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Analysis of Available Hydrogen Data and Accumulation of Hydrogen in Unvented TRU Drums

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Fluor Hanford
P.O. Box 1000
Richland, Washington

Contractor for the U.S. Department of Energy
Richland Operations Office under Contract DE-AC06-96RL13200

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Analysis of Available Hydrogen Data and Accumulation of Hydrogen in Unvented TRU Drums

November 2001

Executive Summary

This document provides a response to the second action required in the U.S. Department of Energy (DOE) approval of the Justification for Continued Operation (JCO) of Assay and Shipment of Transuranic (TRU) Waste Containers in 218-W-4C Burial Ground. The requested analysis presents the expected probability of accumulation of significant quantities of hydrogen gas in unvented TRU drums. This analysis is based on currently available TRU drum data. Drum venting devices and commercially available venting equipment are reviewed. Finally, a plan and schedule for venting the inventory of unvented drums anticipated during the TRU Retrieval Project is included.

The evaluation of DOE complex-wide experience with TRU waste drums included the Los Alamos National Laboratory, Savannah River Site, Idaho National Engineering and Environmental Laboratory, Rocky Flats Site, Oak Ridge National Laboratory, Fernald, and the Hanford Site. In addition, related data from the National Transportation and Packaging Program and the TRUPACT-II Matrix Depletion Program were evaluated. A large number of unvented TRU waste containers (more than 42,000 drums) have been moved without incident throughout the DOE complex. Hydrogen data are available for 23,677 of these drums.

A review of established methods for estimating hydrogen generation, accumulation, diffusion, and leakage is discussed. These methods are reviewed in the context of Hanford Product Receiver (PR) Can Drums. The studies on PR can drums confirmed that drums with vent clips will not reach a flammable hydrogen concentration. However, in unvented non-leaking drums, it is possible to accumulate flammable levels of hydrogen (as confirmed by actual hydrogen measurement in drums). Hydrogen is flammable in concentrations of 4.1 to 74.2 vol% in air. The combination of 5 vol% hydrogen and 5 vol% oxygen presents a deflagration potential. However, ignition of hydrogen concentrations between 5 vol% and 14 vol% in drums is insufficient to breach the drum. In drums with 15 vol% hydrogen concentration or greater, an explosive event is capable of breaching the drum lid. Therefore, data presented and discussed in this report are evaluated at 5 vol% and 15 vol%. These categories are summarized below:

Hydrogen in concentrations less than 5 vol%	Hydrogen below the lower flammable limit
Hydrogen between 5 and 15 vol%	Hydrogen above the lower flammable limit but less than the energy required to breach a drum.
Hydrogen in concentrations of 15 vol% or greater	Hydrogen when in combination with oxygen capable of breaching the drum lid during an explosion event.

Depending on the site, 1% to 8% of the drums had hydrogen concentrations greater than 15 vol%. These drums were safely moved prior to venting. However, due to numerous factors including waste type and physical waste form, it is not possible to predict the hydrogen concentration in any given drum.

This report describes Hanford Site drum packaging and drum storage conditions. In the context of this report, storage conditions involve drums placed in the low-level burial grounds (LLBG) (both covered and uncovered storage modules). The oldest drums placed in the LLBG between 1970 and 1978 are unvented. Vent clips were used on-site between 1978 and 1985, but drums from off-site generators are assumed to be unvented. Based on these factors, it is estimated that approximately 61% of the covered suspect TRU drums to be retrieved between 2001 and 2006 in 218-W-4B and -4C are unvented. A value of 61% is considered an upper limit because some of the drums from post 1978 off-site generators are likely vented.

Based on HNF-SD-WM-SARR-028, Rev. 3, the annual frequency per drum for a drum explosion is 1.15×10^{-7}. This probability is based on the fact that hydrogen is generated, the probability rate that drums are vented, the formation of explosive mixtures of oxygen and hydrogen, and the potential for ignition to occur. Based on the recent review of data, the annual frequency for an explosion due to drum handling of unvented drums is estimated to be 3.52×10^{-6} per drum. The annual frequency for an explosion due to venting of unvented drums is estimated to be 1.60×10^{-7} per drum. An event with an associated frequency between 1×10^{-4} and 1×10^{-6} is considered to be extremely unlikely. The risk associated with the drum explosion accident is determined by comparing the estimates of frequency and consequences to risk evaluation guidelines. None of these calculated dose consequences exceeds the DOE evaluation guidelines for the public.

Based on the frequency estimates, dose consequences, and a graded approach to risk management, the report recommends a remotely operated venting device with operation controls to protect the worker. A venting plan and schedule is presented to address the inventory of unvented TRU drums. Various methods for venting drums are presented from remote operated devices to large contained devices with blast shields to contain an explosion event. These devices have proved successful in various applications at DOE sites.

The review of additional relevant hydrogen data validates existing safety basis calculations contained in HNF-SD-WM-SARR-028 (WHC 1995a). The revised estimated frequency and dose consequence for an explosion in an unvented TRU drum due to drum handling is estimated to be greater than that for drum venting. Physical and/or procedural conditions are identified for consideration to ensure adequate protection for the on-site worker. Based on this analysis and the experience at other sites, venting of TRU waste drums is considered to be a safe activity and is bounded by the accidents associated with drum handling documented in HNF-SD-WM-SARR-028 (WHC 1995a). TRU waste drum venting is a routine activity at many DOE sites.

Contents

Figures

Tables

Glossary

The following terms are used in the document and are defined for consistency.

Deflagration: The term "deflagration," as a type of explosion, is used to describe a vigorous combustion reaction accompanied by a large release of heat energy. In a deflagration, the flame front propagates through the volume of the gas at speeds well below sonic velocity, and all of the gas within the volume is compressed at (or close to) the same rate.

Detonation: A "detonation" is an alternate state of combustion characterized by flame front propagation at supersonic speeds.

Explosion: An "explosion" is generally defined as a large-scale, rapid and spectacular expansion of material. An explosion may result from either a deflagration or detonation.

1. Introduction

This document provides a response to the second action required in the approval for the Justification for Continued Operations (JCO) Assay and Shipment of Transuranic (TRU) Waste Containers in 218-W-4C.

The Waste Management Project continues to make progress toward shipping certified TRU waste to the Waste Isolation Pilot Plant (WIPP). As the existing inventory of TRU waste in the Central Waste Complex (CWC) storage buildings is shipped, and the uncovered inventory is removed from the trenches and prepared for shipment from the Hanford Site, the covered inventory of suspect TRU wastes must be retrieved and prepared for processing for shipment to WIPP.

1.1 Purpose

Accumulation of hydrogen in unvented TRU waste containers is a concern due to the possibility of explosive mixtures of hydrogen and oxygen. The frequency and consequence of these gas mixtures resulting in an explosion must be addressed. The purpose of this study is to recommend an approach and schedule for venting TRU waste containers in the low-level burial ground (LLBG) trenches in conjunction with TRU Retrieval Project activities.

This study provides a detailed analysis of the expected probability of hydrogen gas accumulation in significant quantities in unvented drums. Hydrogen gas accumulation in TRU drums is presented and evaluated in the following three categories:

- Hydrogen concentrations less than 5 vol%
- Hydrogen between 5 – 15 vol%
- Hydrogen concentrations above 15 vol%

This analysis is based on complex-wide experience with TRU waste drums, available experimental data, and evaluations of storage conditions. Data reviewed in this report includes experience from the Idaho National Environmental Engineering Laboratories (INEEL), Savannah River Site (SRS), Los Alamos National Laboratories (LANL), Oak Ridge National Laboratories, (ORNL), Rocky Flats sites, Matrix Depletion Program, and the National Transportation and Packaging Program.

Based on this analysis, as well as an assessment of the probability and frequency of postulated credible accident scenarios, this study presents a plan and schedule for accomplishing necessary venting for segregated unvented TRU drums. A recommended method for venting TRU drums is proposed. Upon revision of the authorization basis document to include TRU drum venting, and successful completion of readiness activities; TRU drum venting will be implemented in the LLBG.

1.2 Scope

The scope of this document applies to the retrievably stored suspect TRU and TRU waste in the 200 Area LLBG trenches and applies to 55-gallon drums. Specifically, this study supports the retrieval of suspect TRU drums from the covered portions of 218-W-4B and -4C burial grounds over the next five years. TRU waste disposed prior to May 1970 and remote handled TRU wastes are not included.

2. Flammability of Hydrogen-Air Mixtures

2.1 Introduction

The generation/accumulation of hydrogen in unvented TRU waste drums pose a risk due to the potential to form explosive gas mixtures. This section describes the flammable range for hydrogen in TRU waste drums that might result in deflagration or detonation.

2.2 Hydrogen-Air Flammability

Hydrogen is flammable in the concentration range between 4.1 and 74.2%, provided that a minimum of 5 vol% oxygen is present (Swain 1983). The reaction is sluggish and incomplete when hydrogen concentrations are below 8% (EPRI 1988), and requires significant ignition energy. However, for hydrogen concentrations between 20 vol% and 40 vol%, very little energy (on the order of 0.02 mJ) is required to initiate a vigorous reaction known as an explosion, provided that sufficient oxygen is present to achieve complete combustion. Ignition energies are much greater again for hydrogen concentrations above 40 vol%. Increasing pressure effects a given hydrogen-air mixture by reducing the minimum ignition energy.

Hydrogen-air mixtures do not burn unless enough energy is supplied to cause spontaneous combustion on a local scale. If the localized "hot spot" is large enough and persists long enough, a flame front will grow and the gas will be ignited. Ignition may be accomplished in any of the following ways (Postma 1983):

- A spark may be discharged across a gap occupied by a small volume of the gas mixture.
- The gas mixture may be ignited by exposure to a heated surface.
- The entire volume of gas may be heated to the auto-ignition (spontaneous combustion) temperature.

In laboratory experiments, combustible gas mixtures are commonly ignited with a spark plug or a glow plug. Auto-ignition temperatures for hydrogen-air mixtures vary with composition and the amount of water vapor present. Water vapor raises the auto-ignition temperature. Auto-ignition has been shown to occur between 500 and 600 °C for a wide range of conditions (Shapiro and Moffette 1957). Auto-ignition temperatures decrease with increasing pressure (Postma 1983).

The term "deflagration," as a type of explosion, is used to describe a vigorous combustion reaction accompanied by a large release of heat energy. In a deflagration, the flame front propagates through the volume of the gas at speeds well below sonic velocity, and all of the gas within the volume is compressed at (or close to) the same rate. Flame speeds in hydrogen deflagrations peak out at about 300 cm/sec (or about 10 ft/sec) (Postma 1983). Rise times to peak pressure also are fairly slow (less than 1 sec for mixtures in the 25 to 35 % range, up to 5 sec for concentrations near the flammability limits (EPRI 1988).

A "detonation" is an alternate state of combustion characterized by flame front propagation at supersonic speeds. The normally quoted range of detonable hydrogen concentrations, 18.3 to 59 %, (Lewis and von Elbe 1987) is smaller than the flammable range. The detonable limits increase slightly with increasing pressure and temperature (Guirao et al. 1989). The input energy required to initiate a hydrogen detonation is 4 kJ or more (i.e., at least 6 orders of magnitude more than the energy required to initiate a deflagration). The credible risk of a detonation occurring in a TRU waste drum has been evaluated and discounted (Thomas 1994).

A 15 vol% hydrogen-air concentration has been shown to cause a large enough pressure rise from a deflagration to remove the lid from a drum (i.e., to cause a drum explosion). Explosion testing was conducted at the E.I. duPont Explosion Hazards Laboratory, and documented in WSRC-TR-90-165, to determine the minimum concentration at which a drum lid removal occurs. A secondary objective was to investigate the maximum pressure and rate of pressure rise as a function of hydrogen concentration. Observations made during the series of tests showed that drum lid removal occurred at concentrations of 35 vol%, 22 vol%, 18 vol%, and 17 vol%. In the five successful tests resulting in hydrogen ignition at concentrations less than 17 vol%, only bulging of the drum top and bottoms occurred. It was concluded from the tests that an explosive mixture up to 15 vol% of hydrogen can be contained in a 55-gallon TRU drum without total integrity failure via lid removal.

Prior to beginning drum explosion tests, reported in WSRC-TR-90-165, small-scale pressure vessel tests and drum mixing tests were completed. The pressure vessel tests established a relationship between hydrogen concentration and maximum pressure rise. These small-scale tests were used to establish the concentration range over which a drum lid removal might occur. Controlled small-scale pressure vessel tests were conducted over a range of 5 vol% to 50 vol% hydrogen-air concentrations to determine the pressure and pressure rise as a function of hydrogen concentration. It was determined from the pressure vessel tests that both the maximum pressure and pressure rise values occur at slightly above the stoichiometric (2:1 hydrogen:oxygen) concentration of hydrogen in air, a value that corresponds to 30 vol% hydrogen in air.

For a perspective on the temperatures and pressures achieved during a hydrogen deflagration in a 55-gallon drum, Table 1 presents calculated values of the heat energy released, corresponding temperatures, and pressure changes as the result of deflagrations for various 2:1 hydrogen-oxygen mixtures. The 67 vol% case represents the energy release form ignition of a pure 2:1 hydrogen-oxygen mixture in a 55- gallon drum. Note that results from this pure 2:1 mixture would exceed the 2:1 mixture of hydrogen in air. The nitrogen in the air would also tend to decrease temperatures.

Table 1 - Energy Released Based on Hydrogen Volume Percent

Hydrogen Concentration (vol %)	Heat Released by Deflagration (kJ)	Max Temperature (°K)	Calculated Pressure Rise (psig)
15	310	1850	70
30	860	3075	115
67	1370	>5000	180

The following factors tend to reduce the actual consequences (i.e., heat energy, flame temperature, pressure rise) of a hydrogen deflagration relative to the calculated upper-bound estimates. This is achieved by limiting the amount of fuel available to participate in a reaction inside a drum or by altering the temperature and/or pressure rise:

- Void volume
- Leakage and diffusion
- Intensity of radiolysis
- Oxygen depletion in closed drums
- Ignitability of hydrogen-air mixtures
- Heat transfer to solids in the drum
- Volume change of the drum
- Compressibility of solids in the drum
- Sustainable pressure rise before breaching occurs.

2.3 Conclusions

It has been shown that hydrogen is flammable in the concentration range between 4.1 vol% and 74.2 vol%. Ignition of hydrogen concentrations between 4.1 vol% and 15 vol% in waste drums do not contain sufficient energy to remove the lid from waste drums. Deflagration of hydrogen concentrations above 15 vol% causes a large enough pressure rise to remove the drum lid. An evaluation of the accumulation of hydrogen in unvented TRU waste drums and methods to address the hydrogen are discussed in subsequent sections.

3. Evaluation of DOE Complex Wide Experience with TRU Waste Drums

3.1 Introduction

From available data on studies and testing performed on TRU drums stored at SRS, INEEL, LANL, and Rocky Flats, compilations are made of the populations of unvented drums, and what fraction of this group contain hydrogen. The population of drums containing hydrogen is further subdivided based on quantities (volume percent) of hydrogen present.

3.2 Savannah River Site (SRS) Data

SRS began segregating TRU wastes from other radioactive wastes in 1970. The TRU wastes at SRS were further separated, with waste containing less than 0.5 curie (Ci) placed on TRU earthen pads and waste containing greater than 0.5 Ci placed in metal culverts or caissons. Most of the retrievably stored TRU wastes at SRS are ^{238}Pu. The TRU drums stored on earthen pads were unvented. The storage of unvented TRU waste drums on earth-covered pads continued until 1985. TRU drums that were stored after 1985 were vented (Demiter 1998).

3.2.1 SRS TRU Retrieval Project

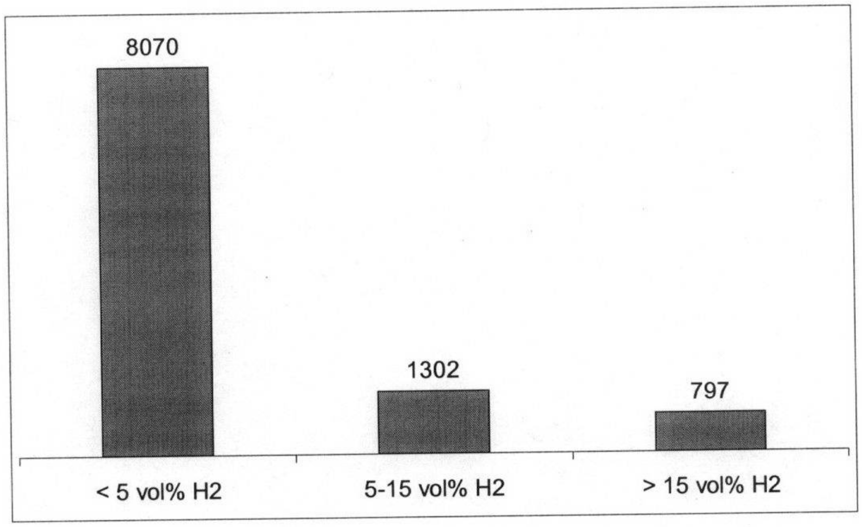
In late 1994, SRS began preparation for a project to retrieve unvented TRU drums from Pads 2 through 6. In January 1997, retrieval and venting of the drums began. The retrieval process began by removing the soil from a mounded pad to within approximately 2 feet of the containers. Next, additional soil was removed from around the edges to prepare a stable surface for safe and easy equipment access to the pad. The remainder of the soil was then removed from around the drums. The drums were lifted, removed, and visually inspected to ensure integrity. Potentially weakened containers were overpacked. Once a drum was retrieved, it was staged awaiting transportation to the vent and purge stations. The drum was vented by drilling a hole in the drum lid. The headspace was sampled for hydrogen concentrations and volatile organic compounds. After sampling, the drum was purged, if necessary, and a filter installed. Finally, the drum was moved to a staging area for transporting to long-term storage or to a facility for further evaluation.

During 1997-2000, 10,169 drums were vented and the combustible gases analyzed. The retrieved waste consisted of job control waste contaminated with ^{239}Pu, (i.e., gloves, cans, pipes and fittings, misc. tools, plastic). The activity in most of the waste was <0.5 Ci. However, a few drums were found with levels up to 7-8 Ci. Drums were standard 55-gallon (DOT 17C). The gaskets were neoprene-butadiene nonporous, 3/8-inch thick tubular gaskets.

Data provided by SRS (Dayley 2001) showed that of 10,169 drums, 8,070 drums had hydrogen concentrations of less than 5 vol% and of these 8,070 drums, 1,824 had no hydrogen. Seven hundred ninety seven (797) drums (7.8%) contained greater than 15 vol% hydrogen and ranged from 15 to 67 vol% (see Figure 1). Oxygen concentrations were not determined.

In some instances, these drums contained concentrations of hydrogen that could not be accounted for by radiolytic processes. It was postulated that the excess hydrogen is a result of hydrolysis of metal components in the waste (Gibbs 1998), *Dispersion of Hydrogen from Vented TRU Drums*). Savannah River Site wastes contain enough moisture from the air in normal circumstances to support such a reaction. The reaction that produces the hydrogen also ties up the oxygen as a metal oxide, so the atmosphere becomes deficient in oxygen. Gibbs (1998) points out that the oxygen in the drums would be depleted from any of the reactions that can produce hydrogen, so the drums, as retrieved, were not potentially flammable.

Figure 1 - Hydrogen Concentration Data for SRS Drums



General Observations:

- Drums stored retrievably under earthen cover, for up to 24 years, were in very good condition. A small percentage (1%) of the 10,170 unvented TRU drums required overpacking.
- Unvented drums were transported approximately one half mile from the SRS retrieval site to the venting building without incident.
- None of the drums had exterior contamination. No loose or airborne contamination was detected at retrieval.
- No hazardous gases (including hydrogen) or materials were detected during retrieval.
- It was demonstrated that TRU drum retrieval, transportation, venting, and subsequent storage could be accomplished safely in an open-air atmosphere without jeopardizing any burial grounds operations standards.
- During retrieval there were no hydrogen related explosion events.

3.2.2 SRS Drum Testing and Results

An experiment was initiated in 1976 to acquire data on TRU drums under actual storage conditions at SRS (Ryan 1982). The experiment was designed to measure the pressure buildup and gas composition within drums that contained TRU waste of high specific activity. To accomplish this, four drums were filled with a known inventory of highly contaminated material consisting of typical SRS waste. The waste was treated normally in all ways, except that special provisions were made to monitor the pressure, temperature, and gas composition in each drum. Measurements were made and data were collected on a monthly basis for over four years.

The magnitude of the maximum pressure was proportional to the activity in each drum. The highest total pressure observed was 6.2 psig, which occurred in Drum #122 (141.6 Ci) after 1,268 days of storage. However, in separate experiments with the drum and gasket combination, drums leaked at least 1 cc/(min)(psig) at 10 psig no matter how tightly the lid was fastened. Because it takes 100 Ci of ^{238}Pu to produce gas at 1 cc/min, even 600 Ci of alpha activity would not cause the pressure to reach 10 psig.

The highest average leak rate was calculated by using the pressure losses for a one-month interval. These calculations were based on an assumed total gas generation rate based on experimental data and on a free internal volume estimate of 70%. The estimated leak rate ranged from 0.4 to 1.7 cc/min for the four drums. It was concluded in the report that the drums leak slowly and continuously, probably from pores or small cracks in the gasket seal.

Figures showing the hydrogen and oxygen concentrations are found in DP-1604. Two drums containing 37 and 47.5 Ci did not approach concentrations of 15 vol% hydrogen and 5 vol% oxygen. The two drums that contained 112.6 and 141.6 Ci of ^{238}Pu showed concentrations of 15 vol% hydrogen and 5 vol% oxygen several times during the experiment.

All of the test drums exhibited significant oxygen depletion as hydrogen gas accumulated. This occurred at slightly different rates because of the random nature of the waste, the differences in contact efficiency with the source of radioactivity, and the variability of the gasket seal. An exact relationship was not observed between oxygen depletion/hydrogen accumulation rates and radiation load because of the variable waste composition and drum seal performance.

3.3 Idaho National Environmental Engineering Laboratories (INEEL) Site Data

The Radioactive Waste Management Complex (RWMC) at INEEL was established in 1952.

In 1970, the 56-acre Transuranic Storage Area was established. Asphalt pads were constructed on which transuranic waste was stacked and then covered with plywood, plastic sheeting, and 3 feet of soil. From 1975 to 1996, air-support buildings were used to protect the stored waste. These were emptied in 1996 and the waste drums moved to newly constructed waste storage facilities in the Transuranic Storage Area at the RWMC. Some 32,000 drums containing waste are currently stored at RWMC pending shipment to the Waste Isolation Pilot Plant (WIPP).

Waste shipments to WIPP from RWMC began in 1999. The INEEL completed 13 shipments of stored transuranic mixed debris waste to WIPP in 2000, for a total of 497 drums. As of February 2001, another 21 shipments were completed and the project is currently operating.

3.3.1 INEEL Waste Retrieval

INEEL uses the process described below in current retrieval activities. Waste drums are removed from permitted above-ground storage facilities, loaded onto trucks, and taken to the venting facility. All stored drums are unvented and have to be vented. Venting is usually the first activity in retrieval, because Real Time Radiography (RTR) is used to verify that the drum liner was penetrated in the venting process. After venting, drums are loaded into trucks and taken to the Stored Waste Examination Pilot Plant (SWEPP), where Nondestructive Analysis (NDA) and RTR are performed. Following these certification activities, drums are transferred to another facility where gas generation testing and headspace gas sampling are performed. Then the drums are transported to permitted storage areas until packaged and sent to WIPP. Waste drums are not analyzed for gases prior to or at the time of venting, so no hydrogen concentration data are available on the retrieved unvented drums.

In the period between 1985-1988, over 17,000 drums were handled. In the early 1990's, thousands more were handled. INEEL staff estimated that each drum was moved about ten times, resulting in hundreds of thousands of drum handling activities. There have been no hydrogen-related fires or explosions during waste retrieval activities at INEEL.

3.3.2 INEEL Testing

A TRU Waste Sampling Program was established in 1983 to evaluate various types of wastes contaminated with TRU isotopes (Clements 1985).

Data are available for 210 drums that were sampled to determine the drum pressure, drum void volume, and gas composition. Drums that were sampled had been stored for six months, three years, and twelve years. Table 2 shows the results. Five of the six drums with greater than 15 vol% hydrogen had less than 1 vol% oxygen. One of the 210 sampled drums contained 17.7 vol% hydrogen and 11.4 vol% oxygen. It had been stored for twelve years.

Table 2 - Hydrogen Concentration Distribution

Waste Form Category	Total Drums Sampled	Drums with no H_2	Drums with <1 vol% H_2	Drums with 1-5 vol% H_2	Drums with 5-15 vol% H_2	Drums with >15 vol% H_2
Combustibles	43	4	21	14	3	1
Metals	29	3	21	4	1	0
Glass	26	9	12	3	2	0
Nonmetal molds and crucibles	11	5	6	0	0	0
Uncemented Sludges	44	2	19	13	9	1
Cemented Sludges and Solutions	11	0	5	2	2	2
Concrete, Brick	9	1	6	1	0	1
Salts	3	0	3	0	0	0
Leaded Rubber	7	0	2	5	0	0
Benelex, Plexiglas	7	0	4	3	0	0
Resins	13	0	3	3	6	1
Mixed Waste-paper, metal, glass	1	0	0	0	1	0
Filters	3	1	2	0	0	0
Particulate Waste	3	0	2	1	0	0
Totals	**210**	**25**	**106**	**49**	**24**	**6**

3.4 Los Alamos National Laboratories (LANL) Site Data

LANL stored 16,600 drums in 20-year retrievable storage on TRU Pads 1, 2, and 4 from 1970 to 1988. The drums were primarily 55-gallon drums with a rigid 90-mil poly liner placed inside the drum. The storage pads were ground-level storage on asphalt pads. Drums were stacked four and five high, usually surrounded by FRP boxes, and covered with 4 feet of earth.

3.4.1 LANL TRU Waste Retrieval

TRU Waste Inspectable Storage Plan (TWISP) operations were as follows:

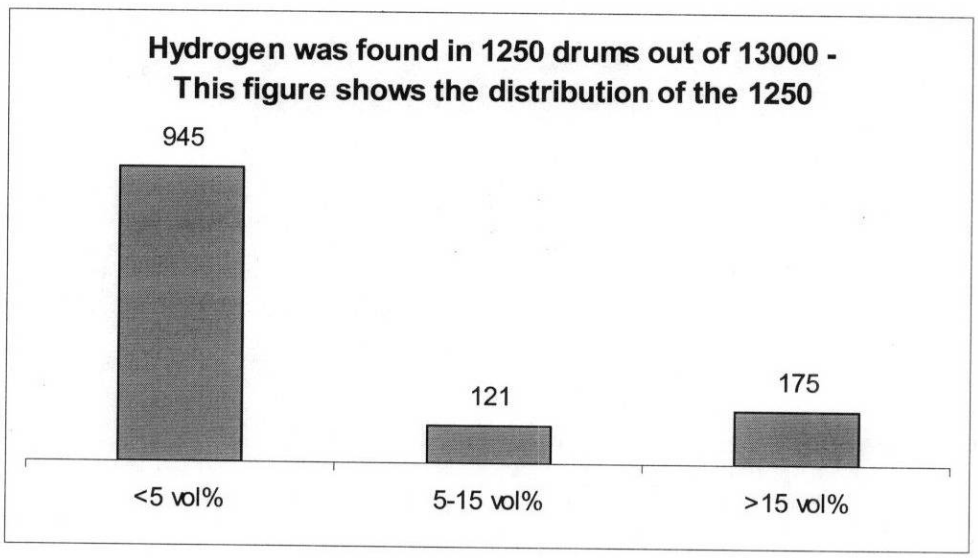
The overburden (approximately 3.5 feet) was removed to the extent necessary to allow retrieval. Upon completion of overburden removal, containers were retrieved one at a time and in such a manner that a stepped working face was generally maintained on the array. Drums that were damaged or severely corroded were over packed. Drums were moved out of the pad area and placed on the transfer truck, then transferred, unloaded and staged for washing. The unvented drums were retrieved and transported approximately one-quarter mile from retrieval to the location where sampling and venting were performed. An operating procedure provided instructions for safely venting pressurized drums on Pad 2. After washing, the drums were transferred to the drum venting system (see Section 7) and placed in the venting vessel. A glovebox is sealed to the top of the drum and the drum lid is drilled under confined conditions. The gas is sampled, purged if necessary, and a filter installed.

About 60% of the waste stored on Pads 1, 2, and 4 were identified as TRU mixed waste. Drums contain a cemented chemical treatment sludge that resulted from radioactive wastewater treatment operations performed at the LANL, and combustible and noncombustible trash (including paper, plastic, and rubber materials generated in glovebox operations). Some of the waste includes asbestos and beryllium. (LANL 2000)

Retrieval of 4,880 drums and one hundred sixty one 161 boxes stored on TRU Pad 1 was completed in August 1998. Drums were retrieved containing greater than 300 grams plutonium. The drums were in very good condition after being in earth-covered storage for seventeen years. Only 126 of the 4,880 retrieved drums (less than 3%) required over packing (Demiter 1998).

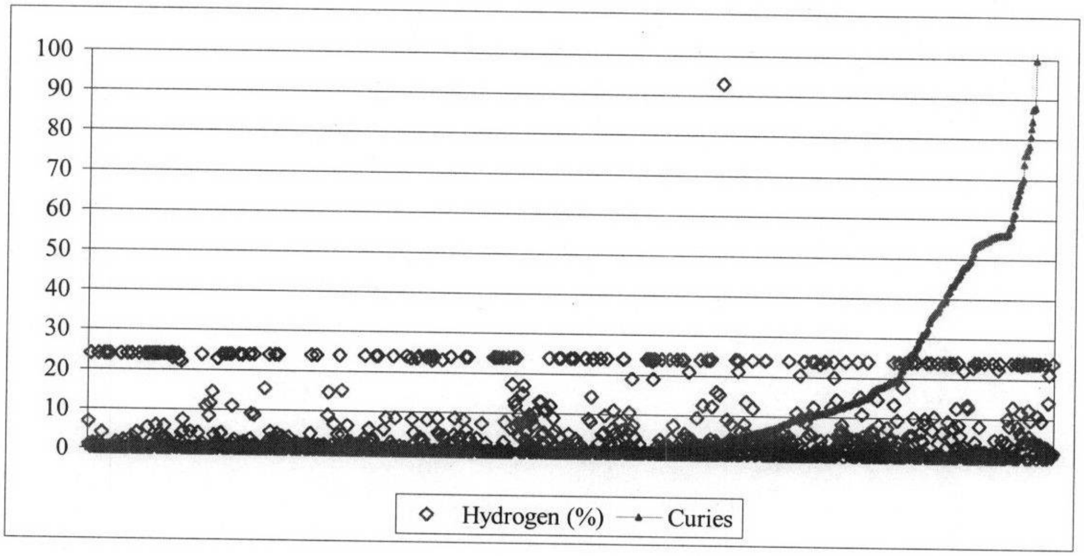
As of September 2001, over 13,000 drums have been retrieved, transported, washed and vented without any hydrogen-related fires or explosions. Eleven thousand seven hundred fifty drums (11,750) (90 % of 13,000) had no detectable hydrogen. Hydrogen was found in about 1250 drums. Hydrogen concentration data are shown in Figure 2 (Dayley 2001).

Figure 2 - Hydrogen Concentration Distribution in TRU drums at LANL



Radionuclide activity of the TRU waste drums was examined to see if a correlation existed between the number of curies in the drum and the hydrogen concentration. Figure 3 shows the results. These data were sorted by curie content in increasing values and ranges from zero to 589 Ci. The Y-axis represents both curies and hydrogen volume percent and was cropped to a scale of 100 to enable the hydrogen data to be shown more clearly. For each drum containing hydrogen, the hydrogen concentration and curie content is plotted on the graph. Because of the mass of data (1250 drums) vertical connecting lines are not shown. However, it is obvious from the uniform scatter of hydrogen concentrations throughout the range of curie values that there is no correlation.

Figure 3 - Hydrogen Concentration in Relation to Curie Content in LANL TRU Drums



Of the 175 drums with hydrogen concentrations greater than 15 vol%, 138 measured essentially the same amount (24 vol%). In conversations with LANL operations staff, it was proposed that this could be the result of the analytical instrumentation lines not being sufficiently purged prior to analysis. Regardless of hydrogen concentration, there were no hydrogen-related fire or explosion events.

3.4.2 LANL Drum Testing

In 1983, LANL participated in a TRU waste sampling program (Clements 1985). Forty-one (41) LANL waste drums were sampled to determine the gas composition. The drums were at atmospheric pressure because the drums were sealed with a semi-permeable gasket that allowed gas in excess of atmospheric pressure to diffuse out of the container. The three-year old and nine-year old ^{238}Pu-contaminated waste drums showed negligible concentrations of hydrogen. The test report concluded that hydrogen generation had ceased in these drums, possibly due to depletion of the organic matrices, and any significant quantities of hydrogen had diffused through the semi-permeable drum gasket. No ^{239}Pu-contaminated waste drums from any age category contained hazardous levels of hydrogen. The ^{239}Pu drums contained less than 15 alpha Ci.

3.5 Rocky Flats Site Data

Transuranic waste at Rocky Flats is primarily contaminated with plutonium. It includes such items as sludges, filters, plastic, leaded rubber gloves, ceramic crucibles, glass resins, combustibles, and scrap metal. Rocky Flats has been storing TRU waste on site since 1988, when shipments of TRU waste to the INEEL were stopped. This waste will be disposed at WIPP. Venting and aspiration have been performed on at least 1,885 unvented TRU waste drums preparatory to shipping offsite.

Data provided by Rocky Flats on hydrogen analysis performed on 298 unvented drums in the years 1993-1996 are shown in the following figures (Dayley 2001). Figure 4 shows the hydrogen concentration distribution of the 298 drums. Five drums (1.7%) had hydrogen concentrations greater than 15 vol%. As shown in Figure 5, one of the five drums (0.3%) contained sufficient oxygen to constitute a flammable mixture.

Figure 4 - Rocky Flats Hydrogen Concentration Distribution

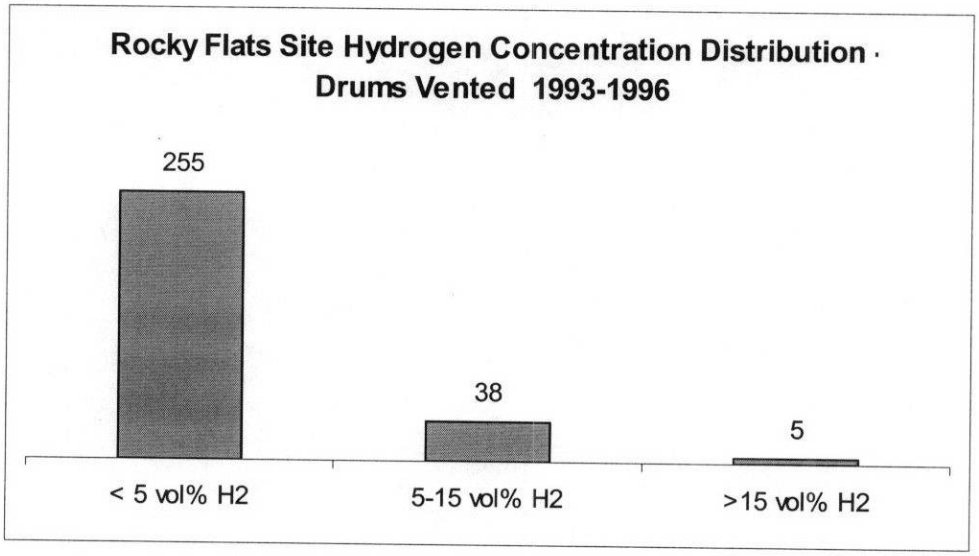
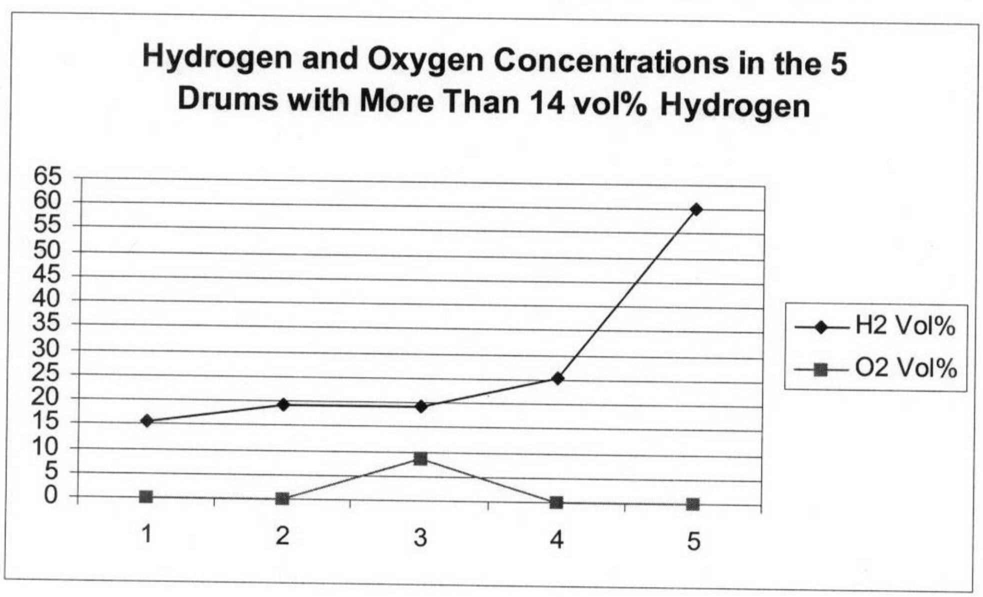


Figure 5 - Hydrogen and Oxygen Concentration



3.6 Oak Ridge National Laboratories Site Data

Oak Ridge is not currently doing any TRU waste retrieval activities and none are planned for the immediate future. Oak Ridge has not performed any gas analyses on the TRU drums.

3.7 Fernald Drum Fire

Fernald has been the repository for thorium metal for the U.S. Department of Energy (DOE) complex. In July 1999, while punching a hole in a drum, the venting tool contacted the uranium and thorium metal, causing a fire. The drum punch bit extended into the container at a sufficient depth to violently contact the thorium metal within, sparking the fire. The drum contained metal of small particle sizes (i.e., 1/8 inch) making it more likely to be pyrophoric.

Because Fernald stores a large amount of uranium and thorium, the site has completed a study of hydrogen reactions in the drums. As a result of the study, all drums are vented, a short punch of ¾ inch diameter is used, drums with greater than 10% of the Lower Explosive Level (LEL) of hydrogen are purged with argon, water is removed from drums, and Fernald is not currently processing drums containing the smaller sized materials.

This is the only drum fire known to have occurred in the DOE complex and is included here for completeness. It is important to note that there are significant differences in the conditions surrounding this fire and the contents of the drums found in the LLBG and the TRU Retrieval Project.

- The drum contained uranium and thorium metals with vastly different characteristics from plutonium waste.
- The fire was due to thorium pyrophoricity. There was no link to hydrogen.
- Ignition was from the violent contact of a long drum punch with the thorium metal.

3.8 Hanford Data and Pilot Retrieval

Hanford began segregation of TRU wastes in 1970, following the U. S. Atomic Energy Commission (AEC) directive to segregate TRU wastes and place such wastes in retrievable storage. Wastes containing greater than 10 nanocuries transuranic material per gram of waste (10 nCi/g) were segregated as TRU wastes. The waste containers, mainly 55-gallon drums, were initially placed in the trench in a horizontal arrangement, then covered with soil. In 1973, a concrete "engineered V-Trench" (V-7) was used for TRU waste storage. After three cells were filled, this method was discontinued due to the high cost. Approximately 1,340 drums were placed in the V-7 trench.

Subsequent to use of the V-7 trench, TRU trenches were constructed on a sloping asphalt pad. The drums were arranged in modules 12 drums wide by 12 drums deep, usually stacked 4 high. A layer of plywood was placed between each tier. The finished module was covered with plywood, over which a plastic tarp was placed, then covered with approximately 4 feet of soil.

From May 1970 through May 1988, Hanford placed approximately 37,400 containers in retrievable storage. The majority of the TRU containers are located in six trenches in the 218-W-4B and 218-W-4C Burial Grounds. These trenches contain approximately 28,000 stored containers.

3.8.1 1982 TRU Storage Inspection

Hanford TRU drums, stored 8.5 years under soil cover, were uncovered and inspected in 1982 to determine the corrosion rate of drums placed in 20-year TRU retrievable storage. The project inspected drums placed in 1973. During the course of the project, no contamination (surface or airborne) was detected; hydrogen in the riser pipes was not detected; corrosion rates averaged 1 mil/year at the drum/tarp interface and was undetectable for drums not in contact with the tarp covering.

3.8.2 1994 Pilot TRU Retrieval Project

The Hanford 1994 TRU Drum Retrieval Project began development in 1988. It began with a study of existing records for TRU waste that were released in 1990.

In situ inspections were performed on tarp-covered 55-gallon drums of TRU waste to evaluate drums for corrosion degradation. Corrosion was much less than expected. Only a small percentage of drums were affected and the maximum corrosion rate was small (2 mils/year). Although there was little corrosion, one breached drum was found.

The TRU Drum Retrieval Project began retrieval and inspection in 1996. About 1,100 drums were retrieved between fiscal year (FY) 1996-2001. No bulged or breached drums have been found to date.

3.8.3 Hanford TRU Waste Headspace Gas Analysis for Hydrogen

Headspace gas was sampled from vented TRU waste containers at T Plant in support of the TRU waste certification project. Samples from 107 vented TRU drums were analyzed for hydrogen. Hydrogen concentrations ranging from 0.0041 vol% to 0.046 vol% were found in 34 drums. Data of the radionuclide content of each of the 34 drums were collected from the WRAP Radioassay Data Sheets. Plutonium values ranged from 1-40 grams. These two values were compared in an effort to correlate the radionuclide activity with the amount of hydrogen generated. No correlation was found.

3.9 National Transportation and Packaging Program Data

A calculation-based technique for quantifying the concentration of hydrogen generated by radiolysis in sealed radioactive waste containers was developed in a study conducted by EG&G Idaho and the Electric Power Research Institute (EPRI). The study resulted in acceptance by the NRC of the methodology in 1984. Subsequently, EPRI developed a simple computer program in a spreadsheet format using the methodology. The computer code was named RADCALC and is accepted by the NRC for Certificates of Compliance for shipping casks containing materials that may result in the radiolytic formation of hydrogen gas (McFadden 1999).

RADCALC calculates a projection of the amount of hydrogen gas in the waste matrix of radioactive material containers. It contains a library of approximately 260 radionuclides and a G-value (see Section 4.3 for a discussion on G-value) database for a large number of material types. These are used to determine the theoretical amount of hydrogen that could be generated since the drum was closed.

Although RADCALC works well in its current application, it would not be an appropriate application to retrieved waste for the following reasons:

1. Most of the TRU waste documentation contains little content description. Without detailed knowledge of the contents of the drum, only the most conservative G-values would be used, resulting in unrealistically high estimates of the concentrations of hydrogen.
2. There is no provision in the program for diffusion or leakage.
3. There is no capability for estimating oxygen concentrations.

3.10 Summary of Site Data including Current Site Safety Basis Documentation

During 1997- 2000, 10,169 drums were vented and the combustible gases analyzed at SRS. Seven hundred ninety seven (797) or ~7.8% contained greater than 15 vol% hydrogen. There are no data on oxygen concentrations. Table 3 presents a summary of the site hydrogen data.

Over 17,000 drums were retrieved at INEEL in the period between 1985 and 1988 and many more since then. In the current project, waste drums are not analyzed for gases prior to or at the time of venting. Therefore, no hydrogen concentration data are available on the retrieved unvented drums. Two hundred ten (210) drums were sampled in 1983 as part of a testing program. Of these, six drums (2.8%) contained hydrogen concentrations greater than 15 vol%. One (0.5%) contained greater than 15 vol% hydrogen and greater than 5 vol% oxygen.

As of September 2001, over 13,000 drums have been retrieved and vented at LANL. One hundred seventy five (1.3%) had hydrogen concentrations above 15 vol%. Oxygen concentrations were not determined.

Analysis results of 298 drums that were sampled and vented at Rocky Flats during the years 1993-1996 were obtained. Five drums (1.6%) had hydrogen concentrations greater than 15 vol%. One drum (0.3%) contained greater than 15 vol% hydrogen and greater than 5 vol% oxygen. Venting and aspiration has been performed on over 1,800 drums.

Table 3 - Summary of Site Hydrogen Data

SITE	TOTAL DRUMS	DRUMS WITH > 15 VOL% H_2	FRACTION	DRUMS WITH > 5 VOL% O_2	FRACTION
Savannah River	10,169	797	0.078	No data	
INEEL	210	6	0.028	1	0.005
LANL	13,000	175	0.013	No data	
Rocky Flats	298	5	0.017	1	0.003

Each DOE site had an authorization basis document to cover the drum retrieval and venting activities. These sites and their corresponding authorization basis document are listed in Table 4, along with the estimated frequency associated with the accident analyzed.

The SRS began venting waste drums containing TRU in 1996. Safety analysis calculations showed that a maximum of 12% hydrogen would be produced in a 30 Ci drum of the waste type that occurs at SRS; the safety evaluation was based on this limit. The first occurrence of a drum having greater than 12% hydrogen stopped operations while the safety was reconsidered. Since there was no oxygen in any of the high hydrogen drums, it was determined to be safe to resume vent and purge operations (Gibbs 1998).

The Radioactive Waste Management Complex Safety Analysis Report describes the hazards and risks for retrieving and venting TRU waste drums. All waste drums shipped to the RWMC since 1983 are equipped with semi permeable lid gaskets. These gaskets are designed to allow internally generated gases to escape the drum while internal particulates are contained. Because studies have shown that flammable hydrogen gas concentrations do not accumulate in drums equipped with semi permeable gaskets, no further mechanical venting is necessary. Transuranic waste drums are vented consistent with the criteria imposed for shipping the waste to WIPP. As part of the hazards evaluation, two explosion scenarios were developed. A drum explosion in the Drum Venting Facility is considered an anticipated scenario (frequency of 1.0×10^{-2}): an incident that may occur several times during the lifetime of the facility. The second explosion scenario postulated an impact-induced breach of a drum resulting in an explosion. A drum explosion and resulting fire in a waste-handling or storage area are extremely unlikely (frequency of 1.0×10^{-6} to 1.0×10^{-4}) events; events that would probably not occur during the life cycle of the facility. There are no safety-class structures, systems, or components (SSC) as a result of the INEEL safety analysis. An administrative control for appropriate procedures and training is in place (INEL 2000).

Two scenarios were developed in the LANL safety analysis (LANL 2000). The first scenario evaluated a deflagration of hydrogen gas inside a drum during handling. The TWISP BIO cites documentation (Restrepo 1989) that leads to the conclusion that the ignition of hydrogen inside a waste drum leading to the release of radioactive material is not a likely credible accident. This conclusion is based on (1) the results of tests of pressure buildup inside drums; (2) the fact that most drums have some type of breathable gasket; and (3) data indicating that over 30,000 TRU drums have been handled (at Rocky Flats and Idaho) in 33 years without any over pressurization problems. In addition, retrieval of over 9300 waste drums by the TWISP has been accomplished without such an event. Based on these data, the likelihood of this event could be reasonably estimated to be extremely unlikely (1×10^{-4} to 1×10^{-6}). However, for conservatism, the unlikely category (1×10^{-2} to 1×10^{-4}) was assigned.

The second scenario evaluated the frequency of an explosion of hydrogen gas inside a drum during venting. This event was assigned the frequency of 1 to 1×10^{-2}. The BIO states that even though experience with drum venting does not indicate that an explosion during venting would be anticipated, this is based on operations conducted with safety measures. Therefore, the more conservative frequency was assigned.

Chapter 8 of the Rocky Flats safety analysis delineates the evaluation of the hazards associated with the transportation of radioactive material. Rupture of a drum due to hydrogen buildup and ignition was analyzed. The scenario described an explosive mixture of hydrogen and oxygen that could accumulate in a drum over time and then be ignited by a small energy source (pyrophoric material, electrostatic spark). The accident was postulated to occur on the transfer vehicle during movement or during drum movement between the transfer vehicle and the dock. Ignition of a flammable concentration of hydrogen within a drum results in a deflagration). The summary of transportation accidents with nuclear materials and radioactive wastes concluded that accident scenarios involving a hydrogen deflagration in a drum containing radioactive wastes falls into the extremely unlikely ($6.6X\ 10^{-6}$) frequency bin.

Table 4 - Summary of Site SAR Drum Handling and Venting Accidents

Site and SAR ID	Vent Method	Design Basis (Worst Case)	Frequency (/yr)	Discussion
Savannah River WSRC-TR-451, Rev 1	Drum Venting System (DVS)	Drum Explosion	$1 \times 10^{-2} - 1 \times 10^{-4}$	Includes drum handling. Same venting system as LANL
INEEL INEL-94/0226, Rev 5	Drum Venting Facility (DVF)	Drum Explosion	$1 - 1.0 \times 10^{-2}$	Drum explosion in DVF
LANL TWISP-001 Rev 0	DVS	Drum Explosion	$1 - 1.0 \times 10^{-2}$	Drum explosion during venting
			$1 \times 10^{-2} - 1 \times 10^{-4}$	Drum explosion during handling
Rocky Flats Site SAR, Chapter 8	N/A	Drum Explosion	6.6×10^{-6}	Transportation Accident
Hanford HNF-SD-WM-028 Rev 3C	Only vented drums authorized for retrieval	Drum Explosion	1.15×10^{-7}	Venting not authorized

SRS and LANL regularly vent and sample the drums. If the hydrogen concentration is greater than the lower flammability limit, then the drums are purged. INEEL vents drums routinely without sampling or purging. There have been no hydrogen-related fire or explosion incidents to date at any of these sites. From a comparison of practices at the three sites, there is no clear indication that sampling and purging are essential for risk mitigation.

Over 42,000 drums have been retrieved across the complex. Most drums were handled multiple times. Hydrogen analysis data were available for 23,677 drums. Nine hundred eighty three (983) drums contained greater than 15 vol% hydrogen. Of the 508 drums for which oxygen analysis was available, two drums (0.3%) contained greater than 5 vol%. Therefore, even though greater than 15 vol% hydrogen was present in 4% of the drums, the probability of a flammable mixture is very low. Supporting this conclusion is the fact that no hydrogen-related fire or explosion events have occurred across the complex.

4. ANALYSIS OF UNVENTED DRUM DATA

4.1 Introduction

This section presents a discussion of hydrogen generation, accumulation, diffusion, and leakage from drums. Based on the fraction of sampled drums with hydrogen concentrations exceeding 15 vol% of the total gas in the drums, the basic mechanisms involved in hydrogen accumulation in TRU drums will be investigated in this section.

A detailed study of hydrogen accumulation in Product Receiver (PR) drums in the Plutonium Finishing Plant (PFP) was documented in Cooper (1999). The results of the study identify the leakage through the drum lid seal as the determining factor in the amount of hydrogen that is retained in any drums. A summary of the methods used in this analysis and its findings are reported in this section. The findings of Section 2.0 demonstrate that the vast majority of drums containing TRU waste have no hydrogen buildup or only quantities less than flammability limits. There is a small fraction with larger quantities. The analysis in this section shows that these occur because of a lack of leakage through the drum lid seal (i.e., exceptionally good seals).

4.2 Calculations for Gas Concentrations

Gas concentration is predicted by making a mass balance on the gas phase in any given space, accounting for gas generation and depletion by leakage and diffusion:

$$\text{Accumulation rate} = \text{input rate} - \text{output rate} \qquad (1)$$

where:
Accumulation rate = gas buildup rate in a volume, moles/s
Input rate = gas generation, moles/s
Output rate = depletion by leakage and diffusion, moles/s

Formulating these components in terms of parameters of the system gives:

$$\text{Accumulation rate} = \frac{VdC}{dt} \qquad (1a)$$

$$\text{Input rate} = G \qquad (1b)$$

$$\text{Output rate} = QC + DC \qquad (1c)$$

where:
V = volume of gas space, cm^3
C = hydrogen concentration, moles/cm^3
G = hydrogen generation rate, moles/s
Q = headspace ventilation rate, cm^3/s
D = diffusional admittance, cm^3/s
t = time, seconds

Substituting equations 1a, 1b, and 1c into Equation 1, the differential equation that describes the buildup of concentration with time is:

$$\frac{VdC}{dt} = G - QC - DC \qquad (2)$$

4.3 Hydrogen Generation (G-Value)

Extensive laboratory experiments on gas generation from degradation of transuranic wastes have been conducted. A comprehensive summary of applicable gas generation data by various degradation mechanisms has been prepared by Molecke (1984).

Mechanisms by which gases may be generated in TRU waste include radiolysis, thermal decomposition and dewatering, bacterial action, and chemical corrosion. The major gases produced in TRU wastes by these mechanisms are hydrogen (H_2), carbon dioxide (CO_2), carbon monoxide (CO), water (H_2O), methane (CH_4), oxygen (O_2), nitrous oxides (NO_x), and helium (He) (Molecke 1984). Radiolysis and chemical corrosion action are considered to be the major gas-generating mechanisms in TRU wastes stored at Hanford.

Degradation of organic materials by bacterial action generally produces only CO_2 in aerobic and anaerobic atmospheres. Methane is also a potential gas produced in an anaerobic atmosphere (Molecke 1984). Hydrogen can be expected to be present in any closed container in which both radioactive and hydrogenous materials are stored. Laboratory experiments indicate that radiolysis of organic material primarily produces H_2, with the remaining gases being CO_2 and CO. The primary gaseous products from radiolysis of water are H_2 and O_2. Formation of carbon oxides depletes O_2. In addition, nitrites may be produced by radiolysis of nitrates.

The amount of gas generated by radiolysis is dependent on the amount of radionuclide activity present, the organic waste matrix type, and distribution of the radionuclide on the organic matrix. The radiolytic gas generation rates (G-values) depend upon the types of radioactive particles, the integrated energies, and the chemical composition of the organic waste with which the particles are in contact. Studies such as HNF-2061 (1999) have shown that alpha radiation from plutonium dominates the production of radiolytic gases from hydrogenous substrates. The integrated alpha energies can be calculated by summing the alpha energies obtained from each isotope. This isotope energy is calculated from the plutonium mass, the isotopic distribution, the decay constants for each isotope, and the isotope decay energy.

G-values represent the number of gas molecules produced per 100 eV of radiolytic energy absorbed by the substrate. G-values are not truly constants. These values are more appropriately considered as "snapshots" of the gas production efficiency for a given set of conditions.

4.3.1 G Values Defined in the TRU Waste Sampling Program

In tests performed in 1983 as part of the TRU Waste Sampling Program (Clements 1985), twelve drums of newly-generated ^{239}Pu wastes, representing six content codes, were evaluated. Waste forms in the drums included sludge, grease, dry combustibles, wet combustibles, plastics, and leaded gloves. Alpha curies ranged from 0.2 – 15.6 Ci. Prior to initiating the study, the drums were flushed to obtain atmospheric air conditions, and the lid was sealed. Gas samples were taken every week for a three-month period.

Drums were pressure tested twice during the course of the study to ensure seals. All of the drums remained sealed except two. It was concluded in the test report that even though these drums leaked when pressurized to 3 psi, the leak rate would be significantly less at normal conditions. The leaks were not considered in determining the G-values.

Table 5 shows the gas concentration and G-value data. The hydrogen yields for the sludge drums are reasonable for RFP generated sludge. The presence of nitrate significantly reduces the hydrogen yield. The primary radiolysis product from nitrate sludge is oxygen, but only one drum (D32180) showed a net increase in oxygen content. Oxygen depletion in the other three drums was believed to be due to another reaction (corrosion, etc.).

The hydrogen yields for the two grease drums were much higher than the expected G-values of two to three, and the rate of oxygen depletion was too rapid to be attributed to radiolysis. Another type of reaction may be responsible for the high G-values from these drums. Corrosion of the mild steel drum can produce hydrogen gas in an anoxic and wet atmosphere. The oxygen depletion after one week produced an anoxic atmosphere. The contents of the grease drums were analyzed and were found to contain paraffin oils, silicates, sulfates, and approximately 20% water. Therefore, the drum atmosphere was expected to be water saturated. Under these conditions, the total hydrogen gas generation rate from corrosion may be more than twice the rate from radiolysis. Expected values were obtained for the drums containing dry combustibles, wet combustibles, plastics and rubber, and leaded gloves.

The test report stated that the G-values showed satisfactory consistency within each waste category and were reasonable when compared to laboratory values. G-values less than laboratory values could be explained by assuming that the actinides were not uniformly distributed on the organic matrix. A few of the G-values appeared to be greater than expected.

Table 5 - TRU Gas Generation

Drum No.	Content	Alpha Curies (TRU grams)	$G(H_2)$	H2 (vol%)	O2 (vol %)
D29258	Sludge	5.14 (18.32)	0.30	1.23	19.95
D31528	Sludge	3.82 (10.54)	0.28	0.80	19.86
D32180	Sludge	15.6 (71.93)	0.19	2.37	27.57
D32186	Sludge	7.14 (21.15)	0.16	0.86	19.08
D31254	Grease	0.35 (3.223)	15.1	7.31	0.03
D31403	Grease	0.20 (1.476)	22.5	4.30	0.02
D24545	Dry Combustibles	1.21 (16.4)	2.1	0.86	18.74
D31042	Dry Combustibles	2.14 (28.9)	1.4	0.99	15.24
D26048	Dry Combustibles	2.09 (28.3)	0.79	0.69	16.99
D31703	Dry Combustibles	2.40 (32.4)	0.39	0.59	9.15
D25634	Wet Combustibles	1.15 (15.5)	0.74	0.39	21.43
D31216	Wet Combustibles	1.93 (26.1)	0.52	0.39	19.43
D25691	Plastic	2.13 (28.8)	1.1	0.88	12.79
D30688	Plastic	2.55 (34.4)	0.65	0.64	18.73
D29758	Leaded Gloves	0.15 (2)	0.32	0.06	22.07
D30175	Leaded Gloves	13.1 (163.8)	0.95	4.26	11.93

In another test performed in the TRU Waste Sampling Program, eight newly-generated, high activity ^{238}Pu waste drums were evaluated in tests to compare gas generation rates to laboratory data. The drum lids were sealed with white silicon caulking compound and pressure tested. Each drum was purged and sealed. Data from two of the drums was not used because the drums were found to be inadequately sealed during drum pressure re-testing. Plutonium-238 gram loadings of the drums ranged from 1.2 to 15.6 grams.

During the test, hydrogen in one drum (Drum BFB-112) gradually increased and oxygen was depleted fairly rapidly. After about ten months, both hydrogen and oxygen were about 5 vol%. If the trend continued, the oxygen would have been depleted before hydrogen concentration reached 15 vol%. Drums BFB-113, 116, and 120 followed essentially the same pattern. Results are shown in Table 6.

Table 6 - LANL Drum Hydrogen Generation Data

Drum No.	Waste Matrix	^{238}Pu Ci (grams)	Time of gas Generation (days)	H_2 vol % (initial)	H_2 vol% (final)	O2 vol% (final)	$G(H_2)$
BFB-112	Plastic, leaded gloves	16.8 (1.2)	318	0.1	5.2	5.3	0.20
BFB-113	Leaded gloves	30.8 (2.2)	75	1.2	2.9	15.2	0.14
BFB-114	Rags, plastic	218.4 (15.6)	75	11.5	26.3	7.5	0.40
BFB-116	Leaded gloves	31.9 (2.28)	318	0.3	6.8	6.5	0.15
BFB-118	Rags, plastic, furnace, Al & Zr oxides	68.9 (4.92)	294	0.9	20.8	3	0.27
BFB-120	Leaded gloves	22.4 (1.6)	208	0.3	2.7	16.2	0.12

The hydrogen concentration in Drum BFB-114 was greater than 15 vol% in about three weeks and continued to increase to 26.3 vol%. The oxygen concentration decreased.

Hydrogen increased to about 15 vol% in Drum BFB-118 in about six months, but similar to drum BFB-114, the rate of generation decreased with time. The oxygen levels ranged from 10 to 5 vol% during the next two months. After eight months, the oxygen concentration was below 5 vol%.

The test report concluded that G-values vary with the physical state of the radioactive contaminant, its distribution in the waste, and the waste matrix. The G-value can slowly decrease with time because the contact of the radioactive contaminant with the substrate becomes less effective due to matrix depletion. Given sufficient time, the radioactive contaminant may no longer be in effective contact with the waste, and gas generation essentially ceases.

In all drums examined in this test, decreasing oxygen concentrations would result in a nonflammable mixture within several months. However, the results of this test cannot be used to accurately predict hydrogen generation rates in the stored wastes, unless there is detailed knowledge of the drum contents and packaging.

4.3.2 Matrix Depletion Program

Early experiments conducted at LANL resulted in the first substantive proof that matrix depletion has an effect on gas generation rates. In 1981, a series of experiments were performed in which a conclusive reduction in gas generation rates with increasing dose (defined as the product of the decay heat and elapsed time from loading) was observed. Other experiments were conducted focusing on alpha radiolysis. All of the test canisters in these experiments showed hydrogen gas generation rates slowed down with increasing dose. The effective G-value for the cellulose simulated waste experiments started at a value of approximately 1.0 and decreased to 0.3 or below. For polyethylene-simulated waste, the effective G-value initially ranges from 0.8 to 1.8 and decreased to below 0.3 (INEL 2000).

In the Matrix Depletion Program, laboratory experiments were performed to determine the effective G-values and evaluate the effects of isotope, matrix, and heating. Results were compared with real waste measurements. Headspace samples were collected and analyzed from a representative subpopulation of existing TRU waste containers at ambient temperatures to determine hydrogen gas concentrations in drums. Theoretical analyses were performed to demonstrate consistency with experimental measurements.

The test report concludes that matrix depletion accounts for the gradual reduction in the rate of hydrogen gas generation (i.e., G-value) from a material over time and constant exposure to radiation. Hydrogen is removed from the matrix, thus decreasing the number of hydrogen bonds available for radiolytic breakdown. When the alpha-generating source is dispersed in or on the target material in a particulate form, it will affect only that portion of the target material in a small spherical volume surrounding the source particle. Additionally, some energy is lost within the particle itself, and some is absorbed by nonhydrogenous materials (such as air) that are part of the waste matrix. Because over time the amount of available hydrogen is reduced, matrix depletion causes the effective G-value to decrease asymptotically with increasing dose to a limit that is characteristic of the matrix affected.

The three-year Matrix Depletion Program testing demonstrated matrix depletion in simulated waste materials that is consistent with results of past research. The following observations were noted in the report:

- Increasing dose decreases the effective flammable gas generation rate of hydrogenous materials, due to depletion of the target material.
- The values of the G-values are highly dependent on the material that is irradiated.
- The G-values for wet cellulosics are higher than those of dry cellulosics because of the presence of water.
- There was no significant effect of temperature on the G-value.
- Previous experiments indicated that agitation did not affect G-values.
- The analysis indicated that only the waste matrix has a significant effect on G-value.

4.4 Hydrogen Diffusion and Leakage

In this section and Section 4.5, an existing analysis of hydrogen generation in product receiver (PR) drums, and diffusion and leakage through the drum lid seals (Cooper 1999) will be used to illustrate how the concentration of hydrogen in the drum headspace is dependent on the degree of leakage past the drum lid. The radiological source material in the PR drums was plutonium nitrate-nitric acid liquid solutions stored in plastic bottles within the PR containers (drums). This analysis is applicable to hydrogen generation in TRU drums because the G-value is very similar to one that would result from TRU isotopes in contact with typical waste material. G-values taken from Restrepo (1989) show that plastic and rubber have values that range from 0.3 to 0.5 mL/day-Ci, and 0.2 to 0.9 for dry combustibles. The reference analysis used for a worst case, a combination of 4 molar (4 M) nitric acid and Tributyl-phosphate (TBP) organic. As explained in Section 4.3, a hydrogen G-value of 0.5 for wet TBP-HNO_3 mixtures was used to estimate the hydrogen generation rate in the organic phase. As a reference, the hydrogen G-value in pure water is 0.45, while the hydrogen G-value in 8 M nitric acid is 0.024.

Ventilation rate (Q) could occur by atmospheric pressure fluctuations and by the outflow of gases. The flow admittance of leak paths is uncertain. It is has been established that the drum inhales and exhales in response to atmospheric pressure fluctuations.

Hydrogen has a high molecular diffusivity (D), and can diffuse through porous boundaries at an appreciable rate.

Two studies were performed and published on drum leak rates. Cooper's tests show average drum leak rates ranging from 143 to 274 mL/min over one year at 5 psig for three drums (Cooper 1988). Cooper's leak rates at 5 psig are included in the attachment to Cooper (1999), and show that the lowest average leak rate was 143 cc/min.

Ludowise (1979) also measured leak rates for five drums. The first four contained vent clips; the fifth drum did not contain vent clips and is comparable to Cooper's tests. The fifth non-vented drum leaked at 837 cc/min at 5 psig. The four vented drums leaked approximately four to five times faster than the unvented drum (Ludowise 1979).

In calculating the gas flow through leak paths in the drum seal, both the drum internal pressure and the external atmospheric pressure must be known. The internal pressure is calculated from the gas inventory in the drum. The external pressure distribution was determined from Crippen's atmospheric variation results (Crippen 1993). Crippen's report contains a description of the distribution of pressure fluctuations per hour over a four-year interval. Since the pressure fluctuations are random, an average hourly pressure fluctuation (0.0003768 atmospheres) was calculated and applied alternately in a plus and minus direction, such that the drum experienced a constant breathing frequency.

Using the slowest experimentally measured leak, Darcy's formula was used to calculate an equivalent hole area. Using the equivalent hole size, and assuming an initial pressure differential, one can calculate the flow rate by Darcy's formula. This is done in the finite difference model, so that flow rates and pressure differentials can be updated on whatever time frequency is desired. The model shows that starting with Crippen's average pressure swing, the pressures equalize within approximately 30 minutes and that maximum gas flow is achieved for each hourly pressure change (i.e., the model is not limited by too small of an equivalent hole). When the pressure differential drops to 1% of Crippen's average hourly pressure swing, the gas flow through the drums was still larger than that required for the annual flow (14.4 g-moles/yr).

Once it is understood that the maximum flow is achieved for each pressure swing, one may calculate the annual flow by calculating the hourly flow and multiplying by the number of hours per year. This annual flow was used to calculate the steady state hydrogen gas concentration.

4.5 Hydrogen Accumulation

Using all of the above concepts, as described in detail in Appendix A of Cooper (1999), a finite difference model was prepared and updated in 0.01 hourly increments. The gas inventory in the drum was determined at the beginning of each time increment then adjusted for the gas generation rate the diffusion rates and leak rates. From the gas inventory, the partial pressure of each gas was calculated.

Two PR drums were chosen for this analysis. The first PR drum (L1050) was filled with weapons grade plutonium nitrate several years ago and stored in Room 236 of the Hanford Plutonium Finishing Plant (PFP). This PR drum is fairly representative of many other PR drums in the PFP inventory. The second is PR drum (PN-48-02-02-003) was intended to represent a "worst case." The plutonium nitrate in this drum was separated from contaminants in 1988 at the PUREX plant, and has been stored at PFP since that time. The contents of this drum have the highest alpha activity of any PR drum in PFP for which complete isotopic data is available.

From the isotopic data from these two PR drums, the gas production rates were calculated. Using the gas generation rates and an average hourly pressure fluctuation (as calculated from Crippen's data), the steady state hydrogen concentration was calculated.

The most difficult decision in modeling this system was deciding on leak rates through the drum gasket. Leak rates from the two separate studies described in Section 4.4 where leak rates were observed through the gaskets of four unvented drums and four vented drums were considered. Using the slowest of these observed leak rates, the following hydrogen concentrations are presented in Figure 6.

Figure 6 - Hydrogen in PR Can Drums with Leaking Gaskets and 8 Molar HNO_3

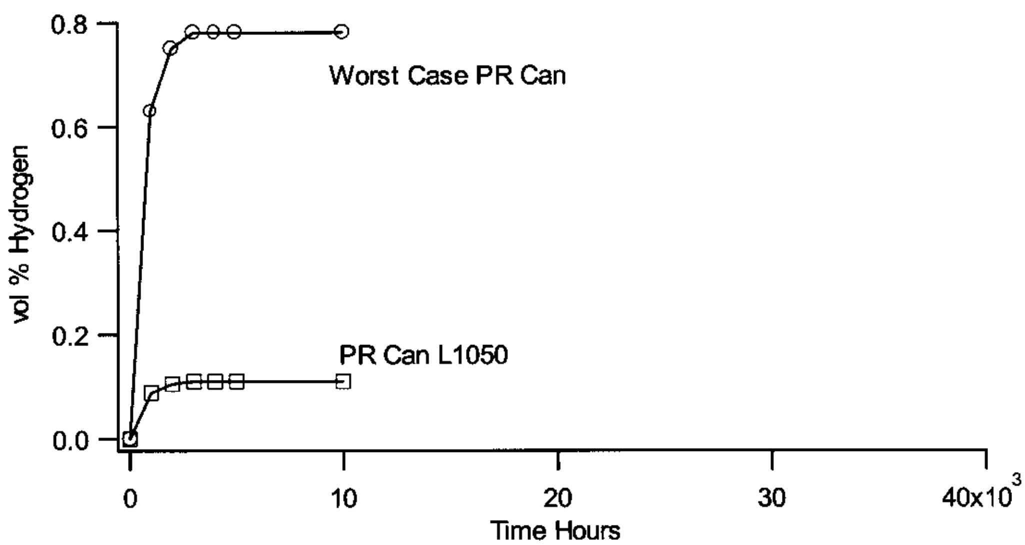


Figure 6 shows that the hydrogen concentration does not reach the flammable concentration for either weapons grade plutonium nitrate solutions or the "worst case" fuels grade plutonium nitrate when the slowest (and therefore the most conservative observed leak rate measured) is applied to the system.

Factors that can increase the hydrogen generation rate as compared to those calculated above are:

- Decreased nitric acid concentration. The G-values for hydrogen production increase by a factor of 20 as the nitric acid decreases from 8 to 0 M.
- Slower leak rates
- Increased radiolytic energy
- The presence of organic compounds

To establish a more conservative case, the following parameters were established:

- The worst case isotopic concentrations (i.e., 13.1% ^{240}Pu were used)
- A 4 M nitric acid concentration was assumed

- 1 vol% organic was included in the model
- The organic was assumed to be a 20 vol% TBP-CCl_4 mixture.

A hydrogen G-value of 0.5 as measured by Rigg and Wild (1958) for wet TBP-HNO_3 mixtures was used to estimate the hydrogen generation rate in the organic phase. This calculation showed the initial hydrogen generation rate in the organic phase was approximately 20% of that occurring in the aqueous phase. The hydrogen generation rates in both organic and aqueous phases were summed to prepare Figure 7.

Figure 7 - Hydrogen in PR Can Drums with Leaking Gaskets, 4 Molar HNO_3 and 1% Organic

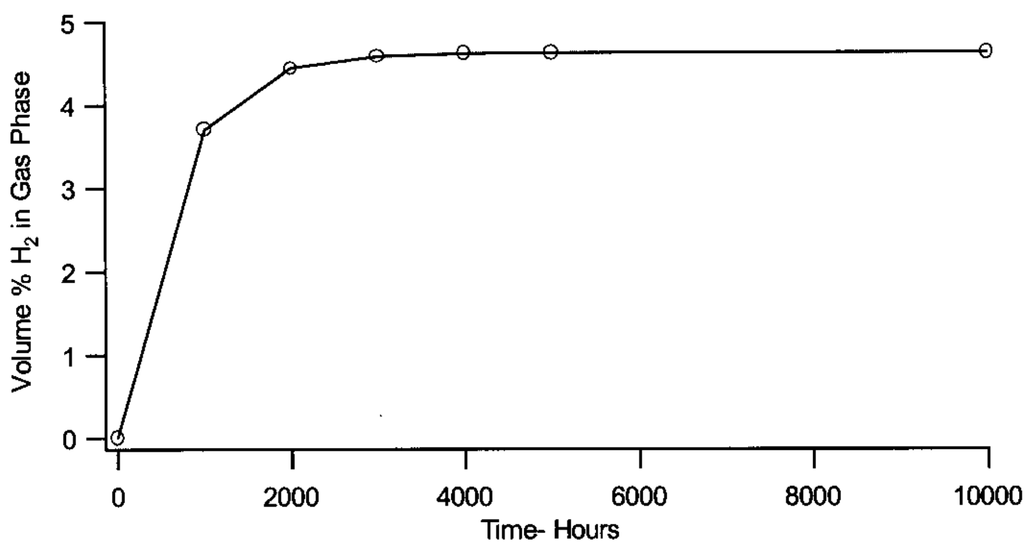


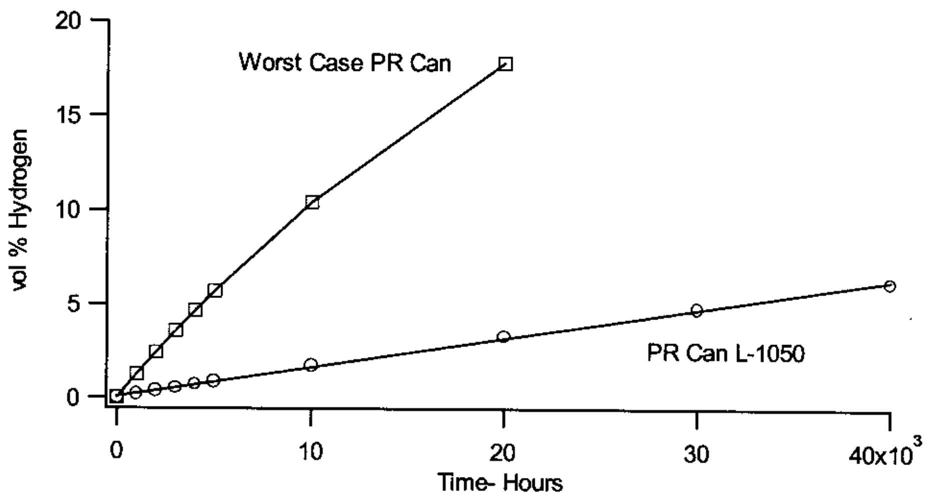
Figure 7 shows that the hydrogen concentration plateaus at 4.6 vol% within 5000 hours. This is just barely into the flammable range.

The hydrogen generation is much higher in Figure 7 because of the choice of worst case conditions. The primary factors driving the higher hydrogen generation are a higher G-value resulting from the lower nitric acid concentration and higher total alpha radiolytic energy rates.

The results of Figure 5 and Figure 6 were obtained using measured leak rates for non-vented drums. Since vented drums have openings at least ten times larger than those estimated above, no flammable hydrogen concentrations will be found in vented drums.

To be extremely conservative, a bounding hydrogen concentration was calculated for PR drums L1050 and PN-48-02-02-003, assuming no gross leaks and only diffusion through a neoprene gasket. The results are presented in Figure 8.

Figure 8 - Hydrogen in PR Can Drums Assuming Diffusion Through Gaskets and 8 Molar HNO_3



For this "diffusion only" case, the worst case fuels grade PR drum reaches the flammable concentration in approximately 3000 hours and reaches the detonable concentration in 20,000 hours. The total pressure within the worst case PR drum is 1.4 atmospheres at 20,000 hours.

The weapons grade PR drum reaches the flammable limit in 20,000 hours and reaches the detonable limit in 109,000 hours. The total pressure within PR drum L1050 is 1.05 atmospheres at 20,000 hours.

This section shows that PR drums with vent clips will not reach a flammable hydrogen concentration under "worst case" conditions. This is primarily because the vent clips increase the vent hole area by roughly a factor of ten over the natural hole area.

Non-vented but leaking PR drums (as defined by four test drums with bolted ring closures) only reach flammable hydrogen concentrations in PR drums with the highest isotopic energies.

If non-vented, non-leaking drums that can lose hydrogen only through diffusion are assumed, one may calculate a gaseous diffusion rate through a neoprene gasket that may reach a flammable hydrogen concentration within 3,000 hours and a detonable concentration within 20,000 hours under "worst case" conditions.

4.6 Summary and Conclusions

This section presented a discussion of hydrogen generation and accumulation in, and diffusion and leakage from drums. Section 4.5 presented a hydrogen accumulation model with a conservative gas generation rate and a study of depletion based on measured values of leakage through the drum gaskets. The model demonstrates that it is the quality of the drum lid seal that accounts for the wide variability in the hydrogen concentrations found in the data in Section 3.0.

Summaries of experiments presented in this section demonstrate that prediction of hydrogen generation where knowledge of drum contents and contamination is not known in great detail, is not accurate. This is a result of both the complexity of G-values for many different materials present and of the depletion of the waste matrix. Because of the complex makeup of waste materials in TRU waste drums, measured data as presented in Section 3.0 are the most valuable source of information on hydrogen generation and accumulation in TRU waste drums.

Further, the test results indicate that oxygen depletion is a significant parameter, and that decreasing oxygen concentrations negate the hazard created by the accumulation of hydrogen. As a result, only the data from

Chapter 3.0 yielding information about hydrogen concentrations equal to or greater than 15 vol% and oxygen concentrations greater than 5 vol% will be used in Chapter 6 to determine the probability of significant hydrogen concentrations in TRU drums.

Finally, as seen from the discussion in this section, even if a filter plug or a vent clip is not installed, sufficient gas can leak and diffuse from drums to minimize flammable hydrogen concentrations.

5. REALISTIC EVALUATION OF HANFORD DRUM PACKAGING DATA AND DRUM STORAGE CONDITIONS

5.1 Introduction

Data on TRU waste retrievably stored at Hanford have been collected and included in published reports. These reports describe the physical (Anderson 1990), radiological (WHC 1996, WHC 1991a, and WHC 1991b), and hazardous constituents (WHC 1992) of the stored material. The characterization data are derived from solid waste storage/burial records prepared at the time of storage, from process histories, and from interviews with personnel from the generating facilities. The specific conditions for the Hanford retrievable storage will be presented in this section.

5.2 Drum Packaging including gaskets, catalyst packs, vents, and vent clips

The referenced reports indicate that the waste consists primarily of contaminated material enclosed in one or more layers of plastic wrapping, placed in an outer structure of a drum, box, or other container. The majority of the drums are 55-gallon; most are 17C or 17H drums. The boxes are a variety of sizes and materials.

Drum lid gaskets consisted primarily of EPDM (Ethylene Propylene Di-Monomer) material. This material is tested to have an operating range of -40 to 170 °F. Durometer of the gasket material is above 65. Expected shelf storage life is indefinite. Gasket material may degrade upon exposure to ozone, sunlight (ultra-violet), and elevated temperatures. Degradation of gasket material is not expected in the covered portion of the Hanford trenches due the constant conditions and protection from the sun and temperature extremes (see next section). Other gasket materials include neoprene or Neozan gaskets, which consist of a plastic gasket material fabricated from a mixture of butadiene and styrene. Gasket materials are semi permeable to the diffusion of hydrogen. Drum closure mechanisms has varied slightly over the 25 years that drums were placed in the burial ground trenches between 1970 - 1985. One off-site waste generator is known to have glued gaskets in place at the time of closure. Glued gaskets would improve the drum leak tightness, but not prevent hydrogen diffusion.

Transuranic waste was first retrievably stored on the Hanford Site in May 1970. Installation of the Hanford vent clip on TRU waste drums generated at Hanford began in 1978. The Hanford vent clip is a 1-inch wide strip of stainless steel that clips over the edge of the drum lid and allows the package to breath without releasing any of the particulate material contained within. The clip protruded approximately 1.5-inches below the drum lid ring. Another device installed on some drums was a threaded filter vent inserted into the drum lid. The filter is carbon/carbon-composite filter, which effectively allows gases to vent and has an efficiency greater than 99.97% retention of 0.3-micron particulate. It is anticipated that TRU drum retrieval will come upon some number of drums that are unvented or the visible portion of the vent clip may have been destroyed during storage.

The following is a snap shot in time summary of various containers in each trench based on the release date of the references. Since that time, some of the containers have been moved between trenches or moved from the LLBG to another TSD, but no additional TRU waste has been moved into these trenches.

- 4C-T01 lists approximately five thousand (5,000) drums, thirty two (32) casks, seven (7) FRP boxes, sixty-three (63) metal boxes, four (4) 30-gal drums, and fifty-two (52) 110-gal drums.
- 4C-T04 records approximately ten thousand (10,000) drums, thirty-seven (37) metal boxes, one (1) FRP box, and fifty-seven (57) 110-gal drums.
- 4C-T07 is a box storage trench listing sixty-three (63) FRP boxes, ten (10) metal boxes, and forty-three (43) drums.
- 4C-T20 contains approximately five hundred (500) drums, seventy-three (73) metal boxes, eighty (80) miscellaneous cans and drums, one (1) miscellaneous cask, and one (1) plastic wrap.
- 4C-T29 contains approximately two thousand five hundred (2,500) drums and ten (10) metal boxes.
- 4B-TV7 contains one thousand three hundred twenty (1,320) drums.

- 4B-T07 is recorded as containing approximately eight thousand (8,000) drums, one (1) FRP box, thirty-eight (38) metal boxes, three (3) concrete boxes, one (1) plywood box, thirty-five (35) 110-gal drums, an item of equipment, scrap metal, several plastic bags, fourteen (14) filters, and one (1) cask.

5.3 Drum Waste Contents (hydrogenous materials)

Historical data on the form of waste contained in about one half of the containers can be found in Anderson (1990), *Contact-Handled Transuranic Waste Characterization Based on Existing Records*. The waste materials in containers that are not listed in Anderson (1990) are expected to be similar to the waste in the containers that are listed in the document, because the mixed fission products contained in the waste streams from plutonium processing are basically the same for all processes.

Approximately two-thirds of the TRU waste in drums to be retrieved is combustible material (paper, plastic, rubber, etc.) and the remaining one-third is noncombustible (metal and glass) (Anderson 1990). Table 4-5 of Anderson (1990) lists the waste components and the percentage contribution. A summation of combustible material percentages yields 65%. The TRU material is assumed to be distributed evenly throughout the drum contents. The remaining 35% is the contamination associated with the noncombustible waste material. A summation of this information is given Table 7.

Table 7 - Transuranic Waste Contents
Vol% = volume percent based on 51% of retrievable stored suspect TRU containers

Waste Material	Quantity
Metal	22 vol %
Lead	Trace
Dirt	2 vol %
Filters	1 vol %
Wood	2 vol %
Concrete	2 vol %
Glass	2 vol %
Absorbent	2 vol %
Subtotal Hard Waste	33 vol %
Rubber	8 vol %
Plastic	27 vol %
Paper	20 vol %
Cloth	6 vol %
Subtotal Soft Waste	61 vol %
Other	6 vol %
Total	100 vol %

5.4 Curie content

Only TRU drums will be transported from the LLBG trenches to a TSD facility; however, it is likely that every container, whether it is a drum, box, or some unique package, will be lifted and moved during the retrieval activities. Therefore, the following information from WHC (1991a) gives an overview of the quantity of TRU in the trenches and in the highest loaded containers. Additional information about container contents can be found in Table 6-13 and Table 6-15 in Chapter 6.0 of WHC (1995).

- 4C-T01 contains a total of 178,800 g of Pu. The highest TRU loaded container, a 10-L Shipping/Storage Container (110-gal drum), contains 910 g of Pu. The highest TRU loaded 55-gal drum contains approximately 244 g of Pu.

- 4C-T04 contains a total of approximately 120,000 g of Pu. The highest TRU loaded container is a 55-gal drum containing 219 g Pu.
- 4C-T07 is primarily a box storage trench containing a total of approximately 8,633 g of Pu. The highest TRU loaded container, a CI 667 container (corrugated metal box 6 feet W x 6 feet H x 7 feet L), contains 2185 g Pu. The highest TRU loaded 55-gal drum contains approximately 100 g of Pu.
- 4C-T20 contains 39,454 g of Pu. The highest TRU loaded container, a metal box, contains 395 g Pu. The highest TRU loaded 55-gal drum.
- 4C-T29 contains approximately 59,750 g of Pu. The highest TRU loaded container, a metal box, contains approximately 250 g Pu. The highest TRU loaded 55-gal drum contains approximately 200 g of Pu.
- 4B-TV7 contains a total of 3,000 g of Pu. The highest TRU loaded container, a 55-gal drum, contains approximately 100 g Pu.
- 4B-T07 is recorded as containing a total of 48,330 g of Pu. The highest TRU loaded container, which is a metal box, contains 494 g Pu. The highest TRU loaded 55-gal drum contains approximately 216 g of Pu.

WHC (1994) describes a DOT-6M shipping container holding 335 g of plutonium located in the uncovered portion of 4C-T01 near the EBR-II casks. The DOT 6M design uses a type 2R inner container with a diameter of 5 inches centered in a 55-gallon drum. However, Table 4-2 of WHC (1991a) shows that because of the isotopic distribution of the material in the drum, the DE-Ci value is only 36.73 DE-Ci, which is equivalent to 207.5 g of 12% ^{240}Pu, 20-year aged TRU. For this reason, the 244 g drum in 4C-T01 is considered the highest TRU loaded drum.

The 208 L (55-gallon) drum with the highest TRU content is located in the 218W-4C burial ground, trench 4C-T01, module 11. This drum contains 244 g of TRU. There is a metal box in the 218W-4B burial ground, trench 4B-T07, that contains 494 g of TRU. These two containers are the highest loaded containers. There are other containers with higher TRU loadings; however, they also contain extra levels of packaging or containment than a standard 17H drum or burial box.

5.5 218-W-4B and 218-W-4C Suspect TRU Drum Storage Conditions

Retrieval activities are planned for the 218-W-4B and 218-W-4C burial grounds over the next five years. All trenches in 218-W-4B are covered (backfilled and revegetated) with relatively constant conditions. Trenches in 218-W-4C have both covered and uncovered portions. Trench conditions are described below.

5.5.1 Uncovered portion of Trenches

The uncovered portion of the TRU retrieval modules includes the portion of the trench that was left open (not backfilled with soil). The number of drums exposed varies from trench to trench. Currently, drums have been moved from the uncovered portion of the module to a point where the surrounding soil is sloughing off over the top and sides of the module. This section of the module is considered the covered portion of the module. The temperature and humidity in this section, at the exposed section of drums, is considered to follow the diurnal cycle. Humidity is low, but temperatures may range from 0 to 110 °F.

5.5.2 Covered portion of Trenches

Waste drums are stacked in trenches with plywood sheeting between drum layers and on top of the drum module, plastic tarps on the topmost layer, and 1 to 1.2 m (3 to 4 feet) of earth over the plastic. The drums in each trench are divided into modules of nominally 12 by 12 arrays of drums stacked up to four drums high. Conditions within the covered modules are expected to remain relatively constant. Humidity in storage modules has been measured at nearly 90% during the summer months and 50 to 60% during other months. Average low and high temperature in Hanford soils below a depth of 4 feet range between 56 °F to 67 °F. Available data suggests that the temperature span in the TRU Modules should be roughly 50 °F to 86 °F. Duncan (1995) presents the temperature and humidity data.

5.6 Summary of Hanford Conditions

Historical data on the retrievably stored TRU waste at Hanford indicates that the waste consists primarily of contaminated material enclosed in one or more layers of plastic wrapping placed in an outer structure of a drum, box, or other container. The majority of the drums are 55-gallon 17C or 17H drums.

Approximately two-thirds of the TRU waste in drums to be retrieved is combustible material (paper, plastic, rubber, etc.) and the remaining one-third is noncombustible (metal and glass). This is consistent with the typical contents of TRU waste from the other DOE sites. Because of the similarities, the conclusions summarized in Section 3.10 for retained hydrogen and oxygen in site wide TRU drums is applicable to TRU drums at Hanford.

6. SAFETY BASIS CALCULATIONS

6.1 Introduction

This section provides a discussion of proposed changes to the "annual frequency of a drum explosion" and/or the "onsite and offsite dose consequences from a drum explosion presented in WHC (1995), Section 6.4.2.3.3.

6.2 Accident Frequency for an Explosion Event

6.2.1 Existing Assessment

An evaluation of the expected annual frequency of occurrence of a TRU drum explosion is provided in Section 6.4.2.3.3 of the Solid Waste Burial Grounds Interim Safety Analysis (WHC 1995). The focus for this assessment was the uncovered drums in 218-W-4C Burial Ground (i.e., the initial group of drums to be retrieved). The basic event requirements for a drum explosion and the assigned frequencies in Revision 3 of the SARR are summarized below.

- **Hydrogen is generated in TRU drums.** Radiolysis of hydrogenous materials is expected and has been observed in TRU waste drums. A frequency of 1.0 is assigned to this event.

- **Drums are not vented.** - Solid waste acceptance criteria require TRU drums to be vented (i.e., with a vent clip or filter). The focus of this assessment was the uncovered drums in Burial Ground 218-W-4C. The vent status of many of these drums was verified by direct visual inspection. A frequency of 1.0×10^{-4} was assigned, based on visual inspection and standard human reliability (Swain and Guttman 1983), to address the likelihood that an operator would fail to install a vent clip as required.

- **Hydrogen reaches explosive concentration with oxygen.** Information summarized in a 1985 INEEL study (EG&G 1985) was used to develop a probability value for this event. Direct measurements indicated that only one TRU waste drum out of 184 Rocky Flats drums and 33 Los Alamos drums contained a potentially explosive mixture. Based on this information, a frequency of 4.6×10^{-3} was determined.

- **An explosive hydrogen-oxygen mixture is ignited.** In WHC (1995) four potential ignition sources were considered: over pressurization due to solar heating, a static discharge due to jarring a container during handling, toppling (jarring) of a container from a stack during an earthquake, and jarring a container as the result of a vehicle crash. Of the four sources considered, over pressurization had the highest assigned annual frequency (0.25/yr).

Based on these event frequencies, the annual frequency per drum for a drum explosion event in WHC (1995) was estimated to be 1.15×10^{-7} per drum.

6.2.2 Assessment Provided in Justification for Continued Operations (JCO) Dated July 13, 2001

In June 2001, two unvented drums were discovered in Trench 1 of Burial Ground 218-W-4C. Each contained TRU inventories exceeding the 15-g limit that had been authorized by DOE for handling of unvented drums, resulting in an unreviewed safety question (USQ). A JCO was submitted to DOE on July 13, 2001 containing a discussion of the USQ, the basis for the observed increase in the number of unvented drums encountered in relocation activities, the accident frequency and dose consequences for a drum explosion involving a single unvented drum, and a proposal for resumption of TRU drum assay and relocation activities based on managing the risk associated with the revised expectations regarding the occurrence of unvented drums. For an individual unvented drum (i.e., assuming the probability that a drum is unvented to be 1.0 rather than the 1.0×10^{-4} assigned previously), the frequency of a drum explosion event was determined to be 1.15×10^{-3} per drum.

6.2.3 Revised Assessment

The basic event requirements and assigned frequencies for a drum explosion accident have been reevaluated based on updated information developed in this study and from ongoing retrieval activities. The focus of the revised assessment is on drums in the covered portions of trenches in 218-W-4B and 218-W-4C Burial Grounds. Revised events and frequencies are summarized below, with supporting rationale. Accident frequencies for drum handling and drum venting activities are addressed separately.

Frequency of a drum explosion event during drum handling operations:

Drum handling includes the following event requirements:

- **Hydrogen is generated in TRU drums.** A frequency of **1.0** was assigned previously. This study supports the premise that radiolysis of hydrogenous materials in TRU waste drums is an expected event.

- **Drums are not vented.** Prior to 1978, vent clips were not installed on TRU waste drums by on-site or off-site generators. On-site generators (specifically PFP and PUREX) adopted the practice of installing vent clips on TRU waste drums in 1978. Off-site generators were not required to ship drums with vent clips installed until 1985. Therefore, it is expected that up to 100% of drums packaged and received prior to 1978 will be unvented. For drums with acceptance dates between 1978 and late 1985, the expectation is that nearly all drums from PFP and PUREX are vented, and nearly all drums from other generators are unvented. For drums that were placed in retrievable storage since late 1985, it is expected that nearly all drums will be vented (except in cases where vent clips were not installed due to human error; a frequency of 1.0×10^{-3} was assigned to this event previously). The following table provides an estimate of the percentage of unvented drums that are likely to be encountered during the remainder of TRU retrieval operations in 218-W-4C Burial Ground.

Table 8 - Estimate of Vented and Unvented Drums in 218-W-4C

Location	Acceptance Date	Vented	Unvented
Trench 1	Pre 1/1/79	0	13
	1/1/79-10/31/85	3,198	1,180
	Post 10/31/85	2	0
Trench 4	Pre 1/1/79	0	1,280
	1/1/79-10/31/85	6,011	2,620
	Post 10/31/85	0	0
Trench 20	Pre 1/1/79	0	0
	1/1/79-10/31/85	211	296
	Post 10/31/85	13	0
Trench 29	Pre 1/1/79	0	0
	1/1/79-10/31/85	599	1,059
	Post 10/31/85	120	0
Totals		**10,154**	**6,448**

The majority of TRU drums received between 1985 and 1988 were placed in the uncovered portions of trenches in 218-W-4C Burial Ground. Many of these drums have already been retrieved. Therefore, the percentage of unvented drums is expected to increase as successively older drums are encountered. The estimated percentage of unvented drums among the drums that remain to be retrieved in 218-W-4C Burial Ground is 38.8%. All drums in Trenches 7 and V7 of 218-W-4B Burial Ground were emplaced prior to January 1, 1979. Consequently, it is anticipated that essentially 100% of those drums will be found to be unvented. The combined estimate of unvented drums in 218-W-4B and 218-W-4C is 61.0%.

- **Drums are verified to be TRU and, therefore, are required to be vented.** According to inventory information in the Solid Waste Information Tracking System (SWITS), approximately 2/3 of the drums remaining to be retrieved in Burial Grounds 218-W-4B and 218-W-4C contain less than 1.5 g of TRU constituents. Drums retrieved with inventories of 1.5 g or less are assayed to determine whether they are appropriately classified as TRU waste or are actually low-leve waste (LLW) according to the current statutory definition of TRU. The experience to date is that 50 to 70% of retrieved drums with inventories less than 1.5 g of TRU are determined by assay to be LLW. The specific value varies with the module being retrieved. There is no current plan to vent suspect TRU drums that assay as LLW (Demiter 1999). Therefore, the concern regarding the vent status of drums being retrieved applies specifically to the drums that are determined by inventory or by assay to be TRU. Using the conservative lower limit of the range identified above, it is anticipated that about 2/3 of the drums (i.e., 33% of drums that are greater than 1.5 g by inventory plus 50% of the 2/3 of drums with inventories of 1.5 g or less) to be retrieved will be determined to be TRU waste (which is required to be vented).

- **Hydrogen reaches explosive concentration with oxygen.** A larger body of information is available now regarding hydrogen and oxygen contents in TRU waste drums compared to the information that was used to estimate the event frequency in WHC (1995). The current information from various DOE sites has been summarized in Section 3.0 of this report. Hydrogen and oxygen concentration data are tabulated in Section 3.10. Measurements of gas compositions in 210 INEEL drums indicated that six contained at least 15 vol% hydrogen; only one of the six drums contained sufficient oxygen (i.e., at least 5 vol%) to support combustion. Similar measurements from 298 Rocky Flats drums indicated that five contained at least 15 vol% hydrogen, but only one drum of the five contained oxygen at or above the 5 vol% level. The INEEL and Rocky Flats data indicate that the frequency of occurrence of an explosive hydrogen-oxygen mixture in a drum is approximately 3.94×10^{-3}. Hydrogen concentration data for large numbers of drums are available from SRS and LANL, however, comparable oxygen values were not collected.

- **An explosive hydrogen-oxygen mixture is ignited.** Over pressurization due to solar heating is not, by itself, a potential ignition mechanism. As indicated in Section 2.0, ignition of hydrogen-oxygen mixtures is accomplished by various mechanisms that provide initiation energy in a form that raises the temperature in a localized region of the gas mixture to the auto-ignition temperature. Contents of uncovered drums may experience a daily temperature rise on the order of 100 °F (e.g., from an ambient temperature of 77 °F to an extreme close to 180 °F). Auto-ignition temperatures for hydrogen-air mixtures at 1 atmosphere (atm) are 800°F and above, so auto-ignition due to solar heating is infeasible. However, with this temperature change, there will be a corresponding change in internal pressure from an initial value of 1 atm to about 1.2 atm. As shown in Figure 9, increasing the pressure of the gas mixture increases its susceptibility to ignition by lowering the minimum ignition energy for the mixture. At 1 atm, the minimum energy required to ignite a 30% hydrogen-air mixture is 0.02 mJ (0.02 watt-second). At 1.2 atm, the minimum initiation energy is on the order of 25% lower.

  Therefore, the frequency of an ignition should be determined based on an ignition from a static discharge from a jarred container. In WHC (1995), the frequency for a 0.02-mJ static discharge within a jarred container is given as 5×10^{-3}/yr. If it is assumed conservatively that a discharge of 0.015 mJ is an order of magnitude more likely to occur, then the event frequency for an ignition of a hydrogen-oxygen mixture would be 5×10^{-2}.

From these considerations, the combined annual frequency of a drum explosion event is calculated to be:

$$(1.0)*(0.61)*(2/3)*(3.94 \times 10^{-3})*(5.0 \times 10^{-2}) = 8.01 \times 10^{-5}/\text{drum}$$

The assigned event frequency of 5×10^{-2} for ignition of a hydrogen-oxygen mixture may lead to an annual frequency assessment that is unduly conservative. An alternate estimate for the event frequency of a drum explosion during drum handling operations may be derived from the existing experience basis within the DOE complex. A total of 23,677 TRU drums has been retrieved and vented without incident to date. Each drum was subjected to a minimum of four separate handling steps: loading onto a transport vehicle, transportation, unloading, and delivery/setup at a designated venting location. In most cases, drums actually were handled five to ten times before venting (i.e., the assigned value of four handling steps is conservative). The current number of observations does not include a drum explosion event. To estimate a failure rate from observational data with no failure events, Welker and Lipow (1974) indicate that it is appropriate to assume that the observational data represents 1/3 of the recurrence interval for the failure event. Therefore, the current experience basis supports the following event frequency assessment for a drum explosion during drum handling operations:

$$1 / \{(3)*(4)*(23,677)\} = 3.52 \times 10^{-6}/\text{drum}$$

Frequency of a drum explosion event during drum venting operations:

Drum venting operations include the following event requirements:

- **Hydrogen is generated in TRU drums.** As indicated previously, radiolysis of hydrogenous materials in TRU waste drums is an expected event, for which a frequency of **1.0** has been assigned.
- **Drums are not vented** Based on the information provided in the previous section, the estimated percentage of unvented drums among the drums remaining to be retrieved in 218-W-4C Burial Ground is 38.8 %. It is anticipated that essentially 100% of the drums in 218-W-4B will be unvented. The combined estimate of unvented drums in 218-W-4B and 218-W-4C is 61.0%.
- **Drums contain sufficient TRU inventory to generate significant quantities hydrogen by radiolysis.** As indicated above, it is anticipated that about 2/3 of the drums involved in the TRU Retrieval Program will actually be determined to be TRU.
- **Hydrogen reaches explosive concentration with oxygen.** Data from INEEL and Rocky Flats indicate that the frequency of occurrence of an explosive hydrogen-oxygen mixture in a drum is approximately 3.94×10^{-3}.
- **An explosive hydrogen-oxygen mixture is ignited.** Section 7.0 of this report describes a number of different venting systems that are being considered for use in conjunction with TRU retrieval operations. These systems employ various approaches to venting of drums, which may either take the form of drilling or punching a hole. Bronze punches or punching tools constructed with non-sparking aluminum-bronze housings are used to prevent a spark discharge. Drilling devices utilize a slow (cold) drilling process and a spark-resistant titanium nitride drill bit to minimize the risk of a spark discharge. Consequently, regardless of the specific system selected for venting drums, the frequency of an ignition from a spark must be extremely small (certainly $<1.0 \times 10^{-4}$ and probably $<1.0 \times 10^{-6}$).

If the beneficial effect of venting with non-sparking tools is excluded from consideration, the unmitigated accident frequency is calculated as follows:

$$(1.0) * (0.61) * (2/3) * (3.94 \times 10^{-3}) * (1.0) = 1.6 \times 10^{-3}/\text{drum}$$

In the unmitigated frequency calculation, a value of 1.0 is assigned to indicate that creation of a spark during venting is an anticipated event. With mitigation (i.e., use of non-sparking tools), the calculated accident frequency is:

$$(1.0)*(0.61)*(2/3)*(3.94 \times 10^{-3})*(1 \text{ X } 10^{-4}) = 1.60 \times 10^{-7}/\text{drum}$$

This estimate is two orders of magnitude less than the event frequency estimates for an explosion during drum handling. It may be appropriate to regard a hydrogen ignition caused by venting drums with non-sparking tools to be an incredible event. These calculations demonstrate that the risk of a drum explosion during venting is bounded by the risk of an explosion during drum handling.

6.3 Source Term Analysis

The form of the analysis presented below for material at risk and total release source term is consistent with the analysis presented in the current Waste Receiving and Packaging (WRAP) Facility FSAR (HNF-SD-W026-SAR-002, Rev. 1-C) and the draft Addendum to WHC (1995). This analysis considers a different bounding inventory drum from those considered in Revision 3. The drum explosion accident in Revision 3 considers uncovered drums in Burial Ground 218-W-4C. This analysis considers the larger population of covered drums in Burial Grounds 218-W-4B and 218-W-4C. The drum population under current consideration involves a larger bounding inventory case than was evaluated previously. A three-component model was used in Revision 3 to calculate a respirable release fraction. The draft Addendum to WHC (1995) documents a five-component release fraction model, which is used in this source term analysis.

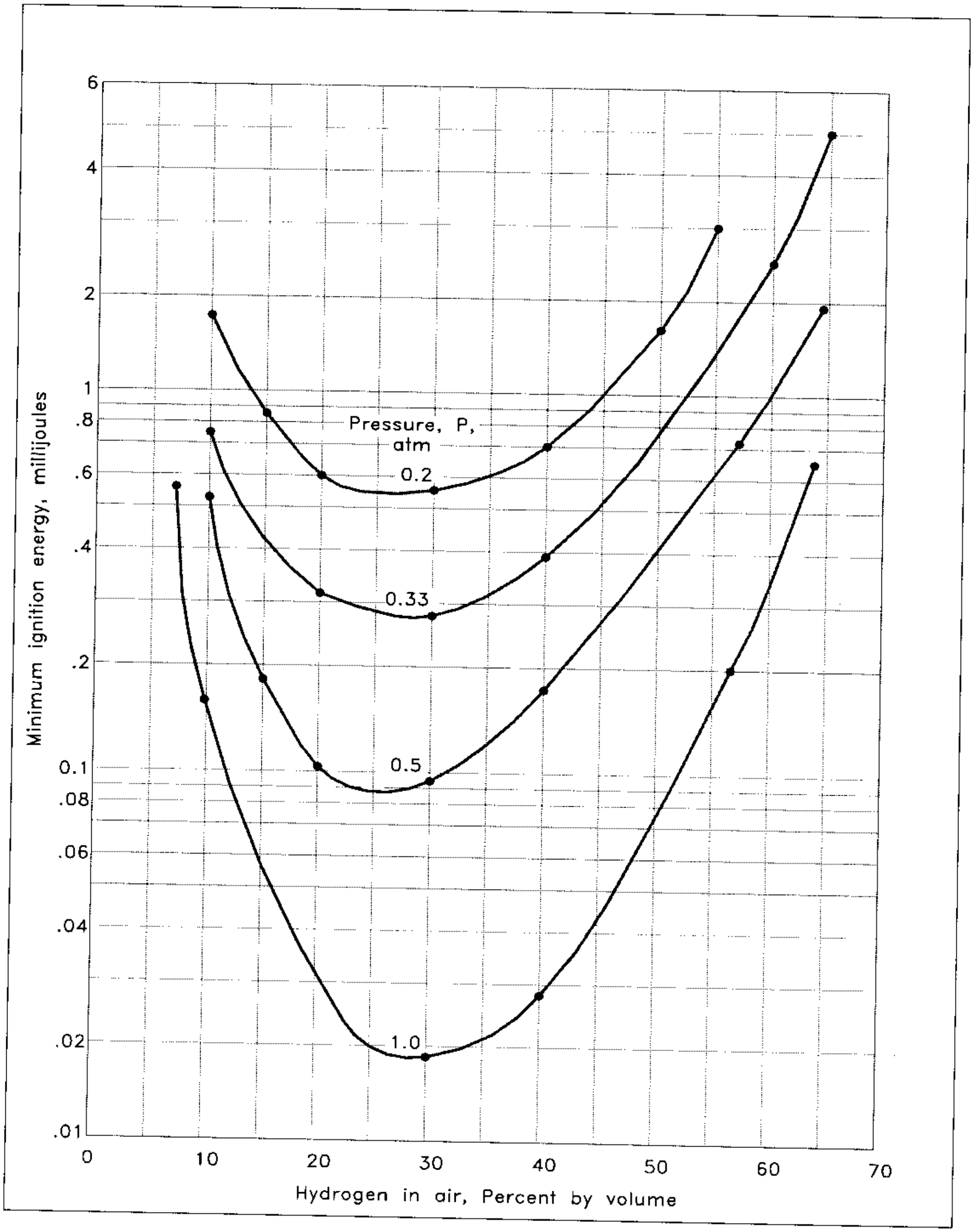
For this analysis, the maximum TRU inventory for a hydrogen deflagration event is considered to be the drum with the maximum inventory within the population of drums in 218-W-4B and 218-W-4C burial grounds that is identified for retrieval during the TRU Retrieval Project. According to SWITS, the maximum inventory (244 g) occurs in a drum in Trench 1 of 218-W-4C. There are a number of other containers in the two burial grounds that have higher TRU inventories than the maximum-inventory drum. Among containers of all types, the highest TRU inventory is found in a container (a corrugated metal box) in 218-W-4B Trench 7, which has an inventory of 2,185 g. Boxes are not regarded to be capable of retaining hydrogen at elevated concentrations or pressures, and are not considered in this analysis. Among containers other than boxes, the highest inventory (910 g) occurs in an L-10 container (also located in Trench 1 of 218-W-4C). L-10 containers are fully-welded 110-gallon drums, with multiple layers of encapsulation, containing fuel rods and oxide powder. Beacuse no hydrogenous materials are present, L-10 containers are not potential hydrogen generators.

Limiting consideration of a drum explosion accident to results involving the maximum inventory drum does not provide a realistic portrayal of consequences for the overall population of TRU drums. Information is presented in Tables 8 and 9 of WHC (1996) regarding the numbers and inventories of 55-gallon TRU drums received for retrievable storage between May 1, 1970 through December 31, 1988. Of the 38,859 drums received during this period, the 50th percentile drum contains less than 1 g of TRU. The average inventory (obtained by dividing the total TRU inventory by the number of drums) is 10.73 g. On a percentile basis, the average inventory drum occurs at about the 85th percentile. Therefore, a disproportionate number of drums in retrievable storage (i.e., 85%) is below the average inventory, and a relatively small number (15%) is above the average. Source terms are evaluated below for 1-g, 11-g, and 244-g inventories. Sample calculations are shown for the 244-g source.

The assumed isotopic distribution for TRU constituents in the following calculations is the distribution listed in Table 1 of Appendix 6D of WHC (1995). Calculations may be shown either in units of grams (as in WHC 1995) or dose-equivalent Curies (DE-Ci) (as in the draft Addendum to WHC (1995). The calculated effective dose consequences are insensitive to the units used, as long as the appropriate baseline unit release dose factor is applied.

Figure 9 – Ignition Energies for Various Hydrogen-Air Mixtures and Pressures

(Redrawn from Postma and Hilliard, 1983)



The source term for a TRU drum explosion from a hydrogen deflagration is a composite of the following five components:

- A release (i.e., material dispersed in air) caused by the blast effects of the explosion (A1)
- A release caused by the burning of ejected combustible waste (A2)
- A released caused by the heating of ejected noncombustible waste (A3)
- A release caused by the burning of the combustible waste remaining in the drum (A4)
- A release caused by the heating of the noncombustible waste remaining in the drum (A5)

Assumptions:

- Dose calculations need to account for both oxide and nitrate forms of TRU material. To determine the dose related to TRU material in nitrate form, the material released by mechanical action is multiplied by ratio of nitrate unit dose to oxide unit dose (1.4) provided in Table 3-21 of the WRAP FSAR.
- Material is assumed to be in an oxide form for determining inhalation doses
- Material made airborne by the explosion is considered to be in a nitrate form (if it is not specifically known to be oxide). Material made airborne by burning is considered to be in oxide form.
- The release fraction for respirable material made airborne as the result of a deflagration is 1.0×10^{-3}. Most contaminated material has a flexible substrate (paper, rubber, cloth, etc.) and little fragmentation is expected to occur. No damage to adjacent drums is anticipated.
- In scenarios involving the burning of waste container contents, 65% of the TRU material is directly released by combustion. The remaining 35% is contamination associated with the noncombustible material, which is released by heating.
- The release fraction for respirable material made airborne by a fire involving combustible materials ejected by a deflagration is 1.0×10^{-2}.
- The release fraction for respirable material made airborne because of a fire involving combustible materials remaining in the drum is 5.0×10^{-4}.
- The release fraction for respirable material made airborne from a fire involving noncombustible materials is 6.0×10^{-5}.

For a 244-g container, the quantity of contents ejected by the explosion is:

$$(244\ g) \times (0.1) = 24.4\ g$$

and the material remaining in the drum after the explosion is:

$$(244\ g) \times (0.9) = 219.6\ g$$

Table 9 - Total Release Source Terms for 1-, 11-, and 244-g TRU Drums

Component	Release Fraction	1-g Drum Source	11-g Drum Source	244-g Drum Source
A1	$(1.4)(1.0 \times 10^{-3})$	1.40×10^{-4}	1.54×10^{-3}	3.42×10^{-2}
A2	$(0.65)(1.0 \times 10^{-2})$	6.50×10^{-4}	7.15×10^{-3}	1.59×10^{-1}
A3	$(0.35)(6.0 \times 10^{-5})$	2.10×10^{-6}	2.31×10^{-5}	5.12×10^{-4}
A4	$(0.65)(5.0 \times 10^{-4})$	2.93×10^{-4}	3.22×10^{-3}	7.14×10^{-2}
A5	$(0.35)(6.0 \times 10^{-5})$	1.89×10^{-5}	2.08×10^{-4}	4.61×10^{-3}
Total Release Source Term (g)		1.10×10^{-3}	1.20×10^{-2}	2.70×10^{-1}

6.4 Consequence Analysis

The radiological dose consequences for the drum explosion accident are determined by multiplying the source term released by the appropriate baseline unit release dose, taking into consideration the form of the plutonium (oxide or nitrate), and the appropriate dispersion factor X/Q' to obtain the dose consequence (i.e., the total effective dose equivalent, TEDE) in rem. The X/Q' values used in the following calculations are from Appendix A of the draft Addendum to WHC (1995). The source of the baseline unit release dose is Table 5 of Appendix D, WHC (1995). Sample calculations are shown below for the drum explosion with fire scenario for the maximum inventory (244-g) drum. Consequences for the 1-g, 11-g and 244-g source cases are listed in Table 10.

For a 244-g source:

- The maximum hypothetical onsite (100 meters) dose is:

$$(2.70 \times 10^{-1}\ g) \times \left(\frac{2.0 \times 10^{4}\ \text{rem EDE}\ \ m3}{g\ \ sec}\right) \times (1.13 \times 10^{-2}\ sec/m3) = 61.0\ \text{rem EDE}$$

- The maximum onsite (120 meters) dose is:

$$(2.70 \times 10^{-1}\ g) \times \left(\frac{2.0 \times 10^{4}\ \text{rem EDE}\ \ m3}{g\ \ sec}\right) \times (7.89 \times 10^{-3}\ sec/m3) = 42.6\ \text{rem EDE}$$

- The maximum Highway 240 (3.96 kilometers) dose is:

$$(2.70 \times 10^{-1}\ g) \times \left(\frac{2.0 \times 10^{4}\ \text{rem EDE}\ \ m3}{g\ \ sec}\right) \times (4.66 \times 10^{-5}\ sec/m3) = 0.25\ \text{rem EDE}$$

- The maximum near river (9.65 kilometers) dose is:

$$(2.70 \times 10^{-1}\ g) \times \left(\frac{2.0 \times 10^{4}\ \text{rem EDE}\ \ m3}{g\ \ sec}\right) \times (1.97 \times 10^{-5}\ sec/m3) = 0.11\ \text{rem EDE}$$

- The maximum offsite fence line (11.78 kilometers) dose is:

$$(2.70 \times 10^{-1}\ g) \times \left(\frac{2.0 \times 10^{4}\ \text{rem EDE}\ \ m3}{g\ \ sec}\right) \times (1.42 \times 10^{-5}\ s/m3) = 0.076\ \text{rem EDE}$$

These limiting dose consequence values are summarized in the following Table.

Table 10 - Limiting Dose Consequences at Specified Locations for 1-, 11- and 244-g Sources

Location	1-g Source (rem EDE)	11-g Source (rem EDE)	244-g Source (rem EDE)
Onsite at 100 m	0.25	2.71	61
Onsite at 120 m	0.17	1.89	42.6
Hwy 240 (3.96 km)	0.001	0.011	0.25
near river (9.65 km)	0.0004	0.0047	0.11
Offsite fence line (11.78 km)	0.0003	0.0034	0.076

Based on the limiting dose consequences in Table 10, the off-site receptor will not be exposed to potential consequence exceeding 1 rem. The criteria provided by DOE-RL for determination of the need for safety class SSC's, as implemented in HNF-PRO-700, would not require any safety class SSC's for drum venting. The potential need for safety significant SSC's and their selection will be established in the DSA for the drum venting activities.

6.5 Measures to Eliminate, Control, or Mitigate Hazards Associated with Drum Venting

Safety significant SSC's and defense in depth provisions (design features and/or administrative controls) should be considered on the drum venting operation to limit associated worker safety hazards. Specific hazards at issue for the onsite worker are:

- Physical injury from forceful release of the drum lid, retaining ring, and/or drum contents during an explosion.
- Contact with hot and/or burning material expelled from the drum.
- Internal or external contamination from radiologically contaminated particulates (which may be either finely divided contents of the drum expelled by the explosion, smoke particles containing radionuclides, or radionuclides in oxide form released into the air with other products of combustion.

The following physical and/or procedural conditions are identified for consideration to address these hazards:

- The venting operation will be performed with non-sparking equipment. The intent of this control is to minimize or eliminate the potential for a deflagration to be initiated by the activity.
- Venting should be performed in the same burial ground where an unvented drum is retrieved. The purpose of this control is to minimize the number of drum handling steps that must be performed between the time it is removed from the face of the trench and the time it is vented.
- Venting equipment should be designed so that the actual venting step in the procedure can be performed remotely with the operator positioned a safe distance away from the drum to avoid exposure to projectiles or any burning debris expelled from an exploding drum.
- Before a drum is vented, it should be covered with a blast net capable of restraining the lid, retaining ring, and/or any large fragments of contents so that these items are retained in the immediate vicinity of the drum in the event of an explosion. The intent of this provision is to shield on-site workers from projectiles and burning debris if an explosion should occur, and limit (to the degree practical) the extent of the area that becomes heavily contaminated as a result of the accident.
- A job hazard analysis (JHA) will be prepared that is specific to this activity. The JHA will identify appropriate protective measures (e.g., personal protective equipment) to be implemented for onsite workers involved in the venting operation. Specifically, the JHA will identify protective measures necessary to minimize the potential for onsite workers to be contaminated as a result of a drum explosion.

7. Venting Strategy and Plan

7.1 Introduction

This section provides the criteria and proposed schedule for drum venting related to the TRU Retrieval Program. Alternative techniques for drum venting are discussed and analyzed from a cost-benefit standpoint. Based on this analysis, a technique is recommended for application to the TRU Retrieval Program.

7.2 Venting Criteria

Drum venting is required to provide an escape route for hydrogen and volatile organic compound gases in the headspace of TRU waste drums. For TRU drums to be accepted into the CWC, the drums must have a venting device installed. A previous plan for handling unvented drums was described in McDonald (2000), *Unvented Drum Handling Plan*. The plan evaluated various options, including venting equipment and venting locations. The recommendation was to vent the unvented TRU drums in the LLBG using drum-venting equipment supplied by a commercial vendor.

Based on the supporting analysis described in this report, the current strategy is also to procure equipment and support for drum venting and sample port installation from a commercial vendor. The equipment will be demonstrated during the readiness review process and implemented in the LLBG trenches.

Once approvals have been obtained, venting will commence in the LLBG trenches in ongoing campaigns through the year 2006 as shown in the drum-venting schedule (Figure 15). Twelve hundred (1200) drums are to be retrieved in the first year and 500 of those are expected to require venting. The number of retrieved drums will increase in each of the following years with a maximum of 5000 drums expected to be retrieved in any one year. The maximum expected number of drums to be vented in any one year is 2000. Based on experience at other sites and a typically assumed operational efficiency of 80 %, a maximum of 25 drums will be vented per eight-hour day and venting will take place continuously throughout the year to keep pace with retrieval activities.

7.3 Summary of Vent System Criteria and Specifications

The drum venting system is not proposed to be Safety Class equipment based on the evaluation and the impact to workers and the environment. Actual equipment designation is determined in the DSA. Safety-class applies only to those structures, systems, and components (SSCs) in which failure could adversely affect human safety and health or the environment. The need for safety-class shall not be required when the unmitigated accidental release analysis for an unmitigated accidental release indicates the hypothetical maximally-exposed member of the general public located at the site boundary for an exposure duration of two hours could receive a dose less than 1 rem. The maximum unmitigated off-site dose for a single TRU container explosion accident was shown in Section 6.4 to be 0.25 rem, which is less than the safety-class criterion of 1 rem TEDE (WHC 1995). Therefore, this analysis supports the conclusion that the drum venting system should not be designated Safety Class equipment.

The Quality Level (QL) for the vent system, based on HNF-PRO-259, is proposed to be QL 3. This QL is based on the venting system not being a safety class item and not posing a high or medium project risk.

The criteria used to specify the vent system is based on meeting the project needs within the limits stated in the Safety Basis Document. Venting of drums that are found not to have vent clips will be performed in the trench.

The workers in the trench will be protected by procedures that require remote actuation of the venting operation with all personnel a safe distance from the drum and nets covering the drums to contain the drum lid in the event of an explosion. Safe distances will be determined by industrial safety procedures prior to commencing venting operations.

The vent system shall be able to install vent/filters and sample ports into 55-gallon drums using a method that will not create an ignition source and will not allow a release of radioactive particulates.

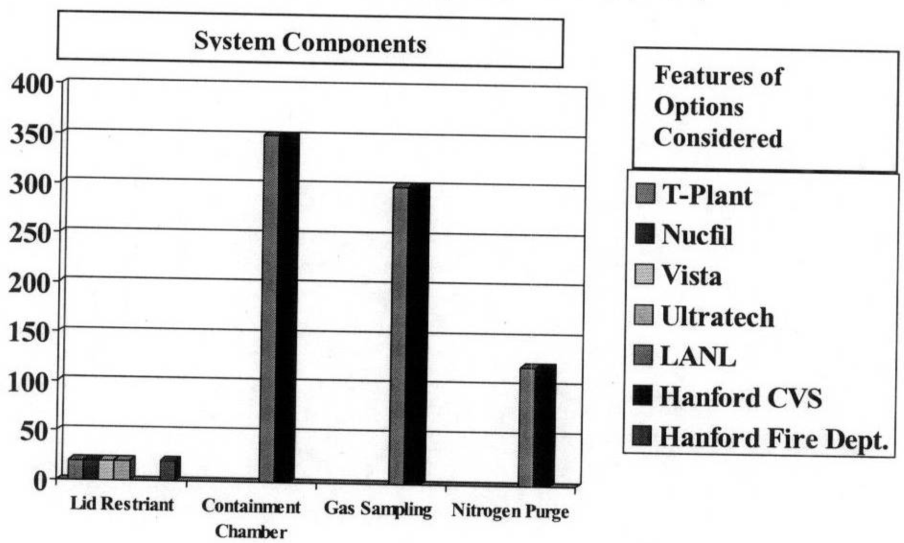
The system will need to be portable, meaning it can be moved from trench to trench, and will need to be able to withstand the environmental conditions. The venting system will be operated outside in a remote desert environment without utility services. Venting will take place during campaigns throughout the year and the temperature can be expected to vary between –10 °F and 110 °F. Significantly windy and dusty conditions are expected to be present periodically at the trenches

The vent system filters must safely and quickly relieve any pressure buildup in a sealed drum to minimize the release of radioactive particulates; they must be certified HEPA filters and meet WIPP WAC and TRUPACT-II SAR requirements. Sample ports, if used, would need to provide the capability to pull headspace gas samples from the drums for analysis. Other system specifications that need to be met include the ability to install vent/filters and sample ports in a minimum of four drums an hour.

A summary of the vent systems available with their advantages, disadvantages and safety features are provided in Section 7.3. Various methods for venting drums are presented, from remote operated devices to large contained devices with blast shields to contain an explosion event. Some of these devices have proved successful in various applications at DOE sites, while others have only been tested in controlled settings of a test facility, are based on designs from other vent system applications, or are concepts that have not yet been built.

Each system evaluated will provide drum-venting capabilities, but some systems would require modifications to meet all the requirements listed above. A few of the systems have capabilities (and along with that higher costs) above and beyond what are required based on the analysis of this report. Figure 10 shows a relationship of the cost for each of the additional risk reducing system capabilities. These costs were based on the component costs of the Los Alamos Drum Venting System which was built with each of these features.

Figure 10 - Safety Feature Costs (in $K)



From Figure 10 it can be seen that the Nucfil, Vista, and Ultratech systems have a low cost but do not have the additional risk reduction features of a gas sampling system, nitrogen purge system, or containment chamber such as the Hanford Container Vent System and Los Alamos Vent System.

Each of the additional features will in some way reduce the risk of an explosion or release occurring during venting. The drum lid-restraining device would prevent the drum lid from being projected into the air and possibly causing damage if an explosion were to occur. The gas sampling system allows the operators to know the hydrogen concentration in the drum and whether or not the hydrogen gas needs purged before the drum could safely be moved. The nitrogen purge system allows the operator to displace the hydrogen in the drum and the containment chamber would prevent the release of radioactive and toxic gasses into the atmosphere.

From the analysis of risks made earlier in this report, it has been shown that a risk of an explosion during venting is estimated to be an "incredible" event. Based on this analysis and the experience at other sites, venting of TRU drums is safe and is considered a routine activity. Therefore, the recommended venting approach will be to use the system that meets all the drum venting requirements listed above and provides the additional non-required benefit of a drum lid restraining device. Gas sampling and purging systems were used at some, but not all, of the other sites evaluated in Section 3. Using these systems has showed no benefit

The Nucfil Vent-N-Go system described below is the recommended vent system, based on its capabilities to fulfill the requirements described above. Of all the systems evaluated the Nucfil Vent-N-Go system is the most simple and cost effective design that fulfills the requirements of providing a method of safely installing both HEPA filter vents and sample ports. A lid-restraining device to provide an added measure of safety with minimal additional cost will augment the vent-n-go system.

7.4 Portable Venting Systems

Nucfil Vent-N-Go System – The Nucfil Vent-N-Go system uses a remotely activated pneumatic device to install dart filters and dart sample ports. The NucFil Dart Filter and Dart Sample Port are designed for safe and rapid installation into metal drum lids. Dart Filters safely and quickly relieve any pressure buildup in a sealed drum. Dart Sample Ports allow for easy sampling of headspace gas in a drum without opening the drum in any manner. The NucFil Dart devices are manufactured with aluminum bronze housings to prevent sparking during penetration of a drum lid. The external design and dimensions of the Dart Filter and Dart Sample Port are identical, so exactly the same installation system is used for both (see Figure 11).

Advantages

- Lightweight and portable, easily moved from one trench to another and within a trench from drum to drum if necessary.
- System is easily mounted on drum lids and adjustable to varying drum dimensions.
- Simple design allows for easy maintenance or equipment replacement.
- Relatively low equipment cost would allow for more than one system to be purchased, if needed, to accelerate the schedule without having a significant budget impact.
- The system is developed and tested.
- If for some reason a filter/sample port were not installed correctly it could be capped and another filter/sample port could be installed on a single drum lid by simply rotating the vent system on the drum lid.
- Tests using fluorescent dye have shown that NucFil Darts are reliably installed in standard drum lids without risk of contamination release. Post installation testing has shown that drums with NucFil Darts continue to meet all DOT Type A package certification requirements.

Disadvantages

- This system has only been demonstrated in a controlled setting and has not been demonstrated in the field or used at any other DOE sites.

Safety Features

- The system can remotely install filters and sample ports to allow operators to work a safe distance from the drum. Thus, the worker will be removed from the hazards associated with venting and installing filtered vents into the lids of drums.
- The dart filters are made with a non-sparking aluminum bronze housing.
- The dart is installed in such a manner that no noxious fumes will escape during the process.

- Installation device would also serve as lid restraint to some extent as the method of attachment consists of clamps that attach to the lid and drum at three points along the circumference of the drum lid.

System Costs

- Initial Equipment Cost – $20K
- Yearly Maintenance Cost – $2K

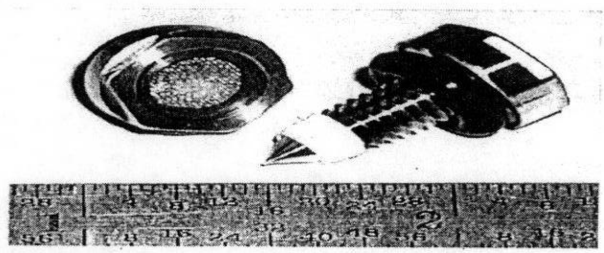
Figure 11 - NucFil Dart Filter Venting Device

NucFil® — Nuclear Filter Technology

NEW
NucFil® Dart Filter

New Dart Filter

- Nuclear Filter Technology's Dart filters are engineered to provide effective hydrogen diffusion in a small easy to install housing
- The Dart filter sample port penetrates the drum lid with an aluminum bronze housing, preventing sparking during penetration of a drum. The sharp point falls into the drum upon entry allowing an opening for sampling gases
- Filters are certified HEPA filters that meet WIPP WAC and TRUPACT-II SAR Section 1.3.5 requirements:
  - ◊ H2 permeability exceeds 3.7 E-06 mol/s/mol fraction
  - ◊ Greater than 99.97% removal of 0.45 micron DOP
  - ◊ Greater than 60 ml/min at <1" W.C.
- NucFil® Dart filters are certified to pass the DOT 7A drop test, stacking, vibrations, dart impact and water entry test



Sample ports are installed remotely

Proprietary—Patent Pending

Ultratech Cold Drilling Vent System – The Ultratech system uses a remotely activated drill to install vented filters and sample ports. The installation process involves placing the 55-gallon drum onto a portable platform and enclosing it in an explosion chamber. A Programmable Logic Controller (PLC) controlled Drill Press is activated and through a slow drilling process an ultra-rad self drilling filter approved for use at WIPP and TRUPACT II is installed (see Figure 12).

Advantages

- Drilling process allows visual verification that filters have been installed correctly.

Disadvantages

- The system is in the development stages and it is a "one-off" design, it is still unproven or demonstrated.
- This system would be skid mounted and portable but drums would need to be moved to it for venting in the trench and it would not be as easy to move from trench to trench as the vent-n-go system from Nucfil.

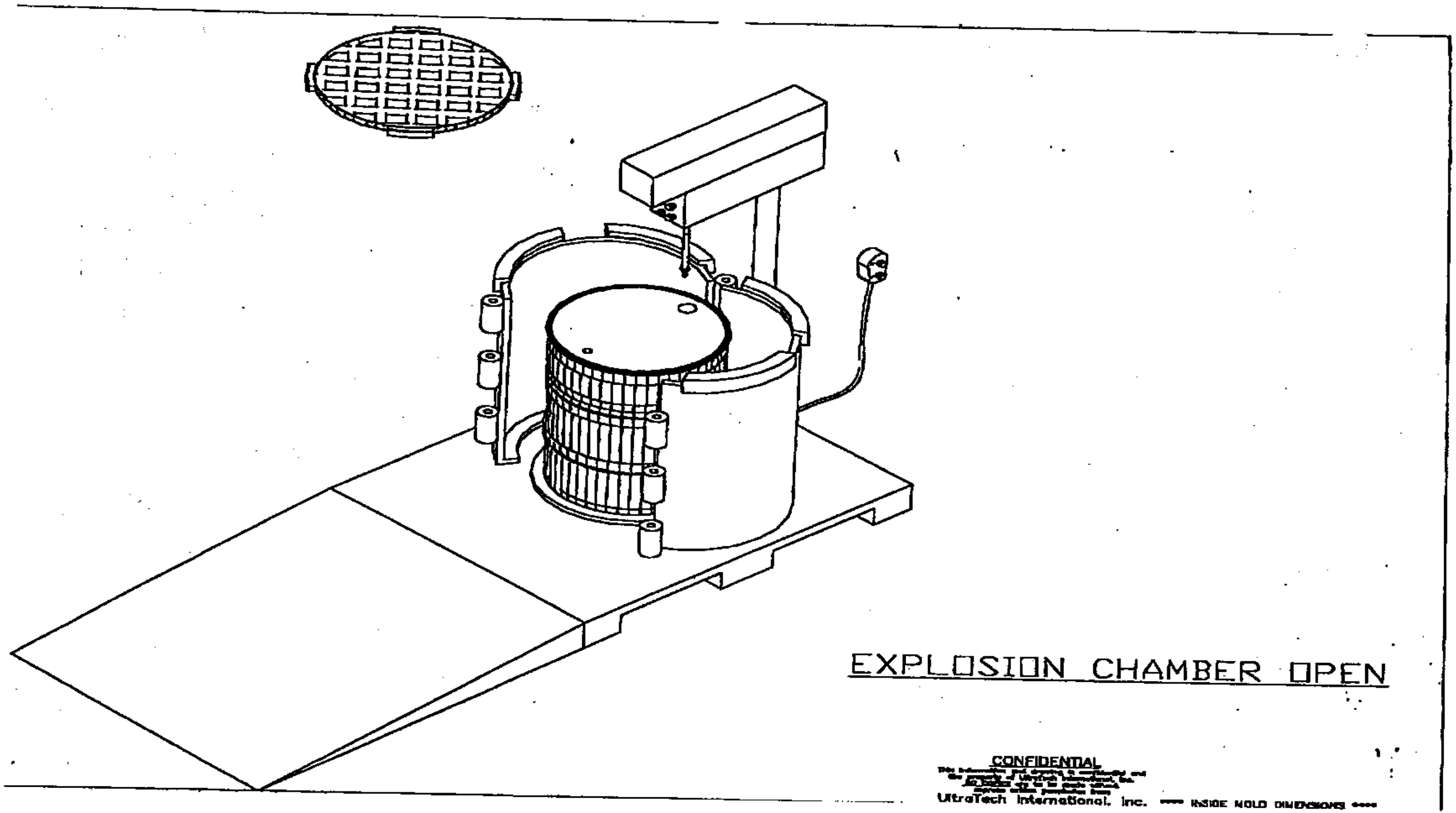
Safety Features

- Venting takes place in an enclosure that will contain the drum lid should an explosion occur during venting.
- The "Cold" (slow) drilling process eliminates the possibility of a spark causing ignition of the drums.
- The system process includes lowering the drum temperatures to control hydrogen pressure buildup before venting.
- Remote operation capability allows operators to work from a "safe" distance.

Cost Estimate

- Initial Venting Equipment Cost - (Remote operated , PLC controlled drill press and Drum Alignment Device) - $64
- Conditioning Chamber (to reduce internal pressure) - $5k
- Drum Restraint Chamber Cost - $16K
- Yearly Maintenance Cost - $2K

Figure 12 - Ultratech Venting Device with Blast Shield



Vista Engineering Filter Injection System– The Vista Engineering System uses a remotely activated spring-loaded injection chamber to install vented filters and sample ports. The installation process involves placing a 55-gallon drum inside a Plexiglas explosion proof chamber where a lid plate with electromagnets is used to attach the spring-loaded injection device to the lid of the drum where a dart filter is installed into the lid of the drum (see Figure 13).

Advantages

- A local company would provide this system.
- This system would be the least complex and therefore easier to maintain.
- This system is very portable and could easily be moved from one trench or one drum to another.

Disadvantages

- This system has not been developed and therefore no testing has been done to prove the concept.

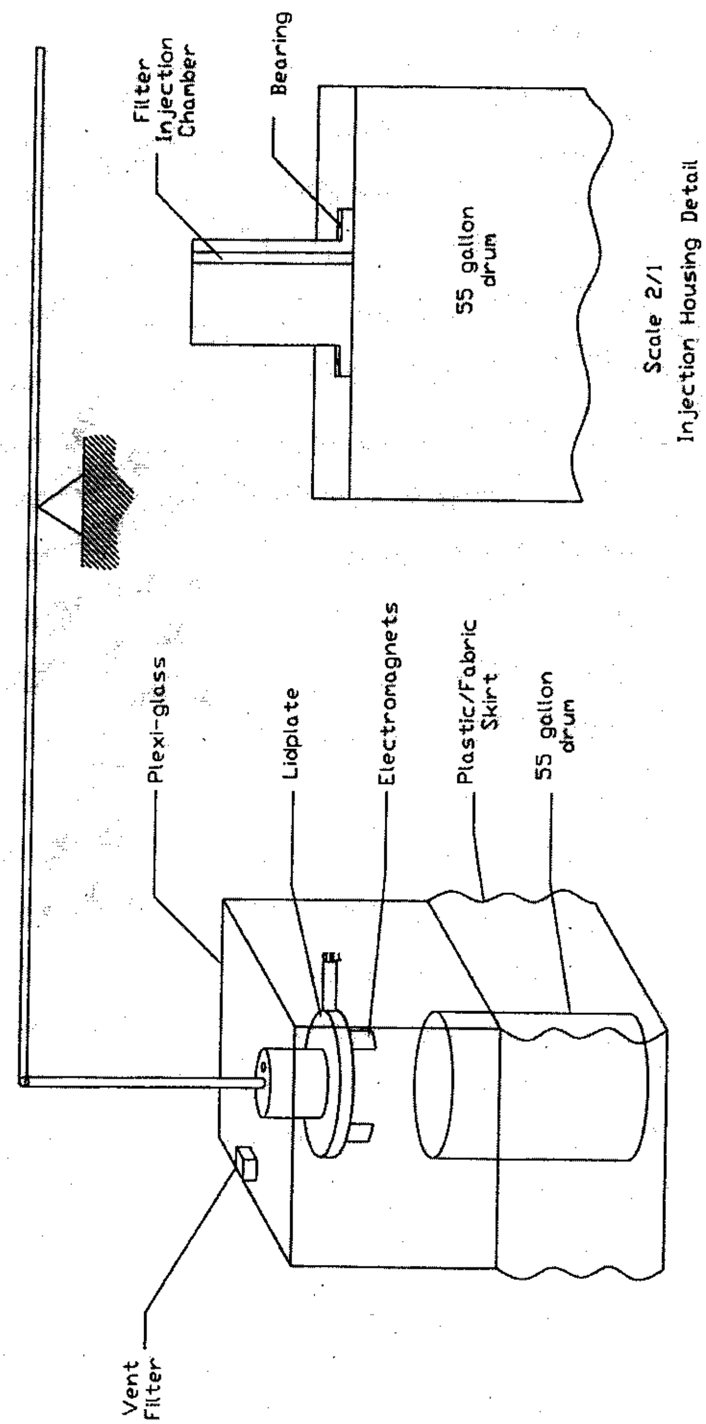
Safety Features

- Remote activation allows workers to vent drums from a "safe" distance.
- Venting would take place in an explosion proof chamber.
- Dart filters are made with a non-sparking aluminum bronze housing.

Equipment Cost

- Vent System Cost – $200K
- Yearly Maintenance Cost - $2K

Figure 13 - Vista Engineering Filter Injection System



Los Alamos Nuclear Lab Drum Venting System (DVS) A Drum Venting System (DVS) is used at LANL to vent and sample the headspace-gas of 55-gallon TRU waste drums. It was designed and built by a collaboration of the Hanford, SRS, and LANL sites. The DVS will become available in September of 2002 and could be transferred to Hanford for use at that time. In the mean time, an alternative drum venting system would need to be used in order to meet the current drum-venting schedule.

The LANL DVS is, by design, a complex piece of machinery. The stringent design was undertaken to provide the margin of safety the early project criteria directed. The DVS was designed and fabricated to maximum credible explosion (MCE) requirements and the drum venting takes place in an American Society for Testing and Materials (ASTM) coded vessel. The DVS design embellished every conceivable control/containment mechanism developed from multi-site (SRS, Hanford, and INEEL) hazards assessments and perceived accidents (see the LANL TWISP BIO for picture of DVS). The DVS can complete a drum venting cycle in 10-12 minutes. On average, 25 drums are vented each day at LANL, but as many as 80 drums have been vented in a 12-hour period.

The DVS drum venting cycle starts by loading the cleaned drum onto the rollers that feed the drum onto the venting vessel base. The DVS venting vessel, attached to the glovebox base, is then lowered over the drum and seals in the lock position. The glovebox provides the containment and confined clean-up capability in the event the top of the drum lid becomes contaminated. The inflatable bladder raises the drum into the final seal and vent position at the base of the glovebox. The drill motor then engages to drill and set the drill-lancet assembly into the drum lid. When the drill passes downward through the drum lid and again as it passes the 90-mil liner, gas samples are taken. The gas sample is monitored for hydrogen only. If hydrogen is detected above the lower explosive limit (LEL), the drum is purged with nitrogen. This purge cycle continues until the hydrogen level falls below 4%.

With the drill motor in the "insert" position, the HEPA-filtered glovebox is isolated from the drum chamber. As the drill motor is retracted to its restart position in the glovebox, the top of the drum lid can be surveyed for contamination. The glovebox is also used for loading the next drill-lancet assembly into the drill motor. LANL uses a short hollow drill bit welded to the bottom of the NucFil, HEPA rated, WIPP approved, filter. The filter has a sintered-metal filter plate embedded in the NucFil filter instead of activated carbon.

Advantages

- No initial equipment cost.
- Proven capability.
- Meets the most stringent safety criteria.

Disadvantages

- Maintenance costs are currently $10K per month for this system being used at Los Alamos, which would be higher than for other proposed systems.
- The DVS is sensitive to cold temperatures and dust and would need to be in an enclosed temperature controlled structure.
- The complexity of the system means a higher probability of breakdowns.
- Potential for contaminating the system and the cost to decontaminate would be higher than with a smaller portable system.
- Although the DVS is skid mounted it would not be as easy to move from trench to trench as alternative systems.
- Operational limitations associated with the DVS can cause significant delays in venting drums once they have been retrieved. One of the most significant issues is the low dimensional tolerance of the DVS CV for drums that are bulging or otherwise deformed on either the sides or the lid. This and other operational issues can result in longer than

anticipated periods between drum retrieval and venting, requiring the staging of unvented drums. Significantly distorted drums, drums with varying dimensions greater than the standard 55-gallon drums and drums that have significantly convex lids cannot currently be vented at all with this system.

Safety Features

- Nitrogen purge system for keeping hydrogen levels below the flammable limit.
- ASTM coded vessel to contain the drum lid during a drum explosion.
- Venting takes place in HEPA-filtered glovebox to isolate drum from the environment and protect workers from exposure to any airborne radiation or potential explosion of the VOC's.
- Drum loading and drill placement can all be done remotely, allowing personnel to keep a safe distance from the drum in case of an explosion or breech of the containment.
- Filters are made with a non-sparking aluminum bronze housing

Equipment Cost

- No Initial Equipment Cost
- Annual Maintenance Cost – $120,000

Hanford Fire Department – The Hanford Fire Department (HFD) has helped facilities vent bulging drums, including drums containing mixed-waste. The HFD is equipped with a remotely operated, air powered, drill made of intrinsically safe materials to prevent sparking. The HFD has operated and recovered this drill successfully inside radiological containment. Drilling does leave a permanent opening in the drum with no filter installed

Advantages

- On-site service that has been proven
- Low cost alternative as no procurement is required.

Disadvantages

- No filter is installed with this process, therefore the drum would need to be overpacked and more waste would be created. Alternately, a filter could be installed separately but would require additional complications to the process such as performing the installation through a glovebag.
- The filter for this process may not currently exist and would require development.

Safety Features

- Remotely operated drill
- Installation device would also serve as lid restraint.

Equipment Cost

- No initial equipment cost (if HFD does the venting with their equipment)
- No Annual Maintenance Cost

Hanford Container Venting System The Hanford Container Venting System (CVS, see Figure 14) is a mobile (can be moved by truck and is skid mounted) unit that can be placed in a trench and is remotely operated from a console. The CVS attaches and seals to the top of the drum. It drills through the drum lid and draws a gas sample through a vacuum chamber into gas sample bottles. The drilling of the hole in the container lid is done with a spark resistant titanium nitride drill bit. The drum can also be backfilled with an inert gas following venting. A NucFil filter or equivalent will then be manually installed. While attached to the drum, the CVS is sealed to the drum such that any emissions are released though the HEPA-filtered exhaust.

The system consists of three components:

- The drum piercing assembly, which weighs approximately 440 pounds and is lifted atop a drum for venting with an additional lifting device added as part of the system.
- The control console, which operates the drum piercing, evacuation, gas sampling, back-charging of the drum with inert gas, and the attachment and detachment of the drum.
- The drum piercing enclosure (optional), in which the drum is placed to be pierced.

Advantages

- On-site system.
- The system is skid mounted and can be moved from trench to trench on the back of a flatbed truck and picked up from either end with a forklift.
- This system can be used to draw gas samples.

Disadvantages

- This system was developed in 1993 and never used. It is currently being stored in a warehouse and it would require some extensive work to get it into an operating state. Additionally there are no manuals or operating procedures available.
- This system was never used other than operational testing and is therefore untested in the field.
- This system is more complex and would have higher maintenance costs than other systems.
- The DVS is sensitive to cold temperatures and dust and would need to be in an enclosed temperature controlled structure.
- The complexity of the system means a higher probability of breakdowns.
- Potential for contaminating the system and the cost to decontaminate would be higher than with a smaller portable system.
- Although the DVS is skid mounted it would not be as easy to move from trench to trench as alternative systems.

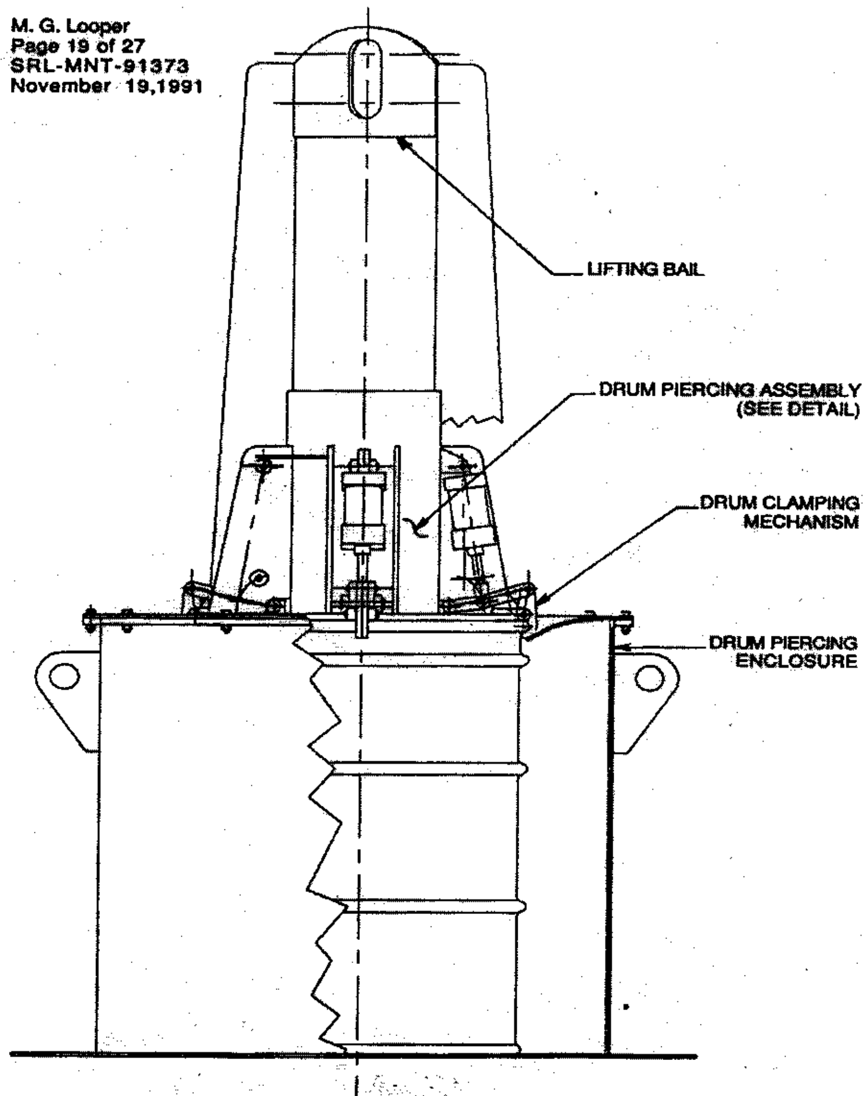
Safety Features

- Remote operation allows workers to vent drums from a "safe" distance.
- The drilling of the hole in the container lid is done with a spark resistant titanium nitride drill bit.
- The system allows the drum to be backfilled with an inert gas following venting.
- While attached to the drum, the CVS is sealed to the drum such that any emissions are released though the HEPA-filtered exhaust.

Equipment Cost

- Estimated cost to develop procedures and get system operational – $20K
- Estimated Annual Maintenance Cost – $60K

Figure 14 - Hanford Container Venting System



HANFORD CONTAINER VENTING SYSTEM

Figure 8

7.5 Other Venting Devices

T Plant – The Solid Waste Treatment (SWT) Facility (T Plant) routinely vents and opens potentially pressurized containers. The equipment used is a drum lid restraining device and a bronze punch. T Plant has an active greenhouse with a HEPA filtered exhaust system set up to perform this activity. This system would require the unvented drums to be moved to the SWT facility and the drums would require overpacking before being transferred to CWC.

Advantages

- On-site service
- Proven process

Disadvantages

- Drums would need to be moved to SWT for venting. The LLBG safety basis does not allow moving of unvented drums from the trenches.
- No filter is installed with this process, therefore the drum would need to be overpacked and more waste would be created. Alternately, a filter could be installed separately but would require additional complications to the process such as performing the installation through a glovebag.
- The filter for this process may not currently exist and would require development.

Safety Features

- Drum lid restraining device.
- Bronze punch used for venting is spark resistant.
- HEPA filtered enclosure protects workers from gasses escaping from the drum.

Equipment Cost

- No initial equipment cost
- No annual maintenance cost

7.6 Venting schedule

The venting schedule and milestones (Figure 15) shows the drum venting activities, which will occur after the DSA has been approved by DOE. The first activities after the DSA approval will be the development of the statement of work and procurement of a venting system. This will be followed by training of operators and readiness activities. The first venting campaign in the trenches will occur in 2002.

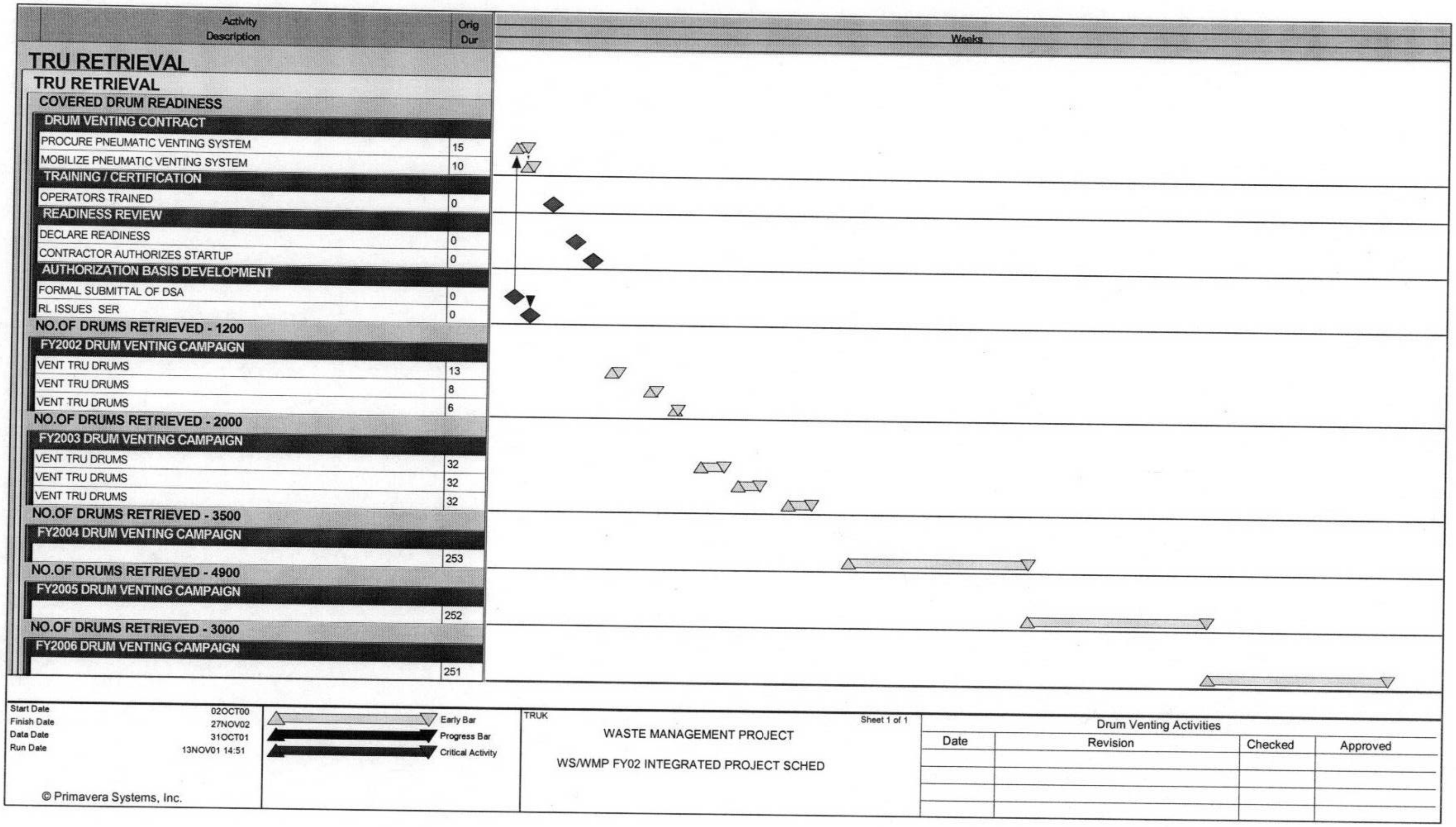
The number of drums assumed to require venting is based on current retrieval experience that shows 1/3 of the drums retrieved will be above 1.5 g and will be TRU. Of the other 2/3 drums it is assumed that ½ of them will assay as low level and ½ will be TRU. Therefore a total of 2/3 of the drums retrieved are assumed to be TRU. Based on earlier discussions, 61% of these drums are expected to need venting. Therefore the formula to determine the number of drums requiring venting is:

(# of drums retrieved)(2/3)(.61) = (# of drums requiring venting)

Based on planned retrieval levels in the year 2002, 1200 drums will be retrieved and 488 of those will require venting. The vent system procured will have a requirement of being able to vent four drums/hour. Based on this production number and assumed efficiencies the venting campaigns will follow the schedule below. In the first year there will be three venting campaigns between 6 and 12 days each. In FY 2003, 2,000 drums will be retrieved and 813 of those will require venting. This will be handled in four campaigns of 32 days each. In FY 2004, 2005, and 2006 between 3,000 and 5,000 drums will be retrieved and up to a maximum of 2,000 drums may require venting in one of these years. During these highest production years, venting will take place in continuous campaigns as needed.

Evaluations of the LANL Drum Venting System would be made after the first year of venting to determine if it would be advantageous to pursue obtaining that system for drum venting activities in the following years. Figure 15 depicts the logic flow for implementation of the venting system for use in the LLBG.

Figure 15 - TRU Retrieval Drum Venting Schedule and Milestones



8. Summary and Conclusions

Available TRU waste data from Hanford and other DOE sites involved with TRU waste retrieval, storage, and venting was surveyed and evaluated. The primary focus of this study is to evaluate the probability and consequence of accumulating significant concentrations of hydrogen in unvented TRU drums and recommend a method for venting these drums. The available data included thousands of TRU drums from around the DOE complex and was summarized in the following three groups based on hydrogen concentration:

Hydrogen in concentrations less than 5 vol%	Hydrogen below the lower flammable limit
Hydrogen between 5 and 15 vol%	Hydrogen above the lower flammable limit but less than the energy required to breach a drum.
Hydrogen in concentrations greater than 15 vol%	Hydrogen when in combination with oxygen capable of breaching the drum lid during an explosion event.

Depending on the site, between 1% to 8 % of the unvented TRU drums had hydrogen concentrations above 15 vol%. Out of all retrieved drums, only a small percentage had an explosive mixture of hydrogen and oxygen. All drums were moved and vented without initiating these mixtures of hydrogen and oxygen.

Hydrogen generation, accumulation, and leakage/diffusion in TRU Waste drums are discussed. Based on process knowledge, it is difficult to correlate or predict the hydrogen generation and concentration solely on the plutonium inventory. Increased plutonium inventory is expected to result in increased hydrogen concentration in a waste drum. Factors such as available hydrogenous material, leakage, and matrix depletion affect the hydrogen concentration. Studies at LANL indicate that drums with a lock ring self-vent when pressure inside the drum increases. Transuranic wastes stored in the LLBG at Hanford have too many factors to allow reasonable correlation between plutonium inventory and hydrogen concentration without quantifying the other factors.

This study evaluated the frequency and consequence of hydrogen accumulation in suspect TRU waste drums. The percentage of unvented Hanford suspect TRU drums is expected to increase as successively older drums are encountered. Transuranic drums placed in the LLBG between 1970 and 1978 are expected to be unvented. On-site PFP and PUREX suspect TRU drums placed in the LLBG between 1978 and 1985 are expected to be vented. Other drums are assumed to be unvented. Drums after 1985 are nearly all vented. Therefore, the estimated percentage of unvented drums among the drums that remain to be retrieved in 218-W-4B and 4C LLBG is 61%.

A postulated TRU waste drum explosion during TRU retrieval is considered a bounding accident. With an estimated frequency of 3.52×10^{-6} for drum handling compared with 1.60×10^{-7} for drum venting, drum handling is considered the bounding activity. The risk associated with the drum explosion is determined by comparing the estimates of frequency and consequence to risk evaluation guidelines.

This study evaluated criteria for drum venting and numerous drum venting devices were evaluated which include:

- Portable and/or remote venting systems
- Los Alamos Drum Venting System (DVS)
- Savannah River Venting System
- Hanford Fire Department vent system
- Hanford Container Venting system
- T Plant Cold Punch

A proposed plan and schedule to vent up to 500 drums in the first year is presented. A remotely operated device with operational controls to protect the worker is proposed to vent the inventory of unvented TRU drums. The selection of this device is based on defense in depth considerations and the revised estimated frequency and consequence for an explosion during drum venting operations.

The drum venting devices discussed are capable of adequately and safely venting drums. However, it is recommended that a remote device with operational controls such as a drum lid-restraining device such as the NFT NucFil Dart Filter Venting Device can provide a reasonable margin of safety. Based on thousands of drums shipped/moved multiple times prior to venting, the use of a venting device is bounded by drum handling activities. This conclusion is based on the following considerations:

- 23,000 drums moved at different sites without incident
- Drums tend to self vent at greater than 1.5 psig pressure
- Explosive mixtures with hydrogen and oxygen are unlikely to occur
- Ignition is unlikely even during drop tests
- Drum venting is bounded by drum handling

These conclusions are consistent with a graded approach to risk management defense in depth considerations. These considerations will be evaluated commensurate with the revised authorization basis for covered TRU waste retrieval and drum venting. Drum venting, a routine activity at many DOE sites, will be implemented at Hanford after approval of a revised documented safety analysis and successful readiness assessment activities associated with TRU waste retrieval.

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