issues with the SSTs, one DST also is known to have a leak into the annular space between the inner and outer shells.

Retrieval operations are performed via deployment of technologies tailored to the tank from which material is being retrieved. These technologies include sluicing, mechanical methods, and low-water methods, such as the Mobile Arm Retrieval System. Sluicing involves spraying a high-pressure stream of liquid to break up the salt cake and sludge in the tank such that they can be pumped out. The dislodged waste material is then pumped to a DST. Water has been used for the sluicing medium, with about three gallons of water being required to retrieve one gallon of waste. In that this introduction of large volumes of water generates a great deal of additional waste material to be stored and eventually treated, supernatant from receiving tanks is now being introduced as the sluicing medium for tanks being retrieved.

While the retrieval operations involve transfer of retrieved materials from SSTs to DSTs, there are also separate transfer operations that take place between DSTs. The transfer operations between DSTs involve transferring the sluicing liquid received from the SSTs from one DST to another. This is referred to as decanting, in that it involves pumping just the liquid layer. Decant may be transferred for a variety of reasons, including transfer to DST 102-AW as the feed tank for evaporator operations that reduce the total volume of supernatant remaining in storage.

Evaporator operations are for the purpose of reducing the volume of liquids. The residual waste materials are then returned to the DSTs for storage in anticipation of eventual vitrification in preparation for ultimate disposal.

SITE CHARACTERIZATION CATEGORIES

Traditional site characterization for occupational risk assessment considers source, pathway, and receptor. The TVAT's charter is to evaluate vapor exposures. Because vapor emissions to the environment and tank-farm employee exposures to vapor emissions are alleged to have occurred throughout the lifetime of the Hanford tank farms and under multiple operating contractors, it appears that the DOE operating policy for the tank farms is one of the factors that we must consider. The primary factors for characterizing the tank farm sites are therefore:

- *Sources* from tank contents include gases formed directly by chemical reactions and evaporation of volatile and semi-volatile liquids stored in the tank or formed by other chemical reactions. Both gases and vapors collect in tank head space air and are emitted into the environment either directly from the tank vents and stacks or from fugitive leakage pathways from the tank head space.
- *Pathways* are primarily through air, although liquid contact also is possible.
- *Receptors* are primarily the workers in or near the tank farms and the fugitive sources.

VAPOR SOURCES

The types of emission sources at the site may be categorized as follows:

1. Vents and Stacks
2. Tank leakage pathways
3. Overflow and transfer lines
4. Waste Incidental Disposal sites
5. Maintenance activities
6. Other.

The sources other than the vents and stacks may be collectively referred to as “fugitive sources.” Each of these sources is described briefly below.

1. Vents and Stacks

Vents and stacks ventilate the underground tanks that store mixtures of radioactive chemical wastes. SSTs are passively vented, meaning that the vents are open and not equipped with any type of mechanical exhauster. There is typically a single passive vent at the top of a riser which extends from the dome roof of the tank up through the pit to an elevation a few feet above the top of the cover blocks. There are high-efficiency particulate air (HEPA) filters at the top of the vent risers to control radioactive contaminants while allowing gases and vapors to readily pass through.

When retrieval is taking place in a given SST, that SST is actively vented by means of a portable exhauster. The stacks of some of the portable exhausters have been extended to 40 feet and are equipped with HEPA filters and continuous air monitors (CAMs). The CAMs monitor only for radioactivity. Currently in C-Farm, several tanks are ventilated from a single exhauster. If a transfer is to occur from one of the tanks, the other tanks are valved off to ensure maximum air flow from the retrieval tank. The other tanks return to passive ventilation.

The tank head space and the annulus between the inner and outer shells of the DSTs are actively vented, with HEPA filters and CAMs as for the active venting of retrieval operations at the SSTs. Groups of two or more DSTs are manifolded to a common exhauster, and some of the stacks have been extended to a height of 40 feet.

2. Tank Leakage Pathways

As noted above, there is typically a concrete-lined pit above each tank, with large concrete blocks covering the pits. Various appurtenances may extend from the tank up through the pit and cover blocks. For tanks that are not actively vented, there is potential for vapor leakage from the tanks into the pits and from the pits to the atmosphere.

3. Overflow and Transfer Lines

There are potential sources of emissions from lines connecting the tanks. These include permanent underground overflow piping to allow liquid to cascade from one tank to another, as well as temporary hoses used to transfer retrieved waste materials from SSTs to DSTs.

4. Waste Isolation Disposal Sites

Waste isolation disposal sites are locations not involved in current operations but at which there is potential for emissions due to legacy disposal operations. These inactive waste isolation disposal sites include places where waste materials have been buried, places where spills have occurred, and underground places where equipment such as old Navy reactor components or radioactively contaminated rail cars have been sequestered. Liquids and solids, including radioactive materials, are known to have led to contamination of areas of the Hanford site. In

April 1991, DOE announced that many billions of gallons of contaminated liquids had been dumped into the soil since operations had begun in 1944. The TVAT has been told that in contrast, the amount of high level radioactive waste that has leaked from waste tanks is estimated to be millions of gallons but that 61 of the 177 tanks have leaked some contents into the soil. Taken together, the information suggests that there are many waste isolation disposal sites with potential for vapor exposures. The TVAT was shown a plot locating a vapor incident outside the tank farms for which the most likely potential upwind vapor source appeared to be a waste isolation disposal site also outside the tank farms. Nonetheless, although many of the waste isolation disposal sites are outside the tank farm areas, most vapor exposure incidents are reported to occur within the tank farms. There is no identified reason that waste isolation disposal sites on or near the tank farms would be more likely to release vapors than those away from the tank farms. It is therefore unlikely that waste isolation disposal sites are the primary sources of the vapor exposure incidents.

5. Maintenance and Operations Activities

Maintenance and operations activities, such as replacement of the HEPA filters and opening of cabinets to take readings, have known potential for releasing emissions. There are miscellaneous cabinets in the tank farm in which vapors may collect, potentially exposing workers opening those cabinets. There is also a category of idle equipment on site, referred to as reusable contaminated equipment (RCEs), which is occasionally moved from one laydown area to another or otherwise handled.

6. Other Sources of Vapor Exposure

This would encompass potential sources of emissions other than those deriving from the tank farm itself, such as the nearby spraying of herbicide upwind from a farm.

CHARACTERIZATION OF EMISSIONS

Emissions from vents, stacks, alternative tank leakage pathways, and overflow and transfer lines originate from the waste material in the tanks. The tanks contain a complex mixture of chemicals, including both radioactive isotopes and toxic chemical compounds. Extensive work was done to identify what went into the tanks, and verify what is actually in them via theoretical reviews, records reviews and field studies. The identification work included evaluation of the sludge, liquid and head space. Then state-of-the-art methods were used for the head space characterization. The materials originally present are subject to complex thermal and radiolytic reactions that vastly increased the compound classes and individual compounds present. It is the head space composition that determines the composition of the vent, stack, and most fugitive emissions. Spills and leaks during transfers and recovery may lead to condensed phase fugitive emissions from fugitive sources such as valves and line connections. Waste disturbing activities can greatly alter the concentration and composition of the head space gases and vapors. Past head space characterization did not evaluate the effect of waste disturbing activities on the chemicals in the head space and their concentrations. Emissions from waste isolation disposal sites, maintenance activities, and other miscellaneous sources may or may not be similar in character to emissions from the tanks.

The occupational exposure limit (OEL) development process and design of the industrial hygiene program flowed from the tank characterization studies. Gaps in that characterization inevitably produced gaps in the Tank Waste Inventory System (TWINS) database, the OEL list, the chemicals of potential concern (COPC) list, the Tank Vapor Information Sheets and the industrial hygiene surveillance program. These gaps, whatever they may be, have existed for decades. Thus, systematic deficiencies in the chemical control program such as it is have also persisted for decades. A comprehensive reevaluation and revision of the characterization is crucial to the IH evaluation and control program, and possibly to the evaluation of environmental hazardous air pollutants.

Characterization of the chemicals that may be released in potentially harmful doses is discussed below under Technical Issue SC 1. It is discussed in even greater detail in the Exposure Assessment, Dose Response and Risk Characterization chapters of this report.

PATHWAYS FOR VAPOR EXPOSURE

The pathway of interest in this report is from a vapor source through the atmosphere to a worker. The dominant source appears to be underground storage tank head space. There is evidence that at least one vapor exposure has

occurred closer to a waste isolation disposal site than to tanks. Once in the atmosphere, vapors are transported by wind. Under stable atmospheric conditions, such as little or no wind beneath a temperature inversion, vapor puffs and vapor plumes can fall to the ground or hug the ground while enveloping workers. The TVAT believes this could be the dominant pathway for worker vapor exposure incidents.

Past practice has been to conduct air sampling as soon as practical after a reported exposure incident. Such sampling has occurred 45 to 120 minutes after the incident for a variety of reasons, including Industrial Hygiene Technician staffing levels, tank-farm entry requirements, and accuracy of worker descriptions of the locations. Without specifying the period of time between the incident and the subsequent sampling event, incident investigation reports state that no COPCs were above the detection limit. The response time is reported to be improving. However, delayed sampling should be recorded as re-entry testing before work is resumed, not as incident characterization sampling. The TVAT suggests that most of the vapor exposure incidents represent transient bolus exposures that last seconds to minutes under atmospheric conditions that support looping plumes.

There are two major deficiencies in vapor control policies. First, DOE is to be commended for the HEPA filters installed to contain radionuclides and the in-stack CAM systems that confirm total containment of those particles, but those same emission points have neither vapor treatment equipment nor chemical monitoring equipment. Vapor incidents would be eliminated if all vapors were captured or treated prior to release, but engineering studies have shown this to be impractical for variable vapor mixtures of known and unknown chemicals. Those technologies should be reconsidered. Second, adding real-time chemical monitoring of stack and vent emissions would, for the first time, provide an opportunity for a local alarm if conditions deteriorated rapidly.

In the meantime, the stack height for mechanically ventilated DSTs has begun to be extended to 40 feet above the stack foundation. As vapor exposure incidents have continued in tank farms where this has been completed, we observe that, by itself, this is an insufficient response. We also question the policy that there is a 5-foot radius from passive vents within which vapor exposure probabilities have been deemed high enough to require respiratory protection. We believe the vapor hazard zone for bolus exposures is much larger than a radius of 5 feet.

WORKERS ARE THE RECEPTORS FOR VAPOR EXPOSURE

As discussed above, the policy for tank vapors has been that dilution is the solution to this vapor exposure problem.

This is driven in part by the need to keep tank head space below the lower flammability limit. The actively ventilated tanks do this with mechanical dilution ventilation and stacks that serve to elevate the vapor plume release point. This does not protect workers on platforms and does not protect workers who are down wind on rising terrain.

In the hierarchy of controls used by industrial hygienists in all types of chemical industries, personal protective equipment is specified only when engineering controls are not feasible. In some critical circumstances, including chlorine or tetraethyl lead manufacture and combat against an enemy who has chemical or biological weapons, the workforce is equipped with a local alarm and an escape respirator. Training is used to assure all workers have the ability to don their escape respirators within 9 seconds of the alarm. During the factual accuracy review, we received a comment that this scenario does not address the problem of a single/partial breath exposure during a bolus event. That is true, but it does prevent multi-breath exposures and may allow other workers in a work team to don their escape respirators before having a single-breath exposure. All members of the team may be protected by in-stack real-time vapor monitoring instruments connected to a local alarm. We have seen no evidence that this strategy of an alarm plus an escape respirator for every team member has been considered for the Hanford workforce.

Although we commend the current evaluation of re-breathing systems, we caution that full time use of these is likely to lead to an increased accident rate, as happened during the 2-year period of mandatory self-contained breathing apparatus (SCBA) use.

We also commend current efforts to find a way to image the plumes during tank farm work. If successful, work planning and work practices can be developed to use that real-time data to avoid future vapor exposures by keeping workers out of the pathway of the vapor plumes, which may involve not entering a tank farm under certain conditions, such as light variable wind with eddy turbulence.

SITE CHARACTERIZATION SUMMARY

In summary, the legal, policy, and regulatory environments have played a major part in the planning, programming, and implementation of efforts to control, stabilize, and finally sequester the underground storage tank contents for long-term safe storage. As the waste is variable from tank to tank, and as its radioactivity catalyzes continuing chemical reactions, tank contents have variable composition over time. There is no prior equivalent experience from which lessons learned can be directly applied.

In this management environment, one problem has remained virtually constant from 1986 to 2014. Appropriate priorities have been given to controlling risk from criticality, radiation, flammability and explosions in the tanks while risk from exposure to chemical vapors has received a lower priority. The flammability and explosion hazards have been controlled by mixing tank contents, by passive and active venting of tank head space gases and vapors. In recent years, stack extensions have begun to be implemented as a response to the problem of rare but serious worker exposure to tank vapors. Other methods have been evaluated but have failed to demonstrate benefit. Further, although professional staffing of flammability, safety and radiation protection programs has been consistently provided, it appears that comparable emphasis on professional staffing and training in industrial hygiene was deferred by DOE and its contractors until spring 2014. The TVAT is guardedly optimistic that as the hiring and training of IH staff progresses and as IH programs are integrated into the risk management activities that have been so successful for radiation, flammability and explosion, the tank vapor issues will likewise be controlled.

TECHNICAL ISSUES

TECHNICAL ISSUE SC 1: SOURCE – CHARACTERIZATION OF RELEASES FROM THE TANK HEADSPACE

Was anything relevant to health protection missed, or inadequately characterized, in the list of chemicals that led to the 59 COPCs?

Observations

A primary source of atmospheric emissions is the head spaces of the underground storage tanks, and identification of the chemical constituents of the tank head spaces has been an essential part of the site industrial hygiene and environmental efforts. The past work to identify the radiolytic and thermal chemical products, involving use of then state-of-the-art sampling and analytical methods, led to an extensive compilation of the volatile constituents present. From the list of 1800+ chemicals, it was estimated that about 1500 had sufficient volatility to be present in head space gas and vapor. As the work progressed to determine the head space concentrations of the chemicals, OELs were developed for many compounds, both carcinogens and non-carcinogens. From this study, a set of 59 COPCs was selected (Meacham 2006).

While the selection of the 59 COPCs with assigned OELs was a necessary and extensive undertaking, it now appears to be incomplete for purposes of characterizing health risks associated with potential releases from the tank head spaces. The present list of COPCs appears to rely on several assumptions all of which may not be valid at all times, including:

- an assumption that the head space is well mixed in each tank (while the head space may be well mixed under quiescent conditions, it is not apparent that this assumption holds during retrieval activities or even during some infrequent tank upset conditions)
- an assumption that the head space composition is stationary over time
- an assumption that characterization of the head space during quiescent conditions is reasonably representative of conditions while the waste materials are being disturbed
- an assumption that emissions from the head space are always subject to dilution by active ventilation.

In briefings received by the TVAT while visiting the Hanford site, it was reported that transient spikes are observed in vapor concentrations at the beginning of retrieval operations. This observation calls into question assumptions of the head space being well mixed and head space composition being constant over time. It further calls into question any assumption that sampling during quiescent conditions would be reasonably representative of conditions while the waste materials are being disturbed. We understand that the transient spikes were reported to be as much as three orders of magnitude greater than the baseline quiescent levels. An assumption that releases are always diluted is questionable in that most of the passively ventilated SSTs are not subject to active ventilation. Furthermore, the tanks that are subject to active ventilation periodically revert to a passively vented condition due to both planned and unplanned power interruptions.

The assumptions listed above appear to inadequately account for the various modes in which tanks may be operated, with each having unique characteristics with respect to how the head space is effectively vented. These modes may be described as summarized below.

Continuous Active Venting

There is continuous venting from the actively vented DSTs, except to the extent that the venting may be disrupted due to some mechanical or operational issue. The venting systems are equipped with multiple interlocks that trigger shutdown of the exhausters, such as a differential pressure (DP) interlock that is triggered if there is an excursion of the differential pressure across the filters outside of the specified range. There are also occasional shutdowns due to power outages, which sometimes occur due to failure of the power infrastructure on site (e.g., a power pole being blown over by the wind). Engineering personnel report that the facility had been routinely achieving better than 90 percent average operating time on the active ventilation systems, but had recently set and met a goal of 95 percent average operating time. However, individual active ventilation systems may not achieve this goal, and the goal does not include planned shutdowns, which increase the actual down time of these systems. Design and operation of the active venting systems is driven by the safety consideration of avoiding the buildup of flammable gas in the head space of the DSTs, and is also subject to regulatory constraints (EPA and RCRA regulations). However, the extension of the stacks was driven by vapor exposure considerations.

Continuous Passive Venting

Passive ventilation is driven by thermal buoyancy and wind-driven Venturi effects, with a smaller contribution from barometric pressure changes.

Engineering data for vapor concentration at the source of passive venting of the tanks provide corroborating information to our hypothesis of brief episodic spikes in the release rates. A number of reports have been developed by WRPS and predecessor contractors on the chemical characterization of the tank emissions. Shown in Figure 4-1 is the continuously monitored data for Tank SX-103 as an example. The y-axis is volatile organic compound concentration in parts per billion (ppb) measured with a direct reading instrument's response calibrated with isobutylene. The emissions from the tank occur over about an hour in duration. The concentration spikes and then returns to "background" after the "breathing" has occurred. The concentration at the highest emission is over 40,000 ppb of organic compounds with the isobutylene response factor. (Farler 2009a) The point of this illustration is not to comment on the potential health effects of the spike shown but rather to underscore the reality of transient peaks in the release rate from tank vents. Potential health effects would depend upon the resultant composition and concentration of the head space mixture of vapors and gases in the breathing zone of personnel present at the time. The TVAT notes that we saw no indication that isobutylene is a component of the head space mixture; rather it was used to calibrate the direct reading instrument.

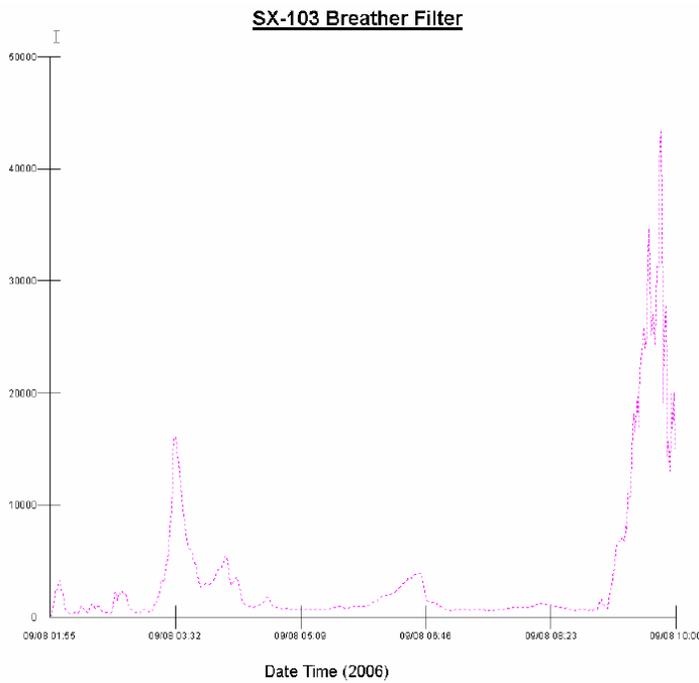


Figure 4-1. Continuously monitored data for Tank SX-103

Temporary Active Venting

Portable exhausters are used to actively vent SSTs during retrieval operations. These portable exhausters are essentially the same as the exhausters used for the DSTs. The characteristics of emissions during temporary active venting of an SST may vary significantly from the emissions vented passively from the same tank, in that active venting occurs during retrieval operations which disturb the waste materials. Disturbance of the waste materials may alter the chemical processes taking place in the tank, as well as release vapors trapped in the salt cake or sludge.

Stack sampling is conducted at the portable exhauster during the first 48 hours of retrieval from a given SST. While the fresh air pulled through the tank by the active venting results in a reduction in the average concentration of vapors in the exhaust, transient peaks are observed that are as much as three orders of magnitude higher in concentration than the baseline established during passive venting. Subsequent stack sampling is conducted when retrieval is approximately 50% complete, and again upon closure of retrieval operations at that SST. These subsequent stack samples suggest that transient peaks are most likely during the initial period of retrieval operations, but do not rule out the potential for transient peaks at other times during disturbance of the waste material in the retrieval tank. As waste materials are being transferred from the SST to a DST, there is the additional potential for transient peaks in the emissions from the DST. As no real time monitoring occurs in either tank or in the exhaust stream from either tank, there is no warning to workers that something has changed until they detect a sudden odor, or worse, suffer sudden and significant physiological response to an unseen and undetected plume.

Table 4-1 below shows the pre-, initial-, and mid-point analyses of samples taken from Tank C-101. Mercury levels continue to rise, whereas others have peaked.

Table 4-1 Percent of Occupational Exposure Limit

Compound	Pre-start	Start	Mid-way
Mercury	12	147.3	923.3
N-Nitrosodimethylamine	19	2390	469
Formaldehyde	26.7	91	65.3
Ammonia	2.7	21.1	2.7

Episodic Venting Due To Shut Down Of Exhausters

The exhausters used for active venting occasionally shut down, as described earlier. When this occurs, an interlock shuts down sluicing and retrieval operations, and the inlet vent on any tank involved is effectively rendered a passive exhaust vent. Although the waste disturbance activities have ceased, the head space then being vented through the inlet vents and fugitive pathways is potentially at orders of magnitude greater concentration of vapors than during routine passive venting. This venting of higher concentration emissions is through a relatively short stack and without the motive force of the exhausters to assist in dispersion.

Recommendation SC1

Develop a prioritized program to sample and characterize tank head space composition during quiescent as well as disturbed conditions.

This investigation should involve an initial sampling and analysis campaign to update the characterization of the tank head spaces during both quiescent and disturbed conditions, as well as an ongoing campaign to routinely collect head space data. The ongoing campaign should include sampling the head space during every tank sampling event, and analyzing the head space samples as appropriate to the frequency of such sampling. Characterization of releases from the tank head spaces should be further differentiated on the basis of whether the release would be expected to be diluted, as is the case for stack exhaust during active ventilation, or undiluted, as is the case for releases through passive vents or fugitive pathways. It is imperative to account for the unusual operating scenarios when planning to prevent the unusual exposure incidents.

TECHNICAL ISSUE SC 2: SOURCE – CHARACTERIZATION OF NON-ROUTINE RELEASES FROM VENT RISERS, STACKS AND HEPA FILTERS

Interruptions in the operation of the vent risers, stacks and HEPA filters could contribute to episodic releases with non-routine characteristics.

Observations

Semi-volatile compounds in the exhaust stream may plate or condense on the inside of vent risers or exhaust stacks, or collect in HEPA filters. Releases of these plated or condensed materials may have characteristics that differ from either diluted or undiluted head space gases.

HEPA Filters Suffer from Condensation and Freezing Problems

The HEPA filters suffer from condensation and freezing in the cold months of the year, due to being wetted by either condensate or fog. While this apparently does not occur often, site personnel and local environmental regulators are aware that this is an ongoing problem.

In-line radial filters have reduced, but not eliminated, the problem

There has been an evolution of filter technologies, with the current technology being an in-line radial filter. Condensation concerns have been a driver in the evolution of filter design. Engineering personnel indicated that the radial filters have reduced, but not eliminated, the condensation issue.

Episodic venting due to weather changes

There may be potential for compounds to either plate or condense on the inside of vent risers or stacks, particularly during cooler weather, in addition to the potential for collection of condensate in the HEPA filters as noted above. After materials have plated or condensed in a vent riser, stack or HEPA filter during cold weather, a period of warmer weather may result in evaporation of these residual materials, resulting in a short-term increase in the concentration and, potentially, change in the characteristics of the emissions. Off-loading of residual materials may be further aided by a drop in pressure within a vent riser or stack, resulting from either a drop in barometric pressure or a change in wind conditions.

Recommendation SC2

Assess the potential for materials to plate or condense in vent risers, stacks and HEPA filters, and characterize the emissions for each condition.

This investigation should involve sampling and analysis of plated or condensed materials from vent risers, stacks and HEPA filters. Again, it is imperative to account for the unusual operating scenarios when planning to prevent the unusual exposure incidents.

TECHNICAL ISSUE SC 3: SOURCE – NON-HEADSPACE FUGITIVE EMISSIONS

There are numerous potential sources for chemical releases other than from the tank head spaces, and these fugitive sources are neither adequately located nor characterized.

Observations

For purposes of this report, all potential pathways for emissions other than the vents or stacks are referred to as fugitive sources. Fugitive sources include pathways from the tank head space occasioned by various tank appurtenances, leakage from overflow or transfer lines, leakage from valve pits, off-gassing from waste isolation disposal sites, incidental releases during maintenance activities, and unrelated other activities such as the spraying of herbicides. Some of these fugitive sources are not connected to the tank head spaces, and thus any associated emissions may have significantly different characteristics than is assumed for the diluted plumes from exhaust stacks.

Overflow and Transfer Lines

Groups of two or more tanks are connected by overflow lines that are intended to allow liquid from one tank to cascade to another in the event of an overflow, but which have the additional effect of manifolding the tank head spaces. Tanks are also temporarily connected for retrieval or transfer operations. These temporary lines are referred to as hose-in-hose, in that the line consists of one hose inside another. Leakage at connection points for these overflow and transfer lines, as well as leakage through the walls of the lines, have the potential to cause fugitive emissions. We understand that the annular space between the concentric hoses has drains attached at low points, and we believe these drains to be a potential source of bolus release events. This potential is deemed sufficiently likely that there is some degree of surveillance of these lines. However, the current surveillance would likely not detect an episodic chemical vapor release of short duration.

The flow from manifolded DSTs is controlled by dampers set annually by a vent and balance team. It appears that automatic flow control from each tank is used either rarely or not at all. If true, upset conditions in a tank could result in conditions in the associated tank head spaces substantially different from the assumptions made by the vent and balance team, thereby resulting in flow behavior and emissions that differ from those under the assumed routine conditions.

Valve Pits

Flow through transfer lines is controlled by valves located in valve pits. These valves are actuated manually by means of valve stems that extend up to handles above the cover blocks. A given valve pit may have as many as a dozen or more valve stems, and each valve stem is a potential path for emissions. The emissions originate from the transfer line, which in some cases may have characteristics that differ from the characteristics of the tank head space, particularly if the line has a full flow of liquid or is nominally empty and abandoned.

Waste Isolation Disposal Sites

Waste isolation disposal sites are known locations of contaminated soil or buried material left over from prior operations. To the extent that there is trapped volatile material at a waste isolation disposal site with the potential to occasionally off-gas, the characteristics of such releases would likely be different from the characteristics of the diluted exhaust from stacks. Many of these sites have been investigated by the collection and analysis of soil samples, with the results reportedly near or below detection limits. However, the concern is not that these sites are universally or routinely generating vapors, but rather that there could be a non-characteristic site with potential to

generate episodic releases. Given that vapor events are not routine, it is likely that the source of vapors during such events also is not routine.

Maintenance and Operations Activities

Maintenance and operations activities often involve handling contaminated materials or equipment. Some of the reported exposure events have occurred when maintenance or operations activities resulted in releases that had not been anticipated in the planning of the work. In some cases, the source of vapors encountered during maintenance or operations activities may be condensate that has collected in a filter or in RCE wrapping. In such cases, the character of the chemical release may differ from routine head space releases. In other cases, the vapors may have originated in the tank head spaces, but the release may be from an unexpected location, such as the opening of a cabinet.

Other

There are activities taking place on site which may involve handling or release of potentially toxic vapors, but which are unrelated to tank farm operations. One example is the spraying of herbicides, which has been recorded as a potential cause in at least one vapor exposure event.

Recommendation SC3

Implement technologies to assess fugitive sources of emissions that are not connected to tank head spaces, and characterize the emissions for each non-head space fugitive source.

Fugitive sources of emissions that are not connected to the tank head spaces include leakage from overflow and transfer lines, leakage from valve pits, releases from waste isolation disposal sites, releases during maintenance activities, and releases from activities unrelated to tank farm operations. These non-head space fugitive sources have the potential for releases that would not be adequately represented by the head space characterization. Again, it is imperative to account for the unusual operating scenarios when planning to prevent the unusual exposure incidents.

TECHNICAL ISSUE SC 4: DETECT FUGITIVE AND EPISODIC RELEASES

Monitoring and sampling policy for chemical vapors appears to be focused on regulatory requirements, which do appear to be met, but this approach fails to address the short-term episodic events that appear to be the cause of most if not all current chemical exposures.

Observations

Monitoring and sampling policy appears to be inadequate with respect to detecting short-term episodic exposure. The current policy does not address the potential for wafting plumes or puffs of chemical vapors in relatively high concentrations, which may be occasional and isolated in nature. Worker experience suggests these releases are very short in duration and thus would be substantially diluted if included in a typical-duration time-weighted average (TWA) sample. Furthermore, the short duration of the event would likely preclude detection of a given puff by the follow up monitoring and sampling program, in that the puff would have dissipated. The relatively low frequency of vapor events experienced by workers suggests these releases are infrequent and isolated, and thus a person carrying a Direct Reading Instrument (DRI) would only detect such a release if they happened to be holding the probe of the DRI in the right place at the right time. In that the IH tech cannot be continuously holding the probe of the DRI in the breathing zone of each worker, it is unlikely that the current usage of the hand-held DRIs would detect these puffs in a manner that would be protective of workers.

Furthermore, without fully knowing the chemical(s) triggering the acute effects, the photoionization detector DRI may or may not be capable of detecting these plumes. Limitations in the DRI technology with respect to detecting short-term exposures is discussed in the 2010 independent review by Breysse and Stenzel (Breysse 2010).

WRPS recognizes this short-coming, and the Chemical Vapor Solutions Team (CVST) New Technology sub-team is actively investigating improved detection technologies. While technologies being selected for

demonstration would move closer to addressing short-term peaks (e.g., the HAZ-SCANNER by SKC Inc.), they may still fall short of positively detecting and locating these events.

Sources of fugitive or episodic releases include the following:

Alternative Tank Leakage Pathways

It is known that there are alternative leakage pathways from the tank head spaces, such as through leaks in tank roof appurtenances. However, it is believed by site engineering personnel that, under normal operations, the path of least resistance for vapor travel is through the vent. On the other hand, site engineering relies on the alternative tank leakage pathways to relieve pressure build-up in the head space in the event of flow being restricted through the vent riser, stack or filter by virtue of freezing fog or condensation. Thus, it is expected that there may be brief and infrequent releases through these alternative tank leakage pathways.

Releases during Non-Routine Operations

There are leakage pathways during tank sampling prior to retrieval, during nozzle installation or transfer pump installation, and at fittings between the tank and the transfer line. Similar leakage opportunities occur during set up and re-closure of the receiving tank. While these activities generally involve active ventilation to preclude fugitive releases, certain special conditions are exempted from the active ventilation requirement.

Non-Headspace Fugitive Sources

The site has conducted studies to determine locations of the non-head space fugitive sources discussed under the previous issue. However, releases from these fugitive sources are expected to be episodic in nature, and would typically occur without warning. Furthermore, there may be fugitive sources that have not yet been located.

Recommendation SC4

Identify and implement new technologies to detect, locate and quantify fugitive and episodic releases.

The CVST New Technology sub-team is investigating improved monitoring and sampling technologies. It is important that senior management assure priority and provide resources for field demonstrations of the most promising detection technologies, and full deployments as appropriate. A particularly promising technology already used in the petroleum and petrochemical industries is optical gas imaging (OGI) cameras, such as those marketed by FLIR Systems, Inc. These cameras can remotely detect sources of episodic releases, and may be hand-held for walk-arounds or mounted on platforms for continuous surveillance of an area. In addition to detecting and locating fugitive sources, visualization of plumes from vents and stacks would be much more robust than reliance on models to evaluate plume behavior, in that it would allow real-time identification of the occurrence of a downdraft and allow warning of workers. If the detection capability of these cameras is inadequate, it may be enhanced by the use of tracer chemicals in the head spaces. Investigation of OGI technology by the CVST New Technology sub-team should continue to be an urgent priority. Continuous surveillance may be necessary for some period of time in order to locate the sources of episodic fugitive releases. Once fugitive sources have been located, they should be monitored whenever workers are in the vicinity as well as monitored on an appropriate periodic schedule. For example, equipment such as valves are monitored on a monthly or quarterly basis in the petroleum and chemical industries.

TECHNICAL ISSUE SC 5: - NEAR TERM WORKER PROTECTION

Identify and Implement new technologies to provide worker protection from vapor plumes without interfering with assigned duties.

Observations

The observations about this technical issue are straightforward:

1. Worker vapor exposures are continuing.
2. There is no immediate local alarm that can be sounded when an incident occurs.
3. Without continuous chemical monitoring in the stack, there is no record of source strength.
4. Workers do not carry escape respirators.
5. Work teams have not carried grab samplers to activate during a vapor exposure incident.
6. Some change houses have been located on a hillside at the same altitude as the elevated stacks.

Recommendation SC5

Identify and implement new technologies to quantify stack and vent emissions with suitable local alarms so that workers can react in a timely fashion.

To maximize its effectiveness, a local alarm system should be implemented that works in conjunction with inputs from the area RAE Systems, Inc. gas detection system now being deployed and with in-stack chemical monitoring as soon as it can be deployed. As an example, every work team, if not every worker could carry a suitable grab sampler that can be quickly operated right after the emergency respirator is donned, and during an exposure incident. We are encouraged by current efforts to use accordion bag samplers and consideration of evacuated canister samplers. After-incident reviews should consider the location of change houses and administrative offices in the tank farms. Any that are at risk of intercepting vapor plumes need to be moved to a better location and/or equipped with a suitable supply of fresh air to allow positive pressure operation

5.0 EXPOSURE ASSESSMENT

INTRODUCTION

A core exposure assessment (EA) program objective is provision of reliable exposure data to adequately characterize employee health risks from those exposures. The EA program faces significant challenges at the Hanford tank farm operations. WRPS has significant resources with many notable capabilities dedicated to the tank vapor EA. If the vapor exposure effects arose from a relatively constant exposure during work tasks, and arose from a well-characterized, stable and simple chemical mixture, the EA would be relatively straightforward. If so, the current EA would have successfully identified and controlled the exposures with the resources now deployed. The approach is well designed, of high quality, and suitable for a more traditional material and time duration exposure scenarios. Unfortunately, the mixture of chemicals is not simple, consistent, or well-characterized. The tank vapor sources present variable composition and are unpredictable in location, direction and duration. For short and intermittent but high concentration releases, the current personal and work zone EA is largely an exercise in futility and is consuming significant resources. The current strategy has not provided data adequate to clarify the exposure agents, concentrations and dose rates in the tank vapor events. Past and future mathematical modeling, if interpreted and used, can estimate the potential range of concentrations and durations of the intersection of emissions plumes and puffs with inhabited work zones. The modeling may give a more insightful estimate of the potential concentration ranges than would continued monitoring using the current personal and area sampling methods. Some of the newly identified field instrumentation and quick sampling methods may improve the EA characterization, but that has not yet been proven. Although the new equipment may provide new and critical data, the TVAT is not convinced that equipment will rapidly or completely provide the type of EA data needed to design and verify an effective control strategy.

CURRENT WRPS EXPOSURE ASSESSMENT STRATEGY

WRPS is following a task/exposure potential adaptation of the American Industrial Hygiene Association (AIHA) Similar Exposure Groups (SEG) strategy (AIHA 2006). The WRPS SEGs are

- SEG1. This is the lowest expected risk work with activities that do not involve access to Vapor Control Zones (VCZs) or contact with tank head space emissions.
- SEG2. This covers work activities that may require entering VCZs, but exposure to tank emissions is restricted or controlled.
- SEG3. This group is assigned when work activities are non-isolated and intrusive with potential exposure to tank emissions.
- SEG4. This covers work activities associated with abnormal conditions, such as when DST ventilation is inoperable.

These SEGs and the task-oriented adaptation of the AIHA strategy are appropriate given the nature of the Hanford Tank Farm work. If used with Sampling and Analytical Methods for intermittent brief exposure, the strategy would eventually give appropriate data for Risk Management decisions. However, the personal and most of the work area sampling and analytical methods will not capture transient events effectively, as discussed below in the Current WRPS Sampling and Analytical Methods section.

In addition to the SEG structure, WRPS describes its strategy in several documents, referenced in Appendix A.

The EA Survey Data Summary approach is discussed in TCF-PLN-34 (WRPS 2013):

- “For each SEG/stressor pair, the frequency and duration of exposure will be evaluated and assigned a numeric rating between 1 and 5....
- “Control mechanisms, such as point source ventilation should also be considered and assigned a numeric rating....
- “Available exposure monitoring and sampling data should also be considered during this step, and assigned a numeric rating, based on the levels with respect to the Occupational Exposure Limit (OEL).”

The document also summarizes (pages 19 to 20) a qualitative approach to rank risk when no monitoring data are available: Risk Rank = Exposure Rating * Hazard Rating * Uncertainty Factor.

Tank Vapor Information Sheets

Tank Vapor Information Sheets (TVIS) are used in the work planning process, including the IH surveillance plan. The TVIS cover the Chemicals of Potential Concern (COPCs) present at > 10% of the OEL based on tank source samples (TWINS database). These have focused on vapors. A presentation on 25 July 2014, Summary Section 3, "Dose Response," commented: "Particulate monitoring is being planned after recognizing that most analyses focused exclusively on gases collected through radiation control filters." A TVIS is specific to a tank farm, including what is known about the emissions from the tanks in that farm. WRPS states that TVIS is reviewed for updates annually for the COPCs and any other chemicals identified by the investigations.

Current WRPS Sampling and Analytical Methods

Personal breathing zone samples are collected using a suite of pumped sorbent tube media, and passive diffusion samples. The methods are directed at gases and organic vapors. WRPS procedures call for all samples submitted for gas chromatography/mass spectrometry (GC/MS) analysis to be evaluated for all chemical constituents to the accredited limits of detection (LOD). Unexpected compounds near the LOD are reported to IH for consideration. The final report then covers the COPC and other chemicals noted by IH for inclusion. The methods are directed at gases and organic vapors. Use of a prefilter to prevent radiologic contamination of the sampling devices precludes sampling aerosol phase COPCs. WRPS is currently revising their methods to include specific techniques for aerosols. Ammonia, mercury and VOCs by photoionization also are measured with Direct Reading Instruments (DRIs) to evaluate exposures too. The sampling and analytical methods used are based on NIOSH or other validated criteria, or on accepted state-of-the-art approaches, such as for nitrosamines. All are appropriate for TWA and STEL OEL evaluation, when used with adequate sampling time, which varies from several minutes to an hour or more depending on the analyte. The DRI detectors all have internal averaging times, with initial but not necessarily full response varying from sub-second to 10s of seconds. Gas bag sampling is added as a capability for the work zone area sampling and other (e.g., AOP-15) investigations. The gas bags, given sufficient volume and sensitive analytical finish, may be more productive for evaluating transient events than are the sorbent tube and passive diffusion monitoring devices.

New Initiatives in Sampling and Analytical Methods

The CVST has an active project to evaluate new technologies to improve the ability to identify and characterize tank emissions and resulting exposures. Examples include a fleet of SKC Haz Scanner Model EPAS area monitoring stations that have remote activation, wireless data communication, local zone meteorological data, multiple sensors and pumped samples to sorbent media or gas bags. These are under final evaluation or may have moved to purchase and deployment. Area RAE and photoionization and multi-gas sensor monitors are deployed in grids around work activity areas. Many other tools for plume visualization, chemical characterization and measurement are under evaluation. Examples include Forward Looking Infrared (FLIR) cameras for plume and fugitive emission visualization, Fourier Transform InfraRed (FTIR) scanning for plume evaluation, and more. Additional methods to characterize aerosols are also in development for deployment.

Additionally, personal detectors and alarms for organic vapor should be evaluated for efficacy in detecting the tank vapor emissions. As discussed in the dose-response chapter, odor provides an unreliable warning of the presence of complex and varying mixtures of odorous and non-odorous chemicals. Personal alarms based on photoionization, supersensitive flammable/combustible gas, or other technique deserve consideration and evaluation as possible means of early warning of tank vapor exposure. Off-the-shelf devices may or may not prove adequate in terms of response, response time, and sensitivity. Some device manufactures might be willing to develop or modify a device for the unique Hanford tank vapor application.

Minimum Sample Volumes to Detect Key COPCS

Each COPC has a minimum analytical detection limit ADL, and a minimum reliable quantitation limit with the latter typically five times higher. For N-Nitrosodimethylamine (NDMA), the modified NIOSH 2522 method of the RJ Lee Group laboratory used by WRPS has a reporting limit of 0.02 micrograms per tube. Thus, to detect

NDMA, the field sampling must collect at least 0.02 micrograms of that chemical. At the OEL of 0.30 ppb (0.91 micrograms/m³), the required air volume for OEL level concentration detection according to the method specifications is approximately 22 liters. Given the method flow rate of 0.2 to 2.0 liters/min, the minimum sampling time for OEL concentration detection is approximately 10 to 110 minutes for the higher and lower flow rates, respectively. The sampling flow rate and minimum time to collect a detectable quantity can be developed for each COPC. Doing so is beyond the scope of this review. Continuing with NDMA as the example, at the maximum method sampling flow rate, a 30 second sample might just detect a concentration 20 times the OEL concentration of 0.9 micrograms per cubic meter of air. Extended time sampling can and will miss (by lack of sufficient sensitivity) short duration but high concentration bolus events.⁴

TECHNICAL ISSUES

EA TECHNICAL ISSUE 1: TIME-WEIGHTED AVERAGE EXPOSURE VERSUS BOLUS EXPOSURE

Observations

Evidence suggests that the vast majority of worker exposures with adverse reactions to Hanford tank farm vapors are from intermittent and very short-term (seconds duration) exposure in breathing zones as a bolus exposure at a significant fraction of the tank head space concentration. (See Appendix H, “Bolus Exposures versus a Time-weighted Average Exposure over a Significantly Longer Time Period.”)

As shown in Appendix H, a time weighted average concentration of less than 10 ppm can be thousands to tens of thousands of ppm when delivered as a bolus. Thus, long term sampling can easily average out and not show intense but short-lived exposures.

Clearly bolus exposure, when it occurs, is a matter of concern since acute bolus exposure to high concentrations can dramatically impact the dose response of the chemicals under consideration. This is discussed in Chapter 6, “Dose-Response Assessment,” in this report.

Appendix I presents evidence for bolus exposure potential from a PNNL 2004 modeling study of Hanford tank farm emissions along with the concordance of this exposure potential with reported worker exposure effects.

To summarize, the evidence presented in that Appendix shows the exposure potential from a competent modeling study that coincides with the almost invariable description of the exposure events by workers.

The pump and passive sampling and analytical methods currently used for personal sampling are adequate for TWA and some STEL duration exposure evaluations to the COPCs when used for appropriate durations. However, these sampling and analytical methods are generally inadequate for the momentary high concentration exposures that could be triggering the acute vapor exposure effects. The known deficiencies are one factor in the lack of credibility as well as lack of success in characterizing vapor event exposure concentrations.

Breathing zone sampling of workers, who subsequently reported an inhalation exposure while being monitored, is rare. We have been advised of 3 instances (all occurring in 2014) in which monitors were worn while symptoms were reported. The circumstances of and data from these few exposure examples have been varied and somewhat incomplete, and there has been no clear indication of overexposure from these samples. As discussed above, however, the limits of detection of a monitoring method and measuring a possible exposure across the full duration of a task (e.g., a few minutes to an hour or more) using a time-weighted average (TWA) can allow a brief but concentrated bolus exposure to go undocumented. Also, these 3 instances are but a small percentage of the total number of workers reporting acute effects over the years.

Recommendation EA1

⁴ 2 liters/minute * 0.5 min = 1 Liter. To collect 0.02 micrograms (the detection limit for NDMA) in one liter, the concentration then needs to be > 0.02mg/M³, which is 20 ug/M³ and thus approximately 20 times the OEL concentration of 0.9 ug/M³

Continue the development and expedite deployment of new techniques for real time response and appropriate sampling for short duration intermittent releases.

Several types of personal vapor detection alarms exist, such as super sensitive combustible gas detectors and pocket photoionization detectors. Evaluate specifications (response time, sensitivity) of such devices, and field test those possibly suitable for detection of tank head space emissions. If they have sufficient response to provide meaningful early warning, deploy them in the tank farm workforce, with alarm events triggering donning of escape respirators and evacuation of the area.

Revise the industrial hygiene strategy to increase the probability of capturing and evaluating bolus exposures.

In the interim (before the invocation of any risk management measures designed to control the releases), monitor passive vents and stacks in real time with alarms for high emission rate excursion events. This is in addition to the current systems for level, temperature, pressure and radiation monitoring. Alarm events should be tied to donning rescue respirators, evacuation and activation of real-time sampling and plume analysis to determine the extent of the event.

The evidence explains the highly sporadic and, to date, unmeasured worker exposures. If we accept the above assessment, then we also need to accept that there will be a small portion of workers not wearing personal protective equipment (PPE) who will continue to occasionally experience significant inhalation exposure to, and adverse health effects from, the momentary inhalation of high concentrations of tank vapor. If true, it is also clear that the current sampling methodology will continue to fail to assess this acute risk (discussed further below). Given the potentially intermittent and limited nature of the releases in time and area, nothing short of a complete 24/7 real-time grid coverage (with alarms) of all worker-inhabited areas within the tank farms is likely to catch and prevent most potential exposure events. However, implementation of the recommendations in this report should greatly improve the situation in the short term while such optimum real-time monitoring and vapor controls are developed and implemented

EA TECHNICAL ISSUE 2: CURRENT SAMPLING AND ANALYTICAL METHODS MAY NOT COVER ALL CHEMICALS OF HEALTH CONCERN

Observations

The current sampling and analytical plan is based on a list of chemicals that is likely incomplete. Radiolytically generated free radicals (Meisel 1993, Bryan 1995, Guffie 2004, Stock 2004) can produce compounds not seen with the tank head space characterization sampling and analytical methods used to generate the lists used to define COPCs. PNNL-13366 comments "Limitations of the analytical methods, such as the inability of the methods to detect formaldehyde and certain other low molecular weight species, are discussed in the Data Dictionary of the Tank Waste Information Network System (TWINS 2004). Some but not all of the possible products had been hypothesized (Still 2004, other reports) but other species such as bismuth alkyls, volatile Cd, Cr, Ni compounds, submicron formates, oxalates) may also exist and may not have been characterized. Some reactive VOCs, such as peroxyacetyl nitrates, if present, may require *in situ* methods for evaluation.

Recommendation EA2

Identify and implement sampling and or *in situ* analytical methods as appropriate for reactive VOCs, submicron aerosol, volatile metal compounds, and volatile metalloid compounds that may be present but would have been missed by past head space sampling and analytical methods.

This may require use of experimental methods and then development of validated approaches.

Possible actions to address this recommendation could include:

- Using the appropriate new methods, survey a stratified statistical sample of past high COPC tanks to evaluate additional species to add to the COPC list, as noted in Chapter 4, "Site Characterization."

- Establish the toxicological concerns and develop OELs for the additional species. (see Chapter 6, “Dose-Response Assessment,” of this report for further discussion.)
- Revise the current personal and area sampling and analytical methods as necessary to include exposure assessment methods suitable for bolus and longer term monitoring of any additional species identified as present and at potential OEL concentrations in tank emissions. Alternately, determine and monitor for reliable surrogate indicator compounds. Collect data and communicate the results to labor force and management.
- Design and conduct field sample stability and recovery studies for key sampling and analytical methods and for any new deployed methods. Report results to employee representatives and management.
- In monitoring reports to workers and management, cite parameters of importance (limit of detection and limit of quantification) and sample duration. See Chapter 8, “Risk Management,” for additional details.

EA TECHNICAL ISSUE 3: DEVELOP PLUME VISUALIZATION TOOLS AND MATHEMATICAL MODELING OF WORK ZONE CONCENTRATIONS AND EVENT DURATIONS

Observations

Past mathematical modeling of plume impacts (e.g., Droppo 2004) shows the potential for relatively undiluted emissions to reach the ground in occupied zones of the tank farm and adjacent locations. Models show this potential in low wind/calm air and stable air conditions. These are the conditions that are most prone to tank vapor exposure events and odor events as well. The modeling suggests the increased stack heights in actively ventilated tanks will fail to remediate the exposure potential in some meteorological conditions, and most notably under conditions expected to correlate with vapor exposure events. The stack extensions without further modifications may be less than satisfactory investments of resources.

Recommendation EA3

Use modeling, including computational fluid dynamics methods, to determine the potential locations, conditions, and next steps in attempting to measure sporadic exposure events.

Potential actions to address this recommendation include:

- Enhance the use of computational fluid dynamics (CFD) modeling to provide 3 dimensional and temporal visualization of plume and puff emission behavior under various conditions. Fugitive sources have not been modelled and require characterization. Use probability density function results from the models, under a range of reasonable worst case meteorological conditions, to estimate the range of exposure concentrations and durations from vent and stack emissions. Modeling results on the potential plume location, concentration, and duration in a personal breathing zone size space will help inform the placement of monitors.
- Continue to develop real-time visualization of tank vapor plumes and provide a recommendation for the best or most reasonable path forward to provide this critical information, if it is technically possible. Expedite implementation of feasible approaches. If not feasible, present all the avenues considered and the reason they did not work.
- If real-time visualization can be realized, it should be used throughout the tank farm complex to assess the emissions from both known sources (vents and stacks) and other less well characterized potential sources of fugitive vapors.
- Continue development and deployment of real-time or near real-time area monitoring networks with detector position and spacing around the entire Hanford site being informed by CFD modeling and plume visualization studies. Match these monitors to audible alarms to promptly alert workers of the appearance of hazardous plumes of tank vapors.

6.0 DOSE-RESPONSE ASSESSMENT

INTRODUCTION

Background IH Program (Dose-Response focus)

The Industrial Hygiene (IH) Technical Basis document (Meacham *et al.*, 2006a) along with other supporting technical documents provides an overall summary of the WRPS IH program and includes reviews of the gas and vapor sources and dynamics, evaluation of head space composition, measurement of gases and vapors in the workers breathing zone, toxicological evaluation of volatile chemicals in tanks, prioritization of COPC and establishment of occupational exposure limits (OELs). All supporting documents/reports cited within the IH Technical Basis document were available to the TVAT and reviewed as needed. Dose-response assessment seeks to understand the relationship between the concentration of chemical vapor(s) delivered to the workers (i.e. dose) and their resulting symptoms (i.e. response) which are critical inputs to the risk characterization strategy. Therefore, the TVAT was particularly focused on understanding the WRPS approaches for evaluating vapors in the workers breathing zones, the toxicological evaluation/review that resulted in establishing COPC and OELs as the basis for evaluating dosimetry/response in workers.

Chemical Evaluation of Headspace

As noted in the IH Technical Basis document (Meacham *et al.*, 2006a) head space gas and vapor characterization of single-shell tanks (SSTs) was initiated in the 1990 and over 1500 organic vapors have been identified (Stock and Huckaby, 2004). The characterization focused on: 1) identification of which chemicals may be released in workers breathing zone; 2) identification of tanks where chemicals may be released; and 3) estimation of maximum concentrations (under non-disturbed conditions) at point of release. Analysis considered the potential for head space vapor concentration variability; a statistical evaluation of multiple head space vapor measurements (of those tanks repeatedly sampled) over time suggested less than an order of magnitude change in concentration (Meacham *et al.*, 2006b). However, it was noted that waste-disturbing activities can profoundly disturb the temporal concentrations of chemicals in the head space. More specifically, waste disturbing activities associated with sluicing of waste with water jets, dissolution and transfer pump operations are believed to have the highest potential to release a large fraction of retained gas and vapors over a short time period (Stewart *et al.*, 2005). The effects are dramatic resulting in organic vapor concentrations increasing by several orders of magnitude (Stauffer and Stock, 1999).

TECHNICAL ISSUES

DR TECHNICAL ISSUE 1: IDENTIFICATION AND QUANTIFICATION OF HEAD SPACE VAPOR CONCENTRATIONS TO PRIORITIZE COPC AND ESTABLISH OELS

Observation

From the perspective of the TVAT, identifying and quantifying vapor head space concentrations were of high importance for the prioritization of COPCs and the establishment of OELs. In this regard, the analytical chemistry analysis was a critical consideration during the toxicological screening and prioritization of chemicals for evaluation and OEL development (Burgeson *et al.*, 2004; Poet and Timchalk, 2006; Poet *et al.*, 2006). For example, of the approximate 1400 chemicals that were identified in the tank head space that did not have OELs, prioritization for developing of screening values was partially dependent upon their maximum reported head space concentration (Poet *et al.*, 2006). For these analyses the head space concentrations were obtained from the Tank Waste Information Network System (TWINS) Tank Characterization Database, which includes data from 118 of the 149 single-shell tanks (SST) and 20 of the 28 double-shell tanks (DST) as well as multiple sampling events from all 5 DST ventilation systems. Chemicals with maximum reported concentrations (under non-waste disturbing conditions) less than their screening values were considered to not pose significant risks to workers. Of the 606 chemicals assigned screening values, 72 were determined to have been reported in head space concentrations at or above their screening values (Poet *et al.*, 2006). However, head space sampling data utilized to identify COPC and establish OELs appear not to be associated with measurements taken during waste-disturbing activities; therefore, these vapor concentrations may not be fully reflective of the maximum chemical

head space concentrations, particularly under transient conditions where vapor/gas plumes may be generated. In this regard, analysis of tank vapor gas concentrations in actively ventilated stacks report at least 5 COPC (ammonia, mercury, nitrous oxide and 2 nitrosamines) exceeding 50% of their OEL during tank-disturbing activities (Farler *et al.*, 2008). More specifically, six identified waste-disturbing activities had at least one stack with at least one chemical at 10-50% of the OEL. One waste-disturbing activity had at least one chemical at 10-50% of the OEL at both the sending and receiving tank stacks, while two of the waste-disturbing activities had at least one chemical over 50% of the OEL at both tank stacks (i.e., sending & receiving). These data suggest that re-evaluation of head-space concentrations are warranted.

Recommendation DR1

Conduct an additional review and re-prioritization of COPCs under tank-disturbing conditions to provide adequate emission characterization, OEL development, and worker exposure surveillance.

DR TECHNICAL ISSUE 2: DOCUMENTATION OF THE COPC REVIEW PROCESS IS INADEQUATE.

Observation

As noted in the WRPS IH Technical Basis (Meacham *et al.*, 2006a) Appendix C documentation, a process was established to assess those headspace chemicals that required further evaluation with regards to COPC and OEL assessments. The evaluation process involved revising the Chemicals Needing Further Evaluation (CNFE) list to address errors, omissions, duplications, and the addition of newly reported chemicals. Evaluations were aimed at (1) verifying (or refuting) the evidence that each chemical was indeed a detected or plausible tank headspace constituent, and (2) establishing reasonable toxicological bases for the inclusion (or exclusion) of each chemical on the COPC list. The inclusion of duplicate entries on the CNFE list, incorrect analytical chemical identification, and the identification of new chemicals identified in the headspace were key elements of this evaluation. Based upon this analysis 29 chemicals were removed from the list between July 2005 and February 2006, with the basis for removal noted in the report (see Table C-9 Appendix C, Meacham *et al.*, 2006a). The resulting COPC list included 48 chemicals that were added between October 2004 and May 2006, of which 19 had established ACGIH TLV/Ceiling or OSHA PEL values and the remaining 29 had their AOEL's assigned based on established criteria (Poet and Timchalk, 2006). WRPS has provided information showing that several processes have been used to update the COPC list on an annual basis. The IH program monitors and updates TVIS on an annual basis, which includes a review of the COPCs. IH also notes any sufficient peaks in gas chromatography/mass spectrometry (GC/MS) data provided either through internal analysis or analytical lab analysis to identify potential new COPCs. The COPC list is currently based on these annual reviews on a farm-by-farm basis and ad hoc when indications arise and during/after waste transfer operations. There are currently 59 COPCs listed by WRPS. Although the technical approach for reviewing and amending the COPC list is described in the IH Technical Basis, the process for regularly updating the COPC list is less clear. The mechanism to identify new COPCs, the process for developing OELs for new chemicals that do not have existing ACGIH TLVs or PELs, and the basis for changes made in the COPC list over time need additional documentation.

Recommendation DR2

Conduct a rigorous review of the COPC list to ensure it is current, and develop a process to document the mechanisms used to ensure COPC updates and the basis for changes in the COPC list over time.

DR TECHNICAL ISSUE 3: ODOR AND IRRITATION-DIFFERENTIATION BETWEEN SENSORY AND PATHOPHYSIOLOGICAL RESPONSE ARE NOT UNDERSTOOD.

Observation

Many compounds are known irritants to the respiratory tract; however, as noted by Paustenbach (2000), the term "irritation" is generally utilized without any discrimination between pathophysiological or sensory irritation. Chemical induced pathological irritation can be considered a local response involving redness, swelling, pruritus or pain; whereas, chemosensory effects produce temporary but undesirable effects upon eyes, nose or throat and involve trigeminal nerve stimulations (Arts *et al.*, 2006). Odors can also result in stimulation of the olfactory receptors responsible for the discrimination of different odorous substances. The potential for chemicals to

produce odors as well as sensory and pathological irritation makes it particularly challenging to differentiate mode of action based upon symptomatology, particularly when dealing with complex mixture interactions within the respiratory system.

Recommendation DR3

Conduct additional evaluations of COPC toxicological studies to provide insight into the sensory and pathophysiological irritation response, including the role of mixture interactions and the potential need for additional toxicological evaluation.

DR TECHNICAL ISSUE 4: ROLE OF ODOR METRIC

Observation

As has been noted, a broad range of odors are routinely noted in the vicinity of the tank farms and workers have characterized these smells with descriptions such as: stinky, dirty socks, locker room, glue like, sweet, pungent, and metallic among others. Although it is reasonable to equate smell with a chemical exposure, as noted by Greenberg *et al.* (2014) and others (Paustenbach and Gaffney, 2006; Arts *et al.*, 2006), the determination of exposure intensity based on a perceived odor is unreliable. More succinctly, detection of a chemical odor does not by itself imply a medically significant exposure to a toxicant; furthermore, when dealing with complex chemical mixtures, the identification of a particular odor (ex. pungent) may not be construed as resulting from exposure to a specific chemical constituent in the mixture. Nonetheless, ~ 33% of the nearly 1,000 chemicals for which OELs have been established have odor or irritation as their most sensitive adverse effect (Paustenbach 2000); hence it may not be surprising that exposure to tank waste chemicals likewise produces a range of odors and respiratory irritation. Anderson (2007) noted that odor thresholds have been determined from the literature for a number of the COPCs, and a chemical odor fact sheet for COPCs has been developed (EH-06-005) to compare odor thresholds with OELs and provides a general description of odor and taste. In addition, the Chemical Hazard Awareness Training (CHAT) includes a presentation focused on odors and their relationship to COPC. The chemical odor fact sheet and CHAT training are positive strategies for communication with workers that can provide needed perspective between odors and irritation.

Recommendation DR4

Perform a comprehensive evaluation of acute odor thresholds and toxicity effect levels for all COPCs to facilitate the establishment of action levels based upon the relationship between odor and toxicity thresholds.

A clear worker communication strategy is needed to facilitate understanding of what can and cannot be adequately discerned from odors.

DR TECHNICAL ISSUE 5: RELEVANCE OF COPC OELS TO SYMPTOMS

Observation

An important dose-response consideration is the relevance of COPC exposures as they may or may not relate to reported symptoms in workers following a reported vapor exposure. To better understand the potential role of identified COPC and relevance of their specific OEL to observed symptomatology, the toxicological basis for their specific OELs was reviewed by the TVAT in this context. For the 59 COPC listed in the WRPS IH Technical Basis (Meacham *et al.*, 2006a) document, establishment of OELs for chemicals that did not have an established exposure guideline were primarily based upon inhalation data for appropriate surrogate chemicals (Poet and Timchalk, 2006). In many cases the relevant biological endpoints were associated with irritation of the eyes and respiratory system; hence, the overarching approach and analysis is appropriate for dealing with observed symptoms. However, it was also noted that for furan and substituted furans the OELs were based upon oral carcinogenicity data resulting from chronic furan exposure in animals, and oral doses were extrapolated to an appropriate inhalation dose-metric. Based upon the importance of reported symptomatology that is focused primarily on acute respiratory irritation, it is important to continue to re-evaluate COPCs and OELs within this context.

Recommendation DR5

Continue to evaluate COPC OEL’s within the context of observed symptomatology, verses 10% of the irritation thresholds and develop a “new” acute OEL list.

DR TECHNICAL ISSUE 6: WORKER EXPOSURES/SYMPTOMS

Observation

A limited number of worker exposure/symptomatology case reports were reviewed by the TVAT to provide some perspective on how these events are documented from both an IH and medical response perspective. The individual case management reports highlighted in Table 1 may have included all or some of the following: Tank Farm Event Report, Individual Accident/Incident Report, AOP-15 Vapor Communication Report, HPM Corporation (HPMC) Occupational Medical Services Record of Visit, Provider’s Initial Report, Kadlec Visit Report, copies of pertinent e-mails, copies of letters to claimant, Personal Physician Report and Washington State L & I Claim Forms. All documentation that was reviewed had personal identifiers removed.

Each of the reports (Table 1) are for individual workers; however, the reported exposures do involve more than one worker; therefore, the IH responses are relevant to a number of the reported cases. Although this is by no means a comprehensive review of reported worker exposure/symptomatology, it does provide some insight in to the chain of events associated with the exposures and medical/ IH responses. The Event Reports do provide a detailed narrative prepared by the manager/supervisor with concurrence from the worker/employee. In all noted reports, events all involved initial odor recognition by workers, although the odor descriptions varied from worker to worker even though in some cases they were associated with the same exposure event (ex. reports 59723-50726). Symptomology was reported to occur concurrently or shortly after the reported exposures and are generally characterized as respiratory irritation (nose/throat/lung) with some reports of headaches. Of the six reports reviewed, only one (59719) involved a subsequent medical evaluation by Kadlec hospital with a diagnosis of chemical pneumonitis, which required modest medical treatment (i.e. prescription medicine). The other 5 reports, all involved transport to HPMC, laboratory test (all within normal range), some non-prescription OTC treatment with workers subsequently being cleared to return to work. The AOP-15 Vapor Communication Report does provide a detailed time-line of events and includes both DRI and GC/MS results taken as area samples (odor) and at the source. As noted, 4 of the 6 reports had high concentrations of ammonia and VOC detected at the source, but GC/MS analysis of bag samples taken within 5 ft. downwind of the source were all at background concentrations for the selected analytes.

Assuming these limited Tank Farm Event Reports, AOP-15 Vapor Communication Reports and associated medical records documentation are an adequate representation of current practices, they do provide a reasonable time-line of events describing exposure scenarios, immediate tank farm response to the event as well as medical and IH responses. Although the IH reports provide reasonably good detail, HPMC Occupational Medical Service Record of Visit reports provides only limited insight into the medical evaluation. However, it is anticipated that more details of the immediate and subsequent medical evaluations can be discerned by reviewing individual medical records.

Table 6-1. Limited worker exposure/symptomatology case management reports.

Report #	Event	Symptoms	Medical Response	IH Response
59719	Work team in AZ farm near AN-102 –pump pit, worker noticed musty odor and had coppery taste in mouth.	Headache, burning sensation in throat and lungs.	Transported to HPMC, no treatment provided returned to work. Next day still experiencing symptoms so went to Kadlec Hospital. Diagnosis: chemical pneumonitis, and	DRI (odor): Ammonia 0 ppm Total VOC 0 ppb Mercury 0 ng/m ³ GC/MS (odor):

			medications were prescribed.	All analytes ~22 ppb Limonene* ~6.1 ppb 2-Ethyl-1-hexanol* ~4.2 ppb
59723	Worker in AY/AZ farm approached instrument panel and got strong ammonia smell. While at change trailer experienced a spoiled smell.	Sore throat.	Transported to HPMC, laboratory work done, and non-prescription strength medication provided.	DRI (odor): Ammonia 0 ppm Total VOC 0 ppb Mercury 43 ng/m ³
59724	Worker in AY/AZ farm approached instrument panel and got strong ammonia smell. While at change trailer experienced a spoiled smell.	Sore throat.	Transported to HPMC, laboratory work done, and non-prescription strength medication provided.	GC/MS (odor): All analytes ~32 ppb Limonene* ~8.5 ppb Dodecane* ~5.4 ppb
59725	Walking towards AY changing trailer, experienced strong sulfur smell.	Dry throat and headache while driving to HPMC.	Transported to HPMC, laboratory work done, and non-prescription strength medication provided.	DRI (source): Ammonia > 100 ppm (>4x OEL) Total VOC 3500 ppb** (1.8x OEL)
59726	Worker in A farm noticed odor not normally present, ammonia like smell. Retreated to AY change trailer.	Dry mouth, burning sensation in nose, throat and chest. Small "buzz" after exposure.	Transported to HPMC, laboratory work done, and non-prescription strength medication provided.	
59729	Worker was repackaging waste (S-farm) and possibly inhaled vapors.	Irritated throat /dry mouth	Transported to HPMC, laboratory work done, and non-prescription strength medication provided.	DRI (odor): Ammonia 0 ppm Total VOC 0 ppb Mercury 0 ng/m ³ Nitrous Oxide 0 ppm GC/MS (odor): All analytes ~124 ppb Nonane* ~20.5 ppb Dodecane* ~50 ppb

				DRI (source): Ammonia 0 ppm Total VOC 0 ppb Mercury 0 ng/m ³ Nitrous Oxide 0 ppm
* Detectable compounds ** Elevated ammonia may cause positive interference with the VOC readings and likely contributed to the total VOC readings.				

The data in this table provide clear testimony that the exposures are to acute, intense concentrations. In four of the six exposures where personnel experienced upper respiratory issues, field measurements at the source found irritants at concentrations far exceeding the OEL.

As noted above, the most common symptoms reported by workers tend to be associated with respiratory tract irritations; however, it appears that medical evaluations by HPMC have not identified relevant clinical signs that are directly linked to those symptoms. This has created frustration on the part of workers who believe that the symptomatology can be directly linked to vapor exposures. In this regard, it is of critical importance to fully understand that symptoms are subjective; whereas signs are objective criteria. For example, reporting a burning sensation in the throat is a symptom, whereas observing the throat and noting that it is inflamed and swollen represents a sign. Although the medical staff at HPMC has clearly noted patient symptoms as they are reported, it does not appear that signs of associated disease have been necessarily observed. In the case of acute respiratory irritation, the potential diagnosis is further complicated by the fact that irritation can result from chemicals directly interacting with sensory receptors or from pathological tissue irritation resulting in signs of redness, swelling or pain. In addition, depending upon the chemical dose and complexity of the mixture exposure, it may be feasible for an irritation response to transition between sensor irritation and pathophysiological response. The perception of an odor also can affect the perceived level of irritation symptoms.

Recommendation DR6

Maintain a robust health surveillance program that follows up with exposed workers to evaluate short- and long-term consequences from vapor exposures.

At this juncture, it is not feasible to discern whether the reported symptoms are due to sensory irritation or early stages of pathological insult. Therefore, it is of critical importance to maintain a robust health surveillance program that follows up with exposed workers to evaluate short- and potentially long-term consequences from vapor exposures.

A number of other opportunities for process improvement have been noted and include the following:

- Although WRPS IH and HPMC medical staff have established monthly meetings, the TVAT recommends continual communication improvement particularly on the COPC constituent exposures (timing and concentrations) and potential relevance to symptoms as well as any follow-up discussions.
- Development of a more comprehensive list of COPC chemicals associated with tanks as part of the potential chemical exposure review process associated with exposure events.
- Conducting appropriate epidemiology studies to evaluate the long-term health consequences of acute and chronic tank vapor exposures.
- Verify that medical staff members understand the potential relationship between COPC chemical exposure, symptoms and resulting signs.

DR TECHNICAL ISSUE 7: CHEMICAL MIXTURE DOSIMETRY-RESPONSE

Observation

Although the WRPS IH Technical Basis Document (Meacham *et al.*, 2006a) does not specifically address the approach utilized to assess chemical mixture interactions. Anderson (2007) notes that the OSHA Mixture Rule is utilized to evaluate the impact of mixtures of chemicals with similar health effects. The generalized approach is to group detectable chemicals at each sampling location (i.e. tank) according to their toxic effect and adding together the mean concentrations divided by the OEL in accordance with the OSHA formula (see equation below). If the equivalent exposure calculation (Em) is greater than unity (>1), then exposure to the mixture as a whole is considered to be above acceptable levels. The WRPS IH program action level for mixtures was set at $Em \geq 0.5$.

$$Em = \frac{C1}{L1} + \frac{C2}{L2} + \dots + \frac{Cn}{Ln} \quad (1)$$

A review of vapor characterization tank farm reports (A-prefix farm, C-farm, T-prefix farm, U-farm, BX- and BY-farms, B-farm and S-prefix farm) indicated that the A-prefix, T-prefix, U-farm and S-prefix had some chemical sources with a derived mixture TWA exceeding the mixture OEL ($Em \geq 0.5$) action levels (Anderson *et al.*, 2006; Hugley *et al.*, 2007; Hugley and Farler, 2008; Farler and Butler, 2008a, 2008b; Farler 2009a, 2009b). These results indicate that mixture interactions associated with similar health effects (i.e., irritation) are a real potential; hence, under tank conditions capable of producing a transient vapor/gas plume, acute interactions between COPC with common modes of action (ex. respiratory tract irritation) or from chemical families (ex. aldehydes) are plausible.

Recommendation DR7

Evaluate tank vapor mixture toxicological interactions at concentrations associated with transient plume exposures to modify OELs to accommodate mixture effects.

Further assess mixture effects to identify the mode of action of target organs for each COPC ORL to support risk characterization efforts. This issue is addressed further in the Risk Characterization chapter of this report.

DR TECHNICAL ISSUE 8: AEROSOL DOSE-RESPONSE

Observation

The potential exposure to vapor aerosols potentially associated with tank vapor condensates has not been previously considered with the WRPS IH Technical Basis Document (Meacham *et al.*, 2006a). However, it is acknowledged that dosimetry from tank chemical aerosols is currently under evaluation by WRPS.

Recommendation DR8

Develop an overall IH strategy for aerosol evaluations that focus on analytical quantification, the evaluation of chemical aerosols for inclusion in the COPC list as well as the establishment of appropriate aerosol OELs.

TECHNICAL ISSUE DR 9: UNIQUE AND HIGHLY COMPLICATED NATURE OF MIXED-CHEMICAL EXPOSURE SCENARIOS.

OBSERVATIONS

It is important to recognize that the complex nature of the mixed chemical exposure scenarios associated with tank waste vapors, gases and aerosols is extremely unique and highly complicated. This complexity results from the facts that there are over 1500 chemicals/reaction products, resulting from complex radiochemical interactions that are occurring within a dynamic tank milieu creating an extremely challenging working environment. The overarching IH approaches have been based upon accepted industry health and safety practices that have been widely utilized to protect the health of workers within the chemical industry and other industrial operations that have potential for worker exposures to chemicals. However, the unique nature of dealing with Hanford tank waste may require the development of novel strategies to effectively evaluate the exposure, dose and response continuum. In this regard, the DOE is uniquely positioned to address this complex problem by exploiting the unique technologies and science that underpins the DOE National Laboratory System. The contribution of the

National Laboratories is clearly evident by the substantial number of Pacific Northwest National Laboratory (PNNL) technical reports specifically addressing critical issues at the Hanford Tank Farms and it is recommended that these types of capabilities continue to be exploited.

RECOMMENDATION DR9

Develop a research strategy roadmap in partnership with DOE, National Laboratories, and University faculty subject matter experts to address critical questions regarding tank vapor emissions and exposures.

It is anticipated that based on the scope of this research problem, many research funding agencies would have interest in and directly benefit from supporting these endeavors. Those agencies might include the National Institutes of Health (NIH), National Institute for Occupational Safety and Health (NIOSH), Centers for Disease Control and Prevention (CDC), Environmental Protection Agency (EPA), and Department of Defense (DOD) as well as the Department of Energy.

Although a key recommendation from this review is to develop the needed sampling and analytical strategies to quantify transient vapor/gas tank exposures, it is conceivable that adequate quantitative analysis of tank plume activity may remain elusive, based upon currently available technologies. In this regard the following actions should be considered:

- Exploit the technology development/application capabilities of the National Laboratory system to develop novel sampling and analysis technologies that provide rapid, real-time, portable, and sensitive analytical instrumentation to quantify the broadest range of COPC within the working environment and within readily obtainable biological samples (ex. breath, urine, saliva, nasal swabs) from workers (i.e. biomonitoring). These technologies should be capable of quantifying exposure and dose at concentrations below acute OEL exposures.
- Exploit capabilities within atmospheric chemistry and computational modeling to simulate vapor, gas and aerosol dynamics that result in plume behavior. These model simulations should be capable of predicting transient plumes and would be of direct relevance for estimating worker exposures and informing dose-response studies.
- Exploit recent advancements in the development and application of computational fluid dynamics (CFD)/physiologically based pharmacokinetic (PBPK) models to simulate and predict reactive chemical vapor/particle dosimetry within the human respiratory tract (Corley *et al.*, 2012). These computational modeling tools can be utilized to quantitatively predict localized respiratory tract dosimetry under a broad range of transient air flow conditions.
- Exploit *in vitro* air-liquid-interface human respiratory cell culture systems to evaluate dose-response for toxicological and odor related endpoints following exposures to waste tank head space vapor/gases. These *in vitro* data could establish a quantitative dose-response for the complex tank vapor/gas mixtures over a broad range of anticipated concentrations and would be a critical experimental input into CFD/PBPK dosimetry models.

7.0 RISK CHARACTERIZATION

INTRODUCTION

Risk characterization is the final step in the risk assessment process and before risk management. In its most fundamental form it is a tool used to predict the likelihood and severity of an unwanted event, such as an explosion, failure of a machine, or a workplace injury. Health risk characterization is a specific type of risk characterization that uses toxicological data, combined with information regarding the degree of exposure, to quantitatively predict a particular adverse response in a specific exposure population such as a workforce (Jayjock, et al., 2000).

In simplistic terms it is the product of the exposure and the rate of the adverse health effect per unit exposure as shown below:

$$Risk = Exposure \times \left(\frac{Adverse\ Health\ Effect}{Exposure} \right)$$

Even highly toxic materials are not risky at low enough doses and given enough exposure any material can be toxic. (Paracelsus, 1530)

Occupational Exposure Limits (OELs)

To fully characterize risk, the risk assessor needs to understand both the toxicology and actual exposure to the substance of interest. Understanding the relationship between adverse effects of a chemical and exposure is called the dose-response assessment. In an ideal situation, the relationship between exposure (or dose) and the toxic effects of that exposure are presented as data or prediction points either as a percent of a population that is adversely affected or the level of adverse response predicted for an individual for all doses up from zero. Such detailed dose-response information is always costly to obtain and often unavailable.

In the realm of Industrial Hygiene (IH), the determination, measurement or estimation of the dose-response toxicity is typically all rolled up or combined in the occupational exposure limit or OEL. The Industrial Hygienist relies on the judgment of those setting the OEL to come up with a level of exposure that does not represent an unacceptable risk to the workers being exposed. In the world of the IH, risk is traditionally characterized with the following ratio:

$$Risk = Exposure/OEL$$

When this ratio (Risk) is greater than one, we have overexposure, and when it is much less than one, the risk is considered acceptable. In the scheme forwarded by the American Industrial Hygiene Association, any scenario in which the exposure is less than 10% of the OEL ($Exposure/OEL < 0.1$) is considered to present an exposure that is acceptable (AIHA, 2006)

The definition of “acceptable risk” relative to human chemical exposure is subjective and politically determined. In a technical sense, it is often more useful and appropriate to simply declare that the risk is “not unacceptable” in accordance with the judgment of some body of technical experts (e.g., the American Conference of Governmental Industrial Hygienists’ Threshold Limit Value Committee, working OELs determined for the Hanford COPC). It is analogous to the statistical construct in which one does not accept the null hypothesis one simply fails to reject it.

This basic comparison of exposure to OEL is often entitled hazard index or hazard quotient⁵ but it is also considered by some to be risk characterization. Please note, however, that this ratio does not provide an estimate of the proportion of individuals exposed at that level of exposure that might see the toxic effect being addressed

⁵ The hazard quotient is as a risk characterization tool in the context of the NAS Risk Assessment Framework used in this report. Note however, this metric does not provide specific risk probability estimates.

by the OEL. Those setting the traditional types of OELs only proclaim that “nearly all” will be protected from the identified adverse effect of overexposure at exposure to the OEL (i.e., ratio of Exposure/OEL = 1) for a working lifetime (Jayjock et al, 2001).

Every OEL has a time-frame associated with its concentration limit value. The vast majority of OEL values are based on an 8 hour time-weighted average (TWA) during a work day. That is typically called the OEL-TWA and provides an exposure limit for an average exposure over an entire workday. For example, the American Conference of Governmental Industrial Hygienists (ACGIH) has set an OEL-TWA for toluene of 50 ppm v/v. This means that an average worker exposed to an 8-hour TWA concentration to 50 ppm v/v day in and day out for a working lifetime is not expected to experience any adverse effects from his or her exposure. The ACGIH states that this level will protect not only the average but “nearly all” workers. The assumption in using any OEL-TWA is that the breathing zone concentration will be relatively constant or at least relatively consistent over the time frame of measurement which is typically tens of minutes to 8 hours in duration. Indeed, because of analytical limitations, the sampling time often has to be long enough to gather enough volume to be able to adequately measure the exposure against the OEL-TWA.

The ACGIH confirms that the rate of exposure during TWA testing should be relatively constant by their invocation of an “excursion rule”: “Excursions in worker exposure levels may exceed 3 times the Threshold Limit Value (TLV)-[8 hour] TWA for no more than a total of 30 minutes during a work day, and under **no circumstances** should they exceed 5 times the TLV-TWA, provided that the TLV-TWA is not exceeded” [*Note emphasis added*].

For chemicals that occur at very high levels for very short durations, the above defined excursion rule effectively becomes the OEL for short-term peaks. That is, the OEL for peak events becomes 5 times the OEL-TWA. Alternatively, an Occupational Exposure Limit-Ceiling (OEL-C) can be assigned based on the anticipated toxic response to peak concentrations of the chemical. The OEL-C has a theoretical zero averaging time. In practical application, this OEL-C is typically compared to modeling results, instantaneous or grab sampling, or DRI monitoring results with the fastest sampling/response time possible. A program could default to utilizing 5 times the 8-hour TWA OEL as the excursion OEL. The TVAT believes that it would be prudent to establish a 3-times-the-OEL concentration as a conservative default OEL-C. As with the current OEL-TWA and OEL-STEL, WRPS would use 10 % of the OEL-C in the same manner that it now uses 10 % of the OEL for an 8-hour TWA.

Because bolus exposures appear to be the primary mode of exposure to Hanford tank farm vapors, they should be compared to the excursion limit discussed above as a default OEL-C or to a specifically assigned OEL-C based on toxicological data.

TECHNICAL ISSUES

RCH ISSUE 1: THE NEED FOR THE DETERMINATION OF OELS THAT ARE PROTECTIVE OF ADVERSE HEALTH EFFECTS FROM BOLUS EXPOSURE TO TANK FARM VAPORS.

Observation:

The OEL represents a critical element of the risk characterization process in that it literally provides half of the information required. The OELs chosen for use at Hanford seem to be appropriate for the measurement of chronic exposure potential (with the caveat that an update may be needed as discussed in the Dose-Response chapter). However, this exposure potential does not appear to be the issue at hand. That is, chronic exposure potential is not the problem that has brought the TVAT to Hanford. Rather, the effects seen at Hanford appear to be, at least initially, acute upper respiratory irritation and distress brought on by short term exposure. Thus, the focus on long-term exposure limits (OEL-TWA) to the exclusion of considering peak exposure limits (OEL-C) is inappropriate. Some of the technical details of this observation are presented below.

The first step in setting an OEL is the determination of the adverse health effect that the OEL will be addressing. This process is called hazard characterization. For example, if cancer has been identified as the critical health

effect from exposure to a chemical, then it will form the basis for an OEL to reduce the cancer risk from occupational exposure. Some other health effects include organ (liver, kidney, lung, etc.) damage, neurological effects, reproductive effects, or upper respiratory irritation. Most OELs are set to protect against the adverse health effects of repeated prolonged (tens of minutes to hours) exposure.

One of the most commonly used and well respected sets of OELs frequently relied upon by the industrial hygienist are TLVs set by the ACGIH. The TLVs are a set of health-based values based on review of the existing published and peer-reviewed toxicological literature. According to ACGIH, the TLV represents a condition under which it believes that nearly all workers may be repeatedly exposed without adverse health effects (ACGIH, 2014).

Every OEL, including the every TLV, has an averaging time against which exposure is measured. Most OELs are represented as eight-hour TWA, meaning they are measured as an average exposure over the entire work day (480 minutes). This is the OEL-TWA. This does not mean that one has to be exposed to or sample over the entire eight hours but only that the exposure is averaged over an entire 480 minute day. For example, consider a task that lasts only one hour; the industrial hygienist samples the worker over the entire task, which results in a measurement of 80 ppm as an average exposure for this time period. If the worker receives no more exposure to this chemical that day his or her eight hour TWA would be calculated as:

$$\text{TWA} = [(80 \text{ ppm} \times 1 \text{ hr}) + (0 \text{ ppm} \times 7 \text{ hr})] / (8 \text{ hr}) = 10 \text{ ppm}$$

This is the value of exposure that would be compared to the traditional eight hour OEL (i.e., the OEL-TWA). If it was assumed that the exposure continued at approximately the same level for the remaining seven hours after the sampling (but was not sampled for whatever reason) then the eight hour exposure could be estimated as 80 ppm.

As mentioned above, most OELs are eight-hour time-weighted averaged (OEL-TWA). Significantly fewer OELs have averaging times that are less than 8 hours. Short term exposure limits (OEL-STELs) are averaged over 15 minutes and Ceiling (OEL-C) limits are considered to have the zero averaging time as peak or instantaneous concentration levels. In the instance of ACGIH TLVs, ACGIH defines a TLV-STEL as a concentration to which it is believed that workers can be exposed consistently for a short period of time (e.g., 15 minutes) without suffering from irritation, chronic or irreversible damage, dose-rate-dependent toxic effects, or narcosis of a sufficient degree to increase the likelihood of accidental injury (ACGIH, 2014). The TLV-C is defined by the ACGIH as the absolute exposure limit for worker exposure that should not be exceeded at any time.

This brings us to the type of health effects being addressed and protected by most OELs used at Hanford. As mentioned above, the majority of OELs have eight hour averaging times. They are designed to protect against health effects arising from exposure that are metered out or incurred by the worker over days, hours or at least tens of minutes. They can be thought of as protecting against adverse health effects from chronic exposure day in and day out over a working lifetime.

Often underplayed in many industrial exposure scenarios are health effects associated with chemicals that, if present in very high concentrations, can react adversely and very quickly when inhaled. The specific situation where high concentrations of a chemical occur in the breathing zone of a worker over a very short period of time is termed a bolus dose. In this situation, the body's defense mechanism can be rapidly overwhelmed and a toxic effect can occur even though the eight-hour TWA exposure during that day could be quite low. OEL ceiling limits (OEL-C) as defined above by the ACGIH are developed for such chemicals.

The TVAT specifically recommends that the 1200 substances identified in the tanks should be re-evaluated by toxicological experts for the identification of an acute COPC (a-COPC) list. Each should receive an assigned OEL-C or an excursion OEL as a default OEL-C. Ultimately, the a-COPC will be comprised of a list of substances that are of putative concern relative to causing acute respiratory irritation or other toxic manifestation occurring as a result of bolus exposure.

Compounds not previously considered (those at $<0.025 \text{ mg/m}^3$ in the head space and considered *de minimus* risk at the time with no further justification) should be considered for their acute toxic effects by compound class/homologous series, or otherwise examined based on new understanding of structure-activity relationships.

Doing the above will facilitate the validity of the risk characterization for acute exposure events by supplying either excursion OELs (OEL-TWA x 3) or (OEL-STEL x 3) as default OEL-Cs or assigned OEL-Cs based on acute toxicology data in the hazard quotient (Exposure/OEL).

It is considered a first step in the characterization of the acute hazards posed by the Hanford tank vapors with the subsequent issues/recommendations presented below representing a necessary refinement.

Recommendation RCH1

Identify an OEL-C for each analyte in Hanford tank head space(s).

RCH TECHNICAL ISSUE 2: EVALUATE TOXICOLOGICAL EFFECTS OF BOLUS EXPOSURE TO HANFORD TANK VAPORS

Observation:

The recommendation for RCH ISSUE 1 above is a first step in characterizing the toxic potential of the Hanford tank farm vapors. It is expected to provide a significant improvement over the current system; however, because the OELs are currently focused on longer term health effects, a significant and unsatisfactory level of uncertainty will remain in this judgment-based characterization of toxicological hazard of many of the chemicals of interest.

The TVAT recommends specific laboratory tests of tank vapor samples by state-of-the-science (in-vivo or in-vitro) methodologies to elucidate this critically relevant short-term dose-response. These would be used to inform the assignment of an OEL-C value for the entire class of head space mixture tested.

Doing this would provide a single toxicological mixture benchmark for each representative head space type, facilitating appropriate characterization of the risk extant on the Hanford tank farms. It would increase the credibility of the IH staff among workers since the real risk of acute exposure would be appropriately characterized and the workers' past experiences of acute vapor exposure could be validated against relevant toxicology results.

Recommendation RCH2:

Classify and conduct toxicological testing on a reasonable number of distinct types of Hanford tank head space vapors (e.g., potential classes of tank vapor types such as ammonia rich, ammonia poor, nitrosamine rich, etc.).

RCH TECHNICAL ISSUE 3: THERE IS A NEED TO EVALUATE OR ESTIMATE TOXICOLOGICAL EFFECTS OF MIXTURES FOR BOLUS EXPOSURES TO HANFORD TANK VAPOR

Observation:

This recommendation deals specifically with mixtures and is complementary to Recommendation DR 7 in the Dose-Response chapter. The TVAT anticipates that the recommendation from RCH Issue 1 will happen before, and perhaps well before, the implementation of the recommendation of RCH Issue 2. Thus, work will most likely happen in two stages. The first stage incorporates the output from RCH Technical Issue 1 above, namely, the individual OEL-Cs or excursion OELs (providing default OEL-Cs) for acute toxicity of each chemical and the identification and assignment of an acute a-COPC. The second will simply use the toxicological data from the mixtures as a reality check relative to acute toxicity potential of these vapor mixtures.

The TVAT advises using the above estimated OEL-C or excursion OELs and the subsequent a-COPC list to characterize the risk from the mixture effect for all a-COPCs during bolus exposures values assuming additivity.

This approach uses the classical equation for additivity but uses the acute measures of both exposure and hazard (OEL-C or excursion OEL).

That is:

- Mixture Risk Characterization (RC) = Bolus Exposure 1/OEL-C1 + Bolus Exposure 2/OEL-C2 + ... Bolus Exposure n/OEL-Cn
- RC > 1 unacceptable
- RC < 1 not unacceptable (suggest using 0.1 as a working threshold)
- Bolus Exposure n = Measured or estimated peak exposure for chemical n
- OEL-C1n = Ceiling OEL for chemical n (could also use excursion OEL if OEL-C not available)

Doing this in the interim before actual toxicological testing of representative head space vapor samples will more promptly and reasonably characterize the risk from short term exposure to these mixtures and hopefully point the way to risk management options that will eliminate unacceptable characterizations. As mentioned above however, considerable uncertainty remains for many of the compounds for which acute data may not be available.

Given good toxicological data on the mixtures that represent the Hanford tank vapor head spaces will provide data to validate the overall determination of acute toxicity for the various mixture components. The analysis of these data should accomplish two objectives. First, it should test and validate (or deny) the above mixture risk characterization as a reasonable portrayal of the toxicological potency while also, most likely, leading to more focused research on the acute toxic potential of individual or groups of vapors.

Recommendations RCH3

Use the OEL-C from analysis or subsequent toxicological testing to characterize the hazard index and risk from the tank vapor mixtures, and control to 10% of the value.

RCH TECHNICAL ISSUE 4: ISSUE: METRICS OF DOSIMETRY AND BIOLOGICAL RESPONSE (D-R METRICS): RELEVANCE OF CHRONIC AND ACUTE HEALTH EFFECTS

Observation

To assess health risks from tank vapors/gases, it is of critical importance to identify dose-response metrics that are consistent with the unique exposure scenarios associated with tank farm operations. In this context it is clear that one metric will not fit all risk management goals. Therefore, metrics of dose-response must fully consider whether the exposures (i.e. dose) are of an acute or chronic nature and the resulting biological response must be consistent with relevant toxicological modes-of-action associated with these differing exposure scenarios. For example, OELs that protect against chronic health effects (long-term) may involve a chronic exposure scenario where repeated exposures over months or years above an OEL are needed to produce disease; however, it is equally likely that persistent adverse health effects can also result from short-term higher concentration exposure where significant organ damage/pathology has occurred (i.e. chlorine gas lung damage). To protect against acute effects, OELs like the Short-Term Exposure Limit (OEL-STEL) or Ceiling (OEL-C) are acceptable exposure limits for a toxic or irritant substance over a short-period of time (usually 15 minutes for the STEL or instantaneously for C). STELs and Ceilings are the maximum concentration of a chemical to which a worker may be exposed continuously for a short-period without any danger to health, safety or work efficiency. It is quite clear that the OELs for chronic or acute exposures can be substantially different, with chronic OELs generally being substantially lower than STELs or Ceiling Limits. Likewise, the time-scale between exposures and response are generally quite different with chronic response often taking months to years to develop while acute responses can often present themselves immediately or a short-time after exposures. Although there are exceptions to the rules, most chronic and acute health effects resulting from chemical exposures follow these trends.

In the current WRPS IH Technical Basis document (Meacham *et al.*, 2006a) the strategy is to base acceptable exposures on established or estimated OEL which is defined as a level of exposure to a given chemical expected to lead to no adverse health effects that is acceptable to management, professionals, and workers at the Hanford Site. However, the current tank farm vapors OELs do not differentiate between chronic or short-term exposures

and are generally expressed as a TWA over an 8 hour period, effectively diluting the dose-rate for exposures that are transient in nature. In addition, the majority of the supporting toxicology data for the OELs is based upon chronic (i.e. lower dose) effects; but as noted, the observed worker symptomologies are of an acute transient nature. In principle one would expect that regulating acute exposures at chronic OEL levels would provide more than adequate worker protection from acute effects. However, based upon the transient nature of the exposures, and an inability to rapidly measure vapor concentrations during an exposure event it has not been possible to quantify transient higher levels of exposures that could result in the reported worker symptoms.

The following provides a more detailed description of the IH strategy for dealing with chronic and acute exposures/health effects:

Chronic Exposure and Health Effects

As noted in the WRPS IH Technical Basis document (Meacham *et al.*, 2006a) procedures were developed and applied to systematically identify chemicals of likely concern amongst the hundreds of chemicals present at trace levels in the head spaces. Toxicological evaluations were conducted on those chemicals identified by the initial screening process as being potential hazards (Poet *et al.*, 2006). OELs for these chemicals were developed using thoroughly reviewed procedures, and reviewed and approved by the Exposure Assessment Strategy Review Group (EASRG). Chemicals present at a tank farm source at a concentration >10% of the OSHA PEL, ACGIH TLV, or Hanford Site Tank Farms OEL were placed on the COPC list.

The COPC list and OELs have subsequently been utilized as the analytical and IH basis for area and worker monitoring across the Hanford Tank Farms. As report by Anderson (2007), area and personal sampling have been done to measure all COPC vapors that could be present both inside and outside of the tank farms. Detection limits for COPC were adequate to quantify at 10% of an individual analyte OEL and any additional chemicals at >10% of a reference peak (mass spectrometry analysis) were identified and considered for further COPC evaluation. In general, vapor measurements far from stacks (>100 meters), near stacks (< 100 meters) or within 5 ft. of the source were below 10% of the OELs. However, at the source a number of COPC OELs were significantly exceeded.

An assessment of worker tank vapor exposures based upon personal air sample monitoring was conducted over 1.5 years from May 2005 through December 2007 (Jabara and Farler, 2008). This assessment included over 4000 personal samples collected over 571 different days in all tank farms during both non-waste-disturbing and waste-disturbing activities. In this analysis, the action level for airborne exposure concentration was at 50% of an 8-hour TWA OEL. The exposures were evaluated while workers were conducting operations, maintenance and construction activities. In addition, extensive area and emission source air samples were collected. The area surveys reported that vapor and gas concentrations although readily detected at the tank source emission points were non-detectable in the immediate area around these sources. Any COPCs that were at concentrations exceeding an action level (i.e. 50% of a TWA OEL) were identified for each tank farm surveyed and were then targeted for personal air sampling. In farms that had not been characterized (e.g. B-Complex) samples were collected for a full suite of COPCs. The overall results of this analysis report that the mean personal TWA exposure to tank farm vapors and gases was less than 10% of the OELs for targeted COPCs during work in the farms (May 2005 – December 2007).

Acute Exposure and Health Effects

As noted above, the current WRPS IH program for the evaluation of acute vapor/gas dosimetry is essentially no different than the chronic exposure assessment approach just discussed. More specifically, the action levels (i.e. OELs) for COPC are the same for both acute and chronic exposure scenarios, which on first evaluation should provide more than adequate protection of workers from acute vapor toxicity (i.e. highly conservative). However, the reported COPC exposure/dosimetry results (i.e. TWA exposures at or below 10% OELs) are inconsistent with reported worker acute symptoms (i.e. shortness of breath, upper respiratory tract irritation, nasal bleeding, headaches etc.) suggesting that transient vapor/gas exposures (i.e. high dose/rate) are substantially greater than what is currently measured.

In reviewing the WRPS IH program there are a number of potential confounders that may contribute to an inability to correlate exposure/dose concentrations with observed symptomatology. In this regard the following confounders need to be considered and critically assessed within the context of acute exposures and resulting symptoms:

- Tank head space vapor/gas concentrations can increase several orders of magnitude during tank-disturbing activities. This could result in substantially higher exposures than what is currently anticipated.
- The vapor/gas events associated with exposures appear to be transient in nature (i.e. random events of a short duration), but the current IH vapor sampling strategies are not adequately designed to capture these transient releases.
- Reported symptoms in workers (i.e. upper respiratory tract irritation, coughing, headaches, nose-bleeds etc.) appear to be consistent with the known acute chemical effects associated with respiratory exposures for a number of the head space COPC.
- For acute effects that may be associated with higher concentrations of vapors/gases the potential for additive, synergistic, potentiation or antagonistic interactions from the complex vapor mixture are feasible and need to be more fully evaluated.

The inconsistency between measured vapor/gas concentrations and observed worker symptoms has made it exceedingly difficult to establish even a qualitative relationship between exposure/dose and observed worker symptoms. However, the radioactive mixed waste spill which occurred at the 241-S-102 (S-102) tank on July 27, 2007 during tank mixing/transfer procedures, provides an important qualitative association between a spill occurrence (i.e. exposure/dose) and reported acute health effects symptoms (Anderson *et al.*, 2007). Evidence from the spill indicates that although workers did not come in direct contact with tank waste; there were potential worker exposures resulting from vapors that were released within the tank farm by the spilled tank waste. Although the timing and amount of waste spilled was well established, chemical monitoring data was not collected at the time of the spill, therefore analytical quantification of vapor concentrations were not determined. However, computer modeling was performed to reconstruct the probable temporal vapor concentrations in the area. Workers within the 200-m perimeter of the spill reported numerous symptoms associated with respiratory mucous irritations (sore throats, cough, teary eyes, raspy voice, difficulty breathing). A few workers had medical complaints of abdominal/ gastrointestinal problems, headaches, blurring vision, nausea, or dizziness. Although the Occupational Physician and Toxicologist who analyzed the S-102 spill concluded that it was unlikely that any workers received an exposure to chemical vapors above established OELs (Anderson *et al.*, 2007); the reported acute symptoms and timing relative to the event suggests that excessive exposures may have occurred. Regrettably, the lack of any chemical monitoring during the spill event creates clear uncertainties, making it impossible to determine any quantitative relationship between exposure (dose) and response (symptoms/signs). Nonetheless, these data are consistent with what is anticipated for a transient vapor/gas exposure event that could produce acute symptomatology.

Recommendation RCH4

- **RCH4a**

(Chronic) The WRPS IH program has in place procedures for evaluating chronic chemical exposures (based on TWA); it is recommended that periodic follow-up monitoring be conducted and analysis of the exposures as compared to OELs be documented to provide needed data for the industrial hygienist to verify that worker chronic exposures have not changed with time.

- **RCH4b**

(Acute) Transient vapor/gas exposures concentrations (i.e., high dose rate) are substantially greater than what is currently measured as a TWA; alternative strategies for evaluating transient plume like vapor exposures is recommended and adherence to excursion limit principles must be implemented (3 times OEL) in the absence of appropriate OEL-C values.

- **RCH4c**

(Medical Surveillance) Routine medical surveillance is a key workplace evaluation tool needed to predict health impairment from vapor exposures; appropriately designed epidemiology studies focused on tank farm workers are recommended to evaluate the potential long-term health consequences.

8.0 RISK MANAGEMENT

INTRODUCTION

Risk management in its most fundamental form is the process of weighing policy or management alternatives and choosing the most appropriate action, integrating the results of a risk assessment with social, economic, and political concerns to reach a policy or management decision (NRC, 1983). In the context of industrial hygiene, risk management involves the development of an exposure assessment and control strategy with the goal to provide reasonable assurance of worker health through proper application of the anticipation, recognition, evaluation, and control of occupational stressors.

Overview of Current Industrial Hygiene Function at Hanford

WRPS has implemented an industrial hygiene program to provide functional support to its mission in managing the waste stored in 149 older single-shell tanks and 28 double-shell tanks within the Hanford site. The scope and key program elements are presented in the WRPS Industrial Hygiene Program Manual (WRPS TFC-55, 2013). According to the manual, the industrial hygiene program requirements and responsibilities are defined and implemented in accordance with the contract between WRPS and the DOE ORP. Currently, the industrial hygiene program provides the following functional support to WRPS at Hanford tank farms:

- Support excellent WRPS project performance through effective integration to support the needs of the functional organizations;
- Evolve strategically and tactically to support program development;
- Achieve continuous improvement in accordance with the Integrated Safety Management System (ISMS) core functions and guiding principles; and
- Enhance organizational sustainability through strategic advancement utilizing a fiscal year planning process.

The overarching goal of the industrial hygiene program is to “protect the safety, health, and well-being of employees, contractors, and the public through the anticipation, recognition, evaluation, and control of biological, chemical, environmental, ergonomic, and physical hazards in the workplace to the satisfaction of the client” (WRPS, 2014).

WRPS DOE Voluntary Protection Program Star Status

In June of 2014, Washington River Protection Solutions (WRPS) received DOE Voluntary Protection Program (DOE-VPP) Star status. Modeled after the U.S. Department of Labor’s Occupational Safety and Health Administration’s Voluntary Protection Program (OSHA-VPP), DOE-VPP promotes safety and health excellence through the cooperative efforts among labor, management, and DOE at its contractor sites (U.S. DOE, 2014). Initiated in 1994 to promote improved safety and health performance through public recognition of outstanding programs, DOE-VPP includes coverage of radiation protection/nuclear safety and emergency management because of the type and complexity of DOE facilities. Similar to OSHA-VPP, DOE-VPP’s goal is to provide several benefits to participating sites, including improved labor/management relations, reduced workplace injuries and illnesses, increased employee involvement, improved morale, reduced absenteeism, and public recognition (U.S. DOE, 2014).

At the core of the DOE-VPP program is the promotion of a strong, performance-driven occupational safety and health management system (OSHMS) that provides the framework for a continuously improving process of identifying hazards, assessing associated risks, taking corrective action including establishing appropriate controls, and reviewing the program performance. Risk assessment and risk management have become critical components of the management systems-based approach to health and safety. The OSHMS makes use of risk assessment and management to assess any given risk associated with a particular hazard. In this context, risk assessment is the process of determining the risk of a particular event within a system. Risk is typically assessed as the likelihood of the hazard and its consequence; therefore, the risk assessment provides management with insight into particular workplace risks and allows these risks to be identified, prioritized and effectively controlled.

WRPS has implemented an integrated environment, safety, and health management system (ISMS) program, which encompasses and OSHMS outlined in the WRPS Management Plan Manual (WRPS TFC-PLN-01, 2009). As stated, the ISMS program focuses on a standards-based approach to planning and controlling of work including “identification and implementation of worker safety and health standards and requirements that are appropriate for the work to be performed and for identifying and controlling related hazards, while facilitating the effective and efficient delivery of work” (WRPS TFC-PLN-01, 2009). WRPS has developed ten ISMS program requirements to ensure that health and safety are integrated into all levels WRPS operations.

Current Industrial Hygiene Program Primary Elements

As presented in the Industrial Hygiene Program Manual, the industrial hygiene program contains six primary program elements:

- Professional Development
- Monitoring
- Record Keeping
- Program Evaluation
- Process Integration
- Exposure Assessment

Professional Development

The professional development element is to ensure that industrial hygiene professionals (IHPs), industrial hygiene technicians (IHTs), and support personnel possess the necessary education, experience, and skills to fulfill their responsibilities. Currently, the minimum requirements for entry-level IHP include a bachelor’s degree in industrial hygiene (IH) or related field and at least two years of job related experience. The minimum requirements for entry level for an IHT includes an associates’ degree in safety and health, applied science or related technology and one year job experience.

Monitoring

According to the Industrial Hygiene Program manual, the monitoring element ensures that industrial hygiene sampling and analysis are conducted in a consistent and professional manner. It also includes the required procedures for the periodic review of sampling and analytical methodologies, new technologies, and the evaluation and procurement of monitoring equipment. Further details regarding the current industrial hygiene monitoring program are presented in the Exposure Assessment chapter of this report.

Record Keeping

The record keeping and communication element includes the implementation procedures necessary to assure that industrial hygiene data is managed effectively for evaluation and communicated appropriately to the workforce, management, the occupational medicine provider, and DOE ORP.

Program Evaluation

The program evaluation element includes the required implementation procedures necessary to manage the continuous improvement process of the industrial hygiene program. As previously mentioned, WRPS has implemented an ISMS program, summarized the WRPS Management Plan Manual (WRPS TFC-PLN-01, 2009).

Process Integration

The process integration element includes the requirements for the implementation procedures necessary to ensure that worker exposure and control information is appropriately coordinated within WRPS and with the occupational medicine provider.

Exposure Assessment

The exposure assessment element includes the requirements for the implementation procedures necessary to ensure the broad scope of hazards are appropriately evaluated and effectively controlled. The exposure assessment program in place with respect to tank vapors is described in further detail in the Exposure Assessment chapter of this report.

WRPS Industrial Hygiene Structure

Currently, the industrial hygiene program falls within the Safety and Health division, as part of the overall Environment, Safety, Health and Quality (EHSQ) function. The industrial hygiene program organization provides direction, subject matter expert (SME), procedures, assessment, and program evaluation to assist line management in effective implementation of the industrial hygiene program throughout WRPS. In its current structure, industrial hygiene personnel assigned to line functions (Base-Ops, SST R&C and TFP) report to the project safety and health manager. The project safety and health managers' report to the safety and health programs manager and are matrixed to the respective line organization manager (WRPS TFC-PLN-55, 2013). According to information received during the TVAT visit, all industrial hygiene personnel assigned to the three line functions report functionally to the WRPS Safety and Health Manager and administratively to the line manager. The current industrial hygiene program manual describes that while the specific duties of project industrial hygiene staff are determined by their line manager, project industrial hygiene professionals will work to achieve a balance in the activities so they advocate and support industrial hygiene awareness build worker safety and health projection features into field work through engineering controls, work planning, and utilizing As Low As Reasonably Achievable (ALARA) principles, and performing inspections and participating in safety assessments (WRPS TFC-PLN-55, 2013).

As described to the TVAT, the Industrial Hygiene Program is broken into two sections, Technical Services and industrial hygiene SMEs. At the time of the TVAT meetings held between August 18 and August 22, 2014, the Industrial Hygiene Technical Services section had two industrial hygiene professionals, only one of which was a Certified Industrial Hygienist (CIH), and five industrial hygiene technicians. The industrial hygiene SMEs section had five 5 industrial hygiene professionals, all of whom were recent hires and contractors and all CIHs, with three more scheduled to start work before the end of September. In addition to the industrial hygiene professionals, WRPS currently employs 55 industrial hygiene technicians; however, more than half of the current technicians are recent hires and not yet fully deployed within the tank farms.

WRPS Industrial Hygiene Tank Vapor Control Program

The current WRPS industrial hygiene program in place to address tank farm vapor issues is explained in detail within its procedure for chemical vapor management (WRPS TFC-ESHQ-S, 2012). This procedure provides direction for managing potential exposures to tank waste chemicals in accordance with the commitment established in TFC-PLN-34 to ALARA. This includes steps for baseline hazard characterization, emission point evaluation, development of similar exposure groups (SEGs) determining control methods, updating the tank vapor information sheets (TVIS), and evaluating field activities (WRPS TFC-ESHQ-S, 2012). The exposure assessment strategy currently deployed is explained in further detail in the Exposure Assessment chapter of this report. With respect to vapor exposure assessment, reduction and control, the current program includes evaluating whether fixed engineering controls (e.g., exhaust systems) are available for implementation or are already in use as a standard operating condition. Current administrative controls include the use of Vapor Control Zones (VCZs) and Vapor Reduction Zones (VRZs). If personal sampling and monitoring indicates that a farm COPC is not maintained below the respective action level with engineering and/or administrative controls, personal protective equipment is used to reduce potential exposures below that level (WRPS TFC-ESHQ-S, 2012).

TECHNICAL ISSUES

RM TECHNICAL ISSUE 1: Industrial hygiene organization, resources, and work activities to properly characterize and assess worker vapor exposure in the tank farms

Observations:

In its current state, the industrial hygiene (professional and technician level) resources available are not sufficiently allocated to properly characterize and assess worker vapor exposure in the tank farms. In addition, there are insufficient resources and expertise currently deployed in the industrial hygiene function to properly recommend and evaluate the effectiveness of work practices, PPE and engineering controls as well as effectively inform, advise, and train line functions and address worker concerns regarding tank farm vapors. Given the

complex nature of the work occurring at Hanford, and the current lack of engineering controls to mitigate tank vapor exposures, it is critical that the industrial hygiene function be given the necessary resources to assess and control worker exposures.

Specifically, while health physics professionals and health physics technicians are viewed as part of the tank farm work teams and participate in all planning, execution, and evaluation phases of tank farm work activity, industrial hygiene professionals and technicians are not able to participate to a similar extent. In particular, it was noted during meetings with WRPS management and focus groups that the industrial hygiene function does not have industrial hygiene professionals for work planning and evaluation.

In addition, the industrial hygiene function has insufficient resources and expertise to conduct short-term episodic monitoring prior to and during work activities where vapor events are possible. Furthermore, there are insufficient resources to communicate back to line management and the workforce the findings of the monitoring in a timely manner. WRPS has acknowledged the delay that has occurred in reporting results and the fact that analytical laboratory resources are overwhelmed with the increased amount of sampling that occurred recently, which created a backlog in reporting sampling results. WRPS has informed the TVAT that they are working to resolve the backlog in reporting results by increasing the resources available to the laboratory.

The lack of industrial hygiene participation, as compared to participation of radiation and flammability control, in critical work activities, and the extreme delay in reporting of monitoring results, lead to the possible belief that WRPS management is not as committed to understanding and controlling chemical hazards as radiological and flammability hazards. In fact, it is well known and documented in past reports by DOE that although radiological releases and exposures from the tanks appear to be well characterized, exposures to chemical vapors and gases are not always well characterized (U.S. DOE 2004). Furthermore, the tank vapor characterizations conducted in the mid to late 1990s, upon which many exposure assessment assumptions are based, may not adequately represent the current tank vapor contents.

The lack of focus on the industrial hygiene function at the Department level does not appear to be unique to Hanford and tank vapor exposure. After examining DOE standards and implementation guidance, we have noticed a clear disparity between the amount of regulatory/management attention paid to radiological hazards compared to industrial hygiene and chemical hazards. While the DOE has published an occupational exposure assessment requirement within DOE Order 440.1, a supplemental implementation guidance document has since been cancelled by order of the Secretary (U.S. DOE, 2010). Included within this guidance are recommendations for the industrial hygienist and the health physicist to cooperate and exchange information in order to combine the strengths of both, maximize controls, eliminate conflicts in approaches, expedite and streamline the process and documentation effort, and communicate a coherent approach to workers and supervision. This guidance document could prove invaluable to implementing a robust, continuously improving exposure assessment strategy that is functionally on par, and aligned with, current radiological and flammability assessment strategies (U.S. DOE, 1998).

Recommendation RM1

WRPS and DOE augment the Hanford tank farm IH program to further develop competencies to address the tank vapor exposure issues.

RM1a

Provide and manage industrial hygiene professional and technician staffing levels to properly characterize and assess worker vapor exposure in the tank farms.

RM1b

Provide and manage industrial hygiene professional and technician staffing levels so that IH personnel participate in all planning, execution and evaluation phases of tank farm work activity, similar to radiological and flammability control functions

RM1c

Provide and manage industrial hygiene professional and technician staffing levels to properly recommend and evaluate the effectiveness of work practices, PPE and engineering controls

RM1d

Effectively inform, advise, and train line functions and address worker concerns regarding tank farm vapors, and re-evaluate and increase the available analytical resources to assure the timely reporting of sample results associated with tank farm vapors.

RM1e

DOE should increase their focus on chemical hazards and develop more specific implementation guidelines regarding the anticipation, recognition, evaluation and control of chemical hazards, comparable to the focus and rigor given to radiological hazards. Consistent guidance on the implementation of the industrial hygiene programs in DOE facilities would assist in assuring functional parity with radiological controls at Hanford and other facilities within DOE.

RM TECHNICAL ISSUE 2: CORE COMPETENCIES OF THE INDUSTRIAL HYGIENE PROFESSIONALS AND THE INDUSTRIAL HYGIENE TECHNICIANS

Observations:

Given the unique nature of the Hanford tank farm and the complexities of the vapor issues at the site, it is critically important to hire, train, and retain highly skilled and talented industrial hygiene staff, both in the line and programmatic functions. Currently, the minimum requirements for entry level industrial hygiene professionals include a bachelor's degree in industrial hygiene or related field and at least two years of job related experience. The minimum requirements for entry level for industrial hygiene technicians include an associates' degree in safety and health, applied science or related technology and one year job experience. Both have some degree of on-the-job training, mentoring and periodic competency reviews. The TVAT questions whether these minimum and competency requirements have been met in the past and have been rigorous enough to address the tank farm vapor issues. Until recently, few CIHs have been deployed either in the line or programmatic functions and only approximately one half of the industrial hygiene technicians currently on staff have been fully trained and deployed. In addition, the industrial hygiene function at WRPS does not have in place a qualification and recertification process similar to the radiological control function, which possibly gives rise to concerns over competency and organizational value regarding industrial hygiene and vapor exposures.

Recommendation RM2

Achieve functional parity of the industrial hygiene program with the radiation control program with respect to worker training and core competencies.

More specifically, WRPS should bolster: the entry-level qualification criteria; on-the-job locally tailored competency training; and, requalification criteria for industrial hygiene technicians to more closely mimic the radiological control technician programs. In addition, efforts should be made to increase the number of CIHs on staff and seek to improve the risk communication skills of the industrial hygiene professionals and other professional staff.

RM TECHNICAL ISSUE 3: TRAINING OF CORE INDUSTRIAL HYGIENE CONCEPTS ACROSS ALL LEVELS OF THE ORGANIZATION

Observations:

The level of industrial hygiene and occupational health training given to workers and line management is insufficient and is not rigorous enough to address the tank farm vapor issues. The industrial hygiene function offers a 4-hour concepts course entitled CHAT to workers and management including first line supervisors. Generally, workers and management do not have a good understanding of the basic concepts regarding chemical hazards, exposures, risks and the potential for acute and chronic effects. Having a better understanding of these

concepts will help first line supervisors and other levels of management, to recognize chemical hazards and assure workers are properly protected. In addition, if properly trained, management can be better equipped to answer the tough questions regarding health risk and mitigating factors and establish a better rapport with workers.

Recommendation RM3

Expand general CHAT training for tank farm workers to be more consistent with the length and intensity of the radiological hazard training currently mandated for all site workers.

In addition, WRPS, through the industrial hygiene function, should develop and conduct specialized training for management starting with first line supervisors, which expands the concepts addressed in the general CHAT training and provides some additional skills in risk communications.

RM TECHNICAL ISSUE 4: VALUE AND CREDIBILITY OF THE INDUSTRIAL HYGIENE FUNCTION

Observations:

Currently, industrial hygiene does not appear to be as fully integrated into the planning, pre-job, execution, and post job ALARA review to the same extent as the radiological control program. Moreover, the industrial hygiene group does not have a dedicated professional that reviews pre-job plans as his/her main function. The current staffing and skills training level of the industrial hygiene function at WRPS does not make available adequate industrial hygiene expertise necessary to assure issues relating to chemical vapors in the tank farm are properly addressed and consequently industrial hygiene expertise is not always recognized as a valuable asset to the success of an overall work plan.

In addition to not being able to participate in all critical work activities, some focus group members voiced concerns that the industrial hygiene function lacks the expertise, training, empathy, and monitoring tools to recognize acute, episodic vapor events and the fact that vapor events are occurring. The strong adherence to occupational exposure levels (OELs) or a fraction thereof and relying on results of sampling performed well after the event as evidence that episodic exposures have or have not occurred undermine the credibility of the function and their ability to ultimately protect workers. Similar observations have been made by past evaluations of the industrial hygiene program. Breysse and Stenzel (2010) similarly concluded that some industrial hygiene staff may not fully appreciate the possibility for over exposures at the site, and therefore may not be open to considering that ill effects reported by the workers could be job related.

Recommendation RM4

Adequately staff the industrial hygiene function to assure proper resources is deployed in the planning, pre-job, job execution, and post-job ALARA review in a similar fashion to that of the radiological control function.

This should include a team of industrial hygiene professionals dedicated to the work planning activities.

In addition, the industrial hygiene function must be properly trained to recognize that the current reliance on 10% OELs and long term or after-the-fact monitoring results is insufficient to properly characterize all vapor exposures that are occurring at the Hanford tank farms. The communication skills of the industrial hygiene staff must also be improved to properly explain the meaning and limitations of industrial hygiene assessments and to show a proper degree of empathy for worker concerns regarding vapor events. To this end, management and industrial hygiene staff should frequently engage staff to solicit feedback regarding the industrial hygiene function performance and areas where communications can be improved. One method to achieve this is to create frequent employee focus groups, different from normal working groups such as CVST and IH Technical Committee, so as to receive general employee feedback on program performance, communications, employee concerns, etc.

RM TECHNICAL ISSUE 5: METHODS FOR DEFINING, COMMUNICATING, AND MANAGING RISK

Observations:

As discussed in the previous chapters, WRPS has generally defined unacceptable exposure and risk to tank vapors as greater than 10% of the established or assigned Occupational Exposure Limit (OEL), associated with what has been identified as chemicals of potential of concern (COPCs). Most OELs are based on the American Conference of Governmental Industrial Hygienists' TLV-TWA or derived 8-hr TWA OELs and have been established to minimize chronic health risk and are typically assessed via long-term monitoring techniques. The vast majority of worker exposure reports are associated with very short exposure events that may exist for just seconds or a few minutes.

The current exposure assessment strategy, while appropriate for longer-term and more chronic conditions, is not suitable for short-term, episodic and acute chemical exposures that may occur in the tank farms. In addition, the current exposure assessment strategy for long-term and short-term assessments depends to a great extent upon monitoring results associated with a select number of known chemicals and in the case of vapor incidents, results from samples often collected well after an event has occurred. The industrial hygiene function is appropriately using 8-hr TWA OELs to characterize chronic exposures in accordance with 10 CFR 851; however, it is the TVAT's belief that the currently established OELs are not necessarily applicable to the short-term, episodic exposures occurring on the tank farms. (See Chapter 5, "Exposure Assessment," and Chapter 6, "Dose-Response Assessment.")

Recommendation RM5

Redefine unacceptable chemical exposure risk to include short-term, episodic exposure to chemicals that can result in adverse health impacts.

The definition of potential health impacts should take into consideration observable physiological signs of exposure and symptoms experienced by workers.

WRPS should further characterize chemicals that may be released into the tank farm and evaluate their potential to cause adverse health impacts as defined above, after episodic, short term and long term exposures, as discussed in Chapter 5, "Exposure Assessment," and Chapter 6, "Dose-Response Assessment.")

The industrial hygiene function should modify its exposure assessment strategy and more appropriately characterize and assess potential short term, acute exposure risks in addition to long term, chronic exposure risks. Some of the resources associated with long term monitoring could be redirected to short term assessments.

The industrial hygiene function should utilize the most technologically advanced fixed and portable direct reading instrumentation to assess vapor events and predict vapor events in order to establish appropriate controls to assure workers are not adversely impacted by tank farm vapors. In addition, the industrial hygiene function should work with equipment manufacturers to develop more effective, direct and continuous monitoring instrumentation for assessing episodic vapor events on a real-time basis.

WRPS and DOE should develop a long term research and development plan to address the technical gaps in our understanding of the health risk associated with episodic exposure to tank farm vapors and develop more effective methods to assess and control risk associated with worker exposure to vapor from DOE tank farms.

RM TECHNICAL ISSUE 6: ENGINEERED CONTROLS: ENGINEERED CONTROLS TO MANAGE EXPOSURE AND HEALTH RISK

Observations

The emphasis with respect to investigation of engineered controls has been on end-of-pipe stack controls in conjunction with active ventilation of the tank head spaces. There has been a prevailing assumption that the exposure events are related to vapor releases directly from the tank head spaces and that these releases could be

controlled by actively venting the tank head spaces and either routing the vapors to control devices or expelling the vapors through stacks having exhaust outlets farther removed from the work space (either vertically or horizontally) than is presently the case. For example, the CH2M Hill *Feasibility Study for Control of Vapors from Waste Storage Tanks* evaluated numerous technologies, and all but one was an end-of-pipe control option for actively vented stacks (Baker 2004). The Baker report expressed the belief that maintaining negative pressure in the tank head space would prevent release of tank vapors from all locations except the exhaust stacks. However, this was in the context of evaluating the operation of active tank ventilation and as such did not address passively vented tanks, nor did it address potential sources of vapor release other than the tank head spaces.

The Baker study noted that end-of-pipe control options had been previously evaluated in terms of environmental compliance, and all of the technologies considered were determined to exceed the cost criteria established by the Washington Department of Ecology for best available control technology for toxics. The Baker study further concluded that most of the then-available technologies did not appear to be technologically feasible for the Hanford tank situation, but identified three alternatives to be advanced for sizing and estimation of capital and operation and maintenance costs (Baker 2004). These alternatives were

1. A thermal oxidizer: The suggested scheme included an ammonia scrubber in front of the thermal oxidizer, and a quencher and acid scrubber after the thermal oxidizer.
2. A carbon adsorption system: The suggested scheme included an ammonia scrubber in front of the carbon system, followed by a cooler to reduce temperature and absolute humidity of the vent stream prior to entering the carbon adsorption system.
3. A biofiltration system: There was scant description of this alternative.

To date, no end-of-pipe controls have been installed on the exhaust stacks, but there are active investigations of engineered controls currently under way. Both the Engineered Controls and the New Technology sub-teams of the Chemical Vapor Solutions Team are engaged in these investigations.

The Baker study considered one alternative that was not strictly an end-of-pipe control, but rather was an area-wide measure. This alternative was the use of orchard fans to maintain a sweep of air across the tank farms during calm weather periods. Baker noted that this would involve relatively low capital cost with short delivery and installation time, but concluded that it would likely not eliminate odor concerns and would not remove contaminants from the air (Baker 2004). However, the report failed to address the potential of these fans for minimizing short-term exposure to isolated vapor puffs having high chemical concentrations.

The only engineered control that has been selected for implementation to date has been to increase the height of the vent stacks. A 2010 study, reported by Breysse and Stenzel in the *Independent Review Panel Report on Chemical Vapors Industrial Hygiene Strategy*, recommended consideration of scrubbers or extending stack heights (Breysse 2010). The site subsequently investigated these recommendations and concluded that stack extensions would be more effective than scrubbers. Some of the active venting stacks have subsequently been extended from about 25 feet to about 40 feet in height, and stack extensions for other exhausters are stored on site waiting for installation.

There are several fundamental flaws to the hypothesis that stack controls would entirely solve the vapor exposure problem. First, stack controls rely on active venting, and active venting relies on uninterrupted power supply. In reality, power to the exhausters is sometimes interrupted. Some interruptions are intentional, such as for switching between exhauster trains, while others are unplanned, such as loss of power due to a power pole collapsing in the wind. When power to an exhauster is interrupted, vapors may escape through alternative pathways, resulting in episodic fugitive emissions. Given the frequency of power interruptions, a control system that relies on uninterrupted power supply cannot, by itself, prevent episodic uncontrolled releases of vapors.

Another flaw inherent to reliance on stack controls is that certain exposure incidents have been associated with maintenance activities, such as removing foam from cover blocks or removing wrapping from RCEs. Exposures due to incidents such as these would not have been prevented by stack controls.

Furthermore, there are potential fugitive sources that would not be subjected to negative pressure by active ventilation of the tank head spaces. These include but may not be limited to waste isolation disposal sites, RCEs, transfer lines, and valve pits. These potential fugitive sources would not be expected to be continuous sources of emissions, and many of them may not be likely sources of emissions at all. At best, emissions from these fugitive sources would be expected to be infrequent and episodic. Given, however, that the vapor incidents also have been infrequent and episodic, these potential fugitive sources should be considered.

Recommendation RM6

Investigate and implement best available technologies to detect and control vapor plumes from fugitive sources as well as from vents and stacks.

Improved detection technology and procedures are needed in order to better define the origins of the short-term episodic releases, thereby informing the effective use of engineered controls. Include continuous surveillance of the tank farms by platform-mounted optical gas imaging cameras among the technologies to be evaluated, and investigate equipping this detection technology with an alarm or warning system. In the absence of knowledge as to the origins of the releases, a great deal of money could be spent on speculative measures that may have little benefit for protecting workers.

Continue to investigate control options for active venting and stack controls, and develop separate strategies for exhaust downtime and fugitive sources. Active venting has the benefit of maintaining a negative pressure in the tank head space, thereby preventing loss of head space gases through fugitive pathways, and routing the vapors either to a control device or to a safe exhaust location. Options to be investigated include using exhausters (permanently or temporarily, as appropriate) for actively venting tanks that are presently passively vented, increasing stack heights, using air flow promoters on the stacks to enhance dispersion of the stack exhaust, relocating stacks away from the work areas (“stack in the sticks”), and routing exhaust from the stacks to a control device. Resolve the efficacy of the three control technology alternatives identified in the 2004 Baker study (Baker 2004), as well as other promising technologies that may have been identified more recently. However, given that stack controls alone will not entirely eliminate short-term vapor exposures; develop separate strategies for exhaust downtime and for fugitive sources. Strategies to consider include the use of large fans to sweep air across the tank farms (orchard fans), and box fans at passive vents to enhance dispersion. Certain potential exposure scenarios, such as during various maintenance operations, may be outside the realm of engineered controls altogether and require procedural controls.

Investigate detection devices which are triggered by changes in the concentrations of selected chemical species in real time, and which are equipped with an alarm system to warn personnel of an increased level of vapor concentration. Evaluate these alarming devices for use as ambient monitors in areas of known fugitive emissions, and as in-line monitors for vent and stack emissions, and implement appropriate devices upon being demonstrated to be effective.

RM TECHNICAL ISSUE 7: MANAGEMENT OF ADMINISTRATIVE CONTROLS AND PERSONAL PROTECTIVE EQUIPMENT TO MANAGE EXPOSURE AND HEALTH RISK

Observations:

When engineering controls are not available or not able to mitigate the risk completely, administrative controls can be deployed to further reduce risk. Administrative controls require a higher level of management interaction to ensure proper implementation and employee compliance. With respect to the tank farms, the industrial hygiene group has implemented a system for establishing VCZs and VRZs, similar to the radiological control zones implemented by the radiological control group. Based on our observations out in the field, and conversations with workers and industrial hygiene staff, the VCZs and VRZs for tank farm vapors appear to be somewhat arbitrary and not based on actual measurements, vapor exposure modeling or other sufficiently predictive methods for assuring workers outside these zones will not be adversely impacted by tank vapors. Moreover, communications regarding the boundary of the VCZ and VRZ as well as steps that employees should take when entering these zones need to be improved.

As a last resort when exposures have not been reduced to appropriate levels using engineering controls and/or administrative controls, personal protective equipment (PPE) should be used. Historically, the Hanford tank farms have relied upon various types of air purifying and air supplying respiratory equipment including powered air purifying respirators and self-contained breathing apparatuses (SCBAs). In fact, there was a period of time where entry into a VCZ required the use of SCBA. Uniquely, the industrial hygiene program has instituted a novel program that allows employees to “upgrade” to a more protective type of respirator than is required for a particular job if he or she chooses. The feedback gathered from the TVAT was mixed; some employees appreciated the opportunity to upgrade, while other employees complained that the upgrading system slowed down the job execution in some situations.

The TVAT’s discussions with WRPS management, industrial hygiene staff, and employees revealed that the workforce understood the utility of using SCBAs as well as the potential safety hazards that might be present when using this type of respiratory equipment. With respect to air purifying respiratory equipment, the TVAT observed some confusion from employees regarding the correct type of air purifying cartridges that should be used for some work activities. Moreover, some employees expressed doubt as to whether the right type of air purifying cartridges were routinely being used, and whether these would protect them against tank vapor exposures. Questions with respect to the efficacy of the respiratory protection selection process were echoed in a 2004 DOE report that concluded “tank vapor characterization is not sufficient to support industrial hygiene exposure assessment and respiratory protection programs” (U.S. DOE, 2004).

Recommendation RM7

RM7a. Establish a more effective methodology for designating Vapor Control Zones (VCZs) and Vapor Reduction Zones (VRZs).

WRPS should establish a more effective methodology for instituting administrative controls (e.g., VCZs and VRZs) that are based on objective data and/or predictive modeling data to further assure workers are properly protected. This issue is also addressed in the Exposure Assessment and Risk Characterization chapters of this report. The methodology should take into account the episodic and dispersive nature of potential releases into worker breathing zones that are associated with specific work activities and meteorological conditions.

RM7b. Confirm that air-purifying respiratory protective equipment is effective in reducing exposure to tank vapors below acceptable levels.

Where neither engineering nor administrative controls are feasible and/or adequate, further respiratory protective equipment should be considered based on recommendations found in the Risk Characterization chapter of this report. When considering respiratory protection, WRPS should confirm that the air-purifying respirator cartridges used in the tank farm are effective for the unique chemical mixtures that may be present in the tank farms. In addition, breakthrough evaluations should be conducted using representative tank farm mixtures to assure the chemical cartridges will remain effective during work activities.

RM TECHNICAL ISSUE 8: MEDICAL AND INDUSTRIAL HYGIENE INTERFACE REGARDING INCIDENT CASE MANAGEMENT

Observations:

The current industrial hygiene information that is used to determine whether a worker was sufficiently exposed during a vapor event and therefore has experienced an illness and/or injury as a result of that event, is often insufficient and inappropriate which could lead to a mischaracterization of the injury/illness and inadequate medical treatment.

Based upon the discussion held during the TVAT visits, industrial hygiene exposure results, such as that from long term personal monitoring, after-the-fact grab samples and non-chemical specific direct readings, are used, to

some extent, by medical personnel to determine whether a work-related illness/injury has occurred and whether a workers' compensation claim would be accepted. Since the current industrial hygiene exposure assessment strategy is focused on long term exposures, in comparison to OELs, and not acute exposures from episodic events, it is inappropriate to use these data for most determinations relating to whether a worker has been adversely impacted by a chemical exposure while working in the tank farm. It is also inappropriate to use these data, which are not timely or relevant to acute exposures, for determining work-relatedness.

While there are established protocols in place to provide industrial hygiene data to on-site and off-site medical providers, the TVAT is concerned that due in part to the limited industrial hygiene data available regarding episodic exposure, medical staff do not have sufficient information to properly evaluate health conditions associated with tank farm vapor events. The limitations of the existing industrial hygiene information, in respect to short term, episodic vapor incidents, should be communicated to the medical community.

Recommendation RM8

Modify the medical case evaluation process and reporting procedures to recognize the appropriate uses and limitations of the available monitoring data and other potential exposure information when evaluations are made regarding vapor exposures.

The medical personnel evaluating whether a work-related illness/injury has occurred and whether a workers' compensation claim should be accepted as a result of a tank farm incident should use exposure data that reflects the short term, episodic nature of vapor incidents and not solely rely upon long term monitoring results, whether 10% of the OEL was exceeded and after-the-fact grab samples or non-chemical specific direct readings.

Medical and industrial hygiene staff should continue to enhance routine communications to address worker health risk associated with chronic as well as short term, episodic exposures in the tank farm. Specifically, the industrial hygiene staff should assure that medical personal understand the value and limitations of existing industrial hygiene data for assessing the relationships between reported effects and vapor exposures. In respect to determining whether an injury/illness is work related, a presumption of work-relatedness is consistent with Occupational Safety and Health Administration (OSHA) guidance. Previous medical determinations should be re-visited based on a more thorough understanding of the uses and limitations of the monitoring data.

RM TECHNICAL ISSUE 9: STANDARD MANAGEMENT SYSTEMS TO ADDRESS AND CONSISTENTLY APPLY RISK MANAGEMENT ELEMENTS

Observations:

The TVAT observed during our site visits that the closure of corrective actions related to vapor incidents and controls are not always adequately vetted, evaluated, and communicated to workers, including the worker who originated the issue. More specifically, the closure of the actions associated with items in the Problem Evaluation Request (PER) system and chemical vapors are not always communicated to workers and the employee who submitted the recommendation or issue. The TVAT recognizes that under the current PER system, originators of items may choose whether or not they want to be contacted regarding the resolution of their PER items. The TVAT believes that by providing this option, the PER system does not encourage workers to be engaged in the resolution of vapor issue. As mentioned above, it is imperative to involve the workforce as a legitimate partner in identifying and resolving safety and health issues. In order to develop and sustain a culture of trust and buy-in in which all workers understand the value they provide to the enterprise, workers must understand the rationale for decisions made regarding corrective actions and help validate proper closure of corrective actions.

Recommendation RM9

Verify that all programs associated with vapor controls are properly vetted, evaluated, communicated and tracked to ensure timely completion.

Evaluate all teams and programs that are associated with tank farm vapor issues (PERs, CVST, etc.), and implement changes to improve the degree of employee involvement.

Specifically, WRPS should encourage employee engagement and assure that employees are involved in the development of corrective actions, are informed of the rationale associated with implementation of those actions, and are provided evidence that the actions have been successfully completed. Particular attention should be given to communication among the affected worker, the originator of a corrective action, and WRPS management to assure that the decisions made regarding the corrective action, including the implementation timetable and completion criteria, are recognized by all. In addition, all of those parties should participate in the evaluation process designed to assure that the corrective action has been successfully addressed and closed.

RM TECHNICAL ISSUE 10: OWNERSHIP OF TANK FARM VAPOR INCIDENTS AND WORKER HEALTH AND SAFETY AND THE INTEGRATION OF CONTINUOUS IMPROVEMENT WITH RESPECT TO HEALTH RISK FROM VAPORS ACROSS ALL LEVELS OF THE ORGANIZATION

Observations:

The ownership for chemical health and safety at the line management level is not sufficient to address the tank farm vapor issues. Due in part to the lack of training in industrial hygiene and inadequate industrial hygiene resources and relevant monitoring data, first line supervision does not own the recognition, evaluation and control of tank farm vapors as they do radiological hazards. In addition, upper management does not embrace health risks associated with tank vapors to the same extent they embrace radiological hazards.

Recommendation RM10

All levels of line management demonstrate that they are committed to reducing the potential for tank farm vapor releases and exposures and continuously improving management systems to assure all workers are properly protected.

It is imperative for the resolution of the tank farm vapor issue that all levels of line management recognize that the health risks associated with episodic releases of tank vapors do exist and that exposures have occurred. In addition, all levels of management must demonstrate that they are committed to reducing the potential for tank farm vapor releases and continuously improving management systems to assure all workers are properly protected.

9.0 RISK COMMUNICATION

INTRODUCTION

Elements of a Successful Risk Communication Program

Risk communication involves the exchange of information regarding health, safety, and environmental risk in a manner that allows stakeholders, such as the Hanford Tank Farm workers, management and the community to make informed decisions with respect to risks and how they are or should be managed (Covello, et al, 1987; Fisher, 1991; Santos, 2007). Effective risk communication does not simply involve the unilateral transmission of information from one source (such as WRPS Management) down to a receiver (a potentially affected worker), but includes a multi-lateral process whereby information is exchanged between both the transmitter and receiver, and both parties develop an appreciation with respect to each other's perception of hazards and the ultimate risk. As discussed in previous chapters, the traditional risk assessment paradigm is a consistent, science-based approach to quantitatively predict a particular adverse response in a specific exposure population. However, in the context of the risk assessment framework, NRC emphasizes that the risk assessment process must also address affected parties' perception of risk in a particular situation, and must incorporate these perspectives within the risk characterization (NRC, 1996). This process can therefore only be achieved through a two-way flow of communications in which the risk communication process is the vehicle for transmission of information. As a result, risk communication is not only an important method to transmit the results of a risk assessment, but an integral step within the risk assessment and risk management process itself.

While there are no prescriptive steps with respect to effective risk communications that apply in all scenarios, generally-accepted guidelines to build a strong line of risk communication dialog between the transmitter and affected stakeholders have been presented. Adapted from Covello and colleagues (1988), below are seven "cardinal rules" for effective risk communication in the workplace environment:

1. Accept and involve the stakeholder as a legitimate partner
2. Plan carefully and evaluate performance
3. Listen to your stakeholder audience
4. Be honest, frank, and open
5. Coordinate and collaborate with other credible sources
6. Meet the needs of the stakeholders and not wait to be solicited for information
7. Speak clearly and with compassion.

From a WRPS industrial hygiene function standpoint, the risk communication process is not only communicating what is known about an occupational hazard and necessary controls; it also must assure that workers understand what is being communicated and have an opportunity to participate in the process or strategy which ultimately leads to characterizing and managing the risks. In all forms of communication with respect to potential tank vapor exposures, the aforementioned seven cardinal rules should be carefully considered prior to presenting any findings related to worker exposure and subsequent risk.

RC TECHNICAL ISSUE 1: THE QUALITY AND FREQUENCY OF WRPS RISK COMMUNICATIONS, ASSOCIATED WITH TANK FARM VAPOR ISSUES, TO AND FROM INTERNAL AND EXTERNAL STAKEHOLDERS

Observations:

WRPS provides general internal communications to workers on a regular basis and since March 2014 has provided additional internal and external communications about vapor incidents and efforts to reduce such events. In addition, WRPS participates in a number of outside panels or councils and has been mostly responsive to questions and concerns relating to vapor incidents. The TVAT believes that WRPS could be more proactive, timely, and effective with internal and external communications about specific incidents, possible health impacts from tank vapor exposures, and efforts to minimize and control future vapor exposure incidents. This belief is in agreement with suggestions shared by external working groups and union representatives. Unsolicited, timely and detailed communications regarding vapor incidents, health risks, and the progress being made to reduce the

frequency and magnitude of vapor events can help improve internal and external relationships and help establish a sense of trust that WRPS is working to reduce health risks associated with tank farm vapors and is committed to preserving the health and safety of its workers and the community.

Recommendation RC1

Develop more routine and unsolicited communications to the Hanford Challenge, Hanford Concern's Council, and other interested community groups regarding potential health impacts, health and safety risks, and WRPS/DOE efforts to reduce risks to employees and the community.

RC TECHNICAL ISSUE 2: COMMUNICATION AND DISSEMINATION OF WRPS HEALTH AND SAFETY POLICY CHANGES AND DECISIONS REGARDING TANK FARM VAPORS

Observations:

It has been observed in several cases that changes to an Employee Job-Task Analysis (EJTA) were not clearly communicated to affected employees. Some of the stated objectives of the EJTA process are to assure that each worker has input into the analysis of the hazards of particular tasks and understands and accepts the measures necessary to protect him- or herself from hazards and to monitor potential health outcomes. The vetting and two-way communication provided by the EJTA process help establish a more accurate job-task safety and health analysis and help assure worker buy-in and adherence to procedures and practices that protect worker health and safety. WRPS informed the TVAT that they self-identified issues related to the EJTA procedure in March 2014 and were developing a plan to improve the process, which included improving the two-way communication between industrial hygiene personnel and employees during the development and approval of individual EJTA's.

Recommendation RC2

Improve the employee job task analysis process to include opportunities for worker engagement and buy-in into the process and protective measure assuring the health and safety of the worker.

RC TECHNICAL ISSUE 3: TRANSPARENCY WITH RESPECT TO HEALTH AND SAFETY DECISIONS THAT POTENTIALLY IMPACT TANK FARM WORKERS AND THE PUBLIC.

Observations:

It is the general observation of the TVAT that, actions taken with respect to industrial hygiene issues are not always vetted and communicated to the affected employees or to the employee who originated the issue. More specifically, the rationale associated with decisions and action plans associated with items in the Problem Evaluation Request (PER), TFC-ESHQ-Q_C-C-01 system or a recommendations made by members of the CVST are not always communicated to the employee who submitted the recommendation or raised the issue. During the internal Voluntary Protection Program (VPP) assessment conducted in November 2013, WRPS self-identified issues relating to communications between the originator of a PER item and employees assigned to correct the issue. As a result, the PER system is currently in review, and improvements are expected. In addition, the TVAT was told that issues identified in the CVST are supposed to be tracked through closure and concurrence of closure documented by a vote from the members of the CVST. Results of these votes are documented in the meeting minutes for the CVST. As mentioned above, it is imperative to involve the workforce as a legitimate partner in identifying and resolving safety and health issues. In order to develop and sustain a culture of trust and buy-in and in which every worker understands she or he provides value to the enterprise, complete disclosure and transparency regarding decisions associated with PERs, CVST, and other work teams involved in assuring worker safety and health must be maintained.

Recommendation RC3

Improve the degree of employee involvement in and ultimate acceptance of all teams and programs that are associated with tank farm vapor issues.

Evaluate all teams and programs that are associated with tank farm vapor issues (PERs, CVST, etc.), and implement changes to improve the degree of employee involvement.

Specifically, WRPS should encourage employee engagement and assure that employees are involved in the development of corrective actions, are informed of the rationale associated with implementation of those actions, and are provided evidence that the actions have been successfully completed. Particular attention should be given to communication among the affected worker, the originator of a corrective action, and WRPS management to assure that the decisions made regarding the corrective action, including the implementation timetable and completion criteria, are recognized by all. In addition, all of those parties should participate in the evaluation process designed to assure that the corrective action has been successfully addressed and closed.

RC TECHNICAL ISSUE 4: THE QUALITY AND FREQUENCY OF COMMUNICATIONS BETWEEN THE INDUSTRIAL HYGIENE TEAM AND THE WORKFORCE

Observations

Feedback received during TVAT focus group meetings with Hanford employees revealed that the current communication process for conveying personal monitoring and work-zone sampling results needs improvement to assure credibility and understanding among the full workforce. Some focus group members expressed lack of understanding of their exposure monitoring results and lack of confidence that all relevant information was being conveyed back to the employees. The TVAT also examined the notification letter sent to employees explaining their personal monitoring results and noted that the letter could be improved to communicate the significance of the results more effectively. In addition, some focus group members voiced suspicions that some industrial hygiene results were not effectively reported back to all employees within the representative SEG. Moreover, there appeared to be some misunderstanding about the differences between the Representative Notification Letter and the Notification Letter of Personal Sampling Results.

Recommendation RC4

Revise the content of the employee monitoring notification letters to include more relevant information regarding the capabilities and limitations of the technology used to collect and analyze samples, which should include clear definitions for concepts such as “ND” vs. “<LOQ” vs. “<RQL.”

Involve employee representatives in the development of the revised notification letters to assure information conveyed is helpful for them in understanding both acute and chronic risks. Assure that all members of SEGs receive notice of monitoring results and that they understand the relevance of those data in respect to acute and chronic exposure risks.

In addition, to the extent possible, industrial hygiene professionals should conduct field validation studies to understand possible workplace collection efficiencies/recoveries, interferences and sample stability for key sampling and analytical methods (SAM) and for any new deployed SAM.

RC TECHNICAL ISSUE 5: INDUSTRIAL HYGIENE FIELD PRESENCE WITH RESPECT TO RISK COMMUNICATION

Observations:

The TVAT observed that the industrial hygiene technicians and professionals were not present in the field as often as the radiation control group and therefore were not readily available to provide timely communications regarding worker exposures and health risks. To the extent communications between the industrial hygiene function and the workforce do occur, the TVAT believes the industrial hygiene function is not as effective as it could be in showing empathy and communicating with the workforce about technical and scientific concepts related to worker exposure and risk.

Recommendation RC5

Establish a greater presence in the tank farms of industrial hygiene technicians and professionals.

Additionally, industrial hygiene technicians, professionals and management should undergo specific risk communication training and improve their ability to deliver effective risk communication to the employee. This would go hand in hand with new approaches to defining exposures and less reliance on occupational exposure limits (OELs), which may not be relevant to acute, episodic exposure events.

This issue also is addressed in the Risk Management chapter of this report.

RC TECHNICAL ISSUE 6: VAPOR EVENT NOTIFICATION AND RESPONSE

Observations:

Through employee focus group meetings held during the TVAT visit, a number of employees expressed concern regarding the effectiveness of the Shift Office Event Notification (SOEN) process which is designed to notify affected employees of a vapor event. Incidences were described where WRPS and Mission Support Alliance (MSA) employees, either working in the area or in an adjacent trailer were not informed of vapor events (SOEN) and therefore potentially at risk during a vapor release.

The purpose of the SOEN process is to alert all workers potentially impacted by a vapor event so that workers in the area can immediately evacuate the area and others avoid the potentially contaminated area to prevent potential health impacts. The SOEN system can send event notifications to a recipient's cell phone, work e-mail, and home e-mail. These notifications are made by the Central Shift Office. The procedure for issuing SOEN messages states that they will be issued to relay operational information to selected personnel as needed. Operational requirements state that when performing work within the boundaries of a tank farm, hand held radios shall be the primary communication device. Cell phones may be used as a backup; however, access to cell phones inside radiological areas is limited. This requirement is not enforced for personnel outside the boundaries of a tank farm and can create a breakdown in event notification to all affected employees. In effective warning systems regarding vapors can not only jeopardized the health and safety of workers they can also undermine the credibility of WRPS's safety and health programs and management's sincerity and commitment to addressing tank farm vapor issues.

Recommendation RC6

Perform an assessment of the current SOEN process to identify other methods to assure that all workers potentially impacted by vapor events (WRPS, MSA, visitors, etc.) are immediately alerted of a vapor event and understand what mitigating actions they must take to avoid possible health or safety impacts.

For example, WRPS should evaluate the use of proximity loudspeaker and/or other alarm systems within the tank farm (similar to that in place for other tank farm hazards) as a method to effectively alert workers of tank vapor events. The SOEN process should be periodically tested to assure the vapor alert systems are effective in reaching all potentially impacted workers, and affected workers respond appropriately. This alert system should carry the same gravitas as radiation related alert systems.

RC TECHNICAL ISSUE 7: TIMELY COMMUNICATION OF PERSONAL AND AREA VAPOR MONITORING RESULTS

Observations:

In an effort to characterize and assure worker exposure to the tank farm COPCs are below acceptable concentration, the industrial hygiene program developed a complex exposure assessment strategy, which includes the collection of long-term personal and area industrial hygiene samples and direct reading measurements throughout the tank farm. The current exposure assessment and characterization process are discussed in detail in the Site Characterization and Dose-Response chapters of this report, respectively, and further observation and recommendations have been made regarding this strategy. However, it was observed during the TVAT team visit that results of individual exposure measurements, area samples and assessments of similar exposure groups

(SEGs) were not communicated clearly and in a timely manner to the affected and representative workers and management.

It was also observed that grab samples were not being analyzed and results communicated to both management and hourly workers in a timely manner. It is as the TVAT understands through our discussions with the industrial hygiene managers, the lead industrial hygiene analytical chemist, and our participation with the CVST sub teams, that there is a backlog of weeks or months in releasing the results of industrial hygiene samples, seriously delaying communications to workers and line management. Maintaining backlogs and delaying the reporting of results undermine the importance of the industrial hygiene program and WRPS's commitment to resolving the tank farm vapor issues and protect the health and safety of workers. As the National Research Council (NRC 1989) suggests, "risk communication is successful to the extent that it raises the level of understanding of relevant issues or actions that satisfies those involved that they are adequately informed within the limits of available knowledge".

This issue was previously self-identified by WRPS. In August 2014, the laboratory developed and implemented a priority schedule for sample processing, which has helped reduce the backlog of personal monitoring results. In addition, part-time laboratory workers have been hired as permanent employees to help reduce the backlog of obtaining and reporting-out personal and area sample results.

WRPS industrial hygiene and laboratory staff have developed comprehensive sampling strategies and sampling and analytical methods, which are available to internal and external stakeholders. The Exposure Monitoring, Reporting and Records Management procedure, TFC-ESHQ-IH-STD-03, and the Industrial Hygiene Reporting and Records Management procedure, TFC-ESHQ-S_IH-C-46, are used to help assure consistent and proper monitoring of employees.

Recommendation RC7

Deploy appropriate laboratory resources to assure timely analysis and reporting of industrial hygiene results, and ensure all exposure data is assigned correctly to all members of the SEG.

The actual results, the limitation of the sampling and analytical methods (chemicals sampled, limits of quantification, etc.) and the limitation of the sampling strategy should be reported more effectively and completely discussed with the employee from which a sample was taken, the employees working on the work activity sampled, the employees within the SEG, and direct management.

RC TECHNICAL ISSUE 8: RESPONSE TIME WITH RESPECT TO INCIDENTS, INCIDENT INVESTIGATIONS, AND COMMUNICATION OF INVESTIGATIVE RESULTS

Observations:

The TVAT observed that communications related to incident investigation have not always been timely and effectively communicated to the workforce. Workers must receive a timely response from every incident investigation in order to appreciate that WRPS is serious about controlling vapor incidents and assuring worker protection.

WRPS has made improvements to the incident investigation process and communication systems related to vapor incidents. The recently deployed Odor Response Cards and the response of the industrial hygiene staff to incidents and events have been well received. Communications have also been documented through Standing Orders that are provided at the Plan of the Day meetings that are expected to flow down to employees. Documented communications are also evidenced in the pre-job briefings and job planning activities. WRPS has also created the Event Protocol Sub-Team, as part of the CVST, which has reviewed and updated the TF-AOP-015, Response to Reported Odors or Unexpected Changes to Vapor Conditions procedure.

Recommendation RC8

Communicate in a timely fashion to all employees the results of incident investigation, including description of event, results of any samples taken, lessons learned, and corrective actions planned and completed.

Results of incident investigation, including description of an event, results of any samples taken, lessons learned, and corrective actions, should be communicated in a timely fashion to all employees. Ensure that a post-incident investigation communication plan is in place. The plan should reflect the importance of quick response time and quick assembly of the facts. WRPS should be organized to assemble all relevant facts quickly, and trained spokespersons should disseminate factual information as soon as practicable.

RC TECHNICAL ISSUE 9: EFFECTIVE COMMUNICATION REGARDING WORKERS' COMPENSATION CLAIMS

Observation:

It was observed that in at least one case the individual involved in a vapor incident did not understand why a Workers' Compensation claim was denied and what medical expenses would be covered by WRPS in order to evaluate the claim. WRPS processes all Labor and Industry (L&I) Workers' Compensation claims for its employees and provides the best available information regarding the claim to Penser, the third party L&I administrator for DOE. WRPS does not make the determination as to whether a claim is accepted or denied. This determination is made by Penser and its agents. Penser also answers specific questions about individual claims.

Recommendation RC9

Evaluate and improve the communication system associated with vapor events and results of Workers' Compensation claims.

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APPENDIX G. STACK HEIGHTS ARE NOT THE ANSWER TO ALL VAPOR ISSUES

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APPENDIX B. TABLE OF OVERARCHING AND SUPPORTING RECOMMENDATIONS

The overarching recommendations are a collection of actionable improvement concepts that aim to reduce the potential for personnel exposures to tank vapors at the Hanford Tank Farms and are supported by over 40 supporting recommendations. Though not derived from the following exercise, the TVAT has cross referenced each of the supporting recommendations to the ten overarching recommendations as means to ensure thoroughness and to assure completeness. Appendix B summarizes the overarching and supporting recommendations and the exercise to cross-reference the two.

Appendix B may be used as a guide to additional detail in this report about the Overarching Recommendations as well as a guide to actions that may be taken to implement recommendations in this report.

Listed below for easy reference are the ten overarching recommendations and the 46 supporting recommendations from the six Technical Assessment Areas followed by a table cross-referencing the recommendations.

OVERARCHING RECOMMENDATIONS

- OR 1: Hanford site contractor and DOE management actively demonstrate commitment to improve the current program and ultimately resolve the vapor exposure concerns.
- OR 2: Implement measurable benchmarks to assure operational and cultural parity among chemical vapor, flammability, and radiological control programs.
- OR 3: Establish a program to sample proactively the head space of tanks to validate and enhance chemical characterization.
- OR 4: Accelerate development and implementation of a revised IH exposure assessment strategy that is protective of worker health and establishes stakeholder confidence in the results for acute as well as chronic exposures.
- OR 5: Modify the medical case evaluation process and reporting procedures to recognize the appropriate uses and limitations of the available monitoring data and other potential exposure information when evaluations are made regarding tank chemical vapor exposures.
- OR 6: To reduce the impacts of bolus exposures, utilize real time personal detection and protective equipment technologies specifically designed to protect individual employees.
- OR 7: Accelerate implementation of tailored engineering technologies to detect and control vapor emissions and exposures experienced in the Hanford tank farms (“tank farm of the future”).
- OR 8: Augment the Hanford tank farm IH programs to further develop competencies to address the tank vapor exposure issues.
- OR 9: Effectively communicate vapor exposure issues and actions proactively with all stakeholders.
- OR 10: Investigate and pursue external research opportunities and partnerships to address data and technology gaps related to vapor exposure, effects, and mitigation.

SUPPORTING RECOMMENDATIONS

SITE CHARACTERIZATION

- SC1: Develop a prioritized program to sample and characterize tank head space composition and stratification during quiescent as well as disturbed conditions.
- SC2: Assess the potential for materials to plate or condense in vent risers, stacks and HEPA filters, and characterize the emissions for each condition.
- SC3: Implement technologies to assess fugitive sources of emissions that are not connected to tank head spaces, and characterize the emissions for each non-head space fugitive source.
- SC4: Identify and implement new technologies to detect, locate and quantify fugitive and episodic releases.
- SC5: Identify and implement new technologies to quantify stack and vent emissions with suitable local alarms so that workers can respond in a timely fashion.

EXPOSURE ASSESSMENT

- EA1: Continue the development and expedite deployment of new techniques for real time response and appropriate sampling for short duration intermittent releases.
- EA2: Identify and implement sampling and/or *in situ* analytical methods as appropriate for reactive VOCs, submicron aerosol, volatile metal compounds, and volatile metalloid compounds that may be present but would have been missed by past head space sampling and analytical methods.
- EA3: Use modeling, including Computational Fluid Dynamics methods, to determine the potential locations, conditions, and next steps in attempting to measure sporadic exposure events.

DOSE-RESPONSE

- DR1: Conduct an additional review and re-prioritization of COPCs under tank-disturbing conditions to provide adequate emission characterization, OEL development, and worker exposure surveillance.
- DR2: Conduct a rigorous review of the COPC list to ensure it is current, and develop a process to document the mechanisms used to ensure COPC updates and the basis for changes in the COPC list over time.
- DR3: Conduct additional evaluations of COPC toxicological studies to provide insight into the sensory and pathophysiological irritation response, including the role of mixture interactions and the potential need for additional toxicological evaluation.
- DR4: Perform a comprehensive evaluation of acute odor thresholds and toxicity effect levels for each COPC to facilitate the establishment of action levels based upon the relationship between odor and toxicity thresholds.
- DR5: Continue to evaluate COPC OEL's within the context of observed symptomatology versus 10% of the irritation thresholds and develop a "new" acute OEL list.
- DR6: Maintain a robust health surveillance program that follows-up with exposed workers to evaluate short- and long-term consequences from vapor exposures.

DR7: Evaluate tank vapor mixture toxicological interactions at concentrations associated with transient plume exposures to modify OELs to accommodate mixture effects.

DR8: Develop an overall IH strategy for aerosol evaluations that focus on analytical quantification, the evaluation of chemical aerosols for inclusion in the COPC list as well as the establishment of appropriate aerosol OELs.

DR9: Develop a research strategy roadmap in partnership with DOE, National Laboratories, and University faculty subject matter experts to address critical questions regarding tank vapor emissions and exposures.

RISK CHARACTERIZATION

RCH1: Identify an OEL-C for each analyte in Hanford tank head space(s).

RCH2: Classify and conduct toxicological testing on a reasonable number of distinct types of Hanford tank head space vapors (e.g., potential classes of tank vapor types such as ammonia rich, ammonia poor, nitrosamine rich, etc.).

RCH3: Use the OEL-C from analysis or subsequent toxicological testing to characterize the hazard index and risk from the tank vapor mixtures.

RCH4a: (Chronic) The WRPS IH program has in place procedures for evaluating chronic chemical exposures (based on TWA); it is recommended that more periodic follow-up monitoring be conducted and documented to provide needed data for the industrial hygienist to verify that worker chronic exposures have not changed with time.

RCH4b: (Acute) Transient vapor/gas exposures (i.e. high dose rate) are substantially greater than what is currently measured as a TWA; alternative strategies for evaluating transient plume like vapor exposures is recommended and adherence to excursion limit principles must be implemented (5 times OEL).

RCH4c: (Medical Surveillance) Routine medical surveillance is a key workplace evaluation tool needed to predict health impairment from vapor exposures; appropriately designed epidemiology studies focused on tank farm workers are recommended to evaluate the potential long-term health consequences.

RISK MANAGEMENT

RM1a: Provide and manage industrial hygiene professional and technician staffing levels to properly characterize and assess worker vapor exposure in the tank farms.

RM1b: Provide and manage industrial hygiene professional and technician staffing levels to participate in all planning, execution and evaluation phases of tank farm work activity, similar to radiological and flammability control functions.

RM1c: Provide and manage industrial hygiene professional and technician staffing levels to properly recommend and evaluate the effectiveness of work practices, PPE and engineering controls.

RM1d: Provide and manage industrial hygiene professional and technician staffing levels to effectively inform, advise, and train line functions and address workers concerns regarding tank farm vapors. In addition, available analytical resources should be re-evaluated and increased to assure the timely reporting of sample results associated with tank farm vapors.

RM2: Achieve functional parity of the industrial hygiene program with the radiation control program with respect to worker training and core competencies.

- RM3: Expand general CHAT training for tank farm workers to be more consistent with the length and intensity of the radiological hazard training currently mandated for all site workers.
- RM4: Adequately staff the industrial hygiene function to assure proper resources is deployed in the planning, pre-job, job execution, and post-job ALARA review in a fashion similar to that of the radiological control function.
- RM5: Redefine unacceptable chemical exposure risk to include short term, episodic exposure to chemicals that can result in adverse health impacts.
- RM6: Investigate and implement best available technologies to detect and control vapor plumes from fugitive sources as well as from vents and stacks.
- RM7a. Establish a more effective methodology for designating Vapor Control Zones (VCZs) and Vapor Reduction Zones (VRZs).
- RM7b. Confirm that air-purifying respiratory protective equipment is effective in reducing exposure to tank vapors below acceptable levels.
- RM8: Modify the medical case evaluation process and reporting procedures to recognize the appropriate uses and limitations of the available monitoring data and other potential exposure information when evaluations are made regarding vapor exposures.
- RM9: Verify that all programs associated with vapor controls are properly vetted, evaluated, communicated and tracked to ensure timely completion.
- RM10: All levels of line management demonstrate that they are committed to reducing the potential for tank farm vapors releases and continuously improving management systems to assure all workers are properly protected.

RISK COMMUNICATION

- RC1: Develop more routine and transparent communications, which offer unsolicited information to the Hanford Challenge, Hanford Concern's Council, and other interested community groups regarding potential health impacts, health and safety risks, and WRPS/DOE efforts to reduce risk to employees and the community.
- RC2: Improve the employee job task analysis process to include opportunities for worker engagement and buy-in into the process and protective measure assuring the health and safety of the worker.
- RC3: Improve the degree of employee involvement in and ultimate acceptance of all teams and programs that are associated with tank farm vapor issues (i.e. PERs, CVST, etc.).
- RC4: Revise the content of the employee monitoring notification letters to include more relevant information regarding the capabilities and limitations of the technology used to collect and analyze samples, which should include clear definitions for concepts such as "ND" vs. "<LOQ" vs. "<RQL."
- RC5: Establish a greater industrial hygiene technician and professional presence in the tank farms and undergo specific risk communication training and improve their ability to deliver effective risk communication to the employee.
- RC6: Perform an alternatives assessment for the current SOEN process to identify other methods to assure that all workers potentially impacted by vapor events (i.e. WRPS, MSA, visitors, etc.) are immediately alerted

of a vapor event and understand what mitigating actions they must take to avoid possible health or safety impacts.

RC7: Deploy appropriate laboratory resources to assure timely analysis and reporting of industrial hygiene results, and ensure all exposure data is assigned correctly to all members of the SEG.

RC8: Communicate in a timely fashion to all employees the results of incident investigation, including description of event, results of any samples taken, lessons learned, and corrective actions planned and completed.

RC9: Evaluate and improve the communication system associated with vapor events and results of Workers' Compensation claims.

Overarching Recommendations	OR 1	OR 2	OR 3	OR 4	OR 5	OR 6	OR 7	OR 8	OR 9	OR 10
Supporting Recommendations										
SITE CHARACTERIZATION										
SC1			X	X		X	X			
SC2							X			
SC3	X					X	X		X	X
SC4	X		X			X	X		X	X
SC5	X			X		X	X		X	
EXPOSURE ASSESSMENT										
EA1	X			X		X	X		X	X
EA2			X	X		X	X			
EA3	X			X			X			
DOSE-RESPONSE										
DR1		X	X		X	X				X
DR2		X	X		X	X			X	X
DR3		X	X		X	X				X
DR4		X	X		X	X			X	X
DR5		X	X		X	X				X
DR6		X	X		X	X				X
DR7		X	X		X	X				X
DR8		X	X		X	X			X	X
DR9		X	X		X	X				X
RISK CHARACTERIZATION										
RCH1			X	X		X	X			X
RCH2			X	X		X	X			X
RCH3				X		X	X			X
RCH4a				X						
RCH4b			X	X		X	X			X
RCH4c					X					
RISK MANAGEMENT										
RM1a	X		X	X		X	X		X	X
RM1b	X			X		X	X	X	X	
RM1c	X				X	X	X	X	X	
RM1d	X					X	X	X	X	
RM2	X						X	X	X	
RM3	X						X	X	X	
RM4	X						X	X		
RM5	X		X			X	X	X	X	
RM6					X	X	X			X
RM7a							X	X	X	
RM7b							X	X	X	
RM8	X				X					
RM9	X					X	X	X	X	
RM10	X							X	X	
RISK COMMUNICATION										
RC1									X	X
RC2								X	X	
RC3				X		X	X		X	X
RC4				X			X	X	X	
RC5	X						X	X	X	
RC6							X			X
RC7	X							X	X	
RC8	X							X	X	
RC9	X			X				X	X	

APPENDIX C. APPLICATION OF PRINCIPLES OF HILL'S CRITERIA OF CAUSATION

What are commonly called Hill's Criteria of Causation [Hill 1965] are the minimal conditions needed to establish a causal relationship between potential disease agents and human diseases. The criteria were originally presented by Sir Austin Bradford Hill (1897-1991), British Professor Emeritus of Medical Statistics of the University of London, as a way to determine the causal link between a specific factor and a disease. Hill's Criteria form the basis of modern epidemiological research and have been used in epidemiological science for sixty years. Hill's Criteria have been further adapted as a standard tool in modern chemical risk assessment.

Applying the principles of Hill's Criteria of Causation to aid in assessing the Hanford tank vapor exposure question, the Hanford Tank Vapor Assessment Team 2014 (TVAT) finds that the weight of testimony and evidence strongly suggests that a causal link exists between chemical vapor releases from Hanford waste tanks and subsequent adverse health effects, particularly upper respiratory irritation, experienced by Hanford tank farm workers and that those adverse health effects are likely caused by acute, transitory exposures to relatively high concentrations of chemicals.

Following is a summary of the TVAT's application of the principles of Hill's Criteria to the Hanford tank vapor exposure question.

TEMPORAL RELATIONSHIP

Exposure always precedes the outcome.

The TVAT has explicitly looked for direct documented evidence of a temporal link between bolus exposures in workers who reported significant symptoms while they were wearing a recording air monitoring device. The TVAT has been advised of 3 instances (all occurring in 2014) where monitors were worn while symptoms were reported. The circumstances of and data from these few exposure examples have been varied, somewhat incomplete and there has been no clear indication of exposure from these samples. However, it is the very nature of time-weighted average sampling versus bolus exposure that can easily allow for a significant exposure to go undocumented. Also, these 3 instances are a very small percentage of the total number of workers reporting acute effects over the years.

This is a case where an absence of evidence is not evidence against a bolus exposure as the putative cause for the worker exposures.

One worker reported experiencing severe upper respiratory irritation immediately after a direct reading instrument (DRI) (provided by an Industrial Hygiene Technician working with him) registered very high or "pegged" DRI readings for ammonia. This same worker reported a separate incident in which a DRI (again operated by an accompanying IHT) indicated very high levels of organic vapors, which were immediately associated with another episode of severe upper respiratory tract irritation for this worker. Some tanks at Hanford are rich in ammonia vapor while some have little or much less ammonia but a significant level of organic vapors.

Also, the data presented in Table 6.1 provide documentation of relatively high DRI readings at the source occurring at the same time as reported symptoms in a number of workers.

Thus, while at this point in time, there is little direct evidence of this linked temporal occurrence, it is believed that fugitive tank emissions always precede worker inhalation exposures. Lending credence to this temporal relationship is the co-occurrence of the inhalation exposure events with low ambient air speed on the tank farm. Additionally, the symptoms and signs reported by the workers occur only during the times in which the workers are physically on the tank farm.

STRENGTH

This is defined by the size of the association as measured by appropriate statistical tests. The stronger the association, the more likely it is that the relation of "A" to "B" is causal. This criterion has also been adapted for toxicological risk assessments to consider both the incidence and severity of effects.

The TVAT has examined the criteria of “strength” from two perspectives: the strength of the correlation between an adverse health effect and presence on a Hanford tank farm and the strength of the potential exposure.

Relative to the strength of the correlation between the tank vapor exposure potential and adverse effects, there is essentially a perfect correlation between the workers having an adverse acute inhalation health effect and being physically present on a tank farm. That is, from what the TVAT can determine, there is a one-to-one concordance ($R=1.0$) between being on the tank farm and the reported occurrence of acute symptoms. This is not to say that every person on the farm would have an adverse effect; indeed, the bolus hypothesis predicts that relatively few persons on any farm on any particular day would have an adverse effect. This criteria measure only points to the fact that the affected persons were invariably within or proximate (within 25' of the fence) to the farm.

With regard to the strength of the exposure potential, examination of the tank vapor head-space and vent concentrations show extremely high concentrations of many of the chemical species present relative to the potential of these vapors, if inhaled, to cause significant acute irritation of the upper respiratory tract. Indeed, this irritation potential of the vapors in the tanks head space (and vents) is generally accepted by all, including the IH professionals at Hanford to be very potent relative to their ability in undiluted concentrations to cause upper respiratory irritation. That is, the inhalation of a few breaths of Hanford tank vapor at essentially undiluted vent concentrations is considered, by essentially everyone, to be strong enough to account for the noted symptoms reported by workers. This conclusion is supported by unsolicited descriptions provided by numerous interviewed workers of immediate and severe onset of irritation or other acute symptoms. The TVAT also believes that the incidence of such effects among workers (based on discussions with workers and leadership in focus groups and individual interviews) goes well beyond what would be reasonably considered as not related to actual exposure events. Thus, this is a strong association.

DOSE-RESPONSE RELATIONSHIP

An increasing amount of exposure increases the risk. If a dose-response relationship is present, it is strong evidence for a causal relationship.

There is little doubt that the chemical species present in the Hanford tank head-space and vents represent a risk of at least acute severe upper respiratory irritation upon inhalation by workers. Acute exposure to these chemicals would clearly and strictly adhere to a dose-response relationship in which monotonically increasing dose or exposure would be associated with increasing response. This increase will occur with both increasing time at a constant concentration and increasing concentration during any constant time interval. The classic description of this dynamic two-dimensional relationship for acute inhalation exposure events is given in the following equation:

$$Y_p = a + b \ln(C^n t)$$

Y_p = Probit value corresponding to $p\%$ response. (e.g., Y_{50} is the probit value that corresponds to 50% response, and is equal to 5)

\ln = natural log base e

C = breathing zone concentration (ppmV or mg/m³)

a, b, n = coefficients

t = time (minutes)

In this case the response would be the probit value that predicts the proportion of the exposed population with the adverse health effect, or the percentage with at least severe upper respiratory irritation that will increase as a function of both concentration and time. That is, as either exposure time or exposure concentration is increased, the effect and the adversely affected proportion of the exposed population will increase. The above equation only predicts the proportion of the exposed population responding; however, a different but conceptually similar model, given the right data input, would predict an increasing level of severity of effects in individuals at any concentration and time.

In this case, our hypothesis is that the time frame of exposure is very short (one second to a few seconds); thus the concentration is concomitantly high enough to achieve a response in essentially everyone ($Y_p > 9$) who is exposed. Inhalation of a significant proportion of the tank vent concentration is fully expected to cause a severe acute toxic effect in everyone.

CONSISTENCY

The association is consistent when results are replicated in studies in different settings using different methods. That is, if a relationship is causal, we would expect to find it consistently in different studies and among different populations.

It is our full expectation that even brief inhalation exposure to tank vapors at or near the level of head-space or vent concentrations will consistently cause workers to experience significant effects. In our interviews of tank farm personnel we learned of a term used on the site to describe such exposure events, “go down in the farm”. This was a phrase provided by a manager during one of our focus session in describing the almost instantaneous response to a breath or two of noxious air on the tank farm often resulting in a severe response of a worker “going down” to one knee or momentarily losing their balance.

The reports of effects of these exposures from numerous individuals in discussions held with various focus groups and individuals has been remarkably consistent relative to their quick onset and resulting upper respiratory symptoms and these facts are consistent with the hypothesis (see plausibility below).

PLAUSIBILITY

The association agrees with currently accepted understanding of pathological processes. In other words, there needs to be some theoretical basis for positing an association between a vector and disease.

Given the workers’ reports of exposure events and working backward from the adverse health effects toward potential sources and time frames of exposures causing the effects presents a plausible hypothesis. The TVAT postulates that vapors are coming out of the tank in high (bolus)

concentration plumes that sporadically intersect with the breathing zone of workers such that the workers receive brief but intense exposures.

There is strong evidence for this supposition in the Hanford vapor tank modeling work of Droppo from 2004. This analysis is summarized within the Chapter 5, “Exposure Assessment,” and Appendix I, “Evidence for Bolus Vapor Exposure Potential on the Hanford Tank Farm,” of this report. However, the salient portion the Droppo study is reproduced here for convenience.

Table 3.1 in the Droppo report presents model predictions for the percent of tank head space concentration that would be predicted to occur in a plume at various downwind distances from passively vented tank vents. Previous work on the ventilation rates of passively vented tanks indicated that the rate is somewhat variable depending mostly on local weather conditions (Huckaby 1998). The high end of this variable ventilation or tank breathing rate was set by Droppo at 100 m³/hr. The reasonable worst case meteorology conditions were the G Stability Class with a wind speed of 1 m/s. As an example, this combination results in the following predicted potential worker breathing zone concentrations around a 4” pipe vent discharging near the surface from a passively ventilated tank.

Distance Downwind (m/ft)	Percentage of Head Space Concentration
0.001/0.0033	100%
0.3/0.99	100%
1/3.28	97%
3/9.8	81%
10/32.8	28%
30/98.4	4.2%
100/328	0.67%

Consider what this might mean for a single COPC compound, N-nitrosodimethylamine, or NDMA. This nitrosamine has been measured in the vent exit of some tanks in excess of 1100 µg/m³.^a Clearly, almost 30% of this concentration or 310 µg/m³ might be highly irritating even under very brief exposures occurring over 30 feet from the source. See Appendix I for a discussion of the irritation potential of inhaled NDMA.

A plume concentration of 4.2% of this head space concentration at a distance of almost 100 feet from the vent would represent a potential breathing zone concentration of 46 µg/m³ or about 46x the current Hanford working OEL of 1 µg/m³ for NDMA. Even at 328 feet downwind the possibility exists for a very brief breathing zone exposure to 7.4 µg/m³. Using similar reasoning, other chemicals in the tank head space are also likely to be present, and the potential for achieving significant concentrations of chemicals (many of which are documented irritants as well as causes of systemic acute toxicity) in the work areas is likely.

The width of the predicted plume is estimated in the 2004 Droppo report as not being wide, perhaps a few feet. It would also be anticipated to meander somewhat even in relatively calm air. Given the limited volume of release and subsequent width of the plume, the probability of any worker encountering it is low and sporadic. However, given the potential concentration within the plume, the health effects from even a few seconds exposure to these high vapor concentrations would be anticipated to be significant.

As mentioned above, the acute exposure events are not expected to occur frequently since the worst case of high-end emission and reasonable worst-case weather conditions have to occur together to provide this plume. However, these conditions can and will occur on these tank farms during the year. Inevitably, workers’ breathing zones will intersect with these high concentration plumes and this brief exposure will result in a significant acute exposure.

^a Data taken from MONITORING DATA 2008-10-01_SourceArea.xlsx provided to TVAT from WRPS.

The above analysis appears to coincide with the almost invariable description of exposure events by workers. Essentially all indicate an instantaneous “hitting the wall” or “going down” as a result of one or several breaths during an exposure. One interviewee described not being affected when in a group of 4 individuals in which two were dramatically and instantly overcome via an inhalation exposure.

These facts taken as a whole significantly add to the plausibility of this hypothesis in that they clearly coincide with the sporadic and localized nature of these reported events of severe upper respiratory irritation.

Thus, while we do not know which chemical or chemicals are most associated with the workers’ experiences, the relationship between tank vapor exposures and the nature of reported health effects is highly plausible.

CONSIDERATION OF ALTERNATE EXPLANATIONS:

In judging whether a reported association is causal, it is necessary to determine the extent to which researchers have taken other possible explanations into account and have effectively ruled out such alternate explanations. In other words, it is always necessary to consider multiple hypotheses before making conclusions about the causal relationship between any two items under investigation.

Other potential hypotheses for consideration:

1. The reported exposures are not real and the workers reporting adverse reactions to exposures are motivated by financial or other interests. For example, one hypothesis is that workers are exaggerating or making up their symptoms in an effort to get out of work or ultimately gain compensation.
2. Environmental effects other than tank farm vapors have been suggested by at least one Industrial Hygiene professional at Hanford. These have included herbicides sprayed in the area, desert conditions causing upper respiratory tract symptoms (*e.g.*, nose bleeds), or other environmental agents associated with the desert as a cause.
3. Affected workers are those who are hyper-susceptible to odors or are perhaps experiencing physiological effects secondary to suggestive hysteria or multiple chemical sensitivities.

From our discussion with multiple workers who have experienced or witnessed the exposure events of fellow workers, it is clear to the TVAT that neither hypotheses 1 nor hypothesis 3 is the primary cause of the adverse effects reported.

While we accept that there may be some exaggeration or other motivation of workers to misreport symptoms, we find the overwhelming majority of accounts to be credible and representative in many instances of tank vapor exposures that are well above the concentrations that would cause essentially everyone to respond with frank upper respiratory symptoms. The number of individuals that independently described their experiences, the consistency in the reports, the plausibility relevant to the nature of the chemicals known to be present, and the inability of current IH sampling and exposure monitoring tools to document such exposures are all aspects of a persuasive argument against a major effect of the above hypotheses 1 and 3.

Relative to hypothesis 2, it has been brought to the attention of the TVAT that non-tank farm workers in the general Tri-cities area experience and report respiratory irritation on what is claimed to be a daily basis from allergens known to be indigenous to the region. Even if the rate of respiratory irritation from allergens in the general population is reasonably significant compared to the rate of acute onset upper respiratory irritation experienced by individuals in or proximate to the Hanford tank farms, reports of these events do not address the strength (severity of effects) or temporality (level and timing of effect intensity) of the incidents. Absent evidence to the contrary, we do not believe there is a reasonable corollary irritation response in the general

population to the effects described to us by Hanford workers during our interviews. These were dramatic and essentially instantaneous events as described by those who had experienced them or those who had not been affected personally but had witnessed this response in others. These descriptions of very rapid and very impactful (e.g., going to one knee) are not consistent with immunologically mediated physiological responses to ambient allergens. Thus, we believe that hypothesis 2 also is not a significant causal factor for the reported vapor incidents.

In conclusion, alternative hypotheses such as allergy, non-work motives, and unique high levels of sensitivity may indeed contribute in a marginal way to the overall worker experience. However, the clear patterns based on our interviews and the overall factual patterns stand as showing that acute exposure to vapors is the primary cause of the reported symptoms.

EXPERIMENT

The condition can be altered (prevented or ameliorated) by an appropriate experimental regimen.

The TVAT believes that placing the Hanford tanks under sufficient and continuous negative pressure and removing the vented vapors to a distant location is an experiment that would essentially result in an elimination of the vast majority of exposure events in tank farm workers. Some residual vapor may still be present in equipment previously wrapped and stored or buried separately, but these exposures would also be amenable to experimental verification of cause.

SPECIFICITY

This is established when a single putative cause produces a specific effect. Causality is most often multiple. Therefore, it is necessary to examine specific causal relationships within a larger systemic perspective.

The “systemic” perspective in this case is supplied by the plethora of noxious vapors within the head-space and vents of the Hanford farm tanks. It is singularly unimaginable that any other source is the cause of the worker exposure which has occurred on Hanford tank farm for decades. That is, we consider that these vapors taken as a whole are clearly the most likely (indeed the only anticipated) single putative cause of the vast majority of reported acute inhalation responses of workers.

COHERENCE

The association should be compatible with existing theory and knowledge. In other words, it is necessary to evaluate claims of causality within the context of the current state of knowledge within a given field and in related fields.

The hypothesis that tank farm vapors are responsible for the sporadic but consistent (over the long term) bouts of worker exposure is completely coherent within the current state of exposure and toxicological science and knowledge related to exposure modeling (using existing measured tank farm variables) and the anticipated physiological response to high-level short-term (bolus) exposure to relatively undiluted vented tank farm vapors.

The TVAT has found no other hypothesis worthy of consideration or analysis; however, we remain open to consideration of other credible explanations that may be presented.

APPENDIX D. EXAMPLES OF REMEDIAL ACTIONS

The TVAT recognizes the complexity of the challenge of addressing the vapor exposures issues. The overarching and supporting recommendations are substantial and will require a comprehensive implementation plan. In some cases, recommendations are related such that as some actions are taken, others may be set aside as the vapor issues improve. The optimal resolution of the vapor issues will require a long-term commitment to achieve. However, the TVAT also recognizes the need for recommendations that can have impacts in the short-term. For this reason, the TVAT has distilled some of the key recommendations in terms of anticipated implementation plan timing. Three time frames are provided: Near-term (days to weeks); intermediate -term (weeks to months); and longer-term (months to years).

Phase I – Near Term (days to weeks)

- Determine the efficacy of posting the SST farms (C, AW, etc.) as VCZ and require half-faced combinational chemical cartridge respirators with sampling plans tailored to job tasks to control vapor exposures within the farm. Same for DST farms when ventilation is not active.
- In addition to 8-hour TWA analysis of personnel sampling data, data should be compared against excursion limits and action levels (10% of those OELs) for the duration and volume of the specific sample for the various chemicals detected.
- Implement a revised form to communicate the personnel monitoring data and develop a means to ensure the SEG exposure data summaries are updated.
- Revise and expressly state the limitations of the data provided to the medical provider and begin determining whether this revises any of the medical determinations.
- Examine the process of valving out tanks connected to manifolds when transferring material from a given tank with the goal of modifying procedures to reduce vapor exposure potential.
- Establish a Vapor Advisory Panel to assist in review and implementation of the TVAT recommendations and to serve as an ongoing sounding board. The TVAT could transition into this advisory panel.
- Require IH participation in the development of work packages and ensure IH professional presence during vapor-risk jobs.
- Determine the effectiveness of deploying orchard fans near the berm in C-farm to increase air dispersion.
- Determine the utility of external fans near SST vents to enhance near-field atmospheric mixing of the emissions.
- Continue the deployment of the Area RAEs and process/communicate the results of sampling from this state-of-the-art instrument.
- Issue the results of field and personnel monitoring data in a published report.
- Develop and implement training for first-line supervisors on tank vapor issues and path forward to address them.
- Begin a quarterly communication on tank vapors to alert employees to the actions being taken and the status of those actions.
- Issue a statement from leadership accepting the findings of the TVAT and assuring commitment to implement recommendations and begin a quarterly communication on tank vapors to alert employees to the actions being taken
- Initiate plans to make progress on the Intermediate recommendations

Phase II – Intermediate (weeks to months)

- Determine the extent to which current stack extensions are effective and under what atmospheric conditions they are not.
- Using evaluation tools including CFD modeling, design the engineering controls that will be used in A and AX farms based on the potential for vapor exposure rather than solely radiological concerns.
- Re-examine data used in the IH technical basis document prorated to a short term bolus exposure and compare to 10 % of the excursion limit to develop a listing of acute COPCs.

- Implement hand-held infrared or other suitable technology to survey for fugitive emissions and to abate the discovered release points.
- Staff IH programs with experienced (full-time or limited-service) personnel to mentor the further development and refinement of the tank vapors programs
- Publish a program plan and schedule for sampling and enhancing the characterization of tank head space constituents.
- Complete an assessment of chemical plating in passively vented systems.
- Conduct field stability and recovery studies for key sampling and analytical methods
- Improve the alarm function of entering an AOP-15 to ensure all affected personnel are notified, while personal alarm devices are developed and deployed.
- Continue stack sampling during retrieval activities and utilize the results to update the COPC listing
- Implement field mentoring of newly hired IH staff
- Revise the mixture rule process to examine chemical homologues
- Develop a process to determine if the updated view of the IH data limitations revises any of the medical and work-relatedness determinations.
- Initiate plans to make progress on the longer-term recommendations

Phase III – Longer Term (months to years)

- Install vapor detection alarms on the passive vent stacks.
- Install chemical monitoring on continuously vented stacks.
- Perform evaluations of COPC toxicological studies to provide insight into the sensory and pathophysiological irritation response, including the role of mixture interactions and the potential need for additional toxicological evaluation.
- Revise the mixture rule process to examine chemical homologues.
- Develop and implement a research strategy roadmap to address these critical questions. It is anticipated that based on the scope of this research problem, a broad range of research funding agencies, including NIH, NIOSH, CDC, EPA, DOD and DOE, would have interest and directly benefit from supporting these endeavors.
- Design the engineering controls that will be used in A and AX farms based on the potential for vapor exposure rather than solely radiological concerns including CFD modeling, including finalizing evaluation of vapor removal technologies from the Baker (2004) report.
- Develop plan for health effects and medical surveillance, including coordination with current epidemiology studies efforts to address potential health effects from acute and chronic vapor exposures.

APPENDIX E. SELECTED LIST OF PREVIOUS HANFORD TANK VAPOR ASSESSMENTS

Concerns about chemical vapor exposures on the Hanford tank farms are not new. The chemical vapor issue has been the subject of assessment efforts accompanied by issuance of formal reports and recommendations over more than 20 years, continuing into the present. However, the degree to which recommendations have been closed and the final decision process regarding each recommendation are not clear. With the intent of finally resolving the issue or at least significantly mitigating the problem, Washington River Protection Solutions (WRPS) is re-examining the Hanford tank vapor issue. As part of that evaluation, WRPS has commissioned the Hanford Tank Vapor Assessment Team (TVAT) 2014 to take a broad look at the issue and offer independent analysis and recommendation. WRPS management has committed to develop and implement an implementation plan addressing this report. Effectively responding to this report not only requires specifying actions for expeditious execution of all TVAT recommendations but also requires clearly defining a process to monitor, document, and report progress and assure continuous improvement. Essential to that control process are a reporting schedule and a list of key stakeholders who will receive updates on progress. Built in to the process must be explicit mechanisms to assure continuity of programs through budget, leadership, and management changes.

1. April 1992. *Type B Investigation of Hanford Tank Farm's Vapor Exposures*. Richland Field Office, U.S. Department of Energy.
2. March 1997. *Health Risk Assessment for Short-and Long-term Worker Inhalation Exposure to Vapor-Phase Chemicals from the Single-shell Tank 241-C-103*. A.D. Maughan, J.G. Droppo, K.J. Castleton.
3. November 2001. *Exposure-Based Health Issues Project Report: Phase I of High-Level Waste Tank Operations, Retrieval, Pretreatment, and Vitrification Exposure-Based Health Issues Analysis*. Pacific Northwest National Laboratory, Hanford Environmental Health Foundation. (R.D. Stenner, et al.)
4. September 2003. *Knowing Endangerment: Worker Exposure to Toxic Vapors at the Hanford Tank Farms*. Government Accountability Project. Nuclear Oversight Program.
5. April 2004. *Investigation of Worker Vapor Exposure and Occupational Medicine Program Allegations at the Hanford Site*. Office of Health Safety and Security, U. S. Department of Energy.
6. July 2004. "Evaluation of Hazardous Waste Vapor Exposures at Hanford Tank Farm Site." *NIOSH Health Hazard Evaluation Report*. Department of Health and Human Services. HTEA#2002-0145-2941.
7. December 2004. *Toxicological Assessment of Hanford Headspace Chemicals – Determination of Chemicals of Potential Concern*. PNNL-14949. Pacific Northwest Laboratory. (I.E. Burgeson, et al.)
8. March 2006. *Proposed Approach to Establishing Acceptable Limits of Exposure to Hydrocarbon Vapors Emitted from Underground waste Storage Tanks at the Hanford Site*. RPP-RPT-29404. (C.R. Mackerer).
9. June 2008. *The Industrial Hygiene Chemical Vapor Technical Basis Review*. Hanford Concerns Council.
10. September 2010. *Independent Review Panel Report on Chemical Vapors Industrial Hygiene Strategy*. Hanford Concerns Council.

APPENDIX F. HISTORICAL PERSPECTIVE: FACTORS AFFECTING HANFORD TANK VAPOR EMISSIONS

The goal of this appendix is to concisely summarize the decades-long history of the source of tank vapors, of tank vapor exposure knowledge and of tank vapor exposure control measures. This appendix is organized around topics believed to be pivotal in understanding the present circumstance and important for improving control of underground tank vapor plumes, and chronological within those topics. Those topics include: Regulatory Mandates, Legal Requirements, Federal and DOE Policies, Schedule, Budget, and Public Groups and Litigation against DOE and/or its contractors.

INTRODUCTION

The Hanford Nuclear Reservation was used to manufacture fissile fuel for nuclear weapons and nuclear power reactors between 1944 and 1986. Between 1986 and 2005 the Fast Flux Test Reactor was used or kept in usable condition. Since 1986, the primary mission of DOE and its Hanford contractors has been to clean up the hazards left over from decades of focus on manufacturing without serious consideration of long term adverse effects of the waste streams involved. The cleanup mission got off to a slow start, because the culture needed for a successful cleanup was dramatically different from that needed for high priority manufacturing of materials deemed essential to national survival. It can be argued that the cultural change is in its final stages in 2014, more than two decades after it started.

There are both similarities and the differences between the production and the remediation phases of the life cycle of the Hanford Nuclear Reservation.

They are similar because in both missions there was no prior art for the equipment, the materials or the processes used. Everything had to be invented over time, and in the absence of prior human experience it was not even possible to accurately estimate either cost or schedule. Both programs suffered delays and cost overruns. In a vicious cycle each delay increases costs, and each cost increase leads agency headquarters staff and congressional committees to withhold or delay funding.

They are different because the production phase was driven by external national enemies and was conducted in strict secrecy. Production goals were the highest priority at all levels of management, from Congress to the sub-contractor. In contrast the clean-up phase needs to be done, but is easily deferred by Congress or DOE when funding is needed elsewhere. Further, most of the remediation has been performed to requirements laid out by federal, state and local regulators. When the public perceives serious problems, they are taken to the courts for resolution.

In 1986, plutonium production was terminated at Hanford and the mission shifted to remediation. Since 1986, the variability in funding levels has repeatedly extended the remediation schedule and forced local field offices and contractors to prioritize tasks that can be accomplished while deferring others. One of the repeated features of this dynamic is that underground storage tank vapors have been the poor step-child of higher priority concerns. This has been true at all levels: Congress, White House, DOE headquarters, DOE field offices and DOE contractors and sub-contractors.

In this chaotic management environment, one problem has remained virtually constant during the period of site remediation, from 1986 to 2014. Appropriate priorities have been given to controlling risk from criticality, radiation, flammability and explosions in the tanks. Further, although professional staffing of flammability, safety and radiation protection programs has been consistently provided, it appears that comparable emphasis on professional qualifications and training of industrial hygiene staffing was deferred by DOE and its contractors until spring 2014. Further, there has never been a funded project to treat chemical vapors rather than to simply release them into the atmosphere.

The extent of the tank vapor problem was first made public in 1986, with continuing new revelations in the years that followed. Remarkably, although Oregon is not a part of the legal mandates that govern cleanup activity, its Department of Energy has consistently, forcefully and effectively worked for timely remediation. The Oregon Department of Energy published a report summarizing important events at Hanford between 1986 and 2009. The portions of those quotes that are reprinted here were chosen to indicate the culture, the legal and the regulatory frameworks that have allowed the tank vapor problem to persist from 1986 to 2014. (OrDE 2009)

The tank vapor problem has persisted for decades in the control of the old Atomic Energy Commission and the larger Department of Energy since 1977. It has persisted during the tenure of many different field managers and many different contractor and sub-contractor entities. In light of this, it is reasonable to conclude that policies or factors external to Hanford drive decisions that have led to similar outcomes no matter who is managing or which contractors are working at the site.

Nearly a decade after remediation began; the challenges of the Hanford remediation were expressed concisely in remarks to the House Energy and Security Committee. The key issues were placed clearly in focus by Louisiana Senator J. Bennett Johnston, speaking to the committee on March 22, 1995 about the challenge of cleanup faced by Energy Assistant Secretary Tom Grumbly: “We have given him an impossible job. We have ordered him to meet standards he cannot attain, to use technologies that do not exist, to meet deadlines he cannot achieve, to employ workers he does not need, and to do it all with less money than that for which he has asked. If he fails, we have threatened to put him in jail.” (OrDE 2009, pg 41)

COMMENTS FROM KEY DECISION MAKERS

The following comments and quotes from key leaders and managers illustrate the frustrations and challenges faced by those overseeing, implementing and affected by remediation activities at the former Hanford Nuclear Reservation.

From Randy Smith (former Lead Tri-Party Agreement Negotiator for the U.S. Environmental Protection Agency): “It took about a year to negotiate the draft Tri-Party Agreement, from January 1988 to January 1989 (followed by public meetings and comment, further negotiations to revise the agreement, and final signing in May 1989). . . . Egregious waste management practices were stopped as a result of Tri-Party Agreement commitments. The best example is the treatment of all liquid wastes, ending the practice of dumping radioactive liquids into the soil via cribs. Credit should go to the public for pushing that milestone into the final Tri-Party Agreement --it was not in the January 1989 draft.” (OrDE 2009, pg *vii*)

W. Henson Moore (Deputy Secretary of Energy, 1989-1992): talking about changing culture from production of nuclear materials to site remediation: “It was a culture change and we were pounded by people within the Defense department. We were pounded by people within the Department of Energy. We were pounded by contractors, who were essentially resisting this change from production to cleanup. We were being pushed on all fronts. Because quite frankly, a culture had been developed in building the nuclear weapons for the nation’s defense. And that came first. It came first before everything else. The environment wasn’t even a consideration. Health and Safety was less of a consideration. The consideration was, succeed at all cost. The nation’s defense depended upon it. . . . There was a toxic mixture of materials in those tanks at Hanford that was new to mankind.” (OrDE 2009, pg *vi-x*)

“The underlying operating philosophy and culture of DOE was that adequate production of defense nuclear materials and a healthy, safe environment were not compatible objectives. I strongly disagree with this thinking.” (Energy Secretary James Watkins. DOE News Release, June 27, 1989).

In March 1994, a report entitled “Train Wreck along the River of Money, an Evaluation of the Hanford Cleanup” was delivered to the Committee on Energy and Natural Resources. The report explained that the Tri-Party Agreement hindered cleanup. “Many of the schedules in the TPA are unworkable, disjunctive, lack scientific and

technical merit, undermine any sense of accountability for taxpayer dollars, and most importantly, are having an overall negative effect on worker and public health and safety." The report also observed that "Hanford is floundering in a legal and regulatory morass." (OrDE 2009, pg 41)

With this necessarily brief summary of the legal background for worker health and safety programs, it is important to turn to evidence of the performance of DOE contractors throughout the duration of activities sponsored by DOE and its predecessor federal organizations. The policies governing Hanford tank farm and general Hanford site remediation activities were extensively reviewed in a 196 page report (OrDE 2009).

The extent of the tank vapor problem was first made public in 1986 (OrDE 2009, pg i), and although Oregon is not a part of the legal mandates that govern cleanup activity, its Department of Energy has consistently, forcefully and effectively worked for timely remediation (OrDE 2009, pg i). The preface of the Oregon report contains quotes from principal players involved in the decisions between 1986 and 2009. The portions of those quotes that are reprinted here were chosen to indicate the culture, the legal and the regulatory frameworks that have allowed the tank vapor problem to persist from 1986 to 2014.

Roger Stanley (Lead Tri-Party Agreement Negotiator for the Washington Department of Ecology): "The state had had virtually no presence on-site and just asking to look around brought a phalanx of attorneys out, which was a bit of a hint... It was an article in a newspaper that tipped me off to (litigation against DOE) in Tennessee, and, after a phone call or two back east, I began taking a closer look, and the state began demanding compliance to the same extent as the private sector. The regulatory authority battles prior to the Tri-Party Agreement were hard fought, and gave me the opportunity to testify in front of a number of Congressional committees as they took up the fight." (OrDE 2009, pg v)

"At the time the Tri-Party Agreement was initially negotiated, the toughest negotiations were over what could be done and would be done about the tank wastes. The uncertainties about what was in the tanks, how to sample them to better understand their contents, and how to develop feasible processes to remove and treat the wastes were enormous. The initial Tri-Party Agreement was quite sketchy about the details of what ought to be done. It was clear to all of us, and to any observer, that the tank wastes and the associated 200 Area problems would be the thorniest problem. I remember thinking that there was no way that these problems would be dealt with within the careers of those then working at Hanford or for Ecology or EPA. Our children, or maybe our grandchildren's generation would still be working on this remediation. I didn't think of that as pessimism, just realism." (OrDE 2009, pg vii-ix)

W. Henson Moore (Deputy Secretary of Energy, 1989-1992): "It was a culture change and we were pounded by people within the Defense department. We were pounded by people within the Department of Energy. We were pounded by contractors, who were essentially resisting this change from production to cleanup. We were being pushed on all fronts. Because quite frankly, a culture had been developed in building the nuclear weapons for the nation's defense. And that came first. It came first before everything else. The environment wasn't even a consideration. Health and safety was less of a consideration. The consideration was succeed at all cost. The nation's defense depended upon it. ... There was a toxic mixture of materials in those tanks at Hanford that was new to mankind." (OrDE 2009, pg vi-x)

Gerald Pollet (Executive Director of Heart of America Northwest): "Some lessons take decades to learn... The most significant step yet taken for Hanford cleanup has been the ending of those (liquid waste) discharges." (OrDE 2009, pg vii)

Randy Smith (former lead tri-party agreement negotiator for the US Environmental Protection Agency, or EPA): "Egregious waste management practices were stopped as a result of Tri-Party Agreement commitments. The best example is the treatment of all liquid wastes, ending the practice of dumping radioactive liquids into the soil via cribs. Credit should go to the public for pushing that milestone into the final Tri-Party Agreement (it was not in the January 1989 draft) (OrDE, vii)."

Bill Dixon (former Administrator of Nuclear Safety and Energy Facilities for the Oregon Department of Energy): “A cleanup mission this large, complex, expensive and long had never been done. Therefore those involved in setting these milestones ‘guesstimated’ many, hoped for others, and quite frankly made up some.” (OrDE 2009, pg 9)

James Watkins (Secretary of Energy, 1989-1993): “Hanford waste is the example of what goes sour when you don’t pay attention to all of these other things that get into the ecology, health, safety of human beings, safety of operations, the top level people from Washington on down knowing what is going on out there in the labs and in the burial grounds and so forth... We had to get control of these things, it was not under control. And that was one of the things that I found and I told the President, ‘You want me to clean this place up, you better help me.’ Because a lot of people aren’t going to like it, see us putting money into things we haven’t put it before. (OrDE 2009, pg xi)

Tom Carpenter, Government Accountability Project Attorney, was quoted in the Tri-City Herald on 16 Sep 2003: “Hanford tank workers are like canaries in a coal mine.” (OrDE 2009, pg 112)

Former New Mexico Senator Pete Domenici and a member of the Blue Ribbon Commission on America’s Nuclear Future, after touring Hanford was quoted in the Tri-City Herald, July 15, 2010: “Boy, oh boy, what a mess we created making those bombs. Now we have to fix it up.” (OrDE 2014, pg 185)

POLICIES, FEDERAL LAW, STATE REGULATORS AND REMEDIATION CONTRACTORS

The policy, legal, and regulatory environments have been variable since Hanford site remediation started in 1986. That has had major impacts on the planning, programming and implementation of efforts to control, stabilize and finally sequester the underground storage tank contents for long term safe storage. As the waste is variable from tank to tank, and as its radioactivity catalyzes and heats continuing chemical reactions, it has variable composition over time. There was no prior human experience from which lessons learned can be directly applied. There was also no proven technology for each step of the clean-up. Inevitably, as in every new venture, there are false starts. These have proven costly and have enabled a stakeholder concept of mediated decision making at each decision point.

Among the public, the state regulators, the federal regulators and Congress there are people who understandably want a guaranteed cleanup timeline at a guaranteed fixed price. When technical issues or mistakes lead to cost overruns, delays or accidents, these stakeholders apply financial and legal pressures to those who are attempting to make progress in remediating the tank farms. Repeatedly, the senior DOE field office staff, the prime contractor, or its subcontractors are replaced as part of this process. There is a partial loss of continuity with some mistakes repeated and a continued deferral of underground tank maintenance activities and of technology development projects that appear to get lost in these transitions.

Because of the Tri--Party Agreement both the public and the regulatory agencies were becoming aware of the unprecedented technical issues that were faced by planners now tasked with cleaning up hazardous waste.

In 1998, DOE began waste removal tests at tank C-106 but suspended work after about two hours because of higher than expected exhaust emissions. Eleven workers were examined after potential exposure to the emissions. Notwithstanding the worker exposure issue, DOE removed 18 tanks from the organic complexants Watch List in December (eight of these were also on the hydrogen Watch List) and closed the organic complexants safety issue. (OrDE 2009, pg 69)

In 2003, The Government Accountability Project (GAP) said Hanford’s tank farm workers were repeatedly being exposed to hazardous chemical fumes. A GAP report said workers’ protective breathing equipment and equipment to monitor vapor releases was inadequate to protect workers from chemicals leaking from Hanford’s

waste storage tanks. GAP said from January 2002 to August 2003, 67 tank farm workers required medical attention. (OrDE 2009, pg 112)

In March 2004, CH2M Hill revised work procedures for tank farm work by requiring self-contained breathing tanks for all workers. This policy was terminated after two years. In part, this was because the loss of peripheral vision and the off-center weight of the tanks had created an unacceptable increase in accidents and injuries, but it was not terminated until after alternate control measures had been validated by a number of vapor sampling events. A Washington State study suggested existing monitoring done for worker protection might be inadequate because much was still not known about the vapors, and identified isolated problems with worker compensation claims. DOE's inspector general said Hanford contractors were underreporting the number of injuries and illnesses. A report by the federal Office of Independent Oversight and Assessment found that not enough was known about the chemicals in Hanford's underground tanks to conclude that tank farm workers had not been exposed to harmful vapors. (OrDE 2009, pg 122)

There were other incidents, but in the interest of brevity, we note that there have been more than 40 reported worker vapor exposure incidents between Jan and Aug 2014, showing clearly that neither the problem of worker vapor exposures nor the problem of worker compensation for on the job illness has been solved.

On 9 February 2006, 10 CFR 851 was published in the Federal Register. The new law replaced DOE order 440.1A which had been part of earlier contracts. Rule 851 requires DOE and its contractors and subcontractors to provide workers with a workplace free from recognized hazards that can cause death or serious physical harm. The Rule also establishes management responsibilities, worker rights, worker responsibilities, and specifies a minimum set of safety and health standards that include applying the more protective of OSHA Permissible Exposure Limits or ACGIH Threshold Limit Values as of 2005, for controlling chemical vapor exposures. (http://energy.gov/sites/prod/files/2014/04/f15/851_Bulletin.pdf, This 1-page summary was Accessed 31 Aug 2014)

There is no doubt that in 2014 DOE contractors are legally required to establish and maintain robust industrial hygiene and occupational health programs for their employees and for employees of any subcontractors. Given only this small portion of the history of contractual policy and regulatory requirements, it is remarkable that the industrial hygiene program has been seriously under emphasized by DOE and by its contractors throughout the history of the Hanford Nuclear Reservation during its production years (1944-1986) and during its ongoing remediation years (1987-2014). Member of the Tank Vapor Assessment Team are encouraged by our observations that more effort and resources are being devoted to establishing a robust vapor control program than at any previous period of site history.

RECENT HISTORY OF HEALTH AND SAFETY REGULATIONS

On 9 Feb 2006, DOE published an 18-page update to the Code of Federal Regulations in the Federal Register. It updated 10 CFR 850 (beryllium program guidance) and created 10 CFR 851 (guidance for other occupational stressors, except radiation and fire/explosion protection to the extent regulated by 10 CFR Parts 20, 820, 830 or 835.). The final 851 Rule codified the legal requirements for industrial hygiene and occupational health programs required of DOE contractors and specified fines and contract penalties in the event these requirements were not performed. The Rule requires a written safety and health plan approved by the field DOE office. It makes managers responsible for implementing the plan in a way that provides a place of employment that is free from recognized hazards that are causing or have the potential to cause death or serious physical harm to workers (10CFR851.10 (a)(1)). Management is required to staff the safety and health program with qualified worker safety and health staff (e.g., a certified industrial hygienist [CIH], or safety professional [CSP]) to direct and manage the program.

We note that the employment of CIH qualified professionals has been the exception in the programs managed by DOE contractors under the supervision of its Hanford field offices. Because the hazards associated with tank farm

remediation are unprecedented in human history, and because workers continue to report serious, if infrequent, encounters with tank vapor plumes we are pleased to see recent efforts to hire certified professionals. (Rule 851, 2006. 10CFR850-851, Federal Register / Vol. 71, No. 27 / Pg 6931-6948./ Thursday, February 9, 2006 / Rules and Regulations/.,]. . Accessed 1 Sep 2014: http://energy.gov/sites/prod/files/hss/Enforcement%20and%20Oversight/Enforcement/docs/cfr/rule_enforcement.pdf)

The Rule requires DOE and its contractors and subcontractors to provide workers with a workplace free from recognized hazards that can cause death or serious physical harm. The Rule also establishes management responsibilities, worker rights, worker responsibilities, and specifies a minimum set of safety and health standards. The term contractor is defined in the Rule to include parent corporations and subcontractors that have responsibilities for performing work at a DOE site in furtherance of a DOE mission. (http://energy.gov/sites/prod/files/2014/04/f15/851_Bulletin.pdf, This 1-page summary was Accessed 31 Aug 2014)

The 91 page preamble to 10 CFR 851 notes that 10 CFR 851 supersedes and codifies the intent of a DOE Order which was part of earlier contracts. In this context, the preamble reads, Currently DOE Order 440.1A, “Worker Protection Management for DOE Federal and Contractor Employees,” establishes requirements for a worker safety and health program. A DOE contractor with DOE Order 440.1A in its contract must have established a worker protection program as stipulated by the Contractor Requirements Document (CRD) that accompanies the order. Similar and legally enforceable requirements pertain in the new 851 Rule. Tables 1 and 2 of the preamble compare specifications of the prior Order with legally enforceable provisions of 10 CFR 851. It is clear that 440.1A. Section 12 is the progenitor of 10 CFR 851.23. Both specify use of the more protective of an OSHA PEL or an ACGIH TLV (2005) and both cite numerous other consensus standards as a basis for providing industrial hygiene and occupational health programs and services to contract workers. Likewise the updated industrial hygiene program guidelines from section 18 of the order appear in 10 CFR 851 Appendix A, Section 6. (Rule 851 Preamble, 2006. Federal Register / Vol. 71, No. 27 / Pg 6858 6948/Thursday, February 9, 2006 / Rules and Regulations. Accessed 1 Sep 2014: <http://www.gpo.gov/fdsys/pkg/FR-2006-02-09/pdf/06-964.pdf>)

Our site visits observed that during the period Jan – Aug 2014 there has been significant growth in the funding, staffing and impact of the industrial hygiene program, although we would be remiss if we did not observe that the decades long emphasis on radiation protection and flammability control still overshadows industrial hygiene. Based on field office and contractor initiatives undertaken in 2014, members of the TVAT believe that management at all levels is starting to take its rightful responsibility for safety and health on the tank farms, and that present efforts to increase qualified industrial hygiene staff and resources suggest industrial hygiene is on track to reach a co-equal status with other important risk management programs: radiation protection, fire/explosion protection and criticality protection.

CHRONOLOGY OF EVENTS

The following chronology of events is based on Oregon Department of Energy publications. In it the reader will find evidence of evolving understanding of tank contents, of tank vapor hazards and of the means to share decision making with public and political stakeholders. The overarching take away is that there are many moving parts to remediating the waste at the Hanford Site. Among these moving parts there is frequent friction which leads to increases in estimated costs and delays in achieving key milestones. Throughout the life of the program, constrained budgets have been accommodated by prioritizing tasks that would be funded. Health effects of tank vapor emissions never had higher priority than criticality, radiological health protection or fire/explosion protection. Careful reading of the following chronology will demonstrate the absolute truth of two observations:

“There is no clearer reminder than Hanford that responsible plans for waste management must be in place before the waste is produced.” – Washington Governor Chris Gregoire, addressing the Blue Ribbon Commission on America’s Nuclear Future taken from the Meeting transcript, July 15, 2010. (OrDE 2014, pg 192)

“Experience in the United States and in other nations suggests that any attempt to force a top-down, federally mandated solution over the objections of a state or community – far from being more efficient – will take longer, cost more, and have lower odds of ultimate success.” – 29 July 2011 Blue Ribbon Commission Draft Report. (OrDE 2014, pg 208)

1989 (OrDE 2009, pg 1-6):

“The underlying operating philosophy and culture of DOE was that adequate production of defense nuclear materials and a healthy, safe environment were not compatible objectives. I strongly disagree with this thinking.” (Energy Secretary James Watkins. DOE News Release, June 27, 1989).

Beginning in 1944, single shell carbon steel tanks were constructed at Hanford to store the most hazardous of the liquid waste streams. In all, 149 of these were constructed ranging in size from 55 thousand to 1 million gallon capacity, with most holding more than a half million gallons. Over time many of these tanks started to leak and in the late 1960s construction started on what became 28 million gallon double shell carbon steel tanks. (OrDE 2009, pg 4-5)

In October 1989, Battelle Pacific Northwest Laboratory released a report withheld from public view for five years. The report discussed the risk Hanford tank explosions in tanks that had been treated with ferrocyanide to separate cesium from the rest of the waste. At this time Hanford manager Lawrence revealed that the bottom of one Hanford tank ruptured in 1965 and released radioactive steam into the air. (OrDE 2009, pg 5)

Because of the Tri Party Agreement both the public and the regulatory agencies were becoming aware of the unprecedented technical issues that were faced by planners now tasked with cleaning up hazardous waste.

Energy Secretary James Watkins observed on 28 Jun 1989 that “The chickens have come home to roost and years of inattention to changing standards and demands regarding the environment, safety and health are vividly exposed to public examination, almost daily. I am certainly not proud or pleased with what I have seen over my first few months in office.” On 29 August 1989, he challenged all parties with his vision, “I’d like to see Hanford become the flagship for waste management research.” (OrDE 2009, pg 6)

1990 (OrDE 2009, pg 7-14):

The phenomena of tank burping were described in tank SY-101. Hydrogen accumulated in the bottom sludge layer until it broke through. Measurements found hydrogen concentrations of 1.1% to 3.4%, deemed below the 5% lower explosive limit in air (no mention of concentration gradient in the head space). In July 1990, a DOE report found that its contractors had known about the hydrogen in tanks for 13 years and had not taken any safety measures during that time. By year end, the crust in the tank had been sampled and found to be damper, softer and less radioactive than previously (since 1944) thought. DOE Headquarters ordered cessation of coring work in tanks when it was learned that drill bit temperatures could reach 475 degrees Celsius, sufficient to offer an ignition source under certain conditions. (OrDE 2009, pg

1991 (OrDE 2009, p15 -20):

Early in 1991, 14 months after awarding the contract to build the high level vitrification plant Secretary James Watkins announced a project delay of at least 2 years, in part to learn from the earlier start of the Savannah River vitrification plant. In response, and with a pattern that was to continue, Washington Governor Booth Gardner threatened legal action and the US EPA and WA department of Ecology both wrote letters to site manager John Wagoner rejecting the delay. In the 31 Jan 1991 EPA letter, Dana Rasmussen NW Regional Manager for EPA, wrote “It’s astonishing that Energy would unilaterally let such a major milestone slip. The (Tri-Party) Agreement

is clear: changes are to be proposed and discussed out in the open, and not pulled like a rabbit out of a hat.” (OrDE 2009, pg 15)

In April 1991, DOE announced that 444 billion gallons of contaminated liquids had been dumped into the soil since operations began in 1944. The waste was estimated to have contained 678,000 Curies of radio nuclides and 93,000 tons of chemicals. In May a Westinghouse Hanford report was released showing 75 containers of spent fuel rods had been placed in a low level burial site during the 1970s. DOE awarded a two year extension to the Westinghouse contract in June and added a separate contractor to manage environmental restoration work. Ongoing studies found that tank C-104 had plutonium above the safety limits and that contents of C-106 could not be pumped if it began to leak—the only option was to add cooling water to the tank if it leaked, a process that would drive the waste towards the groundwater. (OrDE 2009, pg 16)

Congressman Ron Weydon of Oregon proposed legislation that created a “Watch List” of dangerous tanks. The initial March 1991 list included 52 of Hanford’s 177 tanks, 47 SST and 5 DST tanks. Each of these met one of four criteria: hydrogen generation, had been dosed with some of 350 tons of ferrocyanide, had received some of 5 million pounds of flammable organics or had been filled with sufficiently radioactive isotopes to heat the contents to dangerous temperatures. By March DOE and Westinghouse had identified 27 tank safety issues including the initial four. Several more tanks were added later in 1991 and intermittently until the last one was added to the Watch List in May 1994. (OrDE 2009, pg 19)

In September 1991 Hanford’s updated 5 year plan was released. It listed the threat of fire or explosion in an underground tank as its top concern and made resolution of all tank safety issues the top DOE priority at Hanford. DOE and its contractors were trying to solve a problem never before faced by mankind, with variable funding from Congress and with regulators who demanded and expected a firm schedule and with contracting procedures that had been developed for industrial production more than for research and development. The legal requirements for radiation control and for fire protection dominated all other considerations. (OrDE 2009, pg 19)

1992 (OrDE 2009, pg 21-26):

In 1992, the U.S. Department of Energy (DOE) released a report detailing 127 significant accidents at Hanford that occurred over the previous four decades, many of which had previously been made public. They included fires, explosions, fuel melting, safety system failures, and various incidents that exposed workers to radiation and dangerous chemicals. Fourteen of the 127 accidents were considered Category 1, the most serious. These involved serious injury, radiation release or exposure above limits, substantial damage or more than \$1 million in damage. Four of the Category 1 accidents involved reactor operations, seven were related to chemical processing, and three to laboratory or experimental operations. Chronic or repetitive radioactive material releases were generally not included in the report. (OrDE 2009, pg 21)

Also in 1992, a survey by the Hanford Reach newspaper showed many workers were still afraid to raise safety concerns. About 20 percent of the respondents said they did not believe they could raise safety concerns without suffering some retaliation. (OrDE 2009, pg 21)

In 1992, DOE released an RFP for an environmental restoration contractor despite strong opposition from local governments, labor unions, and the local congressional delegation. Westinghouse announced five new projects for accelerated cleanup, projects that would bypass studies otherwise required by law and regulations. (OrDE 2009, pg 22)

A 7,000 gallon leak from tank T-101 when unreported for four months in 1992 because tank farm workers did not trust a malfunctioning leak detection device, and T-101 was listed as the 67th leaking Hanford tank. The Hanford Future Site Uses Working Group held its first meeting in April 1992. The working group had 28 parties and agreed not to seek consensus on a single vision, but to suggest several potential uses for each of six geographic areas. It did agree on common set of values to guide cleanup. Its report was released in Dec 1992 with nine major

cleanup recommendations, including: protect the Columbia River, cause no additional harm through cleanup or development, restrict access to the 200 Area for at least 100 years after cleanup is complete, and prioritize clean up in those areas with high value future uses. (OrDE 2009, pg 23)

1992: It was clear that tank farms were in poor condition and were continuing to deteriorate. In July a DOE review report supported that observation and concluded that workers did not have equipment readily available to quickly respond to a tank leak. Ecology officials announced that monitoring systems for tank SY-101 were either non-functional or not reliable. September saw the largest venting event in that tank's history with waste levels dropping 10 inches in 10 minutes, while severely bending a pipe holding temperature sensors in the tank. Those were successfully replaced in October. (OrDE 2009, pg 25)

In October 1992, President Bush signed into law the Federal Facilities Compliance Act which had the effect of subjecting DOE and its contractors to nearly the same enforcement sanctions under federal and state hazardous waste laws as any other private party or non-federal government entity. DOE could no longer claim sovereign immunity from Washington state regulatory requirements. (OrDE 2009, pg 25)

1993 (OrDE 2009, pg 27-34):

DOE negotiated and new Tri-Party-Agreement in 1993 with an indefinite delay in the startup of the vitrification plant with inputs from a new community group, The Hanford Tank Waste Task Force. A 64 foot tall, 19,000 pound circulation pump was installed in tank SY-101 to continually stir the contents and even out the former "burps" of hydrogen release. In April 1993 a uranium-based waste storage tank exploded and burned in Russia. DOE officials said the tank contents at Hanford were plutonium based, and a similar fire was unlikely. (OrDE 2009, pg 32)

The Defense Nuclear Facilities Safety Board, "has repeatedly expressed its dismay at the continued slow rate of conduct of this (tank waste) characterization program and has urged a greater rate of progress. At last count, only 22 of the tanks on the site have been sampled. Only four of those sampled were among the 54 tanks on the Watch List of tanks that generate the greatest safety concerns." (Recommendation 93-5. July 19, 1993). (OrDE 2009, pg 33)

In December 1993, President Clinton's Energy Secretary O'Leary revealed that during the Cold War the government conducted more than 800 radiation tests on 600 people. O'Leary said she was "appalled, shocked and deeply saddened" to learn 18 people were injected with plutonium without their knowledge. O'Leary also said the U.S. Government conducted 204 unannounced underground nuclear tests between 1963 and 1990, several of which resulted in radioactive material released to the environment. O'Leary also released information on the nation's plutonium stockpile. Hanford had over 12 tons of plutonium on site — most of it reactor-grade fuel, but also about 441 pounds of weapons-grade plutonium. Hanford produced about 60 percent of the nation's plutonium. (OrDE 2009, pg 34)

1994 (OrDE 2009, pg 35-40):

Bechtel took over environmental restoration duties from Westinghouse in July 1994. The Hanford Advisory Board was formed to give all stakeholders a seat at the table and oversee the priorities and choices made during the most challenging remediation in human history HAB members spent much of the first meeting discussing how they would function and what issues they should tackle. The HAB was formed based on stakeholders' and the U.S. Department of Energy's (DOE) experience with two previous advisory groups — the Tank Waste Task Force and the Future Site Uses Working Group. HAB membership was broadly representative of the diverse interests affected by Hanford cleanup issues. Members included Native American tribes, local governments, the State of Oregon, workers, environmental groups, public health, local business, and other public interest groups. The HAB met under authority of the Federal Advisory Committee Act. Its primary mission was to provide informed recommendations and advice to DOE, the U.S. Environmental Protection Agency (EPA) and

Washington Department of Ecology on major policy issues related to the cleanup of Hanford. Near the end of the HAB's first year 1994, Sid Morrison (former Congressman for southeastern Washington) was quoted in the 14 November 1994 Spokesman Review, "We inherited a mindset that said, 'Folks, whatever this costs, it's in the national interest and we do it.' You do it behind closed doors and you just do it. That mindset carried over into the earlier days of cleanup." (OrDE 2009, pg 35)

In March 1994, a report entitled "Train Wreck along the River of Money, an Evaluation of the Hanford Cleanup" was delivered to the Committee on Energy and Natural Resources. The report explained that the Tri-Party Agreement hindered cleanup. "Many of the schedules in the TPA are unworkable, disjunctive, lack scientific and technical merit, undermine any sense of accountability for taxpayer dollars, and most importantly, are having an overall negative effect on worker and public health and safety." The report also observed that "Hanford is floundering in a legal and regulatory morass." (OrDE 2009, pg 41)

1995 (OrDE 2009, pg 41-48):

One of the major issues in the Hanford Cleanup has been the dramatic contrast between the reality of the technical challenges of cleaning up and the demands made through political, public and regulatory oversight. Events in 1995 made this tension clear.

In Dec 1994, there were 17,312 employees on the Hanford Nuclear Reservation, and in Jan 1995 the DOE proposed a budget that would require cutting 5,200 of those. By Dec 1995, the Hanford workforce stood at 13,200, and most were devoted to production of nuclear materials. (OrDE 2009, pg 41)

In 1995, DOE issued its final report showing that nearly 16,000 men, women and children were subjected to radiation during the Cold War. (OrDE 2009, pg 48)

DOE Secretary O'Leary announced an initiative to reduce cleanup cost to taxpayers via privatization of tank waste treatment and reduction in force of 27% of DOE staff. Westinghouse issued a request for proposals for a firm fixed price contract to build and operate a tank waste vitrification facility with payments tied to amount of waste successfully treated, not to the cost of construction. In May 1995 a consultant wrote to DOE that there was no need to construct six new double wall tanks that had been planned for several years. DOE studied whether to add 22 tanks to the Tank Watch List due to concerns about flammable gases, and ordered workers to follow work procedures for Watch List tanks until a decision was made. (OrDE 2009, pg 45-6)

On the bright side, by June 1995, DOE and its contractors were ahead of schedule when they met a major Tri-Party Agreement milestone related to stopping liquid waste discharges into the ground. The 33 worst liquid waste streams at Hanford had all been stopped, treated, or re-routed away from hazardous waste disposal sites by the operational debut of Treated Effluent Disposal facilities in areas 200 and 300. Then, in August more than 430,000 gallons of high-level radioactive waste was moved from a double-shell tank in the 200 West Area to a double-shell tank in the 200 East Area. It was the first time waste had moved through the transfer line in six years. This freed up much needed double-shell tank space in the 200 West Area to allow pumping of liquids from older, single-shell tanks. (OrDE 2009, pg 43)

1996 (OrDE 2009, pg 49-54):

In 1996, DOE Assistant Secretary Al Alm announced his plans to accelerate cleanup to less than 10 years, by 2006, at many of the nuclear weapon sites. He explained that some projects would be accelerated at the largest sites, including Hanford. Hanford lost \$10.1 million of funding that prioritized for accelerated cleanup of smaller sites like Rocky Flats and Fernald. (OrDE 2009, pg 49)

The 1996 aerial survey of radiation sources at the Hanford site was conducted to identify plumes that may have moved since a similar survey in 1987. Bore holes found cesium and cobalt 60 from Hanford tanks much deeper

and much closer to ground water than had previously been believed. The survey also found chromium and technetium 99 in the groundwater. (OrDE 2009, pg 49-50)

DOE announced that in 1996, the TY tank farm was the first to be “Controlled, Clean and Stable.” It was home to six single shell tanks, five of which were presumed to be leakers. The evaporator boiled off another million gallons of liquid, bring the evaporated total to eight million gallons and reducing tank contents to 54 million gallons. Construction began on a new cross-site waste transfer line to replace a barely functional 40-year old system. The new system was to be complete in August 1997 and to move waste by February 1998. Fluor-Daniel Hanford Co. was awarded a five year, 4.88 billion contract in August, replacing Westinghouse who had had been the primary site contractor since 1987. During the transition, 600 site contractors chose early retirement and layoffs of another 750 were announced. (OrDE 2009, pg 50)

In February 1996, a National Academy of Sciences study suggested studying tanks to see if they could be the permanent waste storage facilities if barriers were installed around them to protect the environment. In May Michael Grainey stated Oregon’s strong support for the vitrification alternative, “For these alternatives (that leave waste in the tank), the risk analyses in the EIT show massive plumes of radioactive materials slowly moving across the Hanford Site and into the Columbia River for hundreds to thousands of years.” (OrDE 2009, pg 52)

By September 1996 all of the ferrocyanide tanks were removed from the Watch List and the decision was made to not add 25 other tanks after DOE scientists concluded that their sludges did not generate enough flammable gases to require extra safety measures. (OrDE 2009, pg 53)

Meanwhile, the high-level waste vitrification plant at Savannah River began operations in 1996 (several years behind schedule) with operating problems that would persist for some time. In December DOE announced that Hanford would be the site to convert some plutonium to reactor fuel and to vitrify the rest. (OrDE 2009, pg 54)

1997 (OrDE 2009, pg 55-60):

Fluor’s first year was difficult. In April 1997, regulators complained that communications had gotten worse since Fluor took over. DOE and Fluor reviews found spending 3% over budget and 28% of cleanup milestones were late or incomplete. Hank Hatch, Fluor Daniel president, expressed surprise that the Hanford Advisory Board talked and acted more like an oversight body than an advisory body. Todd Martin of the Hanford Education Action League opined that Fluor did not “realize the magnitude of scale going up from Fernald to Hanford”. Hanford was identified as the destination for six metric tons of plutonium from Rocky Flats as part of that accelerated cleanup. (OrDE 2009, pg 59)

In 1997, DOE released a record of decision favoring privatization as the process for treating Hanford’s tank waste. However, federal anti-deficiency act forbids an agency from promising to spend money which had not been authorized by Congress. (OrDE 2009, 59)

1998 (OrDE 2009, pg 61-70):

By May 1998, 119 SST had been pumped, leaving 29 of the most difficult tanks still holding free liquids. (OrDE 2009, pg 61)

In August 1998, a Los Alamos study increased the estimates of leaks from four tanks in the SX tank farm. The revised leak estimate was 200,000 to 400,000 gallons of waste, about six times more than previous estimates. The report also estimated an additional one million curies of cesium from the four tanks entered the vadose zone. Previous estimates were that all leaked tanks had accounted for about one million curies of cesium. (OrDE 2009, pg 62)

Hanford Site Manager John Wagoner announced in 1998 that leaked tank waste from B, BX, and BY tank farms in 200 East Area had reached groundwater. At this point, at least 8 of 18 tank farms had reached ground water, and that water would reach the Columbia River within 20 years. (OrDE 2009, pg 62)

Fluor's second year, 1998, was also difficult. DOE proposed a \$140,625 fine for Fluor Daniel in March, the largest fine ever levied against a Hanford contractor. Most of the fine was for poor handling of plutonium within the Plutonium Finishing Plant. The remainder of the fine covered emergency response problems during the May 1997 explosion in a chemical tank. (OrDE 2009, pg 65)

It was in 1998 that the Defense Nuclear Facilities Safety Board accused DOE of dragging its feet in cleaning up some of the most contaminated facilities at Hanford and other defense production sites. DOE officials reluctantly admitted part of the problem was a lack of funding. Washington Governor Gary Locke threatened legal action against DOE for missing Tri-Party Agreement milestones, including: failure to begin pumping liquid from some SSTs and delay in awarding a contract to build the promised high-level waste vitrification plant. (OrDE 2009, pg 61)

In 1998 a team of 30 federal and state inspectors began a "multi-media" investigation at Hanford to check for compliance with federal and state environmental laws. The investigation — by EPA and the Washington Departments of Ecology and Health — was the first to be conducted at Hanford. (OrDE 2009, pg 65)

A 1998 DOE review of tank farm operations showed problems with morale, trust and communications. The review focused on DOE management issues and found staff members believed protesting safety concerns to upper management would hurt their career. (OrDE 2009, pg 62)

DOE released its "Accelerating Cleanup: Paths to Closure" plan for Hanford in July 1998. The plan estimated Hanford's cleanup costs through 2046 at \$50.8 billion in 1998 dollars or \$85.3 billion after factoring in inflation. (OrDE 2009, pg 65)

DOE declared an "Unreviewed Safety Question" in March 1998 for tank SY-101 because of rising waste levels inside the tank. The tank contained 1.12 million gallons of waste and the level in the tank had risen nearly five inches during the past year. By December, the level in the tank had risen several more inches. (OrDE 2009, pg 69)

In 1998, DOE began waste removal tests at tank C-106 but suspended work after about two hours because of higher than expected exhaust emissions. Eleven workers were examined after potential exposure to the emissions. (OrDE 2009, pg 69)

DOE removed 18 tanks from the organic complexants Watch List in December 1998 (eight of these were also on the hydrogen Watch List) and closed the organic complexants safety issue. This left 28 tanks on the Watch List. A decade-long, \$48 million project to improve ventilation in four tanks was completed in 1998. (OrDE 2009, pg 69)

1999 (OrDE 2009, pg 71-78):

Researchers from the Fred Hutchinson Cancer Research Center and the Centers for Disease Control and Prevention released draft results from the Hanford Thyroid Disease Study. The study found no evidence that any kind of thyroid disease was increased as a result of exposure to radioactive iodine released into the air from Hanford from 1944 to 1957. CDC officials said the 1999 study results did not prove that a link did not exist and a National Research Council Review of the study found it was basically sound but that the conclusiveness of the findings was overstated. (OrDE 2009, pg 75, 99)

High concentrations of technetium were found in a 200 West Area aquifer during 1999. The readings came from a well about 220 feet deep and less than 20 feet from tank SX-115, a single-shell tank built in the mid-1950s and found to be leaking in 1965. The level of technetium 99 found in the well was about 38 times the federal drinking water standards. A Washington Department of Ecology engineer said the worst-case DOE announced in April that

low-activity vitrified waste produced during the first stage of the tank waste treatment program would be disposed in four empty grout vaults in Hanford's 200 East Area. The vaults were constructed in 1990 and 1991 for disposal of low-activity waste mixed with grout. The grout program had since been discontinued. Additional low-activity waste would be disposed either in new vaults or new waste trenches. (OrDE 2009, pg 75)

CH2M Hill announced in 1999 that it was buying Lockheed Martin Hanford Corporation. Lockheed Martin's 1,158 employees were in charge of maintaining Hanford's tanks plus conducting work to prepare the waste for treatment by BNFL. No major changes were immediately planned for Lockheed's operations scenario that would have the technetium reach the Columbia River within 20 years. (OrDE 2009, pg 76)

Risks were reduced in two troublesome Hanford tanks, C-106 and SY-101. Water had been added to C-106 to cool the waste so it did not damage the tank structure. By October most liquids and sludges had been pumped to AY-102 where the waste was successfully cooled by an air ventilation system. In December 1999 C-106 was removed from the Watch List. The burping in Tank SY-101 had been controlled with a mixer pump installed in 1993, but the resulting tiny gas bubbles had begun to rise in December 1997 and by May 1999 had grown by 30 inches to nearly 90 inches thick. Some hydrogen gas was released by using a mechanical arm to open holes in the crust. In Dec 1999, 90,000 gallons of waste was removed from SY-101 and replaced with water to dilute its 1.1 million gallons of waste. (OrDE 2009, pg 77)

DOE and Washington State Ecology reached a settlement concerning leak detection for the 28 double shell tanks in 1999. DOE agreed to install three leak detector probes between the walls of each tank and at least one surface level monitor in each tank. (OrDE 2009, pg 77)

Ultrasonic testing showed signs of corrosion in tank AN-105 with 0.1 inch pits in the 0.5 inch thick wall. AN-105 held 1.16 million gallons of waste. (OrDE 2009, pg 77)

The GAO said DOE's organization was too complicated to effectively manage all its programs, including environmental cleanup. The report said changes were needed to clear up a complex and jumbled chain of command and some of DOE's missions should be shifted to other agencies. The report said that of DOE's 80 biggest projects from 1980 through 1996, 31 were terminated before completion at a cost of \$10 billion. (OrDE 2009, pg 78)

2000 (OrDE 2009, pg 79-88):

Ecology notified DOE-ORP in 2000 that it was not satisfied with the pace of the single-shell tank waste retrieval program. Ecology said the program was under-funded and DOE had not pursued retrieval technology development with sufficient vigor. (OrDE 2009, pg)

To resolve flammable gas and crust growth, Hanford workers completed the final waste transfer from tank SY-101 in March 2000. About 286,000 gallons of waste was pumped from the tank in the transfer and more than half a million gallons overall. Hanford workers also completed pumping of liquids from tanks T-104 and T-110. All liquid waste in the 40 tanks in the T, TY and TX tank farms in the northern 200 West Area had been pumped. Half of the pumped tanks were suspected leakers. (OrDE 2009, pg 86-7)

2000: Two Hanford workers were slightly contaminated after tank waste leaked during the pumping of tank S-103 in the 200 West Area. About five gallons of highly radioactive tank waste came up through an electrical conduit and spilled onto the ground. (OrDE 2009, pg 81)

DOE notified the Washington Department of Ecology and the Environmental Protection Agency (EPA) in June 2000 that it was in substantial danger of failing to meet 21 Tri-Party Agreement milestones. Many of the milestones were not due for several years. (OrDE 2009, pg 82)

A huge range fire burned 192,000 acres on and near the Hanford Site during 2000. The fire scorched one crib and two dried up waste ponds, threatened nuclear facilities in the 200 West Area, and also threatened FFTF and the HAMMER training facility. About 45 percent of the Hanford Site burned, including nearly all of the Arid Lands Ecology Reserve. Initial surveys found no radioactive contamination spread from the fire, but within a few weeks, air samples taken in Richland and Pasco detected plutonium 100 to 1,000 times higher than normal background, but still well below state and federal safety standards. EPA officials said the readings were similar to those when nuclear weapons tests were routinely conducted in the atmosphere and posed no risk to human health. (OrDE 2009, pg 82)

In 2000 Fluor Hanford's contract to manage a major part of Hanford cleanup was extended for six years and \$3.8 billion. The contract included incentives for Fluor to earn up to \$168 million in profits. Fluor had been the primary contractor at Hanford since October 1996. (OrDE 2009, pg 83)

Enforcement action by the State of Washington to set a schedule to construct and operate Hanford's tank waste treatment facilities was ultimately overcome during 2000 by the collapse of DOE's privatization efforts. (OrDE 2009, pg 84)

BNFL proposed a price of \$15.2 billion with 100% private financing for the \$6 billion of construction to start vitrifying Hanford's high level waste. Energy Secretary Richardson immediately said the price was unacceptably high and not fundable and that DOE would not approve BNFL's proposal. In May, after further evaluation by DOE on available options, Secretary Richardson announced he would terminate the BNFL privatization contract. DOE would seek new bidders and award a new contract by the end of the year to complete the design work and construct the facilities. (OrDE 2009, pg 85)

In December 2000, DOE awarded a ten year, \$4 billion contract to the consortium of Bechtel National and Washington Group International. The contract called for facilities to be constructed and tested by 2007 with full operations by 2011. (OrDE 2009, pg 85)

DOE removed two Hanford tanks from the Wyden Watch List. Tanks C-102 and C-103 were placed on the Watch List in 1990 because of concerns that a floating layer of organic material similar to kerosene could ignite and release radioactivity into the environment. Subsequent sampling and analysis determined that this was extremely unlikely. Twenty five tanks remained on the Watch List. (OrDE 2009, pg 85)

After decades of denials, the federal government conceded that workers in America's nuclear weapons production facilities were exposed to radiation and chemicals that caused cancer and early death. A report prepared by DOE and the White House concluded radiation exposure led to higher-than-normal rates of a wide range of cancers among workers at 14 nuclear weapons plants, including Hanford. President Clinton signed legislation in October to provide the first widespread compensation to nuclear workers harmed by exposure to radiation and hazardous chemicals. (OrDE 2009, pg 88)

"The government is done fighting workers, and now we're going to help them. We're reversing the decades-old practice of opposing worker claims and moving forward to do the right thing."
(Energy Secretary Bill Richardson in the New York Times, April 12, 2000).

"We haven't made thousands and thousands of people sick. But there are hundreds, and we are opening the door wider to make sure we get everyone." (David Michaels, DOE Assistant Secretary for Environment, Safety and Health in the Tri-City Herald, April 13, 2000).

In September 2000 the United States and Russia signed an agreement committing each country to dispose of 34 metric tons of surplus plutonium. (OrDE 2009, pg 105)

2001 (OrDE 2009, pg 89-96):

The Energy Employees Occupational Illness Compensation Program Act took effect in 2001, providing money to nuclear workers who may have had gotten cancer or other diseases as a result of on-the-job exposure to radiation or hazardous chemicals. (OrDE 2009, pg 96)

Washington Group International — a subcontractor for Hanford's tank waste treatment facilities — filed for Chapter 11 bankruptcy in 2001. Washington Group was the primary subcontractor for Bechtel National, which was responsible for the design, construction, and initial operation of Hanford's tank waste vitrification facilities. Ecology officials rejected DOE's request to delay milestones for construction and operation of these facilities. It promised enforcing the Tri-Party Agreement fines of \$5k for the first week and \$10k for each subsequent week of delay. DOE-ORP began work on a recovery plan to promise vitrification operations by 2007. Congress promised to extend the Office of River Protection as a separate entity to 2010. (OrDE 2009, pg 92)

Once the top safety problem in all of DOE because of hydrogen gas, Tank SY-101 was removed from the Wyden Watch List in February 2001 and returned to service in September available to take waste from other tanks. In August, DOE removed the final 24 tanks from the Wyden Watch List, nearly eleven years after its creation and ahead of the Tri-Party Agreement milestone of 30 September 2001. In total, 60 of Hanford's 177 tanks had been on that list. Oregon Senator Ron Wyden was quoted, "A decade ago, I responded to the dangerous threat posed by certain nuclear waste storage tanks at Hanford by passing a law to protect the people of the Northwest from possible radioactive tank explosions. Today, I'm proud to see the Watch List become extinct." (DOE-ORP News Release, August 17, 2001)

A General Accounting Office report recommended DOE look at restructuring itself and shift some missions to other agencies or farm out more responsibilities to private companies. The report said DOE had trouble handling its unrelated missions and that its managerial shortcomings resulted in cost overruns and delays. (OrDE 2009, pg 96)

2002 (OrDE 2009, pg 97-106):

In 2002, Bechtel National estimated that construction and operation of the Hanford tank waste vitrification facilities could occur sooner than existing schedules but at a higher cost. Bechtel estimated that construction and testing could be complete a year early, 2010. The company estimated that vitrifying ten per cent of Hanford's tank waste could be completed almost five years early, by 2013. Overall cost estimates rose from \$3.965 billion to \$4.447 billion. Structural concrete was poured as part of the 5-foot thick, steel-reinforced foundations and basement walls for one of two waste processing buildings. The project would require 58,000 tons of steel, 160 miles of piping and 1,260 miles of electrical cable. Two cement processing plants had been installed to produce the concrete that would be needed over the next five years. (OrDE 2009, pg 104)

From a 22 February 2002 letter written by Oregon Office of Energy Acting Director Michael Grainey to Energy Assistant Secretary Jesse Roberson, "We do have concerns about the wisdom of trying to run the Environmental Management cleanup program like a business. We agree that DOE must be efficient in its spending. But, a commercial model is not appropriate for an environmental cleanup. The primary motivation for a commercial enterprise is profit... The primary motivation for cleaning up toxic and radioactive waste should be worker, public and environmental safety and a vision of restoring and healing a damaged land." (OrDE 2009, pg 106)

About 150,000 gallons of high-level waste was pumped into tank SY-101 in November 2002 — the first time that waste had been transferred to that tank in many years. In December, Hanford workers began pumping liquid waste from tank C-103, the last of Hanford's single-shell tanks which had not had liquids previously pumped. (OrDE 2009, pg 103)

In 2002, DOE announced its plans to move forward with the disposal of 34 metric tons of surplus weapons grade plutonium by turning it into mixed oxide (MOX) fuel for use in nuclear reactors. The MOX conversion process was expected to cost \$3.8 billion over 20 years, including the construction of two new conversion facilities at DOE's Savannah River Site in South Carolina. (OrDE 2009, pg 105)

In December 2002, President Bush signed into law a provision that would award South Carolina up to \$100 million a year if the federal government failed to remove surplus weapons-grade plutonium from the state on schedule. If the MOX program did not meet schedules or was not successfully operating, DOE must remove all the plutonium from Savannah River or pay the fines. (OrDE 2009, pg 105)

A General Accounting Office (GAO) report published in 2002 said despite massive changes in DOE's contracting, it did not appear that its contractors were accomplishing nuclear waste cleanup any better than under the old contracts. DOE had moved from mostly cost-reimbursement contracts to performance based contracts. However, the GAO found that DOE's focus was on changing its contract process, rather than improving cleanup results. (OrDE 2009, pg 106)

2003 (OrDE 2009, pg 107-116):

2003: The Government Accountability Project (GAP) said Hanford's tank farm workers were repeatedly being exposed to hazardous chemical fumes. The GAP report said workers' protective breathing equipment and equipment to monitor vapor releases was inadequate to protect workers from chemicals leaking from Hanford's waste storage tanks. GAP said from January 2002 to August 2003, 67 tank farm workers required medical attention for problems including headaches, skin irritation and breathing difficulties, a sharp increase from 15 years ago. DOE and CH2M Hill officials declined to comment on the specifics of the report but said numbers had increased because of more stringent reporting requirements. Tom Carpenter, Government Accountability Project attorney remarked, "Hanford tank workers are like canaries in a coal mine." (Tri-City Herald, September 16, 2003)

DOE announced in January 2003 that construction of Hanford's high-level waste vitrification facilities would be delayed by up to 10 months because of poor engineering and the planned 2007 hot-start might need to be delayed. As a result, DOE withheld \$3 million in payments to Bechtel National, the lead design and construction contractor. (OrDE 2009, pg 113)

A 2003 General Accounting Office report said DOE faced significant legal and technical challenges to successfully reduce the costs and time required for cleanup of its high-level wastes, including the 53 million gallons of waste stored in Hanford's underground tanks. Litigation arose between Washington state Ecology and DOE after DOE announced savings planned by leaving Tc-99 in the low level waste stream for burial, rather than pre-treating it before putting it into the high level waste stream for vitrification. At the same time, New Mexico opposed DOE's plans to send some tank waste DOE said was transuranic to the Waste Isolation Pilot Plant (WIPP). Hanford officials said about one million gallons of waste in eight tanks was transuranic waste, even though it had been managed for many years as high-level waste. (OrDE 2009, pg 115)

Worker safety issues — especially related to vapors from Hanford's underground waste storage tanks — were the focus of considerable attention in 2003. A September 2003 report issued by the Government Accountability Project (GAP) prompted an investigation by Washington Attorney General Christine Gregoire and other state agency representatives. Officials for CH2M Hill, which maintained the tank farms for DOE, said they had taken a number of steps to reduce the hazards since the GAP report was released. (OrDE 2009, pg 121)

For the 14 years, since Rocky Flats was shut down (1989 to 2003), the United States has been the only nuclear power who could not make a pit. Los Alamos National Laboratory began limited production of pits and other components for the existing stockpile of nuclear weapons. (OrDE 2009, pg 115)

2004 (OrDE 2009, pg 117-130):

In 2004, there were two significant rulings on the Hanford down-winder litigation. A federal judge ruled that former Hanford contractors would not necessarily be able to avoid liability for possibly exposing downwinders to radioactive emissions. U.S. District Judge William Nielsen ruled that the five companies could not simply claim they were following government orders when they operated Hanford. Judge Nielsen later ruled that making plutonium at Hanford in the mid-1940s was an “abnormally dangerous” activity which put thousands of Eastern Washington residents at risk. The ruling meant that downwinders would not have to prove that Hanford contractors acted recklessly to cause airborne releases of radio-active materials. The ruling affected a scheduled trial of 11 “bellwether” cases that could possibly determine an outcome for thousands of others who sued, alleging harm from radio-active material released from Hanford. The lawsuits were initially filed in 1990. (OrDE 2009, pg 177)

In March 2004, CH2M Hill revised work procedures for tank farm work by requiring self-contained breathing tanks for all workers. A Washington State study suggested existing monitoring done for worker protection might be inadequate because much was still not known about the vapors, and identified isolated problems with worker compensation claims. DOE’s inspector general said Hanford contractors were underreporting the number of injuries and illnesses. A report by the federal Office of Independent Oversight and Assessment found that not enough was known about the chemicals in Hanford’s underground tanks to conclude that tank farm workers had not been exposed to harmful vapors. (OrDE 2009, pg 122-23)

In June 2004, DOE awarded a \$61 million contract to AMEC Earth and Environmental Inc., of London to build and operate a pilot facility to conduct full-scale tests of bulk vitrification using Hanford tank waste. Ecology approved a permit to allow DOE to treat up to 300,000 gallons of waste from tank S-109 as a demonstration of the bulk vitrification technology. By the end of summer, costs to demonstrate the viability of bulk vitrification rose to about \$102 million. (OrDE 2009, pg 128)

DOE challenged an independent study which said there was a 50 percent chance of a major radiation or chemical accident during the 28 years that Hanford’s WTP facilities would be operating. The 2004 study, by the Institute for Policy Studies, was published in a Princeton University peer review journal. According to the study, the worst hazard was from a steam explosion at one of the melters. The study cited a three year old Nuclear Regulatory Commission (NRC) study. But DOE officials said design changes made since the NRC study was conducted had dramatically reduced the risk of an accident and eliminated any possibility of a steam explosion. (OrDE 2009, pg 129)

In December 2004, construction on Hanford’s WTP facilities was slowed to ensure the design was adequate to withstand seismic forces. Studies had indicated that sound waves caused by an earthquake could move much faster in Hanford’s soils than was previously believed. Engineers were trying to determine if that would require the design standard to be raised. (OrDE 2009, pg 129)

2005 (OrDE 2009, pg 131-140):

A health study of Hanford workers indicated that older workers exposed to low levels of radiation may have had an increased chance of dying from cancer. The increase was not evident in workers under the age of 55 who were exposed to similar amounts of radiation. The study found that cancer death rates for workers 55 or older increased an average of three per cent for each additional rem of radiation they received. Incidences of lung cancer increased at a greater rate. The study included more than 26,000 Hanford workers hired between 1944 and 1978. Study authors speculated that older workers might be more sensitive to radiation because age brought declines in immune function and the ability to repair genetic damage. One of the authors was quoted, “We think it raises some interesting questions...Because the predictions from the (atomic bomb studies) said we shouldn’t find anything, the finding is important and a reason for concern.” (Steven Wing, associate professor of epidemiology

at the University of North Carolina at Chapel Hill and a study co-author, on a health study of Hanford workers. (Tri-City Herald, June 21, 2005))

The National Academy of Sciences released two reports dealing with waste clean-up at DOE sites in 2004. One report recommended that some transuranic and high-level wastes could be left at Hanford and other DOE sites rather than sent to deep underground geologic repositories. The report recommended a six-step decision-making process based on risk and other factors before a decision was made to exempt waste from deep geologic disposal. (OrDE 2009, pg 133)

Hanford workers made progress in retrieving waste from several underground storage tanks. In March 2005, Hanford workers completed work to empty their second tank. They demonstrated a vacuum system to remove about 3,000 gallons of sludge from tank C-203, a 55,000 gallon tank. Less than 100 gallons of waste remained in the bottom of the tank and stuck to its walls, well within the amount allowed by the Tri-Party Agreement. (OrDE 2009, pg 134)

The original production mission of the Hanford Nuclear Reservation ended when workers drilled through the core of Hanford's Fast Flux Test Facility in May 2005 to remove the last of the liquid sodium from the reactor. (OrDE 2009, pg 136)

By August 2005, work was complete in emptying a third Hanford tank. Workers again used a vacuum hose to suck sludge and salt cake out of tank C-202, which was a suspected leaker. A high-pressure spray of water was also used to break up clumps of waste that could not be vacuumed. The process took about six weeks, far quicker than the nine months it took to empty the previous tank. About 20 cubic feet of waste was still in the tank — under the limit allowed by the Tri-Party Agreement. (OrDE 2009, pg 134)

In November 2005, workers began to remove 71,000 gallons of sludge from tank C-103, the seventh Hanford tank to undergo waste retrieval efforts. Since the tank was not believed to have leaked, workers used a hydraulic spray to dissolve the sludge so it could be pumped from the tank. Rather than adding new water to the tank system, Hanford workers used liquid waste from the double-shell tanks in the hydraulic spray. (OrDE 2009, pg 135)

In July 2005, the GAO said DOE's goal of saving \$50 billion by accelerated clean up at DOE sites was likely not attainable. DOE announced the plan in 2002 — hoping to shorten clean up by 35 years. While the GAO had found progress and some clean-up programs were ahead of schedule, plans to treat and dispose of high-level waste stored in tanks at Hanford and other sites had fallen behind schedule. These projects were among the most expensive and where DOE announced the biggest potential cost reductions. The GAO also questioned whether it was realistic to expect almost 30 percent less costs because of new technology development. Continued delays in opening a national high-level waste repository at Yucca Mountain also resulted in significant extra costs at Hanford and other sites. (OrDE 2009, pg 139)

After more than a decade since litigation was initially filed against companies that built and operated Hanford in its early years, the first verdict in Hanford "down winder" litigation was split. Two people who claimed radiation releases in the 1940s from Hanford caused their thyroid cancer won their cases in federal court; but a jury ruled against three others and hung on a sixth case. (OrDE 2009, pg 135)

2006 (OrDE 2009, pg 141-152):

Due to discovery that shock waves move more quickly in Hanford soil than designers knew, the WTP facilities needed to be strengthened by about 30%. Construction was halted until redesign was at least 90% complete. During the summer of 2006, drilling was started on four new bore holes to be used to repeat studies from 2004 on seismic wave behavior at Hanford. By June 2006, the WTP cost estimate had risen to \$11.55 billion with completion delayed until August 2019. (OrDE 2009, pg 148)

An independent technical review identified 19 technical issues to resolve for the demonstration bulk vitrification tests to move forward. The demonstration tests were necessary to determine if the technology was viable to immobilize Hanford tank waste. The review also identified 26 areas of concern and offered 13 suggested improvements. A cost and schedule review of the project was also planned. (OrDE 2009, pg 150)

In September 2006, DOE released the Army Corps of Engineers validation report on Bechtel's estimated schedule and cost for completing Hanford's WTP. The Corps recommended adding \$650 million to Bechtel's estimated cost to account for potential fluctuations in labor rates and additional project contingency. That brought the total cost to complete and test the WTP to \$12.2 billion. The Corps added an additional three months to the schedule, pushing the completion date to November 2019. Both the cost and schedule estimates assumed consistent federal appropriations of \$690 million from fiscal year 2007 through completion of the project. More than \$3 billion had already been spent. (OrDE 2009, pg 150)

The National Academies' National Research Council recommended in 2006 that DOE should not be in a hurry to close underground high-level waste storage tanks. The Research Council report, directed by Congress in 2004, encouraged DOE to not close individual tanks where existing technology could not remove hard heels of waste remaining in the tank bottoms. The report questioned whether enough was known about long term stability of grout as a water intrusion barrier, and whether enough was known about vitrification and its long term stability. (OrDE 2009, pg 151)

In 2006 New Mexico granted DOE a permit to dispose of "remote-handled" transuranic waste at the Waste Isolation Pilot Plant (WIPP). Since WIPP opened in 1999, more than 5,000 shipments of "contact-handled" transuranic waste — which did not contain much penetrating radiation — had been disposed at the site. But, Hanford was not on the schedule to begin shipment of remote-handled waste in the near future. (OrDE 2009, pg 152)

2007 (OrDE 2009, pg 153-162):

Hanford workers completed waste retrieval from the seventh of Hanford's 149 underground single shell tanks in March 2. S-112 was a 758,000 gallon capacity tank and held 614,000 gallons of waste when retrieval work began in 2003. Waste retrieval operations continued at several other tanks. (OrDE 2009, pg 155)

Full construction resumed at Hanford's WTP complex in mid- September 2007. Thirty-five truckloads of concrete were poured at the high-level vitrification facility, which marked the first major structural construction completed on the facility since late 2005. Construction had been halted for about 20 months while DOE confirmed seismic standards for the facilities. Major structural construction on the Pretreatment Facility was expected to begin in January. Workers would continue to focus on completing the laboratory, the low-activity waste vitrification facility and support facilities by 2012. The number of workers would gradually increase to about 1,400 over the next year as the contractor, Bechtel National, resumed full-scale construction. (OrDE 2009, pg 160-61)

"Originally, DOE justified the bulk vitrification project as a relatively low-cost, rapidly deployable supplemental technology to assist the department to complete the tank waste treatment at Hanford by 2028. However, none of the key components to this justification remains today...It is now apparent that completing tank waste treatment at Hanford by 2028 is not possible under any reasonable scenario and that the waste treatment plant must operate far longer than DOE previously planned." – Government Accountability Office Report GAO-07-762, (June 2007).

In addition to the \$12.26 billion it would take to construct the treatment facilities, the estimated cost to treat Hanford's tank waste and close the 177 underground storage tanks increased by \$18 billion to \$44 billion. Contingency costs of as much as \$18 billion could raise the total cost to \$62 billion to do that. A study performed by CH2M Hill Hanford Group for DOE indicated the LAW facility could begin operating as early as June 2014, more than five years earlier than the rest of the WTP complex. Other advantages to the early start were freeing up tank space and providing early operational experience. Among the negatives, some type of interim pre-treatment

system would have to be built and the early start could hamper construction at the rest of the complex due to radiological control and security restrictions. DOE had not made a decision as to whether to pursue early LAW. Under the revised DOE schedule the work would be completed in 2042, well beyond the current 2028 Tri-Party Agreement milestone. Starting up Hanford's low-activity waste (LAW) vitrification facility five years before the entire WTP complex was operational could result in early treatment of more than seven million gallons of radioactive waste in Hanford's tanks. However, it would cost nearly \$1 billion to do that. A study performed by CH2M Hill Hanford Group for DOE indicated the LAW facility could begin operating as early as June 2014, more than five years earlier than the rest of the WTP complex. Other advantages to the early start were freeing up tank space and providing early operational experience. Among the negatives, some type of interim pre-treatment system would have to be built and the early start could hamper construction at the rest of the complex due to radiological control and security restrictions. DOE had not made a decision as to whether to pursue early LAW. (OrDE 2009, pg 161)

Jane Hedges, Manager of Ecology's Nuclear Waste Program, in announcing a \$500,000 fine following a July 2007 leak in Hanford's S tank farm noted that, "Before the spill was discovered, a series of poor decisions put workers in grave danger from exposure to the tank waste and vapors. This accident calls into question the adequacy of the safety culture which is so critical at the tank farms." (Washington Ecology News Release, December 4, 2007). (OrDE 2009, pg 162)

In 2007, the Ninth Circuit Court of Appeals overturned four of six jury verdicts from 2005 involving people who had claimed health impacts from past releases of radioactive materials during Hanford's operating years. The Court found procedural errors in three cases, where people with non-cancerous thyroid disease had all lost their verdicts. The Court ruled they deserved new trials. A fourth case, found in favor of a woman who developed thyroid cancer after growing up downwind of Hanford, was found to have exceeded the statute of limitations. (OrDE 2009, pg 158)

2008 (OrDE 2009, pg 163-6):

In 2008, DOE and the state reached agreement in principle on new cleanup deadlines which were substantially the same as made public in mid-2007. The start of operations at the WTP would be delayed eight years to 2019, with all waste treated by 2047 instead of the current deadline of 2028. The deadline for emptying Hanford's 149 single shell tanks would be extended from 2018 to 2040. Work to contain several of Hanford's groundwater plumes would be accelerated by as much as 8 to 12 years from current plans. DOE would also commit to developing technologies to clean waste deep in the soil and would be required to produce an annual report that estimated the total cost of remaining cleanup and a schedule for getting it done if Congressional funding was not restricted. (OrDE 2009, pg 156, 164)

The Ninth Circuit Court of Appeals ruled in 2008 that the statute of limitations had not expired for individuals suing for health impacts they contended were caused by radioactive material releases to the environment from Hanford during its operating years. The ruling also restored a \$317,000 judgment for an individual that had been overturned in 2007. The Court also ruled that past Hanford contractors were not entitled to blanket legal immunity just because they operated Hanford under contract to the federal government. An appeal to the U.S. Supreme Court was denied. (OrDE 2009, pg 167)

In 2007, Hanford workers had completed installation of a temporary "cap" over a portion of the T Tank farm, in an effort to stop rain and other water from soaking into the soil and moving contamination into the groundwater. The 70,000 square foot cap covered T-106, which was believed to have contaminated the vadose zone with about 115,000 gallons of waste — the largest leak among any of Hanford's tanks. Parts or all of nine other tanks were also covered by the cap. A synthetic fabric was placed over the soil then sprayed with a plastic which was somewhat similar to the liner in a pickup truck, but more chemically resistant and longer lasting. (OrDE 2009, pg 160)

In 2008, DOE selected new contractors to manage its tank farms and continue cleanup of Hanford's Central Plateau. Washington River Protection Solutions, LLC was selected as the tank operations contractor to store, retrieve and treat Hanford tank waste and close the tank farms. The contract was valued at \$7.1 billion over ten years (a five-year base period with options to extend for up to five years). The company replaced CH2M-Hill Hanford, a subsidiary of which was awarded the contract for cleanup in Hanford's Central Plateau. CH2M Hill Plateau Remediation Company received a contract valued at \$4.5 billion over ten years (a five-year base period with options to extend for up to five years). The company replaced Fluor Hanford. (OrDE 2009, pg 169)

In 2008, The Government Accountability Office (GAO) said DOE continued to be plagued by cost increases and project delays on its 10 largest projects — five of them at Hanford. The largest increases had occurred in Hanford's tank waste treatment program, which had caused additional delays and cost increases in the program to empty waste from Hanford's tanks. (OrDE 2009, pg 171)

Through December 2008, design of the WTP complex was 69 percent completed and construction was 41 percent completed. The Nuclear Regulatory Commission (NRC) concluded that DOE's regulatory processes for Hanford's WTP were adequate to ensure public health and safety. An NRC report identified several technical issues and offered suggestions for DOE in areas including transparency of its processes and radiation safety. (OrDE 2009, pg 171)

2009 (OrDE 2009, pg 172-178):

As Hanford had numerous shovel ready jobs, it received and obligated stimulus money that accelerated some of its soil disposal projects. By the end of March 2009, Hanford's share of the stimulus money was set — \$1.961 billion. DOE said the money should create and save about 4,400 jobs. DOE's Office of River Protection received \$326 million. DOE was required to obligate the stimulus money by the end of September and spend it all before September 2011. That money would be used to upgrade equipment and facilities, including the 222-S analytical laboratory, the effluent treatment facility and the evaporator. Work would also be done to upgrade the tank farms to ensure they were able to support operation of the Waste Treatment Plant (WTP) when it became operational around 2019. DOE would also conduct structural integrity analysis of its single-shell tanks. In addition, the omnibus spending bill gave Hanford about \$140 million more than the President's proposed budget and increased Hanford's budget for fiscal year 2009 to just under \$2 billion. (OrDE 2009, pg 173-4)

In 2009. Attorneys for former Hanford contractors said they were willing to offer cash settlements to some of the Hanford downwinders who blamed their health problems on past radioactive material releases from Hanford. The settlement offers would be made only to those downwinders who had received among the highest radiation doses. The offer came a few days after the judge overseeing the case admonished attorneys for not having yet reached some settlement. (OrDE 2009, pg 177)

Initial tests at DOE's Pre-treatment Engineering Platform — a quarter-scale mock-up of a portion of the WTP's pre-treatment facility — confirmed that the facility should operate as expected. Phase one testing of the facility began in late January and was completed in April of 2009. (OrDE 2009, pg 178)

In another of a string of changed directions was announced in 2009. President Obama and Energy Secretary Chu said that new alternatives for dealing with the nation's high-level nuclear waste would be evaluated and that the Yucca Mountain site would not be used as a waste repository. In his Senate Confirmation Hearing, Steven Chu said "The Department has legal and moral obligations to clean up wastes left over from 50 years of nuclear weapons production..." (OrDE 2009, pg 178)

In November 2009 the states of Oregon and Washington sued DOE for its inability to meet the Tri-Party-Agreement's promised 2011 start date for its waste treatment plant and numerous milestones for the retrieval of waste from the single shell tanks. The 9th Circuit Court of Appeals affirmed the state of Washington's authority over mixed hazardous and transuranic waste buried at Hanford. (OrDE 2009, pg 176)

2010 (OrDE 2014, pg 185-196):

Not all worker health risks have been identified by 2010. High levels of radioactivity were discovered beneath a hot cell in the 300 Area. The 324 Building contained five highly contaminated hot cells, which were built to allow Hanford personnel to work with radioactive materials without being exposed to radiation. During preparations to demolish the three story building, a visible breach was discovered in the stainless steel liner at the floor of the sump. Upon further exploration, an apparent localized high level of radioactive material was discovered beneath the hot cell. A large spill into the cell of concentrated cesium and strontium was referenced in a report as having occurred in 1993. Radioactivity was measured at 8,900 rads per hour, about 10 times the lethal dose on contact. (OrDE 2014, pg 193)

Health and safety issues were front and center around underground tank waste. After allegedly being fired for raising health and safety issues about the WTP that was under construction, Walter Tamosaitis wrote in a 16 July 2010 letter to the DNFSB, “There has been an immediate chilling effect on the Project safety culture that has already caused Project team members to question me whether they should raise safety and Project design concerns in the future.” Bechtel officials disagreed. When DOE turned its investigation over to the Department of Labor without resolution, Tamosaitis filed suit in Benton County Superior Court. (OrDE 2014, pg 193-4)

The competition between policy, litigation and technical reality continued. DOE announced closure of the 28 technical issues surrounding the WTP identified by an expert panel in 2006. The DNFSB found reason to doubt some of those, but agreed that WTP construction could proceed. Specifically, DNFSB doubted the veracity of the small scale test demonstrations and asked for full scale vitrification testing with simulated waste to settle possible issues with mixing, hydrogen generation and criticality during vitrification. The US District Court in Spokane issued a consent decree to settle a suit filed by Washington in 2008 and joined by Oregon in 2009. It set an enforceable schedule with new milestones: retrieve of all waste from the C Tank farm in 2014; start treatment of tank waste beginning in 2019 with full operations in 2022; complete retrieval of all single-shell tank waste no later than 2040; and complete all tank waste treatment no later than 2047. At the same time, and 21 years into Hanford site remediation, DOE announced a goal to develop “transformational technologies” to potentially complete the tank waste treatment missions at Hanford and Savannah River years earlier and for billions of dollars less than the current baselines indicated. The Washington Department of Ecology later reiterated in writing that “glass from vitrification of some kind is the only acceptable primary waste form” for Hanford tank waste. (OrDE 2014, pg 194-5)

The DOE plans for ultimate disposal of both low level and high level waste were completely undone in 2010. Carol Browner, White House Energy Advisor, confirmed President Obama’s decision to close the Waste Isolation Pilot Plant in NM, “We’re done with Yucca (Mountain). We need to be looking at other alternatives.” (Las Vegas Sun, January 29, 2010). And Washington Attorney General Rob McKenna disagreed in a Washington Attorney General News Release, March 3, 2010: “We vigorously oppose any efforts to remove this facility from consideration and are prepared to staunchly defend the interests of Washington in identifying a safe repository for the millions of gallons of hazardous waste our state currently houses.” Nevada Governor Jim Gibbons was quoted by the Associate Press on 14 Apr 2010: “Since the state of Washington is so enthusiastic about underground storage of spent nuclear fuel, perhaps their governor and their citizens will volunteer to have the nation’s nuclear waste dump located within their borders.” (OrDE 2014, pg 195-6) Political decisions and debates in 2010 were clearly impeding technical progress in stabilizing and disposing of Hanford’s tank waste.

In the midst of an uncertain direction for the technology program, DOE struggled a bit in 2010 as it planned for the abrupt end of the stimulus funding.

2011 (OrDE 2014, pg 197-208):

September 2011 marked the end of the Recovery Act funding. With nine months of Recovery Act funding available through September 30, considerable cleanup progress was made at Hanford before the funds ran out. As expected, the end of the program led to significant layoffs with estimated total of voluntary and involuntary layoffs approaching 2,000 workers. (OrDE 2014, pg 197, 201)

The progress made with that money is remarkable. Most projects were under budget and ahead of schedule. The waste footprint at Hanford had been reduced from 586 to 200 square miles, and 303 wells had been drilled to depths ranging from 60 to 520 feet, 40 more than programmed. This allowed a more aggressive aquifer clean up schedule. Plutonium facilities had been dismantled and buried in grout. An extra \$324 million was used to accelerate progress in the tank farms. (OrDE 2014, pg 200-201)

DOE agreed to settle claims brought by 139 people with thyroid disease who claimed radioactive material released from Hanford caused their illnesses. It was the largest settlement in Hanford downwinder litigation that had stretched for more than 20 years. Remarkably, each plaintiff received \$5,683. Nearly 1,400 plaintiffs remained in downwinder litigation at Hanford. (OrDE 2014, pg 204)

[Bringing more waste to Hanford] “runs counter to everything that Oregon and Washington, Northwest tribes and health advocates have sought to achieve in taming a Hanford nuclear beast that menaces underground water, the Columbia River, and human and wildlife populations nearby.”
– The Oregonian 8 May 2011 Editorial. (OrDE 2014, pg 208)

2012 (OrDE 2014, pg 209-220):

The first leak in a double shell tank was discovered via routine video surveillance in August 2012. The inner shell leaked into the annular space between the inner and outer shell. An investigation found that A-102 had been the first tank constructed and according to a 7 November 2012 Leak Assessment Report, “Tank AY-102 construction records detail a tank plagued by first-of-a-kind construction difficulties and trial-and-error repairs. The result was a tank whose as-constructed robustness was much lower than intended by the double-shell tank designers.” It was also understood as a reminder that underground tanks have a finite life. (OrDE 2014, pg 209)

Stakeholders and regulators were concerned about the implications of a leak in a double shell tank, even though it did not get to the environment. The DNFSB re-emphasized its 2010 findings by recommending again improved ventilation on all 28 double shell tanks to reduce flammability hazards. The HAB recommended that construction of new double shell tanks be started immediately. (OrDE 2014, pg 210-11)

In the meantime, delays in the WTP milestones meant that waste would need to be stored in tanks for much longer than previously thought.

DOE’s engineering division director for the WTP said in a memo to his superiors that Bechtel National should be immediately removed as the design authority for the WTP. Gary Brunson listed 34 instances and technical issues in which Bechtel provided design solutions and technical advice to DOE that he said were determined to be factually incorrect; not technically viable or were technically flawed; or that were not safe for the WTP operators, among other concerns. Bechtel National project director Frank Russo responded that the issues raised in the memo were not new; that many had already been resolved; and that other issues were currently being addressed. (OrDE 2014, pg 219)

Washington State officials demanded detailed explanations from DOE about what they were doing to meet existing deadlines. In a letter from Governor Gregoire and Attorney General Rob McKenna to Secretary Chu, the state indicated a willingness to resume legal action if DOE could not demonstrate “good cause” for schedule delays. The letter also said, “DOE appears to have already decided it will not comply with the Consent Decree

based upon the self-imposed limitations of annual funding caps and a judgment that resolution of technical issues...is only possible if the schedule for those facilities is extended.” Gregoire later said she would not leave office in January without either resuming legal action or resolving issues with DOE. (OrDE 2014, pg 219)

Bechtel received its lowest award payment for work completed during the first six months of the calendar year. DOE awarded Bechtel just under 50 percent of its possible award payment — an award of \$3.1 million out of a possible \$6.3 million. Bechtel received “satisfactory” marks for cost and project management. DOE recognized an improvement in safety and health performance and positive steps in nuclear safety and quality culture. (OrDE 2014, pg 220)

So, as had happened so many times before, technical challenges of treating a complex waste stream became policy, political and litigious challenges, distracting all stakeholders from their primary concern ... site remediation.

2013 (OrDE 2014, pg 221-232):

The combination of sequestration and the absence of a federal budget severely hampered planning and progress at Hanford. Automatic federal spending cuts that went into effect on March 1 reduced Hanford’s budget by about \$156 million for the seven months remaining in the fiscal year 2013 budget. Up to 4,700 workers were expected to face layoffs or as much as six and a half weeks of forced time off through furloughs. By a combination of reprogramming out of the WTP project and from non-cleanup funds, DOE and its contractors mitigated most of these layoffs. Additional program disruption occurred in October when the government shut down due to a Congressional impasse. Again, workarounds delayed most layoffs long enough to give Congress time to end the shutdown with a continuing resolution good through the end of the year, but at the expense of technical progress. The 2013 calendar year ended with more layoffs due to budget uncertainty and possible additional sequestration cuts. (OrDE 2014, pg 221-2)

Liquid levels were observed to be falling in six tanks at a rate suggesting the possibility of 1000 gallons per year of leakage. By the end of the year, DOE said further evaluation concluded that evaporation, and not leaks, was the reason that liquid levels were declining in five of the six tanks. T-111 was still considered to be leaking. (OrDE 2014, pg 223)

Retrieval efforts were successful at tank C-110, which was declared completed in late October — the 11th tank at Hanford to be emptied. Workers used a remotely-operated track-mounted tool to help push waste to pumps in the tank. The “Foldtrack” has a plow-blade, two on-board water jet systems, three high-pressure nozzles and a water cannon that operators can use to break down difficult-to-remove waste. (OrDE 2014, pg 225)

Nevertheless, it was another mixed year for tank waste retrievals. The budget sequestration, failed equipment, and an emergency declaration led to only one tank being emptied by the end of the year. Work on tank C-101 progressed well through much of the year then was halted when higher-than-expected radiation readings were found near an equipment box. Work was stopped, workers were evacuated, and an alert was declared. An investigation determined that the source of the radiation was pre-existing contamination on a concrete cover block whose shielding had somehow been moved. There was no spill and waste retrieval resumed. (OrDE 2014, pg 225)

The Mobile Arm Retrieval System (MARS) — a robust mechanical arm — continued to work well in tank C-107, but once again was forced to shut down because of a failed pump. Workers also successfully cut a 55-inch diameter hole in the top of tank C-105 to install a MARS arm in that tank. (OrDE 2014, pg 225)

Four tank farm workers were given medical evaluations after they smelled vapors in the BY and C tank farms. They were cleared to return to work the following day. (OrDE 2014, pg 225)

DOE notified the State of Washington that it would be unable to meet two target milestones related to the retrieval and certification of transuranic waste. DOE said available funds were needed to perform work that ranked higher on their mutually agreed list of priorities. (OrDE 2014, pg 226)

DOE issued what it called the first in a series of Records of Decision for tank closure and waste management activities at Hanford. The decision included plans for retrieval of 99 percent of the waste in Hanford's underground tanks; landfill closure of the single-shell tank farms; and a continued moratorium on [accepting] off-site waste until the WTP was operational. (OrDE 2014, pg 227)

DOE notified the states of Washington and Oregon in June and again in October that various milestones related to WTP construction and tank waste retrieval were at risk. October's announcement in effect meant that all remaining milestones through 2022 were at risk. The State of Washington responded that they were disappointed, but not surprised. (OrDE 2014, pg 230)

Whistleblower Walter Tamosaitis who had been laid off first in 2010 was laid off from his job in Oct 2013 and whistleblower Donna Busche filed her second legal complaint with the Department of Labor claiming she continued to suffer retaliation and harassment since she had filed her initial whistleblower complaint in 2011. (OrDE 2014, pg 231)

After Secretary Chu resigned, Ernest Moniz was unanimously confirmed as Secretary of Energy by the full Senate in May. As promised during his Senate hearings he visited Hanford and had meetings with whistleblowers. He received a 6 September 2013 letter from South Carolina Governor Nikki Haley complaining about funding increases at Hanford when funding for the Savannah River Site was cut. She wrote, "For its decades of litigation and lack of progress, this same administration has proposed about 20 percent more financial support for the Hanford Site in Washington State...the true effect of this policy is to punish success and fund failure." (OrDE 2014, pg 232)

2014 (OrDE 2014, pg 233-242):

This year opened with a strong difference opinion between Washington Ecology and DOE over the double shell tank AY-102 whose inner shell had been identified as leaking in 2012. In a 9 January 2014 letter, Jan Hedges of the Washington Department of Ecology wrote to DOE-ORP Manager Kevin Smith and Washington River Protection Solutions President Dave Olson "Your proposal, as we understand it, is to monitor the leaking Tank AY-102 and take no action to remove its waste until conditions get worse. This is unacceptable." (OrDE 2014, pg 232)

After a review of construction records for all 28 double wall tanks, Tom Fletcher, DOE Assistant Manager for the tank farms was quoted in the 28 February 2014 Tri-City Herald: "All (double-shell) tanks had some levels of construction challenges, but all were accepted or repaired and put into service." (OrDE 2014, pg 234)

By March 2014 both sides had clarified their positions. "Waiting another two years, at best, to initiate actions to address this hazardous condition is neither legally acceptable nor environmentally prudent." – Washington Ecology Director Maia Bellon in an Ecology News Release, March 21, 2014. On the same date, a DOE statement read, "The Department believes there are risks associated with pumping tank AY-102 at this time. The tank is not leaking into the environment, and there is no immediate threat to the public or the environment posed by AY-102." (OrDE 2014, pg 233)

The DOE explained that the sludge in this tank was hot and needed to be covered with liquid to control its temperature. Further the liquid should not be pumped until the sludge had been removed unless conditions significantly worsened. DOE proposed to begin buying equipment so that sludge could be pumped starting no earlier than March 2016. The following day, a third area of leaked waste was discovered – one not present during the prior survey in September 2012. By late March, the State of Washington issued an Administrative Order, directing DOE to begin removing liquid waste from the tank by September 1, 2014. DOE was also directed to

begin removal of sludge by December 1, 2015, and complete sufficient removal of waste to determine the cause of the leak by December 1, 2016. DOE filed an appeal of the Administrative Order with the State Pollution Control Board, arguing that the state requirements conflicted with the safe handling of nuclear materials, which came under the authority of DOE. (OrDE 2014, pg 234)

As of 2014, it is estimated that Hanford's tanks contain at least 1,200 different chemicals. The tanks vent head space gases and vapors through particulate filters that prevent radio nuclides from reaching the atmosphere, while allowing the gases and vapors free passage. The tank vapors have been a periodic problem for workers at the site for decades. Washington River Protection Solutions required respirators to be worn in the A complex of tank farms, though other workers were encouraged to wear respirators if they chose to do so. Workers for Mission Support Alliance called a "stop work" order after complaining that non-tank farm workers were not receiving sufficient information about potential hazards. Additional monitoring was conducted within many of the tank farms. In late April, Washington River Protection Solutions announced that Savannah River National Laboratory would establish an expert panel to assess the vapor management program and related worker protection measures. This report is written by that panel, the Tank Vapor Assessment Team. (OrDE 2014, pg 235)

The Oregon Department of Energy created a concise table of what it considers significant events affecting the Hanford site remediation project between 1989 and 2014. The interested reader is encouraged to review that table. (OrDE 2014, pg 243 - 251)

SUMMARY

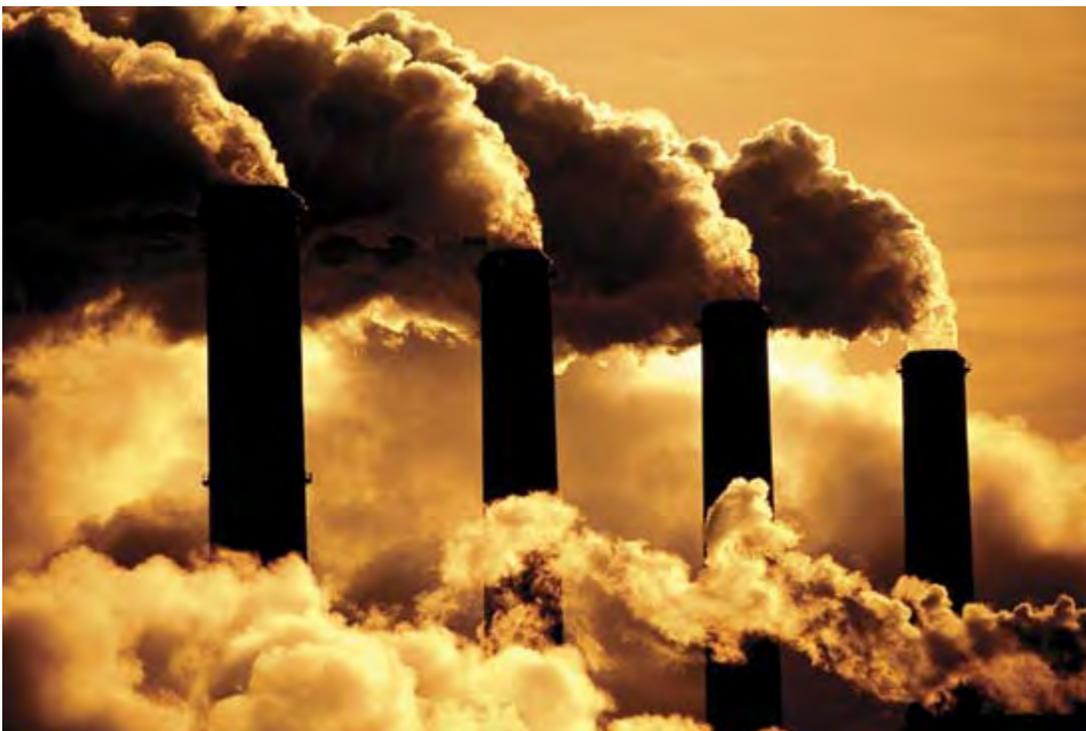
Members of the TVAT are guardedly optimistic that as the recent initiatives of the field offices and site contractors mature, line management will take ownership of the tank vapor exposure issue. Their initiatives to hire and provide site specific training of a credible IH staff are encouraging signs of progress. When this expanded industrial hygiene program is integrated into budgeting and planning of work as well as those that have been remarkably successful for radiation, flammability and explosion, we anticipate that satisfactory tank vapor worker exposure controls will be implemented.

It seems appropriate to end this Appendix with insight about the realities of the Hanford site remediation program from Adrian Roberts, Battelle Vice President. He explained in the 13 Nov 1994 Spokesman Review his frustrations of trying to move forward with new cleanup technologies. "If putting a man on the moon had been opened up to a stakeholder process that included EPA, the [Washington] Department of Ecology, the downwinders, the upwinders, the press, and the Native Americans...would we ever have got a man on the moon in that time frame?" (OrDE 2009 p 40)

APPENDIX G. STACK HEIGHTS ARE NOT THE ANSWER TO ALL VAPOR ISSUES

In recent years an initiative has been pursued at Hanford to raise the height of underground tank vents to 40 feet above local terrain. This was based on atmospheric modeling showing a 1000 fold reduction in ground level exposure potential outside a radius of 5 feet from the base of each such stack. What is the uncertainty interval around that point estimate? Does this protect against short “bolus” releases beneath a low inversion layer on days characterized by stack plume patterns known as fumigation or looping?

Continuing worker experience with adverse physiological effects from the invisible tank vapor plumes suggests that 40 foot stack heights are not a complete preventive measure. To help understand why, consider the image below. In that photo the plumes are visible because of particulate loading, a feature not present in tank vapor plumes. There is clear evidence of plumes below the stack opening, presumably originating from upwind stacks. This shows that there is no guarantee of safety outside a 5 foot radius of the base of a stack under all meteorological conditions.



<http://www.bizzyblog.com/wp-images/Smokestacks.jpg>

The policy of extending stack height to improve ground level air quality is similar to the now deprecated policies used by chemical companies and heavy industry during the first half of the 20th century. This trend is well illustrated by the history of local contamination from the ASARCO copper, lead, zinc smelter in El Paso TX. The facility is situated in a climate not unlike that of Hanford WA. In 1951 ASARCO built a 612-foot smokestack to reduce ground-level concentrations of sulfur dioxide and in 1967 built a taller 828-foot stack, designed to help alleviate local air pollution (Kohout, 2010).

“In December 1971 the El Paso City-County Health Department reported that the smelter had emitted 1,012 metric tons of lead [through the newer and taller stack] between 1969 and 1971 and found that the smelter was the principal source of particulate lead within a radius of a mile. When lead was discovered in the soil of Smelertown, the company removed the top foot and a half of soil and replaced it with fresh soil. When lead poisoning was suspected in the children living in Smelertown, the company bought the land in Smelertown and removed the residents.”

When one realizes that the 612 foot stack was found over a 16 year period to be too short to reach the design reduction factors and that the larger 812 foot stack was found over a two year period to be too short to reach the design reduction factors, one is given pause to wonder if a 40 foot stack height for a tank at Hanford can be expected to provide desired protection under all conditions. Some might argue that the ASARO plumes were loaded with particles and so behaved differently than the particle-free tank vapor plumes at Hanford. The particle loading was small enough that the visible plume behavior at ASARCO and the invisible vapor plume behavior at Hanford were both dominated by meteorology rather than by plume average density.



<http://journalisminjuly.com/2012/files/2012/07/AsarcoStack.jpg>

Because of significant public health crises (i.e., Cancer Valley: Kanawha Valley WV), the early 20th century concept of taller stacks as the primary means to protect community health has been discarded. In its place are combinations of scrubbing technology and moderately tall stacks. In 1987 the Smithsonian magazine published an article discussing the future of stacks. The article concludes that stacks are a necessary technology and that hazardous chemicals should be removed from the exhaust stream, to the extent possible, before releasing the residual gases and vapors to the air (Wernick 1987).

Ray Warren, who makes smokestacks in Atlanta, is quoted on the topic, "As long as you are burning a fuel, you are going to have waste, for no combustion process is perfect. And the only places to put that waste are land, sea and air. Land and sea pose their own problems, as the chemical and nuclear industries have been learning over recent years. Only the air is left, and the only way to get to the air is through some form of smokestack—hopefully a nonpolluting one."

The Photo of N-Reactor shown below has a visible plume in the background. The plume shape illustrates fumigation of ground level receptors downwind of its release point. (OrDE 2009, p 68). This is not a tank vapor plume, but it does confirm that there are weather conditions at Hanford that support fumigating behavior in atmospheric plumes. The tank vapor plumes are invisible, but behave similarly.



APPENDIX H. BOLUS EXPOSURES VERSUS A TIME-WEIGHTED AVERAGE EXPOSURE OVER A SIGNIFICANTLY LONGER TIME PERIOD

Introduction

This appendix is intended to serve as technical background for several important concepts associated with:

- 1) Assigning default occupational exposure limits for short bolus exposure events as a pair of numbers, herein illustrated as a concentration in parts per million (ppm) and an averaging time in minutes (min);
- 2) Selecting the limit of quantification for assigned occupational exposure limits so that the sampling and analytical method can quantify exposure events down to 10% of the assigned occupational exposure limit;
- 3) Understanding the convenience of conceptualizing laboratory analytical data in units of ppm*min;
- 4) Interpreting TWA air sample data when the duration of the sample is longer than the independently determined duration of the bolus exposure event that is partially or wholly contained within the time of the sample;
- 5) Evaluating differences between a simple moving average estimate derived as the average concentration estimated by an integrated sample of duration dt (min) and an exponential moving average estimate derived from a direct reading instrument.

This appendix does not cover the application of chemical specific OELs to mixtures of chemical vapors. Mixtures are discussed in Chapter 7 - Risk Characterization.

Occupational Exposure Limits - Concise History and Recommended Default Values

Occupational Exposure Limit (OEL) is a generic term that is here applied to the limits set within an organization to protect its own workforce. OELs can be adopted from one or more of many differently named sources of occupational exposure regulations and guidelines.^a

Industrial Hygiene has depended upon Occupational Exposure Limits (OEL) for limiting risk of chemical exposures for more than half a century. And our understanding of their utility has evolved over this time. The first widely used OELs were the ACGIH Threshold Limit Values (TLV), a copyrighted term for a specialized set of OELs. The 1964 TLV booklet explained: “The TLVs refer to airborne concentrations of substances and represent conditions under which it is believed that nearly all workers may be repeatedly exposed, day after day, without adverse effect.”

By the time ACGIH published its 1970 TLV booklet, the TLVs were further explained: “TLVs refer to time-weighted average concentrations for a 7 or 8 hour workday and 40 hour workweek. They should be used as

^aExamples of recognized standard setting and regulatory agencies, and web sites with curated OEL data include:

OSHA permissible exposure limits (PELs, most based on 1968 TLVs, <https://www.osha.gov/dsg/annotated-pels/>)

ACGIH threshold limit values (TLVs, <http://www.acgih.org/store/ProductDetail.cfm?id=2233>),

NIOSH recommended exposure limits (RELs, <http://www.cdc.gov/niosh/npg/pgintrod.html>),

OARS workplace environmental exposure levels (WEELs, <http://www.tera.org/OARS/WEEL.html>),

European Union’s indicative occupational exposure limit values (IOELVs,

<https://osha.europa.eu/en/legislation/directives/exposure-to-chemical-agents-and-chemical-safety/osh-directives>) and

OELs set by numerous other countries and non-governmental agencies as summarized by ILO

(http://www.ilo.org/safework/info/publications/WCMS_151534/lang--en/index.htm) and/or those published on

international chemical safety cards (<http://www.cdc.gov/niosh/ipcs/icstart.html>).

All websites were verified 12 Oct 2014.

guides in the control of health hazards and should not be used as fine lines between safe and dangerous concentrations.”

Excursion factors for concentrations above the 8 hour TLV were presented in Appendix C of the 1970 TLV booklet to be used for exposures up to 30 minutes per day. The appendix explained that the average concentration permitted for a short time is larger than the average concentration permitted for a full shift, so long as the full shift average is not exceeded. In 1970, default values for the excursion factor depended on the TLV: “... for TLV = {0, 1} ppm it was 3x, for TLV = {1,10} ppm, it was 2x, for TLV = {10, 100} ppm, it was 1.5x, and for TLV = {100, 1000} ppm, it was 1.25x. The 2013 TLV booklet says of excursion factors, “Excursions in worker exposure levels may exceed 3 times the [8-hour] Threshold Limit Value (TLV-TWA) for no more than a total of 30 minutes during a work day, and under no circumstances should they exceed 5 times the TLV-TWA, provided that the TLV-TWA is not exceeded.”

The application of default excursion factors serve to emphasize the health risks associated with highly variable exposure concentrations during a work day and imply that a workplace without transient peaks is the preferred work environment -- the one for which minimum adverse health effects are anticipated.

Substance specific short term exposure limits (usually 15 minute duration unless otherwise stated) and substance specific ceiling limits are established for some substances. This is usually because the high dose rate associated with short bolus exposures saturates the physiological mechanisms responsible for one’s ability to tolerate exposures with average concentrations up to the listed OEL concentrations for up to 8 hours per day.

For clarity in this appendix, we introduce an unambiguous acronym, OEL_{nnn} which denotes the average concentration allowed for “nnn” minutes. Thus, the variable OEL₄₈₀ is the occupational exposure limit in ppm for up to an 8 hour shift of 480 minutes. In like fashion OEL₁₅ denotes the average concentration for any 15 minute period and OEL₅ denotes the average concentration for any 5 minute period. The short period OELs are to be balanced by periods of exposure below the concentration specified by the OEL₄₈₀ so that the 8 hour limit is not exceeded.

To put this nomenclature in its proper historic perspective, what we here call OEL₄₈₀ is also cited in the ACGIH Threshold Limit Value booklet as a Time Weighted Average, abbreviated TLV-TWA, and in the NIOSH Pocket Guide as the OSHA Permissible Exposure Limit (PEL). In like fashion, our unambiguous OEL₁₅, is analogous to the default Short Term Exposure Limit, abbreviated by ACGIH as TLV-STEL and in the NIOSH Pocket Guide summary of OSHA exposure limits as ST-PEL. There is no traditional default limit for 5 minute intervals, although some ceiling values are specified so that compliance is achieved when a 5 minute sample demonstrates a 5 minute average concentration smaller than the OEL₅.

The ACGIH Threshold Limit Value-Ceiling is the TLV-C and for OSHA it is C-PEL. The formal definition for the TLV-C in the 2007 TLV booklet reads, “The concentration that should not be exceeded during any part of the day. If instantaneous measurements are not available, sampling should be conducted for the minimum period of time sufficient to detect exposure at or above the ceiling value.” (2007 TLVs and BEIs Based on Documentation of the Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices, ISBN: 978-1-882417-69-8, ACGIH, Cincinnati, OH). In this appendix, we use the OEL₅ as the occupational exposure limit for average exposures measured during a 5 minute period. Shorter bolus exposures can occur, but a 5 minute sample with a sufficiently small LOQ can often be used to quantify those. Where possible based on available monitoring technology even shorter averaging times might be quantifiable as envisioned in the TLV-C concept.

To make it clear, for the purpose of this appendix an OEL is a pair of numbers, one concentration and one averaging time. The averaging times emphasized in the following numerical examples are full shift (480 minutes), 1/32 shift (15 minutes) and 1/96 shift (5 minutes). This appendix highlights that default excursion factors might be applied to supplement an OEL₄₈₀ as has been embedded in the current TLV methodology and recommended

in the main body of this report using the OEL-C terminology. The TVAT notes that a documented excursion limit approach could be developed for use by the IH Program at Hanford that provides a greater level of specificity than the basic OEL-C approach. Such values would reflect the time course of toxicity and the LOQ for the chemical being assessed. The remainder of this appendix provides additional background on the key concepts that might be considered in developing these more specific limits based on the coupled effects of concentration and exposure time on the onset of health effects.

Illustration of typical scenarios where these concepts are important

Figure H-1 illustrates possible peak concentration differences between three different exposure histories with the same exposure dose, when each is measured with a full shift time integrated sample (TIS). Three scenarios are shown: in Scenario 1 the breathing zone concentration rises to 1680 ppm with an exponential time constant of 0.2 min and starts falling to zero after 2 minutes; in Scenario 2, it rises to 140 ppm with an exponential time constant of 4 minutes and starts falling to zero after 24 minutes; in scenario 3 the concentration is a steady 7 ppm for 8 hours. All three scenarios have the same 8 hour cumulative exposure dose. That is easily computed for Scenario 3 as $7 \text{ ppm} \times 480 \text{ min} = 3360 \text{ ppm} \cdot \text{min}$ and by integrating over time for Scenarios 2 and 3.

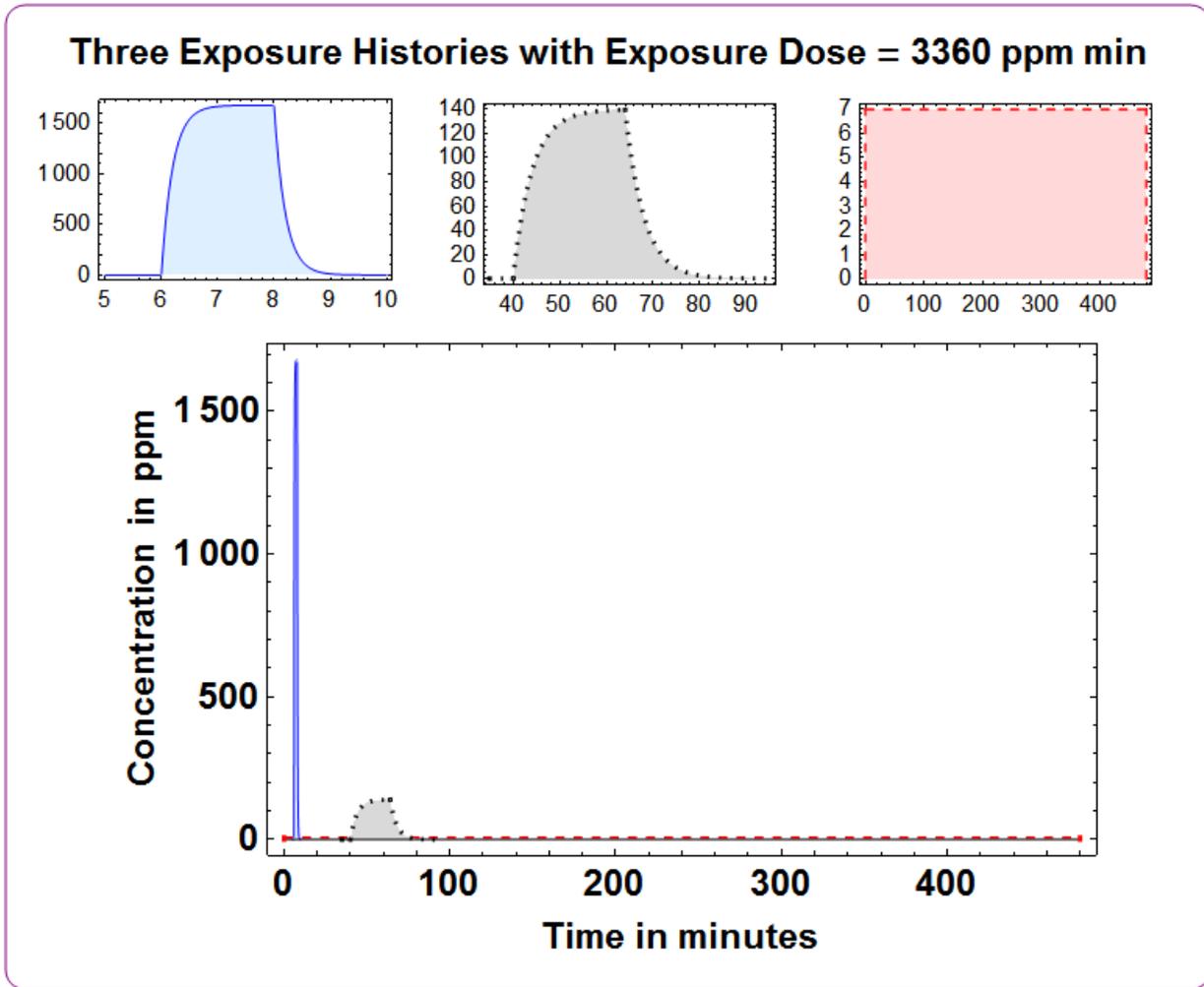


Figure H-1. Three Exposure scenarios. Scenario 1 is 140 ppm for 24 minutes, Scenario 2 is 1680 ppm for 2 minutes, and Scenario 3 is 7 ppm for 480 minutes. If sampled for 480 minutes, all three scenarios have the same time integrated exposure dose, 3360 ppm*min or 7 ppm as an 8 hour time-weighted average. This illustrates that an 8-hour sample does not distinguish peak exposures that may have occurred during short periods during the sample, but does contain enough information to estimate peak values of short intervals within the longer sample period.

Limit of Quantification (LOQ) for OEL5, OEL15 and OEL480

In developing excursion limits with differing averaging times consider an example where substances without short term limits are assigned $OEL_{15} = 3 \cdot OEL_{480}$ and $OEL_5 = 5 \cdot OEL_{480}$. To see how this works in practice, consider a substance with $OEL_{480} = 30$ ppm for a full shift of 480 minutes. It follows that the default 15-minute value is $OEL_{15} = 3 \times OEL_{480} = 90$ ppm; and that the default 5 minute value is $OEL_5 = 5 \times OEL_{480} = 150$ ppm.

The quantity of a chemical collected in an air sample is proportional to its average concentration in the air (parts per million, abbreviated ppm) and to the duration of the sample (minutes, abbreviated min). That quantity, here called the exposure dose to distinguish it from the toxicologically significant retained dose, is conveniently

expressed in units of ppm*min.^a To quantify concentrations at 10% of an OEL, the laboratory should have a limit of quantification that is no larger than the quantity collected over the specified duration when the concentration = 0.1 OEL. Thus, if OEL480 = 30 ppm, we expect a tolerable full shift exposure dose of (30 ppm) * (480 min) = 14400 ppm*min. To quantify 10% OEL480, the sampling and analytical method needs a limit of quantification so that LOQ480 < 1440 ppm*min.

Likewise, for OEL15 = 90 ppm. Expect a one event exposure dose of 90 ppm * 15 min = 2700 ppm*min. To quantify 10% of OEL15, need LOQ15 < 270 ppm*min.

Similarly, for OEL5 = 150 ppm. Expect a one event exposure dose of 150 ppm * 5 min = 750 ppm* min. To quantify 10% OEL5, need LOQ5 < 75 ppm*min.

It has been fairly common practice in large industry and government agencies to select sampling and analytical methods (SAMs) with a detection limit sufficient to quantify 10% of the OEL480, which in this hypothetical example would be LOQ480 = 1440 ppm min. It is our observation that when bolus exposures are possible, the 10% should have been applied to the 5 minute OEL as a more appropriate SAM performance criterion. To implement this recommendation, we need LOQ5 = 75 ppm*min. Clearly the analysis based on LOQ480 = 1440 ppm*min is unable to quantify a bolus exposure with an exposure dose between 75 ppm*min and 1440 ppm*min.

Based on this example, and to be useful for both bolus and continuous exposures, the sampling and analytical method (SAM) should have a calibrated range sufficient to quantify exposure doses from 5 minutes at 10% of OEL5 to 480 minutes at 200% of OEL480. The SAM should quantify in a range from LOQ5 = 75 ppm*min to 2*LOQ480 = 28800 ppm*min. Because it is easy to extend the upper limit of any analytical procedure by serial dilution of the analyte, the saturation level of the instrument at the upper end is not much of an issue in practice. It is the lower limit of quantification that needs to be verified for the chosen sampling and analytical method.

Interpreting Air Sampling Results

It is virtually impossible to collect a short sample with a duration that exactly matches the duration of a random bolus exposure. Consider 5 minute samples with a time resolution of 1 minute. There are 476 ways that such a 5 minute sample can be collected in a 480 minute shift, with samples starting from time 0 to time 475 minutes. In a week of such shifts involving a work team of 5, any one of whom may encounter a short bolus, there are 5*5*476 = 11,900 opportunities to collect a relevant sample. If a bolus exposure occurs at an average rate of once every six months (25 weeks), then the probability that a random 5 minute sample will match the bolus event is 1/(11,900*25) = 0.000 0034, or slightly more than 3 per million. That leads to the question of whether fewer longer samples could help estimate exposure doses for bolus events. The answer is yes, if there is an independent estimate of the duration of the bolus encounter.

Some simple conclusions are illustrated in Fig H-2 and Table H-1, which show the pairs of duration and concentration that equal an exposure dose of 75 ppm*min (left side) or 1440 ppm*min (right side). When using a SAM with LOQ480 = 1440 ppm*min, a 1 minute bolus of 1430 ppm would not be quantified. In contrast, by switching to a SAM with an LOQ5 = 75 ppm*min, all 1 minute bolus exposures above 75 ppm would be quantified, including remarkably short events such as 0.5 minute above 150 ppm and 0.2 minute above 750 ppm.

^aA lab report will normally include duration of the sample and vapor concentration in ppm. The exposure dose is the product of these two numbers. If a vapor concentration is given in mg/m³, it is easily converted to ppm with the molar mass (g/mol) of the substance sampled:

$$C_{PPM} = (24.45 C_{mg/m^3}) / M_{molar}$$

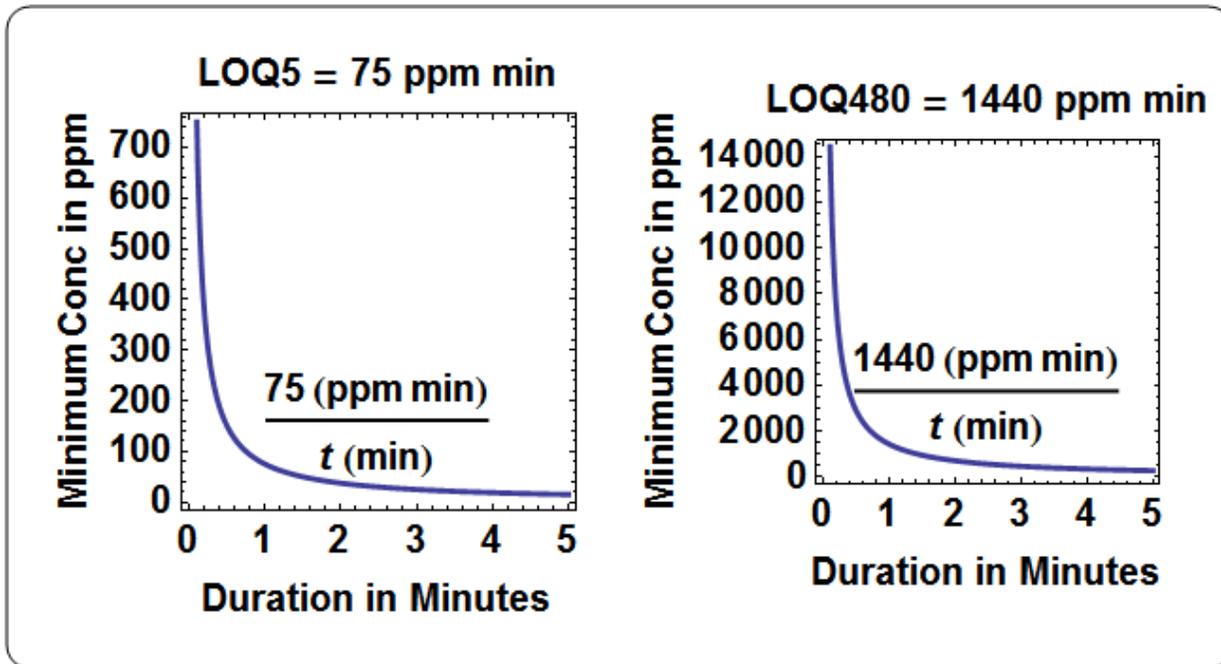


Figure H-2. Locus of constant exposure dose in ppm*minutes. Left panel for 75 ppm*min. Right panel for 1440 ppm*min. Any point on the curve is located by the combination of duration in minutes and average concentration in ppm whose product equals the exposure dose that defines the contour.

OEL5 = 150 ppm, LOQ5 = 75 ppm * min OEL480 = 30 ppm, LOQ480 = 1440 ppm * min

Dur, minutes	Minimum Concentration, ppm	Dur, minutes	Minimum Concentration, ppm
0.1	750.	0.1	14 400.
0.2	375.	0.2	7 200.
0.3	250.	0.3	4 800.
0.4	187.5	0.4	3 600.
0.5	150.	0.5	2 880.
1	75.	1	1 440.
2	37.5	2	720.
3	25.	3	480.
4	18.75	4	360.
5	15.	5	288.
10	7.5	10	144.
20	3.75	20	72.
40	1.875	40	36.
80	0.9375	80	18.
160	0.46875	160	9.
320	0.234375	320	4.5
480	0.15625	480	3.

Table H-1. Left panel lists pairs of concentration in ppm and duration in minutes that multiply to 75 ppm*min. Right panel pairs multiply to 1440 ppm*min.

Note that all of the pairs of duration and concentration in each table above represent the same cumulative exposure dose. The table on the left is the set of durations and concentrations that equal 75 ppm*minute and are detectable with a sampling and analytical method whose LOQ ≤ 75 ppm*min. The table on the right is the set of durations and concentrations detectable with a sampling and analytical method whose LOQ = 1440 ppm*min.

Reporting Results

A common practice in IH programs that are based on 480 minute OELs is to report that exposures were less than 10% of the OEL480 when the lab result was less than or equal to the LOQ480 = 1440 ppm*min. In many cases independent evidence can be found sufficient to estimate the duration of a bolus exposure. When that is true, what should be reported is that the duration of the alleged exposure was not monitored. Consider the situation when it is likely that the exposure was between 24 and 60 seconds. A bolus exposure whose duration lies in that interval, {0.2, 1.0} minute, represents an average concentration in the range 1440 ppm to 7200 ppm. This is evident from the right sides of Figure H-2 and Table H-1. Note the importance of the LOQ used. If the SAM is based on LOQ480 = 1440 ppm*min, a bolus must have a concentration greater than 7200 ppm for 24 seconds to be quantified. On the other hand, if the SAM is based on LOQ5 = 75 ppm*min, all 24 second bolus exposures with average concentrations above 375 ppm could be quantified.

Going forward, a table and figure like the Table H-1 and Figure H-2 above should be considered to inform design of IH sampling and communication of incidents. Such tables depend on the LOQ for each analytical method, and SAMs with lower LOQs have the ability to quantify lower exposure dose bolus events and improve precision of such estimates. This is dramatically important. With independent estimates for the duration of the bolus encounter one can estimate the range of possible 5 minute average exposures based on data collected from longer air samples.^a It is only by properly interpreting long duration samples that one could hope to increase the probability of estimating the peak concentration for bolus exposures, because it is impossible to collect and process enough 5 minute samples in a workforce numbering in the hundreds.

As another example, the left part of Table H-1 allows one to easily convert an exposure dose of 75 ppm*min from a 40 minute sample to a 0.2 minute exposure that occurred during the 40 minute period of the sample. Note from the table that the 40 minute sample represents a 1.875 ppm time weighted average concentration. If investigation shows that there was no exposure for 39.8 minutes and there were 0.2 minutes of exposure during this sample, then the average inhaled concentration (aka 24 second TWA) was 375 ppm.

Simple Moving Average vs Exponential Moving Average

The discussion above is focused on samples collected on sampling media at a constant flow rate for a defined interval.^b This represents an equally weighted average over a defined time interval. Such averaging is known as a simple moving average. The figures and data above are for simple moving average sampling methods.

Every direct reading instrument (DRI) has a response time constant. For vapors in air, these typically range from seconds to minutes. A DRI typically applies an exponential weighting function that gives more weight to recent readings and progressively less weight to progressively older readings while calculating the average value it reports. This is called an exponential moving average. Simple and exponential moving average are compared in Fig H-3 to show that a calibrated DRI with a time constant approximately equal to or longer than a short bolus exposure event typically reports a smaller concentration peak than found with properly interpreted sorbent tube samples.

Figure H-3 compares the measurement made with a 24 second simple moving average and that made with an exponential moving average having a 24 second time constant. The bolus event in this figure lasts 20 seconds. The shaded area in each panel is the reported exposure dose in ppm*min.

^aFigures for internal use by IH would have multiple hyperbolic contours, one each for various exposure dose levels above that associated with the LOQ of the SAM used. Figures for reports would have the contour for the exposure dose observed in the air sample(s) that bracketed the bolus exposure.

^bThis includes both pumped flow sampling trains and diffusion monitors.

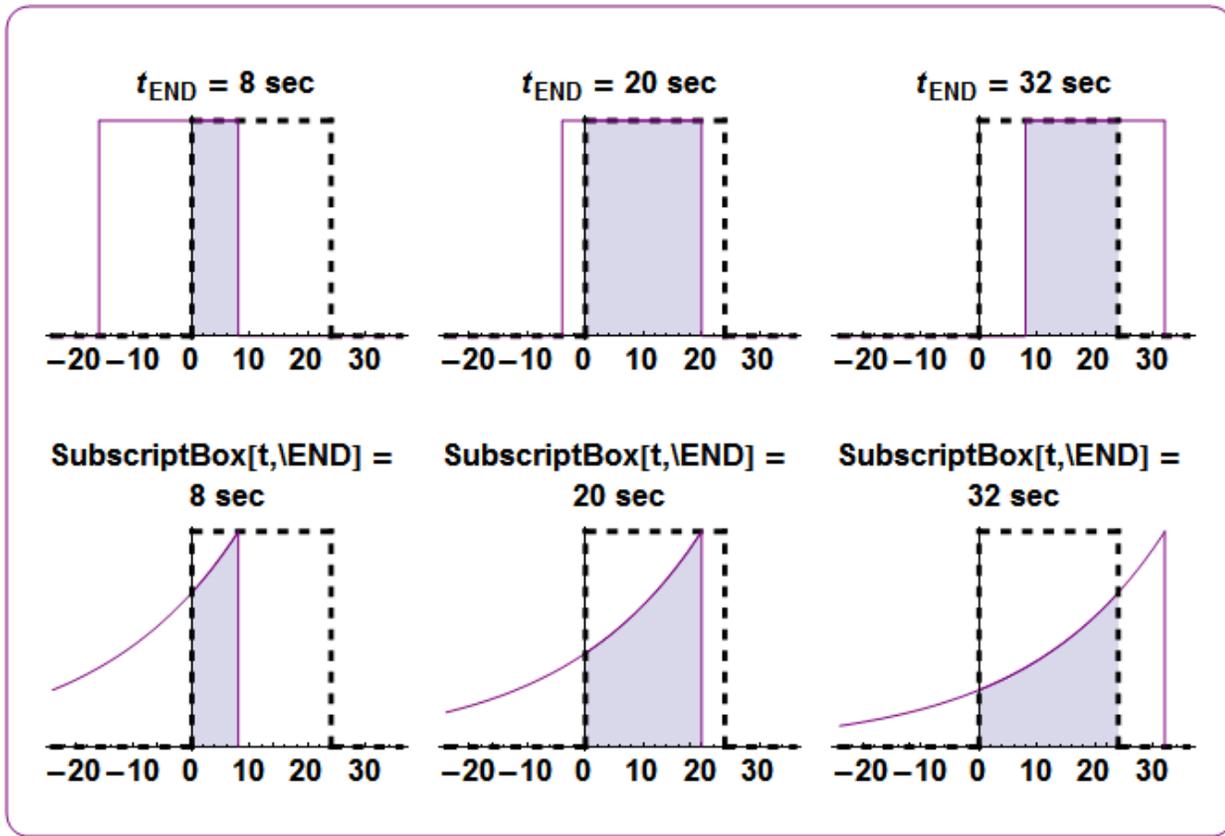


Figure H-3 Top row, simple moving average with 24 second duration, varying stop times. Bottom row, exponential moving average, 24 second exponential time constant, also illustrating varying stop times. The area of the filled regions quantifies the exposure dose reported by the average at the stop time for each SAM.

Users of DRI should be aware of the differences between simple moving average and exponential moving average data. A DRI will significantly underestimate transient peaks of an exposure event whose duration is shorter than about 3x its exponential response time constant.

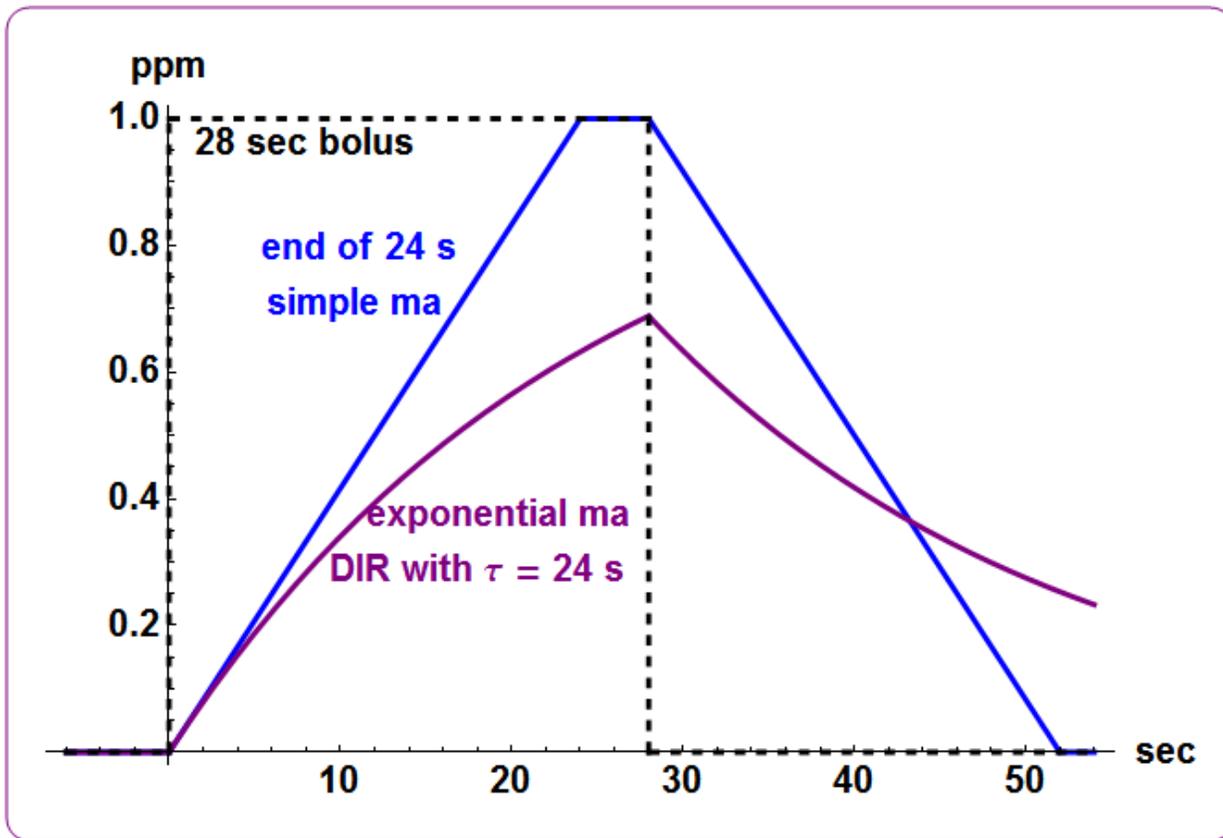


Figure H-4 The straight lines are a continuous plot of concentration measured at the stopping time of a 24 second moving average sampling a 28 second bolus starting at $t=0$. The curved lines are the instantaneous estimate of the bolus exposure reported by a DRI as a function of the time of reading the data for the same 28 second bolus. For all stop times inside the bolus, the DRI underestimates the TIS. For a sufficiently large times (in this example $>$ about 45 seconds), after the simple moving average excludes the bolus entirely, the DRI overestimates the TIS in this example.

By way of summary, Appendix H has proposed and illustrated the following.

- 1 An OEL is a pair of numbers { ppm, min }.
- 2 OEL_{nnn} is symbol for the average concentration allowed for nnn minutes per event so long as the OEL₄₈₀ is not exceeded.
- 3 The sampling an analytical method should have a LOQ not larger than $0.1 \cdot \text{OEL}$. Where bolus exposures are likely the pertinent OEL is the OEL with a short time constant such as an OEL₅.

- 4 When ceiling and 15 minute short term limits are not assigned, then default values should be used based on the OEL-C concept where $OEL-C = 5 * OEL_{480}$. Other specific concentration and time combinations can be specified based on the available data.
- 5 The LOQ for an air sampling and analysis method should be chosen to be no larger than the LOQ needed to detect an exposure relevant to bolus exposure such as $0.1 * LOQ_5$.
- 6 The incident reports should clearly spell out the duration of the sample analyzed and use a table or chart like those illustrated above to interpret that resulting exposure dose for the duration of exposure indicated by the accident investigation and eye witness reports.
- 7 The response time constant of direct reading instruments affects the observed peak value and exposure duration. When the direct reading instrument time constant is approximately equal to or longer than the bolus exposure, the instrument will underestimate the peak value during and shortly after the end of a bolus, overestimate the duration, but can be used to correctly estimate the cumulative exposure in $ppm * min$.
- 8 Many DRI today have digital recording memories with user selectable sampling rates ... selecting a higher digital sampling rate seldom, if ever, reduces the instrument time constant, it merely stores a more complete image of the DRI output waveform.

Scenarios 1 and 2 below illustrate the potential concentration difference between a time-weighted average

APPENDIX I. EVIDENCE FOR BOLUS VAPOR EXPOSURE POTENTIAL ON THE HANFORD TANK FARM

Evidence for the bolus exposure potential to Hanford tank farm vapors to worker comes mainly from two sources; previous modeling studies of tank emissions (Droppo, 2004) and interviews with workers who experienced vapor exposure acute effects.

A Hanford Tank Farm Modeling study of fugitive tank vapors was conducted and reported in 2004 (Droppo, 2004). This study used measured tank ventilation rate along with reasonable worst case meteorological conditions (various atmospheric stability class and air speeds) to estimate plume concentrations downwind from tank emission sources. This report provides a number of conclusions. In one of the primary and perhaps most relevant findings to our investigation, Droppo concludes: “Peak concentrations over **a few seconds time** period can involve exposure **to relatively undiluted air from the tank**. Such exposures are limited to being quite localized because of the very small volumes of air” *[emphasis added]*.

Table 3.1 in the Droppo report presents model predictions for the percent of tank head space that would be predicted to occur in a plume at various downwind distances from passively vented tank vents. Previous work on the ventilation rates of passively vented tanks indicated that the rate is somewhat variable depending mostly on local weather conditions (Huckaby 1998). The high end of this variable ventilation was set by Droppo at 100 m³/hr. The reasonable worst case metrology conditions were the G Stability Class with a wind speed of 1 m/s. As an example, this combination results in the following predicted potential breathing zone concentrations around a 4” pipe vent discharging near the surface from a passively ventilated tank.

Distance Downwind (m/ft)	Percentage of Head Space Concentration
0.001/0.0033	100%
0.3/0.99	100%
1/3.28	97%
3/9.8	81%
10/32.8	28%
30/98.4	4.2%
100/328	0.67%

[emphasis added]

Consider what this might mean for a single COPC compound, N-nitrosodimethylamine or NDMA. This nitrosamine has been measured in the vent exit of some tanks in excess of 1100 µg/m³ (ref: MONITORING DATA 2008-10-01_SourceArea.xlsx). Clearly, almost 30% of this concentration or 310 µg/m³ might be highly irritating even under very brief exposures.

There is little question that NDMA is a chronically toxic material; however, questions have been raised relative to it acute toxicity and its ability to cause rapid onset respiratory irritation. In November 1976, the Environmental Protection Agency (EPA) published a comprehensive (228-page) report entitled: *Scientific and Technical Assessment Report on Nitrosamines*. (EPA-600/6-77-001). The entire report is available online^a and as a non-OCR PDF image from the TVAT. Among many other things, the report addresses the issue of acute toxicity of nitrosamines. To quote this report: “The potency of N-nitroso compounds in causing **acute tissue injury** and death varies considerably (Table 3-1).” Table 3-1 clearly shows that **dimethyl and diethyl nitrosamine** are considered to be the most reactive compounds in the nitrosamine series, and to quote the report again, these most “reactive [nitrosamine] compounds **produce hemorrhagic destructive lesions at the site of contact...**” The

^a <https://play.google.com/books/reader?id=EgZSAAAAMAAJ&printsec=frontcover&output=reader&hl=en&pg=GBS.PP1>

report goes on further in the same paragraph: “Spills have led to **irritation** of the eyes, lungs and skin.” *[emphasis added]*

This EPA report also provides some insight as to why acute toxicity of nitrosamines has not been studied much by stating that the hepato-carcinogenicity of these compounds is so striking that the study of the acute effect(s) has “not commanded such intense interest”. This appears to be an understatement since a literature search could find no mention of acute testing of any nitrosamine beyond this 1976 publication. Given the above determination within this published work, however, it appears that acute contact-site irritation of the respiratory tract from inhalation at orders of magnitude above the assigned chronic 8 hour OEL for NDMA is highly likely.

A plume concentration of 4.2% of this head space concentration at a distance of almost 100 feet from the vent would represent a potential breathing zone concentration of 46 $\mu\text{g}/\text{m}^3$ or about 46x the current Hanford working TLV of 1 $\mu\text{g}/\text{m}^3$. Even at 328 feet downwind the possibility exists for a very brief breathing zone exposure to 7.4 $\mu\text{g}/\text{m}^3$.

Of course, NDMA is but one compound among what is almost certainly scores of potentially acutely irritating compounds extant in the tank head space, vents and subsequent sporadic ground level plume exposures.

The width of the predicted plume is estimated in the 2004 Droppo report as not being wide (perhaps just a few feet). It would also be anticipated to meander somewhat even in relatively calm air. Given the limited volume of release and subsequent narrow path of the plume, the probability of any worker encountering it is low and sporadic. However, given the potential concentration within the plume the health effects from even a few seconds' exposure and inhalation would be anticipated to be significant.

As mentioned above, the acute exposure events are not expected to occur frequently since the worst case of high end emission and reasonable worst case weather conditions have to occur to provide this plume. However, these conditions can and will occur on these tank farms. Inevitably, workers' breathing zones will intersect with these very high concentration plumes and this brief exposure will result in a very significant acute exposure.

Indeed, this is consistent with the experience of the vast majority of workers reporting symptoms. That is, the onset is rapid and, in some cases, very localized with some situations in which workers are profoundly affected with upper respiratory symptoms to the point of “going down” while in a close proximity to (a few feet from) others who do not.

During interviews with the TVAT, essentially all workers indicate an instantaneous “hitting the wall” or “going down” as a result of one or several breaths during the exposure. In one example, an interviewee described not being affected when in a group of 4 individuals in which two nearby member of the group were dramatically and instantly overcome via an inhalation exposure. This points to the sporadic and localized nature of these events and is in complete concordance with the model study reported above.

APPENDIX J. GLOSSARY

ASSESSMENT

- **Hazard:** A source of risk
- **Hazard Identification (HI):** All chemical substances present some hazard given a high enough dose. HI is the identity of the type of hazard or untoward health effect that occurs at a particular time frame of exposure as the dose is increased. For example, at some dose a chronic exposure to N-nitrosodimethylamine (NDMA) will cause liver cancer in animals and presumably people. It occurs in the head space of some Hanford tanks are relatively high concentrations; thus, this nitrosamine is in the COPC and has an assigned chronic 8 hour TWA OEL.
- **Industrial Hygiene Survey Strategy (IH SS).** A survey strategy drives the design of the data collection. Examples include “worst case”, targeted, random, and stratified random. The time course of interest also is a factor, such as full shift, task duration, STEL or Ceiling. For a worst case strategy, the industrial hygiene goal is to identify the most exposed job and workers and evaluate it. If the exposure is acceptable, the remaining jobs are then also acceptable. A targeted assessment selects specific jobs, tasks and conditions of interest, often to evaluate Similar Exposure Group (SEG) exposures. A true random strategy would use random number assignments to select days, shifts, jobs and workers. A stratified random process would select a specific aspect, such as a specific job but then randomize other factors such as days and workers.
- **Long Term Average (LTA).** “Long” is a relative term. In the context of human health risk assessment it can mean an exposure averaged over days, weeks, months, years or a lifetime. In the area of public health and exposure to carcinogens, a lifetime average has been used. In industrial hygiene it is typically the average exposure for an 8 hour work day.
- **Metrics:** Relating to measurement; a type of measurement-for example a measurement of one of the various components of tank waste vapors (e.g., air concentration of benzene). Metrics can be applied to both dose and response (e.g. nasal concentration of formaldehyde (dose) and irritation (response)).
- **Root Cause** A factor that causes a nonconformance and should be permanently eliminated through process improvement.
- **Root Cause Analysis** A collective term that describes a wide range of approaches, tools, and techniques used to uncover causes of problems
- **Task Based Assessment (TBA).** A task based assessment targets specific work activities with materials in the work environment or that are used in the process. Jobs usually handle multiple tasks in a day, week or month. Task Example: replacement of a camera in a tank.

SAMPLING/SAMPLES

- **Area Samples (AS).** Area samples are usually stationary samples taken in an area that a worker might inhabit. They are not personal samples but could represent the possibility of worker exposure for those in that area.
- **Direct Reading Instrument (DRI).** Instruments designed to sample the air usually in real time (very short averaging time) for specific or general classes of analytes.
- **Grab Samples (GS).** A GS uses a volume of air obtained almost instantaneously by rapidly filling a bag or evacuated cylinder. It is designed to measure the concentration extant at that particular point-in-time.
- **Personal Breathing Zone Samples (PBZ).** Air samples taken in worker breathing zones to determine their personal (and estimated work group) exposures. PBZs are worn in the collar or shoulder area in the breathing zone of the worker.
- **Source Samples (SS).** These are samples taken directly in what is anticipated to be the source of the air contamination, such as at a stack exit or breather vent or over an evaporating spill. They do not represent a direct worker exposure, but they do characterize and bound the possibility of a subsequent exposure to a portion of the concentration value. Given the proper circumstances and associated data (e.g., flow rate) these samples can be used for inhalation exposure modeling input.
- **Time-Integrated Sampling (TIS).** Air monitoring that happens over a time period of tens of minutes to hours. The total amount of agent collected is divided by the total amount of air sampled and the result is the average concentration that occurred over that period of time.

CHEMICALS/ EMISSION

- **Aerosol:** An aerosol is a collection of very small particles suspended in air. The particles can be liquid (mist) or solid (dust or fume).
- **Characterization of Emissions.** Characterization of emissions, as used in this report, refers to identifying the chemicals that may be present in an emissions plume, as well as determining the range of concentration that may be expected for each chemical of interest. Chemicals of interest are determined on the basis of known or potential toxicity. This definition also applies both to characterization of releases and characterization of the head space.
- **Chemical Family:** The chemical family describes the general nature of the chemical. Chemicals belonging to the same family often share certain physical and chemical properties and toxic effects. However, there may also be important differences. For example, toluene and benzene both belong to the aromatic hydrocarbon family. However, benzene is a carcinogen, but toluene is not.
- **Chemicals of Potential Concern (COPCs):** The list of chemicals present in tank head space at > 0.025 mg/m³ was the base from which the COPCs were developed. The known chemicals were provided in a number of reports, with this current discussion drawing largely on the list by Stock in PNNL- 13366 Rev1 (Stock 2004) and RPP-22491 Rev1 (Meacham 2006). According to Burgeson 2004, the Hanford TWINS system was used to review the Tank Characterization Database for a list of chemicals to review for OEL development. This process is described in multiple reports (Meacham 2006, Burgeson 2004). An IH Data Quality Objective Team (Banning 2004) developed a preliminary list of chemicals for monitoring, and included consideration of toxicity, including odor thresholds and odor descriptors. The COPC process at the time identified 52 high priority chemicals, 1538 requiring further evaluation, and 236 with low probability of exposure. The OEL development drew on a wide range of available, published OELs, and on toxicology data and methods to derive additional OELs, as described in detail in Burgeson 2004. The OEL development was a significant and necessary undertaking. Some updates and additional COPCs have been included since then. For the most part the COPCs appear to have been developed based on the ratio of head space concentration to 8 hour time weight average OEL (i.e., OEL TWAs) as defined above.
- **Irritant:** A chemical that gives an adverse local tissue response to direct contact by a chemical. It can cause reddening, soreness or physical lesions to the affected area. In the realm of inhalation exposure it causes these effects in the upper respiratory tract which is the target organ.
- **Vapor:** A vapor is the gaseous form of a material which is normally solid or liquid at room temperature and pressure. Evaporation is the process by which a liquid is changed into a vapor.

EXPOSURE

- **Acute Exposure** occurs over a relatively short period of time compared to chronic exposure. The time frame can be a single day or much shorter, down to a single or partial breath.
- **As Low As Reasonably Achievable (ALARA)**, in the context of industrial hygiene, emphasizes that every reasonable effort be made to maintain occupational exposures to as far below the occupational exposure limits as practical, taking into account the state of technology, the economics of improvements in relation to the state of technology, the economics of improvements in relation to benefits to the public health and safety, and other societal and socioeconomic considerations.
- **Bolus Exposure (BE)** is an **acute exposure** to a relatively high concentration of airborne contaminants. Where time-weighted average exposures may be measured in tens of minutes to hours, bolus exposures are measured in seconds to tens of seconds. Bolus exposures can also cause an untoward health effect that is different from the effect caused by exposures metered out somewhat evenly over 8 hours. In the case of some compounds, lung irritation may occur as an acute effect from exposure and represents the hazard for short-term and relatively high intensity exposure. The toxic effects of bolus exposures are typically not investigated with experimental data. When these data are available they would be critical to understanding and gauging the potency of the compound from acute exposures.
- **Chronic Exposure** occurs over a long period of time, usually day after day for many months or years.
- **Dose/Dosimetry:** The amount of a substance to which a person is exposed over some time period. Dose is a measurement of exposure. In general, the greater the dose, the greater the likelihood of an effect. An

"exposure dose" is how much of a substance is encountered in the environment. An "absorbed dose" is the amount of a substance that actually got into the body through the eyes, skin, stomach, intestines or lungs.

- **Dose-Response:** The relationship between the amount of exposure (dose) to a substance and the resulting changes in body function or health (response).
- **Dose-Rate:** The mass per time delivered, such as nanograms per second. A low dose-rate may allow detoxification mechanisms time to work adequately, but a high dose-rate may overwhelm those pathways.
- **Exposure:** Contact with a substance through swallowing, breathing, or touching the skin or eyes. Exposure may be short-term (**acute**), of intermediate duration (**sub-chronic**), or long-term (**chronic**).
- **Exposure Assessment (EA).** EA establishes the extent to which exposure to hazards intersect with worker activities. EA involves defining the agents (e.g., chemicals of concern), identifying suitable sampling and analytical methods, defining the exposure survey strategies, completing the surveys, analyzing the samples, evaluating the data, and communicating the results. Any corrective measures indicated as needed to reduce exposures would be part of the risk management stage. The EA strategy can have components for chronic (long term), sub-chronic and acute (short term) exposures. The EA strategy may also define the frequencies, durations, and concentrations of exposures, for different activities associated with the work done.
- **Exposure Metric (EM).** This is the measurement type that most closely correlates with the adverse health effect associated with the exposure. For example, the best exposure metric for Type IV contact dermal allergy (e.g., poison ivy) is the daily exposure to the worst 1 square centimeter of skin expressed in mg/cm². For a chronic hazard from most inhalation exposures the 8 hour time-weighted average should be the best exposure metric related to risk. For materials that react quickly as irritants to the upper respiratory tract, a short term (STEL) or preferably a ceiling (C) exposure limit would be the best metric.
- **Near Miss** Near misses describe incidents where no property was damaged and no personal injury sustained, but where, given a slight shift in time or position, damage and/or injury easily could have occurred.
- **Occupational Exposure Limit (OEL)** is the concentration of a chemical in the workplace air to which most people can be exposed without experiencing harmful effects. Exposure limits should not be taken as sharp dividing lines between safe and unsafe exposures because it is possible for a chemical to cause health effects in some people at concentrations lower than the exposure limit.
- **OEL Ceiling (C)** OEL-C as used in this report reflects the concept presented in the ACGIH TLV® Documentation as "the concentration that should not be exceeded during any part of the day. If instantaneous measurements are not available, sampling should be conducted for the minimum period of time sufficient to detect exposure at or above the ceiling value." Thus, this limit is meant to protect workers from effects with very rapid onset. See Appendix H for a discussion of issues surrounding the development of duration specific OEL-C values.
- **OEL Excursion Limit:** When an OEL-C does not exist, the American Conference of Governmental Industrial Hygienists (ACGIH), the premiere body setting OELs, has initiated a default limit, the OEL Excursion Limit: "Excursions in worker exposure levels may exceed 3 times the TLV- [8 hour] TWA for no more than a total of 30 minutes during a work day, and under no circumstances should they exceed 5 times the TLV-TWA, provided that the TLV-TWA is not exceeded" [2014 Threshold Limit Values for Chemical Substances and Physical Agents, ACGIH, Cincinnati, OH].
- **OEL Short-Term Exposure Limit (STEL)** is the average concentration to which workers can be exposed for a short period (usually 15 minutes) without the likelihood of experiencing irritation, long-term or irreversible tissue damage, or reduced alertness. The OEL-STEL is typically set for faster acting toxicants that accumulate over time, causing conditions such as cancer or organ damage. This limit is compared to the **time-integrated air sampling** results. The number of times the concentration reaches the STEL and the amount of time between these occurrences may also be restricted.
- **OEL Time-Weighted Average (TWA)** is the exposure for a particular time frame that is considered to present a not-unacceptable risk. An OEL-TWA is typically set for a chronic health hazard such as cancer or organ damage that accumulates over time. This limit is compared to the time-integrated air sampling results as defined above. The ratio of OEL TWA/8 hr time-integrated exposure (sample or monitored) represents the potential risk or risk characterization for the health effect of concern.

- **Time-Weighted Average Exposure (TWA).** TWAs are the average concentration/exposure to a person over a specified period of time. In the realm of industrial hygiene is this typically 15 minutes and 8 hours average concentrations for comparison to OEL STEL and OEL TWA, respectively.
- **Time-Weighted Average (TWA) Exposure Limit** is the time-weighted average concentration of a chemical in air for a normal 8-hour work day and 40-hour work week to which nearly all workers may be exposed day after day without harmful effects. Time-weighted average means that the average concentration has been calculated using the duration of exposure to different concentrations of the chemical during a specific time period. Higher and lower exposures are averaged over the day or week.
- **Peak Exposure.** Associated with **bolus exposures**, the peak exposure is the highest concentration during any particular exposure period. Because it is potentially instantaneous, there is no averaging time for peak exposures (averaging time = 0). In the realm of industrial hygiene, it is typically the highest concentration for comparison to the **OEL C** or **OEL Excursion Limit**.
- **Similar Exposure Group (SEG).** The SEG concept is that workers doing similar work in similar ways in similar environments with similar chemicals experience similar exposures. Determination of the exposure for one or more group members is extended to the whole group.
- **Sub-chronic Exposure.** Exposure that is intermediate between acute and chronic, typically on the scale of a few weeks.

RESPONSE/EFFECT

- **Acute Effects** are adverse health conditions that develop immediately or a short time after exposure to toxic substances. Acute health effects may appear minutes, hours, or days after an exposure.
- **Adverse Health Effect** is any physiological reaction—biochemical, pathological, functional—that impairs performance or the ability to withstand additional challenge in the person exposed to the causative agent. Adverse health effects span a vast potential range from mild and reversible effects to severe effects that may even be life-threatening. Adverse health effects may be acute or chronic. This report focuses principally upon the irritation, mainly upper respiratory, reported by workers exposed to transient chemical vapors on the Hanford tank farms.
- **Chronic Effects** are persistent adverse health outcomes from exposure to toxic substances. Some cancers and Chronic Obstructive Lung Disease (COPD) are examples. Chronic effects are often the result of chronic exposure but can be the result of acute (short-term or even a single) exposure.
- **Irritancy/Irritation:** Irritancy is the ability of a material to irritate the skin, eyes, nose, throat or any other part of the body that it contacts. Signs and symptoms of irritation include tearing in the eyes and reddening, swelling, itching and pain of the affected part of the body. Irritancy is often described as mild, moderate or severe, depending on the degree of irritation caused by a specific amount of the material. Irritancy is usually determined in animal experiments.
- **Mode of Action:** Refers to a range of adverse biological response(s) (e.g., irritation, inflammation) associated with a known exposure (i.e., dose) to a chemical. Toxicants are often classified/grouped according to their mode of action (e.g., irritants, sensitizers, CNS depressants). The mode of action is a measure of adverse response over a range of exposures (doses).
- **Odor Threshold:** As the name implies it is the concentration in air that is just recognized as an odor. This onset of perception varies for different individuals with younger person generally being able to detect chemicals at lower levels than older people. Some compounds are extremely odiferous but relatively harmless even though their odor can be considered unpleasant. Some compounds have no odor at all but are very harmful even fatal at high enough concentrations. A prime example is carbon monoxide. Odor threshold may vary with exposure as those inhaling it can become fatigued. Hydrogen sulfide is a prime example of a very dangerous chemical whose odor threshold can shift as exposure is prolonged or concentration dramatically increases.
- **Response:** The biological result of an exposure. This term is synonymous with effect, but emphasizes the receptor who responds (e.g., a worker) rather than the agent that acts upon the receptor (e.g., a chemical).
- **Sign:** An objective health assessment that can be observed/measured (ex. throat redness and inflammation).
- **Symptom:** A subjective health assessment that cannot be directly measured (ex. sore throat).

- **Target Organ:** This is the area of the body adversely affected by overexposure to any particular chemical or mixture of chemicals. The target organ from chronic exposure nitrosamines is the liver with the effect being liver damage or liver cancer. The target organ for acute or bolus exposures to nitrosamines may be the upper respiratory tract with the adverse effect being local tissue irritation. Neurotoxins attack the body's nervous system as the target organ. Central nervous system (CNS) depression from chemical exposure can result in intoxication and sometimes a headache.

MIXTURE EXPOSURE

- **Additivity:** If two or more chemicals are expected to adversely affect the same target organ (e.g., upper respiratory tract) and their effect is assumed to be proportional to the toxic potency then they are said to have additive effect as a mixture. $1 + 1 = 2$
- **Independence:** If two or more chemicals act independently on separate target organs, then no mixture effect is ascribed to their simultaneous exposure.
- **Potentiatio:** If one element is determined not to have a toxic effect at its typical exposure level but when combined with a second chemical the pair exerts an enhanced effect. $0 + 1 = >1$
- **Synergy:** The potency of chemicals in the mixture is expressed as a much higher effect than their sum. Indeed, it can be multiplicative. $2 * 5 = 10$
- **Antagonism:** The combination of two or more chemicals is less potent than predicted by additivity. $1 + 1 = < 2$
- **Sensitization:** An immunological response to an exposure to a specific chemical such that the body's immune system first recognizes, then marshals defenses against the chemical and finally over-reacts to subsequent exposures to the chemical.
- **Immediately Dangerous to Life or Health (IDLH):** It is an airborne concentration of a chemical that is considered an immediate danger to life and health. The IDLH for ammonia has been set at 300 ppm.

RISK

- **Acceptable Risk:** The risk level deemed acceptable by the individual (worker), organization, or society as a whole. The definition of "acceptable risk" relative to human chemical exposure is subjective and politically determined. In a technical sense, it is often more useful and appropriate to simply declare that the risk is "not unacceptable" in accordance with the judgment of some body of technical experts (e.g., the ACGIH TLV Committee, working OELs determined for the Hanford COPC). It is analogous to the statistical construct in which one does not accept the null hypothesis; one simply fails to reject it.
- **Risk Communication:** The process of communicating the results of a risk assessment to the affected stakeholders and obtaining and incorporating their feedback into the risk assessment process.
- **Risk Management:** The control of risks to acceptable levels through applying various control and/or remediation techniques. Sampling and Analytical Methods (SAM). Validated (proven reliable) methods to collect air samples and the analytical method used to quantify the samples.
- **Unacceptable Risk:** It is the chance of an adverse health effect caused by chemical exposure that is judged to be too high to allow. In the area of industrial hygiene, the exposure that is anticipated to result in an untoward health effect is considered unacceptable. In the scheme forwarded by the American Industrial Hygiene Association, any scenario in which the exposure is less than 10% of the OEL ($\text{Exposure/OEL} < 0.1$) is considered to present an exposure and risk that is characterized as not unacceptable. Note that it is important to choose the correct OEL in order to determine whether any particular health risk from chemical exposure is unacceptable or not. A ratio of time-weighted average exposure/TWA OEL may be less than 0.1 and considered not unacceptable. However, if a bolus exposure occurred then the appropriate determination of unacceptable risk would be the ratio of peak exposure/OEL Ceiling or an OEL Excursion Limit.

GENERAL

- **Contractor.** This term, as used in this report, includes parent corporations and subcontractors that have been hired with DOE money to perform work at a DOE site (like those at the Hanford Site in Washington state) in furtherance of a DOE mission

- **Line Management** A management system in which instructions are passed from a manager or worker to the person at the next higher or lower level
- **Occupational Medicine** The branch of medicine that deals with the prevention and treatment of diseases and injuries occurring at work or in specific occupations.
- **Stakeholder:** Generally, an individual, group or organization with an interest in, or potentially impacted by, the outcome of a risk policy or management choice.

WASTE TANKS

- **Active Venting System.** An active venting system, as used in this report, refers to a venting system that involves air movers to supply motive force for drawing air and vapors out of the tank head space. It does not refer to passive vents that are simply an open riser with a filter and vent cap on top.
- **Double Shell Tank (DST)** underground storage tank with an inner and an outer steel shell and with leak detection in the annular space between the shells.
- **Engineering Controls:** Engineering controls help reduce exposure to potential hazards either by isolating the hazard or by removing it from the work environment. Engineering controls include mechanical ventilation and process enclosure. They are important because they are built into the work process.
- **Passive Vent.** A passive vent, as used in this report, refers to a riser from the tank head space with a filter and cap on top. A passive vent does not have motive force supplied by air movers or any other such equipment. Flow into or out of the tank is driven by changes in barometric pressure or the dynamic pressure of wind
- **Single Shell Tank (SST)** underground storage tank with a single steel wall containing the stored material.
- **Stack.** The term stack, as used in this report, refers to an exhaust stack for an active venting system connected to the tank head space. It does not refer to a riser which supports a passive vent.
- **Vent,** as used in this report, refers to a passive vent on top of a riser connected to the tank head space. It does not refer to the exhaust stack of an active venting system.

ATTACHMENT 1. TEAM MEMBER QUALIFICATIONS**WILMARTH, WILLIAM R.****CURRENT POSITION**

- Chair, Hanford Tank Vapor Assessment Team
- Senior Advisory Scientist, Savannah River National Laboratory, Aiken, SC

PERTINENT PROFESSIONAL EXPERIENCE

- 33 years' experience in the government nuclear industry. Recently:
- Member, Hanford Tank Waste Disposition Integrated Flow-sheet Core Team
- Led a multi-organization review of high-level waste salt processing at Savannah River and a salt processing options study for DOE-SR
- Led a multi-national laboratory expert review group of the ⁹⁹Tc/LAW Recycle Demonstration Project for Washington River Protection Solutions
- Co-Lead breakout session at the Department of Energy's Nuclear Separations Technologies Workshops
- Served as the National Laboratory lead for Technology Development of Pretreatment Solutions

SPECIALIZATION/EXPERTISE

- Radiochemical separations and purification nuclear waste processing and plutonium recovery
- Flow-sheet development of novel processes to address technical problems in the DOE complex
- Actinide Chemistry, Physical Properties and Reaction Chemistry
- Application of spectroscopic methods (Vibrational, thermal analysis, EXAFS, etc.) for the characterization of dilute species in High Level Waste

EDUCATION

- Ph.D., Chemistry, University of Tennessee
- B.S., Chemistry, Clemson University

MAIER, M. ANDREW**CURRENT POSITION**

- Deputy Chair, Hanford Tank Vapor Assessment Team
- Associate Professor, University of Cincinnati College of Medicine

PERTINENT PROFESSIONAL EXPERIENCE

- 21 years' experience in occupational and environmental health
- Chair or Expert Panel member of numerous expert committees on chemical risk assessment including National Academy of Sciences (NAS) and Toxicology Excellence for Risk Assessment (TERA)
- Toxicology Fellow at the National Institute for Occupational Safety and Health (NIOSH); Coauthor of NIOSH Immediately Dangerous to Life or Health methodology and developer of dossiers for NIOSH IDLH values and skin notations.
- Prior IH experience in the Petrochemical Industry.
- Active researcher and recognized scientist in developing occupational and emergency exposure limits. Experience in developing or reviewing chemical risk assessments and exposure guidance for hundreds of individual substances.

SPECIALIZATION/EXPERTISE

- Diplomate of the American Board of Toxicology (DABT)
- Certified in Comprehensive Practice by the American Board of Industrial Hygiene (CIH)
- Past President and current Councilor – Society of Toxicology Occupational and Public Health Specialty Section
- Past Chair and Current member of the Workplace Environmental Exposure Levels (WEEL) Committee

EDUCATION

- Ph.D., Molecular Toxicology, University of Cincinnati
- M.S., Industrial Health, University of Michigan
- B.S., Natural Resources, Ball State University

ARMSTRONG, THOMAS W.

CURRENT POSITION

Principal Investigator, TWA8HR Occupational Hygiene Consulting, LLC

PERTINENT PROFESSIONAL EXPERIENCE

- 35 + years’ experience in industrial hygiene and safety management, last before retirement in a major petrochemical company
- Developed and implemented safety and health management practices across multiple divisions of a corporation
- Member of two National Academy of Sciences committees that delivered critical reviews of the risk assessments for two (Manhattan, KS, Boston, MA) national high containment (BSL-4) microbiological research laboratories
- Member of teams that delivered critical reviews of two US EPA chemical risk assessments
- Led development of IH Mod, an Excel spreadsheet based suite of mathematical models to estimate air contaminant concentrations
- Contributor to several chapters in *Exposure Reconstruction and Mathematical Models to Estimate Occupational Exposure to Chemicals*
- Member of a company committee that reviewed and developed occupation exposure limits

SPECIALIZATION/EXPERTISE

- Dissertation, Quantitative Microbial Risk Assessment for *Legionella pneumophila*
- Developed and deliver courses on mathematical models to estimate exposure to chemicals, and on Monte Carlo Simulation techniques in exposure assessment and risk assessment.
- Deliver graduate school lectures on protective equipment selection and use
- Interpretation of industrial hygiene survey data and associated health risks
- Development of metrics and methods for exposure assessment in epidemiology studies to understand the relationship of diseases and exposure to toxic substances

EDUCATION

- Ph.D., Environmental Engineering, Microbial Risk Assessment, Drexel University
- M.S., Environmental Health, Drexel University
- B.S., Chemistry, Drexel University

FERRY, ROBERT L.

CURRENT POSITION

Partner, TGB Partnership, Hillsborough, NC

PERTINENT PROFESSIONAL EXPERIENCE

- 39 years’ experience in the storage tank industry. Recently:
- Developed emission factors and emissions estimating methodology for storage tanks, published by both industry and the US EPA.
- Evaluated options for control of emissions from storage tanks on behalf of industry in response to proposed US EPA regulations.
- Led training workshops on estimating and controlling emissions from storage tanks for industry, US EPA and State regulatory agency personnel.

SPECIALIZATION/EXPERTISE

- Estimation of emissions from storage tanks.
- Evaluation of venting requirements for storage tanks.
- Determination of storage tank compliance with air regulations.

<p>EDUCATION</p> <ul style="list-style-type: none"> • M. Eng., Civil (Structural), Cornell University • B.S., Civil & Environmental Engineering, Cornell University
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<p>HENSHAW, JOHN</p>
<p>CURRENT POSITION Senior Vice President, Managing Principal, Cardno Chemrisk, Sanibel, FL</p>
<p>PERTINENT PROFESSIONAL EXPERIENCE</p> <ul style="list-style-type: none"> • 40 years’ experience industry and government – industrial hygiene, safety and environmental health. • Served as Assistant Secretary of Labor for the Occupational Safety and Health Administration (OSHA Administrator) - 2001-2004 • President of the American Industrial Hygiene Association (AIHA) 1990-1991 • Fellow of the American Industrial Hygiene Association • Director Environmental, Safety and Health (ESH) - three multinational chemical companies. • Director ESH Quality Assurance - Monsanto • Manager/Director Industrial Hygiene Program/AIHA Accredited Laboratory - Monsanto
<p>SPECIALIZATION/EXPERTISE</p> <ul style="list-style-type: none"> • 35 years’ as a Certified Industrial hygienist (CIH) • OSHA standards and industry practice in industrial hygiene and safety • Industrial hygiene monitoring, exposure assessments and risk assessments for chemical and physical agents • Risk Management and Communications
<p>EDUCATION</p> <ul style="list-style-type: none"> • M.P.H., Industrial Hygiene and Environmental Health Administration, University of Michigan • B.S., Biology/Education, Appalachian State University

<p>HOLLAND, REBECCA A.</p>
<p>CURRENT POSITION Lead Senior Health Physics Technologist , Hanford Nuclear Reservation, Richland, WA</p>
<p>PERTINENT PROFESSIONAL EXPERIENCE</p> <ul style="list-style-type: none"> • 28 years’ experience in the government nuclear industry. Recently: • Member, Hanford Advisory Board • Chair, Health Safety & Environmental Protection Committee, Hanford Advisory Board • Member, Tank Waste Committee, Hanford Advisory Board • Member, Chemical Vapor Solutions Team, Medical Protocol and Event Response Committees • Served on Board of Directors for the United Way of Benton and Franklin Counties and the Community Relations Committee • Chair, Conduct of Operations Committee, Westinghouse Hanford • Served as Recording Secretary for the Hanford Atomic Metal Trades Council
<p>SPECIALIZATION/EXPERTISE</p> <ul style="list-style-type: none"> • Provide contamination and radiation exposure control • Perform special studies in the evaluation of radiological protection for personnel, environment and the public • Worker/Trainer for Respiratory Protection and 40-hour Hazardous Waste Worker qualifications • Provide assistance in the preparation of radiological control documents • Lead, instruct and guide employees in Radiological Protection and Safety
<p>EDUCATION</p> <ul style="list-style-type: none"> • Nuclear Technology courses, Columbia Basin College • Union Leadership and Administration courses, National Labor College • Working toward B.A. in Human Resource Management, Western Governor’s University

JAYJOCK, MICHAEL A.
CURRENT POSITION Sole Proprietor, Jayjock Associates, LLC, Langhorne, PA
PERTINENT PROFESSIONAL EXPERIENCE <ul style="list-style-type: none"> • 30 year experience in assessing Human Health Risk from Chemical Exposure • Lead Author, Risk Assessment Principles for the Industrial Hygienist, AIHA Press • Lead or co-author on numerous publications on exposure/risk assessment and modeling of inhalation exposure • Member, AIHA Exposure Assessment Strategies and Risk Assessment Committees • Member and co-author on the National Academy of Sciences Committee to Review Risk Management in the DOE's Environmental Remediation Program: Building Consensus Through Risk Assessment and Management of the Department of Energy's Environmental Remediation Program, National Research Council, National Academy Press, Washington, D.C.
SPECIALIZATION/EXPERTISE <ul style="list-style-type: none"> • Exposure Assessment, Physical-chemical modeling of inhalation exposure • PhD Thesis: Sampling bias in the exposure assessment of aerosols from size differential and induced electrostatic charge • Developer of the "Backpressure Model" for large vaporizing sources indoors • Contributor to the development of IH MOD user-friendly modeling software for inhalation exposure • Educator and mentor of young professionals in the field of human health risk assessment
EDUCATION <ul style="list-style-type: none"> • PhD in Environmental Engineering, Exposure Modeling, Drexel University • M.S. in Environment Science, Occupational Health, Drexel University • B.S. in Sec Ed (Chemistry), The Pennsylvania State University
LE, MATTHEW H.
CURRENT POSITION Supervising Health Scientist and Regional Manager, Cardno ChemRisk, San Francisco, CA
PERTINENT PROFESSIONAL EXPERIENCE <ul style="list-style-type: none"> • As a consultant, have evaluated industrial hygiene program performance within the energy, textiles, oil/gas, telecommunications, and chemical production industries • Served as Project Director for CDC's Los Alamos Historical Document Retrieval and Assessment Project, a Phase I exposure/dose reconstruction feasibility analysis of the Los Alamos National Laboratory • Served as the Lead Health Physicist and public outreach professional for the Santa Fe Buckman Direct Diversion Health Risk Assessment • Authored numerous peer-reviewed papers and invited lectures on human health risk assessment, hazard communication, exposure assessment, and industrial hygiene • Current President of the Genetic and Environmental Toxicology Association of Northern California
SPECIALIZATION/EXPERTISE <ul style="list-style-type: none"> • Chemical and radiological health risk assessment • Industrial hygiene program evaluation • Exposure/dose reconstruction • Risk communication and management
EDUCATION <ul style="list-style-type: none"> • M.P.H., Occupational and Environmental Health Sciences, Tulane University • B.S., Health Physics, Purdue University • Certified Industrial Hygienist (CIH), American Board of Industrial Hygiene • Certified Safety Professional (CSP), Board of Certified Safety Professionals

ROCK, JAMES C.
<p>CURRENT POSITION Vice President, Research & Engineering, TUPE, Inc., Bryan TX</p>
<p>PERTINENT PROFESSIONAL EXPERIENCE</p> <ul style="list-style-type: none"> • 27 years as USAF officer, retired as Colonel after Commanding the USAF Occupational and Environmental Health Lab, the Air Force Radiation Assessment Team (DOD first responders for nuclear weapon accidents), Superfund site assessment team & Herbicide Orange Incineration Team. Served as Industrial Hygiene Consultant to Surgeon General. • 12 years - Graduate Faculty of Nuclear Engr Dept, Texas A&M College of Engineering; taught, at least once, all graduate & undergraduate courses in safety engineering, fire protection engineering, industrial hygiene engineering and non-ionizing radiation and sponsored graduate student research in all of these areas. • Conducted research in high energy density deuterium fusion with a dense plasma focus based on an earlier design developed at Los Alamos National Laboratory. In 2003 this was the brightest short pulse neutron source in the nation and had the longest beam line. • Started the Exposure Assessment Strategies Committee for the American Industrial Hygiene Association in 1987, served as final editor on 1st two editions of its best-selling publication that started the process of quantifying professional judgment. • Past President and Fellow of the American Industrial Hygiene Association (AIHA) • Past board member of the International Occupational Hygiene Association, a non-governmental organization with standing to recommend standards to WHO and ILO. • Performed due diligence inspection of Pantex Plant for new contractor.
<p>SPECIALIZATION/EXPERTISE</p> <ul style="list-style-type: none"> • Certified for Comprehensive Practice of Industrial Hygiene by Am Board of IH. • Registered as Professional Engineer in two states, Texas and California • Have engineering experience in site characterization, hazardous waste disposal, and engineering controls for air, water and soil contaminants. • Have Created and Taught Professional Development Courses for AIHA in Exposure Assessment and Bayesian Inference, • Have served on 12 and chaired 9 Industrial Hygiene technical committees. • Information processing experience includes: Monte Carlo Simulations, Frequentist Statistics, Bayesian Inference and Time Series Signal Analysis.
<p>EDUCATION</p> <ul style="list-style-type: none"> • Ph.D., Biomedical Engineering, Signal Processing by living neurons, Ohio State Univ. • M.S., Biomed Engr, Micropipette for Electrophoretic Drug Delivery, Ohio State Univ. • B.S., Electrical & Electronic Engineering, Syracuse University

TIMCHALK, CHARLES
<p>CURRENT POSITION Staff Scientist, Exposure Science & Systems Toxicology, Pacific Northwest National Laboratory (PNNL), Richland, WA</p>
<p>PERTINENT PROFESSIONAL EXPERIENCE</p> <ul style="list-style-type: none"> • 28 years' as an Industrial Toxicologist and Research Toxicologist. Specifically: • As an Industrial Toxicologist for the Dow Chemical Company, focused on chemical toxicity evaluation and human health risk from occupational and consumer exposures. • As a Staff Scientist at PNNL, research focus on the development of new technologies for assessing chemical exposures and the application of computational dosimetry/response modeling to quantify human risk associated with these exposures.

SPECIALIZATION/EXPERTISE

- Application of pharmacokinetics to quantify systemic dosimetry from chemical exposures
- Development of multidisciplinary integrated research programs and teams to advance exposure assessment and toxicology through the development and implementation of novel technologies.
- Diagnostic non-invasive biological monitoring (development/validation of sensors).
- Development of physiologically based pharmacokinetic and pharmacodynamic model for single agents and mixtures.

EDUCATION

- Ph.D., Toxicology, The Albany Medical College of Union University
- B.S., Biology, State University of New York at Oneonta
- Diplomate of the American Board of Toxicology (DABT)

ATTACHMENT 2. INITIAL LINES OF INQUIRY

No.	Line of Inquiry	Exploratory Questions
1. Site Characterization		
1.1	Is the inventory of chemicals in the waste adequately known to predict vapor concentrations?	What changes have been made to the inventory that was originally generated by CH2? Have some chemicals been removed from the contaminants of concern listing?
		Does the technical basis documents account for the trap gas concentrations in sludge and salt slurry?
		During the sampling era, was there any analysis of the organic contents of the gas phase?
		How do the technical basis documents incorporate further chemical and radiolytic degradation of the waste compounds?
1.2	Is the tank head space adequately characterized to enable prediction of breathing zone concentrations?	How many tanks have been sampled? What were the methods used? When were they sampled?
		Have the tank head spaces been sampled during retrieval operations? How often have they been sampled and is there any spatial information about the chemical concentrations?
		For passively ventilated tanks, have exhaust samples been taken and how do they relate to head space concentrations?
		For actively ventilated tanks, have isokinetic stack samples been taken and how do they relate to head space concentrations?
		Have head space samples been taken during retrieval operations? Are the chemical distributions different from the stagnant tank distribution?
		Has the potential for aerosol content in the tank head space emissions been evaluated? If yes, what were the aerosol analysis results?
		Has the oxygen, nitrogen and other inert gas composition of the tank head space vapor been determined? What is the potential for oxygen depletion in a high head space vapor plume?

No.	Line of Inquiry	Exploratory Questions
2. Exposure Assessment		
2.1	How have Exposure Monitoring Strategies been implemented in the vapor control program?	<p>How has the exposure assessment strategy been designed to accommodate the different time courses of exposure? There is a particular question about capturing acute events during potentially higher risk task activities. Examples include:</p> <ul style="list-style-type: none"> • breaching an enclosed system, • waste intrusion (such as pump installation and core sampling), • salt well pumping, • transfer of waste, and • a variety of maintenance activities • others to be determined
2.2	How adequate is the WRPS program handle an Acute Event Strategy?	<p>How successful has the strategy for Task assessments been at capturing acute events possibly tied to tank vapor plumes (as described in Droppo 2004) impinging briefly in worker breathing zones?</p> <p>Has an alternate field crew based approach to acute event sampling been considered?</p> <p>For assessing these acute events, does the EA treat the exposure as essentially instantaneously responsive in order to capture data that represents the acute event? What approaches have been considered for collecting instantaneous or nearly so samples from transient tank vent vapor plumes in the worker zone, such as by mini-SUMA canisters, FIDs or PIDs?</p>
2.3	Has there been a Predictive Analysis of Data?	<p>How much of the available exposure monitoring data set has sufficient details available to develop a predictive model of the likely conditions for as well as the magnitude and duration of acute exposures?</p> <p>Have any full shift samples been obtained from workers noting acute effects?</p> <p>Has a statistical analysis of the available data been done to estimate the possible exposures in the upper tail of the distribution, such as at the 99th percentile? If yes, what exposure range did the analysis suggest?</p>
2.4	Are Sampling Tools and Strategy viable for detecting possible worker exposures?	<p>Were any back calculations done to estimate the possible short term concentrations rather than full shift averages?</p> <p>What instrumentation is currently in use as general area and breathing zone monitoring?</p> <p>What additional instrumentation may be better suited for robustly evaluating acute event exposures at the time of occurrence?</p>
		<p>Could real time sampling, with mini-SUMA canisters or suitable sorbent tube trains have a role in developing more robust acute event exposure data? Could these be deployed for work crew use?</p>

No.	Line of Inquiry	Exploratory Questions
3.0 Dose Response		
3.1	Is the data from vapor exposures sufficient to determine Occupational Toxicology?	Can medical reports for each worker that has been exposed be provided for review? Details concerning specific identifiers should be deleted but ideally we would like to have a comprehensive medical history for each exposed individual.
		Can you provide available vapor analysis data associated with specific worker exposures? How soon after reported exposures were the analysis done? What was the rationale for analyzing for specific COPC and what were the detection limits relative to OELs?
		Can you provide any available data associated with the tank type (e.g., single or double, positive or passive venting) , weather and environmental conditions on days of exposure?
		Have any correlations been established between vapor analysis, weather conditions and/or medical histories and symptoms?
3.2	Is the WRPS IH program’s implementation of Occupational Exposure Limits (OELs) adequate and capable of limiting vapor exposures?	Provide details on current rationale for developing, establishing, refining and updating OELs for tank farm vapors?
		What specific changes has WRPS made/implemented since the previous contractor established OELs for COPC?
		How often have the OELs and COPCs been reevaluated, particularly in light of ongoing worker exposure?
		How is WRPS differentiating between acute and chronic health concerns based upon current established OELs for COPC?
		Is WRPS only considering COPC based upon previous assessment or are COPC being refined as part of an ongoing program?
		Does WRPS believe the focus on OEL for COPCs is providing adequate protection? If so why, if not have you considered the implications of alternative exposure metrics?
		How are odor thresholds being utilized in the context of exposure assessment? What is the rationale for using odor as a marker for overall chemical exposure? How many of the COPC have odor thresholds and how do they compare to OELs?
		In light of ongoing exposures have alternative hazard classification systems, like “hazard banding” been considered? If no, why not?
		Have mixture interactions been considered? If not, why not? If so, how are they being evaluated?
4.0 Risk Characterization		
4.1	Are characterizations of exposure acceptability currently performed retrospectively?	What is the procedure and efficacy of the IH group’s use of toxicity data and OELs as the metrics to characterize an acceptable (or at least not unacceptable) exposure to tank workers? How often is this procedure re-assessed?

No.	Line of Inquiry	Exploratory Questions
		<p>How and why are OELs compared to full shift exposures as the primary metric used to judge exposure acceptability?</p> <p>What was the decision logic for identifying chemicals of concern?</p> <p>What analytical resources are available to identify all the important vapor species in the tanks' head space?</p> <p>What was the decision logic for identifying an OEL for each chemical of concern (TLV, PEL, etc.)? What if a published OEL did not exist? How were carcinogens handled differently? How are acute hazards handled differently?</p> <p>What do you see as the reason for the unacceptable number of acute overexposure effects that have occurred around the tanks in recent months and years?</p> <p>Has any thought been given to the characterization of risk from very acute (a few seconds) exposure to high levels of compounds coming from the head space of the tanks?</p> <p>Are you aware that a 2004 Modeling study by Droppo of the Hanford tanks concluded "Occasional short duration exposures of up to several seconds to relatively undiluted head space air can be expected in the immediate vicinity of the tank vents"?</p> <p>How would you characterize the risk of someone inhaling one or two breaths of vapors at 10% to 100% of tank head space concentration?</p> <p>Has any thought been given to the characterization of risk from exposure to multiple chemicals?</p>
4.1, Cont.	Are characterizations of exposure acceptability currently performed retrospectively?	<p>Has any consideration been given to the psychological effects of perception of a strong odor presumably coming from the tank emissions?</p> <p>Can one please explain the use of SEGs to characterize exposure profiles and compare to an applicable OEL?</p> <p>Were exposure profiles for SEGs the sole source of information used to judge worker exposure; for example, was IH professional judgment or previous modeling work used?</p> <p>Regarding IH data interpretation with respect to identifying potential overexposures to applicable OELs, the current methodology and criteria used to interpret IH data appears to be as follows: < 10% of OEL judged acceptable with respect to no further action required?</p> <ul style="list-style-type: none"> • Were carcinogens handled differently? • Were acute irritants considered? • How was process changes handled? <p>How was statistical analysis and considerations used to judge data as representing a potential overexposure?</p> <p>How was the use of industrial hygienist's professional judgment used in the interpretation of data collected?</p>

No.	Line of Inquiry	Exploratory Questions
4.2	From a perspective view, what are the Potential Future Steps to characterize worker risk after reviewing available information in the current system?	How would you differentiate and characterize acute from chronic risk?
		How do you see odor factoring into this consideration?
		Do you believe more engineering controls are needed to lower the exposure potential? If so which control(s) would you think might be most cost-effective?
		Do you believe that a control banding approach would serve as the best system for on-site industrial hygienists to manage such a complex occupational environment?
		How would you view these potential banding approaches to risk characterization? How would you see them working?
5.0 Chemical Vapor Risk Communication		
5.1	Is the Risk Communication from WRPS to the Tank Farm Workers adequate?	Does WRPS effectively communicate that protection of human health and the environment against chemical vapors is a top priority? Do they promote the achievement and maintenance of high levels of safety?
		Are Employees fearful of retribution or retaliation to communicating Tank Vapor issues?
		Openly acknowledge risks as well as discuss benefits.
		Are there established processes that give workers choices with regards to chemical vapor-related issues and are they effective?
		Does WRPS offer clear, understandable information via sources that are trusted?
		Are there established mechanisms for on-going worker input, or for answering questions from the workers, to create a true dialogue?
		Does WRPS provide responders to emergencies including events perceived as emergencies by the public, with requisite training, procedures, etc. such that: <ul style="list-style-type: none"> • Workers are given a sense of control by telling them what they can do to protect themselves? • Honestly acknowledge uncertainty when it exists. • Provide simple information from trusted sources on the nature of the chemicals
5.2	Is the Risk Communication from the Workers to WRPS adequate?	If feedback mechanisms are available, do Tank Workers use them and if not why?
		Is feedback given in the ISMS process to decrease the potential for chemical vapor exposures and is that feedback acted on?
		Are stop work and timeouts utilized by the workers?
5.3	Is the Risk Communication from WRPS to the	Does WRPS demonstrate that they are respectful of public concerns?

No.	Line of Inquiry	Exploratory Questions
	Community and Stakeholders adequate?	<p>Has WRPS provided hospitals and healthcare workers with sufficient information such that they are knowledgeable about the risks and proper protocol for treating affected workers?</p> <p>Is transparency and honest communication with the public, the workforce, and stakeholders an essential element to building and maintaining trust?</p> <p>Are all stakeholders considered and how are the stakeholders viewpoints documented?</p>
6.0 Risk Management		
6.1	Are Policies and Procedures implemented and integrated into quality management system such that exposures to tank vapor are controlled?	<p>What is the established hierarchy and nomenclature of safety and health policies, procedures, work practices, etc.?</p> <p>What are the high level safety and health policies in place at the site and how are they developed and who is involved in developing and approving these policies?</p> <p>What are the next level of management systems used at the site (i.e. procedures, work practices, etc.)? Who determines what management systems are needed, how are they developed and who approves them?</p> <p>How the management systems are officially integrated into the Operational Management Systems at the Hanford site and the Department of Energy?</p> <p>How are these management systems communicated and enforced throughout the site?</p> <p>How is the performance against these systems measured?</p>
6.2	Have corrective actions been taken from previous reviews?	<p>What safety and health assessments (reviews) have been done over the 10 years? Request copies of all assessments performed by outside experts over the last 10 years.</p> <p>Have all recommendation/corrective action been addressed? If not, what items have been properly addressed and what items have not and why?</p> <p>What system is in place to assure all corrective actions are properly addressed, closed in a timely manner and independently verified?</p> <p>What assessment(s) have been made of the occupational health/medicine program at Hanford? Request a copy of the current and most recent past assessment.</p>
6.3	Are the organizational structure relationships capable of control tank vapor exposures?	<p>What assessments, if any, have been made to determine the effectiveness of these organizational structures?</p> <p>What operational performance metrics are in place for operations, safety and health functions, other staff functions, committees, etc.?</p>
6.4	Are adequate resources (personnel and equipment) available?	<p>2) How many people are on the staff safety and health function and/or in operations reporting directly to operations? Request listing of names, titles, job descriptions, background, education, and training.</p>

No.	Line of Inquiry	Exploratory Questions
6.5	What Risk Mitigation Measures have been considered in the site Risk Management Plans?	Is wind direction and velocity monitored during work activities in the tank farm? If yes, what plans exist for protection from plume impingement in worker areas during variable or calm/stagnant air conditions? What consideration is given to safe work direction from nearby potential emission points?
		What are the components of the voluntary RPE Upgrade Program? What specific devices are available? Have air purifying cartridges been verified as adequate for the concentrations and kinetics of short acute events such as a plume of 10 to 100% of tank head space vapor?
		What engineering controls have been considered? How is COPUS blower use decided? How are they placed? Has remote venting of all tank vents near a work location been considered? What obstacles might there be to such an approach? Have ventilated enclosures been considered? Could a clean air supply be assured if such positive pressure enclosures are used?