**Department of Energy**
Albuquerque Operations Office
Waste Isolation Pilot Plant Project Office
P. O. Box 3090
Carlsbad, New Mexico 88221

Benito

MAY 21 1991

RECEIVED
MAY 28 1991

RECEIVED
HAZARDOUS WASTE
PROGRAM

Mrs. Kathleen Sisneros, Director
Water and Waste Management Division
New Mexico Environment Department
P.O. Box 26110
Santa Fe, NM 87502

Dear Mrs. Sisneros:

Enclosed is a copy of DOE/WIPP 91-018, Revision 0, "Position Paper On Flammability Concerns Associated With TRU Waste Destined For WIPP," dated April 1991. The paper includes a review of possible scenarios that can potentially contribute to the flammability of waste, discusses existing regulations on flammable waste, and presents analyses of flammability related incidents at DOE sites with respect to the current regulations. Finally, the paper examines the degree of assurance against flammability that these regulations provide during transportation and waste handling.

If you have any questions or comments concerning this paper, please contact Jerry Carr of my staff.

Sincerely,

for Arlen Hunt
Project Manager

Enclosure

cc w/o enclosure:
M. Frei, DOE/HQ
J. Mewhinney, WPO
J. Carr, WPO
R. Farrell, WPO

WIPP:JEC I91-0041

910504

WIPP Library

DOE/WIPP 91-018
Revision 0

# Position Paper On Flammability Concerns Associated With TRU Waste Destined For WIPP

April 1991

Waste Isolation Pilot Plant

491B:0347

This document is issued by Westinghouse Electric Corporation, Waste Isolation Division, as the Managing and Operating Contractor for the Department of Energy, Waste Isolation Pilot Plant, Carlsbad, New Mexico, 88221 .


**DISCLAIMER**

This document was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights. References herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.



This document has been reproduced directly from the best possible copy. It is available to DOE and DOE contractors at the following address:

Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831

Prices available from (615) 576-8401; FTS 626-8401

**Available to the public from the**
**National Technical Information Service**
**U.S. Department of Commerce**
**5285 Port Royal Road**
**Springfield, VA 22161**

1290B:3942

# POSITION PAPER ON FLAMMABILITY CONCERNS ASSOCIATED WITH TRU WASTE DESTINED FOR WIPP

APRIL 1991

# TABLE OF CONTENTS


| SECTION | PAGE |
|---|---|
| LIST OF TABLES | v |
| LIST OF FIGURES | vi |
| EXECUTIVE SUMMARY | ES-1 |
| 1.0 INTRODUCTION | 1-1 |
| 1.1 Background | 1-1 |
| 1.2 Purpose and Objective | 1-2 |
| 1.3 Potential Flammability Concerns | 1-3 |
| 1.3.1 Presence or Generation of Potentially Flammable Gases | 1-3 |
| 1.3.2 Presence or Occurrence of Potentially Flammable Volatile Organic Compounds | 1-4 |
| 1.3.3 Presence of Pyrophoric Materials in the Waste | 1-4 |
| 1.3.4 Presence or Occurrence of Chemical Incompatibilities in the Waste | 1-5 |
| 1.3.5 Presence of Free Liquids | 1-5 |
| 2.0 BEHAVIOR OF FLAMMABLE MIXTURES | 2-1 |
| 2.1 Introduction | 2-1 |
| 2.2 Basic Principles of Flammable Mixtures | 2-1 |
| 3.0 EXISTING AND APPLICABLE REGULATIONS TO ADDRESS SAFETY CONCERNS | 3-1 |
| 3.1 Introduction | 3-1 |
| 3.2 CH-TRU Waste Operations Safety Requirements for the WIPP Site | 3-1 |
| 3.2.1 Restrictions on Pyrophoric Materials | 3-3 |
| 3.2.2 Restrictions on Explosives and Compressed Gases | 3-3 |
| 3.2.3 Restrictions on Free Liquids | 3-3 |
| 3.2.4 Restrictions on Radioactive Mixed Wastes | 3-3 |
| 3.2.5 Restrictions on Particulate Waste | 3-3 |
| 3.2.6 Summary of Operations Safety Requirements Relating to Flammability Concerns | 3-4 |
| 3.3 CH-TRU Waste Transportation Requirements for the WIPP Site | 3-4 |
| 3.3.1 Restrictions on Potentially Flammable Gases | 3-9 |
| 3.3.1.1 Methodology for Restrictions on Potentially Flammable Gas Concentrations for Transportation Purposes - TRUPACT-II SAR Analyses | 3-9 |
| 3.3.1.2 Analyses for Radiolytic Gas Generation Estimates for CH-TRU Waste | 3-10 |

**TABLE OF CONTENTS**
(Continued)


| SECTION | | PAGE |
|---|---|---|
| | 3.3.1.3 Derivation of Decay Heat Limits for Payload Containers | 3-12 |
| | 3.3.1.4 Input Parameters and Margins of Safety for Decay Heat Calculations | 3-13 |
| | 3.3.2 Restrictions on Other Potentially Flammable Gases and VOCs | 3-18 |
| | 3.3.3 Restrictions on Pyrophoric Materials | 3-19 |
| | 3.3.4 Restrictions on Explosives and Compressed Gases | 3-19 |
| | 3.3.5 Restrictions on Chemical Incompatibilities in the Waste | 3-19 |
| | 3.3.6 Restrictions on Free Liquids | 3-19 |
| | 3.3.7 Summary of Transportation Requirements | 3-19 |
| 3.4 | CH-TRU Mixed Waste No-Migration Requirements for the WIPP Site | 3-20 |
| | 3.4.1 Restrictions on Flammable Gas Concentrations in the NMD | 3-21 |
| | 3.4.2 Summary of No-Migration Determination Requirements | 3-23 |
| 3.5 | Test Plan Requirements for the WIPP Test Phase | 3-23 |
| | 3.5.1 Pressure Relief Valves | 3-23 |
| | 3.5.2 On-line Oxygen Monitoring | 3-23 |
| | 3.5.3 Periodic Monitoring of Potentially Flammable Gases | 3-24 |
| | 3.5.4 Summary of Requirements for the WIPP Test Phase | 3-24 |
| 3.6 | Implementation of Regulations and Requirements at Waste Generator and Storage Sites | 3-24 |
| | 3.6.1 Implementation of Operations Safety Requirements and TRUPACT-II Transportation Requirements | 3-24 |
| | 3.6.2 Implementation of No-Migration Determination Requirements | 3-26 |
| 3.7 | Waste Characterization and Process Knowledge | 3-27 |
| | 3.7.1 TRUPACT-II Safety Analysis Report (TRUPACT-II SAR) | 3-27 |
| | 3.7.2 TRUPACT-II Content Codes (TRUCON) Document | 3-27 |
| | 3.7.3 Waste Analysis Plan of the No-Migration Variance Petition (NMVP) | 3-27 |
| | 3.7.4 Sampling Programs | 3-28 |
| | 3.7.5 Summary of Waste Characterization and Process Knowledge | 3-28 |
| 3.8 | Summary of Governing Regulations | 3-29 |

**TABLE OF CONTENTS**
(Continued)


| SECTION | | PAGE |
|---|---|---|
| 4.0 | HISTORY AND ANALYSIS OF UNUSUAL OCCURRENCES AT THE SITES | 4-1 |
| 4.1 | Failure of 55-Gallon Drum at Argonne National Laboratory-East (ANL-E) - Occurrence Date - 12/02/76 or 12/03/76 | 4-1 |
| 4.1.1 | Description of the Event | 4-1 |
| 4.1.2 | Immediate Follow-Up Actions | 4-2 |
| 4.1.3 | Examination of the Contents of the Ruptured Drum | 4-2 |
| 4.1.4 | Findings of the Committee of Inquiry | 4-3 |
| 4.1.5 | Recommendations of the Committee of Inquiry | 4-4 |
| 4.1.6 | Discussion of the Incident with Reference to Existing Regulations | 4-4 |
| 4.2 | Burial Ground Fire in a Barrel of Waste from Rocky Flats Occurrence Date - 06/01/70 | 4-5 |
| 4.2.1 | Description of the Event | 4-5 |
| 4.2.2 | Immediate Follow-Up Action | 4-5 |
| 4.2.3 | Examination of Contents of the Burned Drum | 4-5 |
| 4.2.4 | Findings of Idaho Nuclear Corporation | 4-6 |
| 4.2.5 | Discussion with Reference to Existing Regulations | 4-6 |
| 4.3 | Distortion of Storage Containers at Hanford (Report #78-17) Discovery Date - 02/02/78 | 4-7 |
| 4.3.1 | Description of the Event and Cause | 4-7 |
| 4.3.2 | Corrective Actions | 4-7 |
| 4.3.3 | Discussion with Reference to Existing Regulations | 4-7 |
| 4.4 | Distortion of Storage Containers at Hanford (Report #78-87) Discovery Date - 08/17/78 | 4-8 |
| 4.4.1 | Description of the Event and Cause | 4-8 |
| 4.4.2 | Corrective Actions | 4-8 |
| 4.4.3 | Discussion with Reference to Existing Regulations | 4-8 |
| 4.5 | Pressurization of Storage Containers at Hanford (Report #75-122) Discovery Date - 10/21/75 | 4-9 |
| 4.5.1 | Description of the Event and Cause | 4-9 |
| 4.5.2 | Corrective Actions | 4-9 |
| 4.5.3 | Discussion with Reference to Existing Regulations | 4-9 |
| 4.6 | Rupture of Chemical Storage Drum at Lawrence Livermore National Laboratory (Report #LLNL84-14-TWC612-84) Occurrence Date - 10/25/84 | 4-9 |
| 4.6.1 | Description of the Event and Cause | 4-9 |
| 4.6.2 | Corrective Actions | 4-10 |
| 4.6.3 | Discussion with Reference to Existing Regulations | 4-10 |

**TABLE OF CONTENTS**
(Continued)


| SECTION | | PAGE |
|---|---|---|
| 4.7 | Fire in Bags of Dry Waste Stored in the Toxic Waste Holdup Area at LLNL, (Report #LLNL83-2B161-83-1), Occurrence Date - 06/30/83 | 4-11 |
| 4.7.1 | Description of the Event and Cause | 4-11 |
| 4.7.2 | Corrective Actions | 4-11 |
| 4.7.3 | Discussion with Reference to Existing Regulations | 4-11 |
| 4.8 | Small Fire in a Waste Container at LLNL, (Report #LLNL89-6-B-241) Occurrence Date - 04/11/89 | 4-12 |
| 4.8.1 | Description of the Event and Cause | 4-12 |
| 4.8.2 | Corrective Actions | 4-12 |
| 4.8.3 | Discussion with Reference to Existing Regulations | 4-12 |
| 4.9 | Chemical Reaction During Bulking of Containers at LLNL (Report #LLNL88-7-614), Occurrence Date - 04/26/88 | 4-12 |
| 4.9.1 | Description of the Event and Cause | 4-12 |
| 4.9.2 | Corrective Actions | 4-13 |
| 4.9.3 | Discussion with Reference to Existing Regulations | 4-13 |
| 4.10 | Release of Plutonium-238 (Pu-238) from a 55-Gallon Drum at Los Alamos National Laboratory, Occurrence Date - 09/19/84 | 4-13 |
| 4.10.1 | Description of the Event and Cause | 4-13 |
| 4.10.2 | Corrective Actions | 4-13 |
| 4.10.3 | Discussion with Reference to Existing Regulations | 4-14 |
| 4.11 | Summary of Other Unusual Occurrences | 4-14 |
| 4.12 | Summary of Analysis of Past Unusual Occurrences | 4-37 |
| 5.0 | SUMMARY | 5-1 |
| 6.0 | REFERENCES | 6-1 |
| 7.0 | GLOSSARY | 7-1 |

# LIST OF TABLES


| TABLE NO. | TITLE | PAGE |
|---|---|---|
| ES-1 | Summary of Unusual Occurrences at DOE Sites | ES-4 |
| 2-1 | Combustion Data of Gases and Vapors | 2-3 |
| 3-1 | Regulations Governing TRU Waste Transportation and Disposal | 3-2 |
| 3-2 | TRUPACT-II SAR Payload Sections and Related Documents | 3-7 |
| 3-3 | Waste Classification into Waste Material Types | 3-11 |
| 3-4 | Average G Values for Waste Material Types from TRU Waste Sampling Program | 3-16 |
| 4-1 | Summary of Unusual Occurrences at DOE Sites | 4-38 |

## LIST OF FIGURES


| FIGURE NO. | TITLE | PAGE |
|---|---|---|
| 2-1 | Ignitability Curve and Limits of Flammability for Methane Concentration in Air at Standard Atmospheric Conditions | 2-4 |
| 2-2 | Basic Flammability Factors | 2-6 |
| 3-1 | TRUPACT-II SAR and Related Documents | 3-5 |
| 3-2 | TRUPACT-II SAR Organization | 3-6 |
| 3-3 | Hydrogen Concentration Profiles in a Drum that is Part of a TRUPACT-II Payload | 3-14 |
| 3-4 | No-Migration Determination Flammability Requirements | 3-22 |
| 3-5 | Documents Governing TRU Waste Transportation and Disposal | 3-25 |

# EXECUTIVE SUMMARY

The Waste Isolation Pilot Plant (WIPP), in southeastern New Mexico, is an underground repository, designed for the safe geologic disposal of transuranic (TRU) wastes generated from defense-related activities of the U. S. Department of Energy (DOE). The WIPP storage rooms are mined in a bedded salt (halite) formation, and are located 2,150 feet below the surface. After the disposal of waste in the storage rooms, closure of the repository is expected to occur by creep (plastic flow) of the salt formation, with the waste being permanently isolated from the surrounding environment.

This paper has evaluated the issue of flammability concerns associated with TRU waste to be shipped to WIPP, including a review of possible scenarios that can potentially contribute to the flammability. The paper discusses existing regulations that address potential flammability concerns, presents an analysis of previous flammability-related incidents at DOE sites with respect to the current regulations, and finally, examines the degree of assurance these regulations provide in safeguarding against flammability concerns during transportation and waste handling.

## POTENTIAL FLAMMABILITY CONCERNS

The potential flammability concerns that are associated with the handling, transportation, and disposal operations for TRU waste at the WIPP have been identified as follows:

- Presence or generation of potentially flammable gases (hydrogen, methane, etc.) in the waste.
- Presence or occurrence of potentially flammable Volatile Organic Compounds (VOCs) in the waste.
- Presence or occurrence of potentially explosive or pyrophoric materials in the waste.
- Presence or occurrence of potential chemical incompatibilities in the waste.
- Presence or occurrence of any free liquids in the waste that might result in any of the concerns listed above.

## REGULATIONS ADDRESSING POTENTIAL FLAMMABILITY CONCERNS

A number of regulations and requirements have been formulated by different organizations such as the Environmental Protection Agency (EPA), the U. S. Nuclear Regulatory Commission (NRC), the U. S. Department of Transportation (DOT), and the DOE, to adequately address safety concerns associated with the transportation and emplacement of TRU waste in WIPP. These requirements which collectively address all the potential flammability concerns mentioned earlier, are summarized in the following documents:

- Transuranic Package Transporter Safety Analysis Report (TRUPACT-II SAR) (NuPac, 1989)

- Conditions imposed by the NRC for waste shipments subject to hydrogen generation, addressed as part of the TRUPACT-II SAR (NRC, 1984)

- EPA No-Migration Determination (EPA-NMD) Requirements (EPA, 1990)

- WIPP Waste Acceptance Criteria (WIPP-WAC) (DOE, 1989c)

- DOT regulations for the packaging and transportation of radioactive materials (DOT, 1989c)

The regulations and the waste acceptance criteria are based on conservative analysis, and involve a wide margin of safety for preventing potential flammability-related incidents. Some of these regulations and requirements are summarized below:

- Presence of filtered vents - Under the present transportation requirements, all TRU waste containers are required to be fitted with one or more carbon composite filter vents. These vents provide continuous pressure relief, and thus prevent any pressure build-up within a drum thereby minimizing the chances of any incidents due to overpressurization.

- Restrictions on total amount of flammable VOCs - Under the present transportation and EPA-NMD requirements, the total amount of flammable VOCs in the headspace of a Contact Handled Transuranic (CH-TRU) waste container is restricted to 500 ppm. If the total exceeds this limit, then the EPA-NMD requires that a flame test be performed to assure the safety of the container.

- Restrictions on amount of flammable gases in the headspace - The concentration of a mixture of flammable gases in the headspace of a drum, is required by the EPA-NMD to be below 50% of the lower explosive limit of the mixture as predicted by Le Chatelier's Law. Thus, a factor of safety of two is applied in determining flammability characteristics.

- Restrictions on hydrogen concentration - The decay heat limits on waste containers are controlled to the extent that the hydrogen concentration must remain below 5% in all layers of the payload and the TRUPACT-II package, irrespective of the oxygen concentration (NuPac, 1989). Simulated experiments with 55-gallon drums have shown that an explosion did not occur as long as the concentration of hydrogen was below 15% (WSRC, 1990).

- Restrictions on pyrophorics - No non-radionuclide pyrophorics are allowed in the WIPP waste inventory, and radionuclide pyrophorics are limited to less than 1% by weight. The quantity of these materials is further limited by the criticality and wattage limits for the TRUPACT-II package. TRU waste generation practices at the sites ensure that any radionuclides present in the waste are in dispersed form.

- Restrictions on free liquids - TRU waste containers for the WIPP Test Phase are not allowed to contain more than one volume percent free liquids. In addition, documentation is required to show that the liquids present will not compromise the integrity of the container. Waste for disposal at WIPP cannot be in free-liquid form.

Only minor liquid residues remaining in well-drained bottles, cans, and other containers are acceptable. Waste generation practices at the sites are normally more stringent than the 1% by volume limit on free liquids.

- Restrictions on chemical incompatibility - The waste to be transported to the WIPP is required to be chemically compatible within each drum, between different drums in a payload, and between the payload and the TRUPACT-II package. The waste is also required to be in solid or solidified form.

- Prohibition of heat sealing of bags - Under the current transportation requirements, any bags used as confinement layers in waste containers are required to be closed only by a twist-and-tape closure. Heat sealing of bags is not allowed as per the TRUPACT-II SAR requirements. This prevents the possible accumulation of potentially flammable gases in inner confinement layers.

- Adequate waste characterization prior to transportation - A minimum amount of waste characterization on certain parameters is required before waste can be transported to WIPP. Examples of these parameters include verification of the absence of restricted items like free liquids (in excess of one volume percent), explosives, compressed gases, etc. This waste characterization information is summarized for each content code in the TRUCON document (DOE, 1989b). In addition, the EPA-NMD imposes specific waste characterization requirements (EPA, 1990). This minimizes the potential of shipping a waste container with "unknown" properties, that could present a safety hazard.

## ANALYSIS OF PAST UNUSUAL OCCURRENCES AT DOE SITES

A history of past unusual occurrences at the sites dating back to 1970, was obtained directly from some of the sites, as well as from the DOE database entitled "Safety Performance Measurement System" (SPMS) (DOE, 1990a). These incidents are summarized in Table ES-1. The information in Table ES-1 is organized as follows:

- **Reporting Organization** - The DOE site where the unusual occurrence took place.

- **Report Number** - The reference number assigned to the occurrence by the DOE database.

- **Date** - The date that the occurrence took place, or was initially discovered.

- **Description** - Brief description of the occurrence.

- **Cause** - The reason for the occurrence as determined by investigation.

- **TRU-Related** - A statement reflecting whether the occurrence was TRU waste related, or not.

- **Applicable Existing Regulation** - An example of an existing regulation or criterion which would prevent another occurrence of this type.

TABLE ES-1

SUMMARY OF UNUSUAL OCCURRENCES AT DOE SITES

| Reporting[1] Organization | Report Number | Date | Description | Cause | TRU-Related | Applicable Existing Regulation |
|---|---|---|---|---|---|---|
| ANL-E | N/A[2] | 12/02/76 | Lid blown off of 55-gallon drum | Flammable VOCs, no vents | No | Restrictions on flammable VOCs |
| INC | N/A[2] | 06/01/70 | Burial ground fire in a 55-gallon drum | Pyrophorics | LLW[3] | Restrictions on pyrophorics |
| RHO | 78-17 | 02/02/78 | Distortion of storage containers | Pressurization | Yes | Vents, restrictions on fissile quantities, decay heat |
| RHO | 78-87 | 08/17/78 | Distortion of storage containers | Pressurization, chemical reaction | Yes | Vents, restrictions on free liquids chemical incompatibility |
| ARHC | 75-122 | 10/21/75 | Pressurization of storage containers | Pressurization | Not known | Vents |
| LLNL | 84-14-TWC612-84 | 10/25/84 | Violent rupture of chemical drum | Chemical reaction | Not likely | Restrictions on free liquids, chemical incompatibility, vents |
| LLNL | 83-2-B161-83-1 | 06/30/83 | Fire in bags of dry waste | Pyrophorics, flammable VOCs | Not known | Restrictions on pyrophorics, flammable VOCs, chemical incompatibility |
| LLNL | 89-6-B-241 | 04/11/89 | Small fire in waste container | Chemical reaction | Not known | Restrictions on powders, chemical incompatibility |
| LANL | N/A[2] | 09/19/84 | Release of Pu-238 from a 55-gallon drum | Pressurization | Yes | Vents |
| LLNL | 88-7-614 | 04/26/88 | Chemical reaction during acid bulking | Chemical reaction | Not likely | Restrictions on free liquids, chemical incompatibility |
| WINC | 84733 | 4/20/84 | Fire in a radioactive waste container | Spontaneous combustion of nitric acid | Not known | Restrictions on corrosives, chemical incompatibility |
| LANL | 89819 | 10/26/89 | Depleted uranium fire in 30-gallon drum | Unstabilized pyrophorics | Not known | Chemical incompatibility, pyrophorics, free liquids |

TABLE ES-1

SUMMARY OF UNUSUAL OCCURRENCES AT DOE SITES
(Continued)

| Reporting[1] Organization | Report Number | Date | Description | Cause | TRU-Related | Applicable Existing Regulation |
|---|---|---|---|---|---|---|
| EG&GI | 900216 | 10/19/90 | Release to environment | Not determined | No | Not relevant |
| EG&GI | 89734 | 7/20/89 | Multiple occurrences of contamination events | Inadequate detection capability | No | Not relevant |
| EG&GI | 85733 | 07/09/85 | Unexpected contamination of personnel | Inadequate ventilation | No | Not relevant |
| LANL | 87733 | 08/01/87 | Crates containing TRU wastes partially collapsed | Faulty stacking procedure | Yes | Not relevant |
| BNL | 89712 | 06/29/89 | Release of vehicle with radiation levels above DOT limits | Inadequate personnel instruction | No, (LLW) | Not relevant |
| EG&GI | 85706 | 02/21/85 | Waste improperly disposed of in a low-level waste soil vault | Personnel error | Yes | Not relevant |
| EG&GI | 87706 | 06/09/87 | Improper waste drum storage | Later found to be proper | Yes | Not relevant |
| EG&GI | 90701 | 01/09/90 | Storage of transuranic mixed waste in a non-permitted area | Scheduling problems | Yes | Not relevant |
| WMCOO | 88702 | 01/18/88 | Release of uranyl nitrate | Operator error | No | Not relevant |
| ORNL | 84732 | 10/17/84 | Corrosion of storage drums | Corrosive agents | Yes | Prohibition of corrosives, WAC |
| ORNL | 86705 | 01/15/86 | Contamination of laboratory | Personnel error | No | Not relevant |
| ORNL | 86716 | 10/16/86 | Contamination | Personnel error | Yes | Not relevant |
| BMI (PNL) | 87706 | 10/15/87 | Pu content of waste drum exceeded limit | Personnel error | Yes | Decay heat limit; fissile shipping limit |
| WHC | 84714 | 02/27/84 | Transport of burial box with unbolted lid | Overlapping responsibilities | Yes | Not relevant |

TABLE ES-1

SUMMARY OF UNUSUAL OCCURRENCES AT DOE SITES
(Continued)

| Reporting[1] Organization | Report Number | Date | Description | Cause | TRU-Related | Applicable Existing Regulation |
|---|---|---|---|---|---|---|
| WHC | 83708 | 03/02/83 | Improper control of potentially alpha contaminated equipment | Faulty survey | No | Not relevant |
| WHC | 86734 | 04/11/86 | Failure of computer software results in burial of TRU waste as low-level | Faulty software | Yes | Not relevant |
| WHC | 89745 | 08/24/89 | Free liquids in TRU waste drums | Personnel error | Yes | Restrictions on free liquids |
| WHC | 89764 | 12/20/89 | SARP violation during shipment of mixed waste drums | Procedural error | Yes | Not relevant |
| WHC | 82724 | 09/14/82 | Inadvertently disposed radioactive materials shipping casks | Personnel error | Yes | Not relevant |
| WSRS | 89735 | 11/13/89 | Fissile material movement without Nuclear Incident Monitor coverage | Personnel error | Yes | Not relevant |
| WSRS | 89719 | 03/21/89 | Water intrusion into TRU waste drums | Inadequate Design | Yes | Restrictions on free liquids |
| WSRS | 89726 | 07/27/89 | Pressurized drum of TCE waste | No venting | No | Vents, restrictions on chemical incompatibilities |
| WSRS | 900234 | 12/01/89 | Storage of radioactive waste above ground over six months | Procedural error | Not known | Not relevant |
| MM(Y-12) | 85707 | 11/07/85 | Uranium scrap fire | Liquid coolant, uranium fines | LLW[3] | Restrictions on pyrophorics, free liquids, chemical incompatibility |
| MM(Y-12) | 85705 | 07/20/85 | Fire involving thorium in a scrapped glove box | Pyrophorics | LLW | Restrictions on pyrophorics |
| MM(P) | 90702 | 03/22/90 | Spill of mixed hazardous waste | Operational accident | Not known | Not relevant |

TABLE ES-1

SUMMARY OF UNUSUAL OCCURRENCES AT DOE SITES
(Continued)

| Reporting[1] Organization | Report Number | Date | Description | Cause | TRU-Related | Applicable Existing Regulation |
|---|---|---|---|---|---|---|
| WHC | 82705 | 03/13/82 | Uranium concrete billet autoignition | Pyrophorics | LLW[3] | Restrictions on pyrophorics |
| MM(Y-12) | 88714 | 06/02/88 | Chemical fire | Reaction between liquid chemicals | Not likely | Restrictions on free liquids, chemical incompatibility |
| MM(Y-12) | 85709 | 12/27/85 | Ignition of enriched uranium chips | Pyrophorics | LLW[3] | Restrictions on pyrophorics |
| WMCOO | 86704 | 05/06/86 | Uranium metal fines fire | Pyrophorics | LLW[3] | Restrictions on pyrophorics |
| WMCOO | 85738 | 08/20/85 | Explosion in the mill | Hydrogen | No | Hydrogen concentration restrictions |
| DPR | 90786 | 08/09/90 | Fire in radiologically-controlled lab | Plastic contacted with hot plate | No | Not relevant |
| LLNL | 84708 | 07/12/84 | Fire involving anhydrous nitric acid | Anhydrous nitric acid | Not known | Restrictions on chemical incompatibility, corrosives |
| EG&G RF | 88733 | 05/23/88 | Spill of low level mixed radioactive and hazardous waste | Operational accident | No, (LLW) | Not relevant |
| EG&G RF | 85740 | 09/19/85 | Pressurization of container and release of plutonium | Plutonium fines, calcium, moisture | Not known | Restrictions on chemical incompatibility, vents |
| BMI (PNL) | 83708 | 05/18/83 | Localized hydrogen explosion | Personnel error | No | Not relevant |
| EG&GI | 83753 | 06/29/83 | Contamination spread from waste box | Nonstandard waste box | Not known | Not relevant |
| WMCOO | 90704 | 02/12/90 | Weight loss from drums of hazardous/ radioactive waste | Evaporation of water | Not known | Not relevant |
| WMCOO | 86722 | 09/05/86 | Uranium metal chips and fines fire | Pyrophorics | LLW[3] | Restrictions on pyrophorics |

TABLE ES-1

SUMMARY OF UNUSUAL OCCURRENCES AT DOE SITES
(Continued)

| Reporting[1] Organization | Report Number | Date | Description | Cause | TRU-Related | Applicable Existing Regulation |
|---|---|---|---|---|---|---|
| WMCOO | 86713 | 07/15/86 | Uranium metal chips and fines fire | Pyrophorics | LLW[3] | Restrictions on pyrophorics |
| WMCOO | 86712 | 06/01/86 | Uranium metal chips and fines fire | Pyrophorics | LLW[3] | Restrictions on pyrophorics |
| WMCOO | 86710 | 06/30/86 | Uranium metal chips and fines fire | Pyrophorics | LLW[3] | Restrictions on pyrophorics |

[1] Explanation of Reporting Organization Abbreviations:

| | |
|---|---|
| ANL-E | Argonne National Laboratory-East |
| INC | Idaho Nuclear Corporation |
| RHO | Rockwell Hanford Operations |
| ARHC | ARCO Hanford Company |
| LLNL | Lawrence Livermore National Laboratory |
| WINC | Westinghouse Idaho Nuclear Co. |
| LANL | Los Alamos National Laboratory |
| EG&GI | EG&G Idaho, Inc. |
| BNL | Brookhaven National Laboratory |
| WMCOO | Westinghouse Materials Company of Ohio |
| ORNL | Oak Ridge National Laboratory |
| BMI (PNL) | Battelle Memorial Institute (PNL) |
| WHC | Westinghouse Hanford Co. |
| WSRS | Westinghouse Savannah River Co. |
| MM (Y-12) | Martin Marietta (Y-12) |
| MM (P) | Martin Marietta (Paducah) |
| DPR | DuPont Research |
| EG&G, RF | EG&G Rocky Flats Plant |

[2] Not Available

[3] Uranium, by definition, is not a transuranic element. Some of these incidents involved large amounts of uranium (more than a few kilograms) that were awaiting reprocessing into $U_3O_8$. Since these characteristics are typical of chunks of depleted uranium that are routinely disposed of as low-level waste after reprocessing, it is likely that the waste involved in the incidents would be classified as low-level waste (LLW).

Analysis of these incidents indicates that they either did not involve TRU waste, were not representative of the waste characteristics typical of the TRU waste destined for WIPP, or were not relevant to the flammability concerns associated with the waste. The cause of the incidents that were related to the issue of flammability or overpressurization, were attributed to one or more of the following reasons:

- Presence of pyrophorics in appreciable quantities
- Presence of free liquids in appreciable quantities
- Presence of flammable VOCs in appreciable quantities
- Presence of corrosives in appreciable quantities
- Lack of venting
- Chemical incompatibilities within the waste

A study of the above listed causes in conjunction with the regulations and requirements mentioned earlier, shows that each one of these causes is adequately addressed by one or more regulation(s) applicable today.

## CONCLUSION

The WIPP-WAC, the TRUPACT-II SAR, the EPA-NMD, and other applicable regulations address potential flammability concerns associated with TRU waste, and impose restrictions on the waste to ensure that it is safe for transportation and handling. These regulations are typically based on conservative analysis, and have reasonable margins of safety. Proper implementation of these restrictions should provide an adequate degree of assurance, that the drums reported in past unusual occurrences would fail to comply with existing regulations governing the transportation and disposal of TRU waste at the WIPP. In summary, given the applicable regulations and restrictions, it is unlikely that a TRU waste drum which qualifies for transportation and disposal will contribute to any incident related to overpressurization or the flammability of the waste.

# 1.0 INTRODUCTION

## 1.1 BACKGROUND

The Waste Isolation Pilot Plant (WIPP), in southeastern New Mexico, is an underground repository, designed for the safe geologic disposal of transuranic (TRU) wastes generated from defense-related activities of the U. S. Department of Energy (DOE). The WIPP storage rooms are mined in a bedded salt (halite) formation, and are located 2,150 feet below the surface. After the disposal of waste in the storage rooms, closure of the repository is expected to occur by creep (plastic flow) of the salt formation, with the waste being permanently isolated from the surrounding environment.

The majority of TRU waste is material that is contaminated with alpha emitting radionuclides (e.g., plutonium-239) with half lives greater than twenty years (DOE, 1988). TRU wastes are classified as either Contact-Handled (CH) or Remote-Handled (RH) (DOE, 1988), depending on the dose rate at the surface of the waste container. Contact-Handled Transuranic (CH-TRU) waste containers have an external dose rate less than 200 mrem/hr. CH-TRU waste comprises approximately 97% by volume of the waste to be shipped to the WIPP site (DOE, 1988). CH-TRU waste can be broadly classified into four waste types (discussed in further detail in Section 3.3.1.2):

- Solidified Inorganics
- Solid Inorganics
- Solid Organics
- Solidified Organics

The basis for this classification is the physical and chemical form of the waste, and the potential for gas generation from the waste. Gas generation in TRU waste can potentially occur by the following mechanisms:

- Chemical Gas Generation
- Biological Gas Generation
- Thermal Gas Generation
- Radiolytic Gas Generation

For the long-term disposal phase, the phenomena expected to contribute significantly to gas generation from the above four mechanisms are:

- Microbial Degradation (Biological Gas Generation)
- Anoxic Corrosion (Chemical Gas Generation)
- Radiolysis (Radiolytic Gas Generation)

Microbial activity has the potential to degrade organic materials such as paper, plastic, and wood present in the waste, thereby consuming oxygen and generating methane and carbon dioxide in the process. Anoxic corrosion occurs when iron present in the waste and the waste containers reacts with brine or water vapor under anoxic conditions to form iron oxides or oxyhydroxides, and hydrogen. Radiolysis can potentially generate hydrogen and oxygen from

the decomposition of water, and carbon dioxide, carbon monoxide, hydrogen, and methane from the decomposition of organic materials (NuPac, 1989).

The consequences of gas generation from the waste are presently being evaluated by Sandia National Laboratories (SNL), (Lappin et al., 1989). As part of this evaluation, the composition of generated gases, and kinetic rate data for gas generation are expected to be obtained through planned bin-scale and alcove tests with actual CH-TRU waste (Molecke, 1990a; Molecke, 1990b; Molecke, 1990c). These experiments (also referred to as the full-scale experimental program) comprise the WIPP Test Phase of operations, and the first wastes to be shipped to WIPP will be in support of these experiments. One of the concerns associated with gas generation is the presence of potentially flammable gas mixtures in the waste.

## 1.2 PURPOSE AND OBJECTIVE

The purpose of this paper is to evaluate the issue of flammability concerns associated with TRU waste destined for WIPP, including a review of possible scenarios that can potentially contribute to the flammability. The paper presents a comprehensive study of the existing regulations that address potential flammability concerns, and also examines the degree of assurance these regulations provide in safeguarding against flammability concerns during transportation, waste handling, and during the bin-scale and alcove tests. Possible means of mitigating the effects of potential gas generation after disposal of the waste (if necessary), are being addressed elsewhere (DOE, 1991a). The specific objectives of this paper are as follows:

- A discussion of the potential flammability concerns associated with CH-TRU waste transportation, handling, and disposal operations (Section 1.3).
- A discussion of the principles and mechanisms of flammability and explosivity of gas mixtures (Section 2.0).
- A discussion of existing regulations and restrictions in place to ensure safe practices of TRU waste transportation, handling, and disposal operations (Section 3.0).
- An analysis of flammability-related, past unusual occurrences at different DOE sites, to examine if the recurrence of these incidents can be prevented applying the existing regulations (Section 4.0).
- A summary of the analyses presented in this report, and a discussion of the adequacy of existing regulations in addressing potential flammability concerns (Section 5.0).

The remainder of this document addresses the objectives listed above. Section 1.3 discusses the potential flammability concerns. Section 2.0 presents a general discussion of the behavior of potentially flammable mixtures. Section 3.0 explains the existing regulations and their implementation procedures for addressing the concerns discussed above, and also presents a discussion of process knowledge gained from long-term practices at the sites. Section 4.0 summarizes past unusual occurrences at the sites related to the issue of flammability or overpressurization of containers, and presents an analysis of these incidents with reference to the regulations applicable today for TRU waste to be disposed of at WIPP. The summary

and conclusions of the report are presented in Section 5.0. References are provided in Section 6.0. Finally, Section 7.0 is a glossary of terms used extensively in this paper.

## 1.3 POTENTIAL FLAMMABILITY CONCERNS

The potential flammability concerns that are associated with the handling, transportation, and disposal operations for TRU waste at the WIPP can be identified as follows:

- Presence or generation of potentially flammable gases (hydrogen, methane, etc.) in the waste.
- Presence or occurrence of potentially flammable Volatile Organic Compounds (VOCs) in the waste.
- Presence or occurrence of potentially explosive or pyrophoric materials in the waste.
- Presence or occurrence of potential chemical incompatibilities in the waste.
- Presence or occurrence of any free liquids in the waste that might result in any of the concerns listed above.

In order to avoid any confusion or misinterpretation of the terminology presented in this report (e.g., combustible vs. flammable compounds, etc.), the reader is referred to the glossary of terms and definitions, provided in Section 7.0.

### 1.3.1 Presence or Generation of Potentially Flammable Gases

CH-TRU wastes consist of general laboratory waste (glass, crucibles), solid organic materials (paper, plastic, etc.), organic-based shielding materials (Benelex, Plexiglas), metals, sludges or concreted wastes, and various other materials (NuPac, 1989). Typically, the waste is contaminated with transuranic radionuclides that emit alpha radiation, and other radiation. The radiation from the waste can break the chemical bonds of materials in the waste (such as organics and water), and can lead to the generation of gases from that material. The process is commonly referred to as radiolytic gas generation. The exact ratios of the gases generated by radiolysis from the waste depend on the specific material involved, and the type of irradiation. A detailed description of the gases that may be generated from different types of CH-TRU waste, and their expected quantities, is provided in Appendix 3.6.8 of the TRUPACT-II Safety Analysis Report (NuPac, 1989).

Some of the gases that can be generated by radiolysis, such as hydrogen and methane, are flammable under certain conditions, and therefore pose a potential safety concern for TRU waste. The information presented in Appendix 3.6.8 in NuPac (1989) shows that for a vast majority of the waste types, the amount of hydrogen that can be potentially generated is substantially higher than methane. The potential for generation of each gas from each type of waste material is characterized by its "G Value". The G value for a given material is defined as the number of molecules of gas (e.g., hydrogen) that is produced per 100 eV of radiation energy absorbed by the material.

Although the flammable gases are a safety concern, measurements of actual CH-TRU waste drums have shown that the G values measured in the TRU waste drums are considerably lower than the values predicted by laboratory experiments (NuPac, 1989). This is due to a number of conservative assumptions and extreme conditions under which the laboratory experiments are coordinated. A summary of these assumptions, and the use of theoretical G values in arriving at various restrictions of flammable gas concentrations, are described in Section 3.3.

As explained later in Section 2.0, the mere presence of a flammable gas does not guarantee a combustion reaction. Combustion can only take place if there is simultaneous presence of necessary conditions. These include a flammable material at a certain concentration, a source of ignition, appropriate oxygen concentration, and the absence of any flame retardants.

### 1.3.2 Presence or Occurrence of Potentially Flammable Volatile Organic Compounds

Volatile organic compounds include those organic compounds that exert appreciable vapor pressures at normal temperatures. Some of these compounds are used at the DOE sites as industrial solvents, and in decontamination operations. The presence of VOCs (both flammable and nonflammable) in the waste is of concern for the following reasons:

- The vapor pressure exerted by the VOCs may contribute to the total pressure in the waste container or the transportation package.
- Some of the VOCs are flammable, and therefore could be a potential hazard if present in appreciable quantities.
- Some of the VOCs could potentially cause damage to the butyl rubber O-ring seals in the package during transport.

It should be noted that the VOCs that are normally used at the sites are nonflammable VOCs, examples being Freon-113, carbon tetrachloride, 1,1,1-trichloroethane, etc. The presence of flammable VOCs (e.g., toluene) in TRU waste is rare, compared to the presence of nonflammable VOCs. As discussed in Silva (1990), VOCs such as Freon-113, carbon tetrachloride, etc., do not present a flammability concern. The discussion in this paper is limited to the concerns from potentially flammable VOCs. Regulations which apply to these compounds, and the limits on their quantities are discussed in Section 3.0. As shown in Section 3.2.1, the source term of these VOCs in the waste is very limited, and is further restricted by applicable regulations to mitigate concerns associated with these compounds.

### 1.3.3 Presence of Pyrophoric Materials in the Waste

Pyrophoric materials (e.g., metals such as sodium or plutonium) are prone to spontaneous ignition, unless stabilized and rendered nonpyrophoric. The presence of pyrophoric materials is of potential concern for two reasons:

- Fire hazard from the burning of these materials themselves.
- Possible source of ignition for any flammable materials that might be present in the waste.

Pyrophoric materials can be classified into two groups: radionuclide pyrophorics and non-radionuclide pyrophorics. The restrictions imposed on both types of pyrophoric materials in the TRU waste to be shipped to and disposed of at WIPP are discussed in Section 3.0. As shown in Section 3.0, the use and presence of these materials at the DOE generator sites is limited and controlled, and restricted by the applicable regulations.

### 1.3.4 Presence or Occurrence of Chemical Incompatibilities in the Waste

Different types of CH-TRU waste are considered to be chemically incompatible with one another, if their simultaneous presence can potentially lead to any of the following reactions:

- Explosion
- Heat generation
- Gas generation (flammable gases)
- Pressure build-up (nonflammable gases)
- Generation of toxic by-products
- Corrosion

If chemical incompatibilities are present in the waste, the possibility exists for the reactions listed above. For example, mixing of acids with caustics could result in heat generation. For the purpose of evaluating chemical compatibility, each CH-TRU waste generator and storage site has produced a comprehensive list of all possible chemicals that could be present in their waste, based on an examination of process technology, process flow analysis, and chemical analysis. The concentrations of each chemical in these chemical lists are reported as either "trace" (less than 1% by weight), "minor" (1 to 10% by weight), or "dominant" (greater than 10% by weight). The lists are divided into groups based on chemical properties and structure (e.g., acids, caustics, metals, etc.). Based on this information, and guidelines for determining incompatibilities (EPA, 1980), potential incompatibilities within each type of waste have been analyzed for all waste currently authorized to be shipped to the WIPP site. Details of this analysis are available in the TRUPACT-II Safety Analysis Report (NuPac, 1989). The restrictions on chemical incompatibilities are discussed in Section 3.0.

### 1.3.5 Presence of Free Liquids

The presence of free liquids in TRU waste is restricted due to a variety of reasons. Apart from volatilization of flammable VOCs, there are other concerns associated with free liquids. The presence and volatilization of any flammable organic compounds could lead to similar concerns discussed earlier under the hazards from flammable VOCs. The hypothetical failure of a container during handling or emplacement operations could release contaminated liquids. Although radiological exposures to personnel are not expected to be high, decontamination activities in the salt in the WIPP repository could pose difficulties. Thus, the presence of free liquids in the waste can have radiological impacts in case of a ruptured container.

Restrictions on free liquids in TRU waste are discussed in Section 3.0. As shown in Section 3.3.1, TRU waste generation processes produce the waste as either solid or solidified material, minimizing the free liquid content as far as possible. Applicable regulations and site practices also control the amount and composition of the free liquids that could be present in the waste.

# 2.0 BEHAVIOR OF FLAMMABLE MIXTURES

## 2.1 INTRODUCTION

The purpose of this section is to provide a general discussion of the behavior of potentially flammable mixtures. The discussion of the basic principles (Section 2.2) describes the requirements for and the mechanism of explosions resulting from flammable mixtures, including definitions of relevant terms (also see Section 7.0, Glossary). Since hydrogen gas is one of the flammable gases of concern, a brief discussion of the behavior of hydrogen gas-air mixtures has been used to illustrate these basic principles.

## 2.2 BASIC PRINCIPLES OF FLAMMABLE MIXTURES

Explosions can be of two types: controlled explosions and accidental explosions. Examples of the former are common and widespread and include the internal combustion engine in transportation vehicles, blasting in quarries, forming of metals, welding, and the demolition of buildings. In contrast, accidental explosions are much rarer and possess the potential for unplanned destruction and injury. Most accidental explosions are caused by out-of-control exothermic or combustion reactions. A **combustion reaction** requires a fuel, oxygen (present in air) and, in order to initiate it, a certain quantity of energy from an ignition source. These three components are often depicted as the three sides of a hazard triangle (Bartknecht, 1981). All three of these components must be present in order for an explosion to take place. The concentration of oxygen that will support a flame propagation in a fuel must be above a minimum value, known as the **limiting oxygen index**. The use of diluents other than nitrogen results in different values for the limiting oxygen index of each fuel (Hord, 1976).

The **fuel** is any combustible material regardless of whether it is a solid, liquid or gas. **Combustion** is an exothermic oxidation reaction which may occur with any organic compound as well as with certain elements and inorganic compounds (e.g., hydrogen, sulfur, phosphorus, magnesium, carbon monoxide, hydrogen sulfide). The end products of the combustion of elements and inorganic compounds are oxides; of organic compounds are carbon dioxide and water. A combustible gas or vapor mixture may be burned over a wide range of concentrations when the temperature is sufficiently high. However, a combustible mixture is **flammable**, i.e., is capable of propagating a flame a long distance from the ignition source, within a limited concentration range. The minimum concentration at which a combustible vapor or gas forms a flammable mixture is called the **lower explosion (or flammable) limit (LEL)** while the maximum concentration at which a flammable mixture is formed is called the **upper explosion (or flammable) limit (UEL)**.

The limits of flammability are established experimentally by determining the limiting mixture compositions between flammable and non-flammable mixtures. The limits are affected by a number of parameters including the type of apparatus used, temperature, pressure, and direction of flame propagation. The general effect of an increase of temperature or pressure is to lower the lower limit and raise the upper limit. Decrease of temperature or pressure has the opposite effect. The most extensive flammability limit data is that of Zabetakis (1965)

although several other publications (NFPA, 1986; Lewis and von Elbe, 1961) provide similar information. Table 2-1 lists flammability data for selected gases and vapors for the TRU waste destined for WIPP. For mixtures of several flammable gases and vapors, the flammability limits can be estimated by Le Chatelier's Law, as follows (Baker et al., 1983; Bartknecht, 1981; Drysdale, 1985; Haessler, 1989; Schultz, 1985):

If $P_i$ is the volumetric percentage of gas "i" in the mixture, with a lower explosion limit, $LEL_i$, and an upper explosion limit of, $UEL_i$, the lower explosion limit for the mixture is:

$$LEL(mixture) = \Sigma P_i / \Sigma (P_i / LEL_i)$$

and the upper explosion limit for the mixture is:

$$UEL(mixture) = \Sigma P_i / \Sigma (P_i / UEL_i)$$

The application of energy to a flammable mixture initiates the ignition process (the third side of the hazard triangle referred to earlier). The **source of ignition** may be either in thermal form or in the form of electromagnetic radiation. Typical **ignition sources** include mechanical sparks, mechanical heat (friction, shocks or impacts), electrical sparks, open flames, hot surfaces, and discharge of static electricity. The effects of mixture composition on the energy requirements for ignition of methane-air mixtures are illustrated in Figure 2-1. **Limits of ignitability** which vary with the strength of the ignition source can be distinguished from **limits of flammability**. As can be seen from the curve, the higher the energy transferred to the gas mixture from the ignition source, the wider the range of concentrations permitting autonomous flame propagation.

Considerably larger **spark energies** are needed to establish the flammability limits than the ignitability limits. The **flammability** limits are essentially independent of the ignition source and strength. The minimum on the ignitability curve in Figure 2-1 is known as the **minimum ignition energy**. Thus, another requirement for an explosion to occur is that the source of ignition supply more energy than the **minimum ignition energy**.

Once the **flammable mixture** of fuel-air is ignited with a sufficiently high energy source, the resulting flame will either attach itself to the ignition source, as with an open flame, or propagate away from it, as with electric ignition. The propagation of the flame away from the ignition source, results in an **explosion.** An explosion is always accompanied by a fireball and an audible pressure wave caused by a rapid pressure rise as a result of gas generation and release of energy in a short time interval. The fireball may ignite surrounding combustible material resulting in a **fire** following an explosion. A deflagration is a low-order explosion resulting from subsonic flame speed relative to the unburned mixture. A **detonation** is a high-order explosion resulting from supersonic flame speed relative to the unburned mixture.

**TABLE 2-1**

**COMBUSTION DATA OF GASES AND VAPORS**

| Gas or Vapor | Flash Point °C | Autoignition Temperature °C | Flammable Limits (Percent by Volume) Lower | Upper |
|---|---|---|---|---|
| Hydrogen | Gas | 500 | 4.0 | 75 |
| Methane | Gas | 537 | 5.0 | 15.0 |
| Carbon Monoxide | Gas | 609 | 12.5 | 74 |
| Methanol | 11 | 385 | 6.0 | 36 |
| Butanol | 37 | 343 | 1.4 | 11.2 |
| Acetone | -20 | 465 | 2.5 | 13 |
| Isopropanol | 12 | 399 | 2.0 | 12.7 |
| Trichloroethylene | Nonflammable liquid | 420 | 8.0 | 10.5 |
| 1,1,1 Trichloroethane | Nonflammable liquid | 537 | 7.5 | 12.5 |
| Methylene Chloride | Nonflammable liquid | 556 | 14.0 | 22.0 |
| Carbon Tetrachloride | Nonflammable liquid | Not flammable | Not flammable | Not flammable |

Reference: NFPA, 1986; Sax and Lewis, 1987

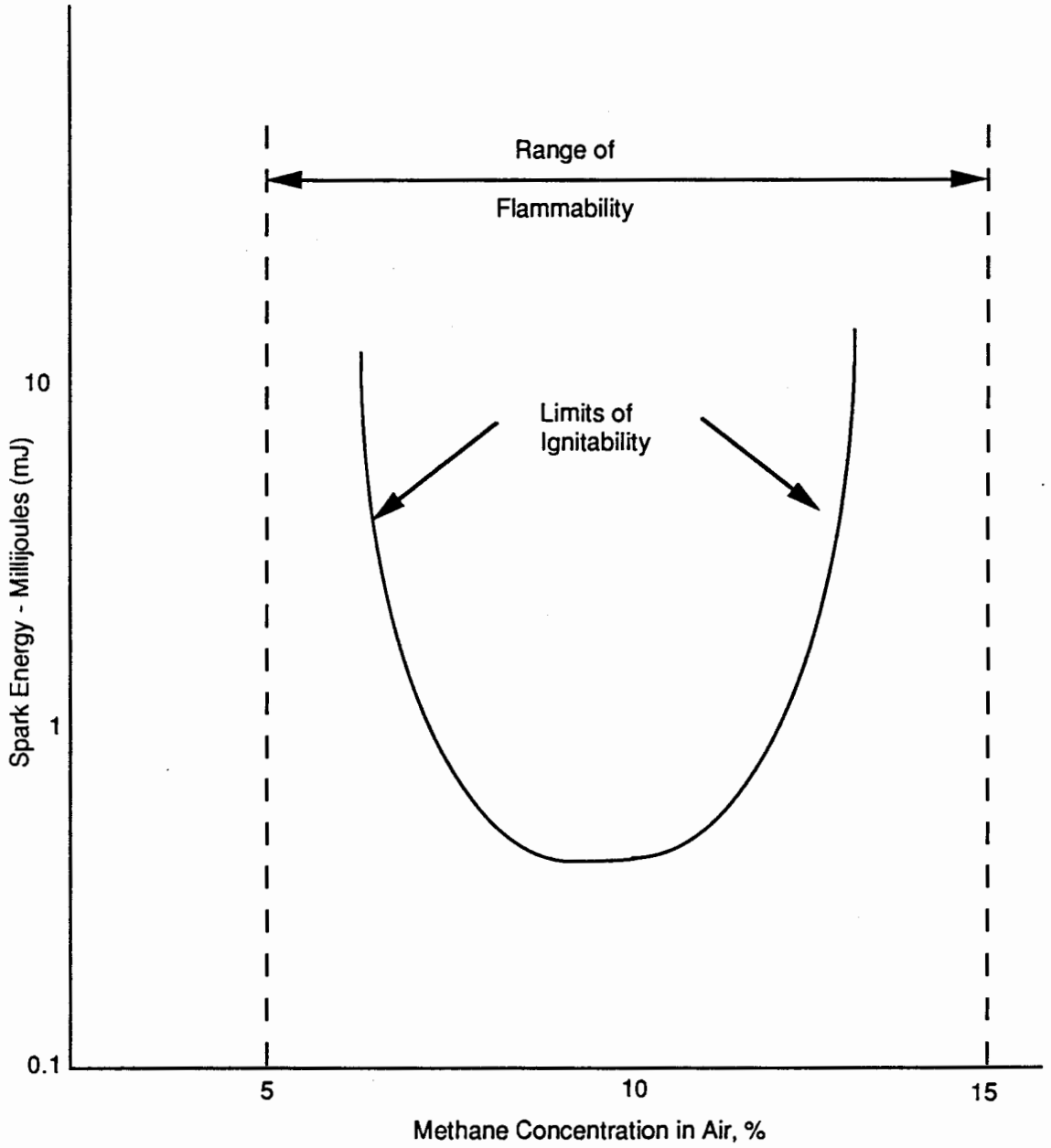



Figure 2-1. Ignitability Curve and Limits of Flammability for Methane Concentration in Air at Standard Atmospheric Conditions (Haessler, 1989)

The effect of temperature on the limits of flammability is shown as Figure 2-2. The region between the upper flammable limit curve and the lower flammable limit curve defines the region of flammable mixtures in Figure 2-2. This figure also presents the basic flammability concepts which are being described in this section. As stated previously (and shown in Figure 2-2), the limits of flammability diverge with increasing temperature. As the temperature increases, the **lower explosion limit** decreases and the **upper explosion limit** increases. Mixtures which lie outside the range of flammable compositions yield **flame caps** when ignited by an adequate source. The **flame caps** propagate only a short distance from the ignition source before being quenched. The horizontal dashed line which is labelled **"stoichiometric mixture"** represents the concentration of the vapor in air at which all of the vapor and oxygen in the mixture are consumed by the reaction and the maximum combustion energy is realized. The **autoignition temperature** (AIT, shown in Figure 2-2) is defined as the minimum temperature at which a flammable mixture can be ignited by a source of heat. Conversely from a safety standpoint, the AIT is the maximum temperature to which a flammable mixture can be heated without ignition. Autoignition temperatures of the gases and vapors of concern are listed in Table 2-1.

Also shown in Figure 2-2 is a point on the temperature axis known as the **flash point**. The **flash point** is defined as the temperature at which a liquid or volatile solid gives off sufficient vapor to form an ignitable mixture with the air above the surface of the liquid or solid which will propagate a flame. It is this temperature which is often cited in the literature. Flash points of the flammable liquids are summarized in Table 2-1. In the remainder of this section, hydrogen is used as a specific example to illustrate these concepts.

The limits of flammability of hydrogen (Table 2-1) in air are 4 volume percent (lower limit) and 75 volume percent (upper limit). The stoichiometric composition of hydrogen in air is 29.53 volume percent, and the minimum energy required for ignition in air 0.02 millijoules (Hord, 1976). The autoignition temperature of hydrogen is 500 °C. No mixture of hydrogen and other gases will propagate a flame if the mixture contains less than 5 volume percent oxygen (the limiting oxygen index). The flash point does not apply to hydrogen since it is a gas. As noted above, the flash point is defined only for liquids and volatile solids.

In summary, it is important to note that the mere presence of a flammable gas is not sufficient to cause an explosion hazard. The proper combination of conditions, including the presence of oxygen, the availability of an ignition source, and the presence of the flammable gas within the required concentration range, are required to cause such an event. As is described in subsequent sections, governing regulations for TRU waste are conservative, and do not take credit for the absence of some of the required conditions.

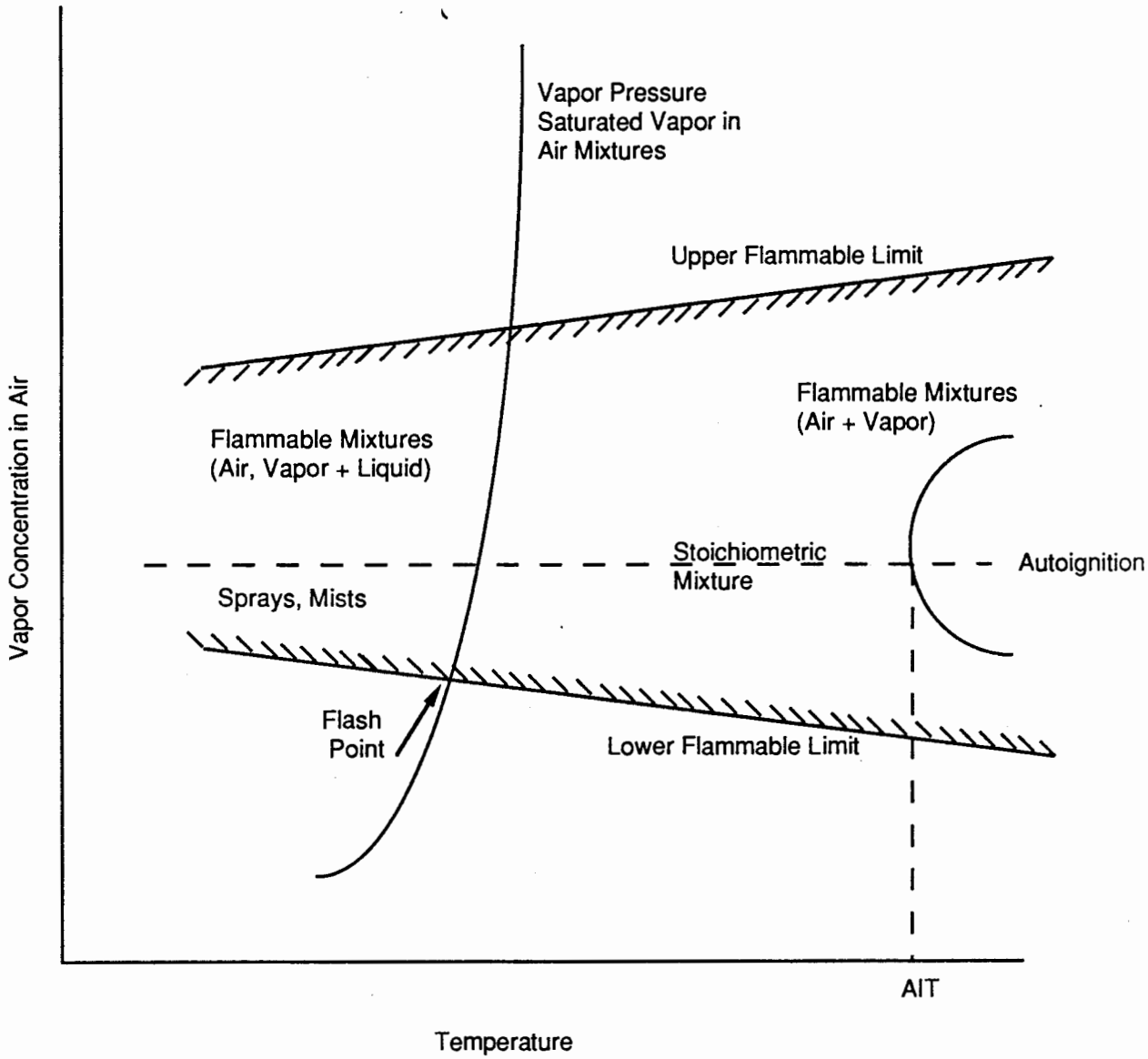



Figure 2-2. Basic Flammability Factors (Haessler, 1989)

# 3.0 EXISTING AND APPLICABLE REGULATIONS TO ADDRESS FLAMMABILITY CONCERNS

## 3.1 INTRODUCTION

A number of regulations govern the composition and nature of TRU waste to be shipped to the WIPP site. The potential for the occurrence of flammable gas mixtures or compounds in the waste is addressed by all of these regulations. The scope of these regulations includes site waste generation and handling procedures, waste transportation, waste characterization, the full-scale experimental program, long-term repository performance, and general operations safety. This chapter discusses these regulations and controls with respect to the potential flammability concerns regarding the waste. These concerns were discussed in Section 1.3, and are listed below:

- Presence or generation of potentially flammable gases (hydrogen, methane, etc.) in the waste.
- Presence or occurrence of potentially flammable volatile organic compounds in the waste.
- Presence or occurrence of potentially explosive or pyrophoric materials in the waste.
- Presence or occurrence of potential chemical incompatibilities in the waste.
- Presence or occurrence of any free liquids in the waste that may contribute to any of the concerns listed above.

The regulations and restrictions that address all of these concerns are presented in Table 3-1. Table 3-1 also indicates the regulatory body in charge of each of these regulations. Each of the regulations listed in Table 3-1 is discussed in detail below.

## 3.2 CH-TRU WASTE OPERATIONS SAFETY REQUIREMENTS FOR THE WIPP SITE

Wastes to be sent to the WIPP site have to meet specific waste acceptance criteria (WAC) intended to ensure the safe disposal of TRU wastes at WIPP. These criteria are documented in "TRU Waste Acceptance Criteria for the Waste Isolation Pilot Plant", WIPP/DOE-069, Rev. 3 (DOE, 1989c). This document is currently under revision to incorporate and consolidate other acceptance criteria for waste being shipped to the WIPP site; the original criteria, however, are still applicable. The WIPP Waste Acceptance Criteria (WIPP-WAC) related to potential flammability concerns are discussed below.

TABLE 3-1

REGULATIONS GOVERNING TRU WASTE TRANSPORTATION AND DISPOSAL

| REGULATION | ISSUE | REGULATORY AGENCY |
|---|---|---|
| 10 CFR Part 71 | Transportation | NRC[1] |
| 40 CFR Part 268 | Land Disposal Restrictions (No-Migration Determination) | EPA-OSW[2] |
| 40 CFR Parts 264 and 270 | Resource Conservation and Recovery Act (RCRA) Permit | NM-EID[3] |
| 40 CFR Part 191 Subpart A | Management and Storage of TRU Waste Prior to Disposal | EPA-ORP[4] |
| 40 CFR Part 191 Subpart B | Disposal of TRU Waste | EPA-ORP[4] |
| Waste Acceptance Criteria | Disposal of TRU Waste at WIPP | WACCC[5] |

(1) Nuclear Regulatory Commission
(2) Environmental Protection Agency Office of Solid Waste
(3) New Mexico Environmental Improvement Division
(4) Environmental Protection Agency Office of Radiation Programs
(5) Waste Acceptance Criteria Certification Committee

### 3.2.1 Restrictions on Pyrophoric Materials

Nonradionuclide materials that are pyrophoric are prohibited from being present in the waste. Any nonradionuclide pyrophoric materials present in the waste must be processed to render them nonpyrophoric, or rendered safe by mixing with chemically stable materials. Potentially pyrophoric forms of radionuclides are limited to less than one percent by weight in each payload container, and are required to be generally dispersed in the waste. As discussed in Section 3.3, the same restrictions apply for transportation of TRU waste, but fissile and decay heat limits further restrict the presence of radionuclides in the waste.

These restrictions are intended to minimize the potential for the presence of an ignition source in a waste package. While minor residues of uranium and plutonium can be present in the waste (under the one percent by weight restriction), wastes with metallic radionuclide constituents are generally oxidized and rendered nonpyrophoric prior to placement in waste containers.

### 3.2.2 Restrictions on Explosives and Compressed Gases

Explosives and compressed gases, as defined by 49 CFR 173, Subparts C and G (DOT, 1989a, 1989b), are prohibited from being present in TRU waste to be shipped to WIPP. The restrictions on these materials are to ensure that potential hazards to operating personnel during shipment and handling of the waste are minimized.

### 3.2.3 Restrictions on Free Liquids

Transuranic wastes to be disposed of at WIPP are required to be in either solid or solidified form. Free liquids are prohibited from being a part of the waste, except in residual amounts in well-drained bottles, cans, or other containers. For the WIPP Test Phase, residual liquids are limited to less than or equal to one percent by volume of the waste container (DOE, 1989c). Restrictions on the free liquids and the physical form of the waste ensure that the waste is in a stable and nonreactive form, and also minimize the potential for the release of any contaminated liquids.

### 3.2.4 Restrictions on Radioactive Mixed Wastes

Hazardous wastes and constituents in TRU wastes to be disposed of at the WIPP site are allowed only as co-contaminants with transuranics. Appropriate Department of Transportation (DOT) identification labels are required for waste containers with hazardous materials. Hazardous materials, as listed in 40 CFR Part 261, Subparts C and D (EPA 1989a, 1989c) should be reported if present in the waste. Specifically, any corrosive materials (regulated as hazardous wastes) that could potentially be present in TRU wastes need to be neutralized or rendered noncorrosive before emplacement at WIPP. These restrictions ensure that only TRU wastes are disposed of at WIPP, and ensure that an adequate inventory of the waste constituents exists.

### 3.2.5 Restrictions on Particulate Waste

Restrictions are imposed on powders, ashes, and other particulate materials in the waste to be disposed of at WIPP based on their quantities and particle size. These materials are required to be immobilized if more than one weight percent of the waste matrix in each package is in the form of particles below 10 microns in diameter, or if more than 15 weight

percent is in the form of particles below 200 microns in diameter. These limits are imposed to minimize the quantity of radioactive material that is available for dispersion or inhalation in the event of the failure of a waste container. These restrictions also limit the amount of fines and other potentially pyrophoric materials that may be present in the waste.

### 3.2.6 Summary of Operations Safety Requirements Relating to Flammability Concerns

As with any industry or waste disposal facility, operations safety is a prime concern in the functioning of the WIPP repository. The restrictions described above relate to controls over the waste as part of this operations safety. These restrictions on the properties of the waste ensure that the waste to be shipped to WIPP is safe for handling and disposal. A discussion of various other aspects of operations safety (emergency readiness, contamination control devices, etc.) is beyond the scope of this study. These aspects of operations safety are described in detail elsewhere (DOE, 1990b; DOE, 1989a). Implementation procedures in place at the waste generator and storage sites to meet the WIPP-WAC are discussed in Section 3.6, along with a discussion of the regulatory body enforcing these restrictions.

## 3.3 CH-TRU WASTE TRANSPORTATION REQUIREMENTS FOR THE WIPP SITE

The package to be used for the transportation of CH-TRU waste to the WIPP site is the Transuranic Package Transporter-II (TRUPACT-II). The TRUPACT-II is a double-contained, Type B package, that carries a payload of either fourteen 55-gallon drums or two Standard Waste Boxes (SWBs) (NuPac, 1989). The TRUPACT-II Safety Analysis Report (TRUPACT-II SAR) defines the package and payload parameters, the allowable methods of determination and control for these parameters, and applicable operations and maintenance procedures for the package (NuPac, 1989). The TRUPACT-II SAR and supporting documents were submitted to the Nuclear Regulatory Commission (NRC) in March 1989. Based on the analyses presented in these documents, the NRC granted a Certificate of Compliance (C of C) for the TRUPACT-II package in August, 1989. The C of C certifies that the TRUPACT-II package meets the requirements of 10 CFR 71, which governs the packaging and transportation of nuclear materials. As will be detailed in subsequent sections, the C of C for the TRUPACT-II package has additional margins of safety for the parameters beyond what is demanded by the applicable regulations.

Figure 3-1 shows the relationship between the primary documents describing the TRUPACT-II package and payload in support of the C of C. These documents include the TRUPACT-II Chemical Lists and the TRUPACT-II Content Codes document (TRUCON), which provide information on waste characterization (DOE, 1989b). Figure 3-2 shows the structure of the TRUPACT-II SAR, which is comprised of payload control procedures, operational and maintenance procedures for the package, necessary specifications, position papers, and the calculational methodology for the various transportation parameters. Table 3-2 defines the different TRUPACT-II SAR sections shown in Figure 3-2, but does not represent a complete table of contents for the TRUPACT-II SAR. As shown in Figure 3-2, the portions of the TRUPACT-II SAR relating to the issue of flammability concerns are those involving the calculation of the decay heat limits.

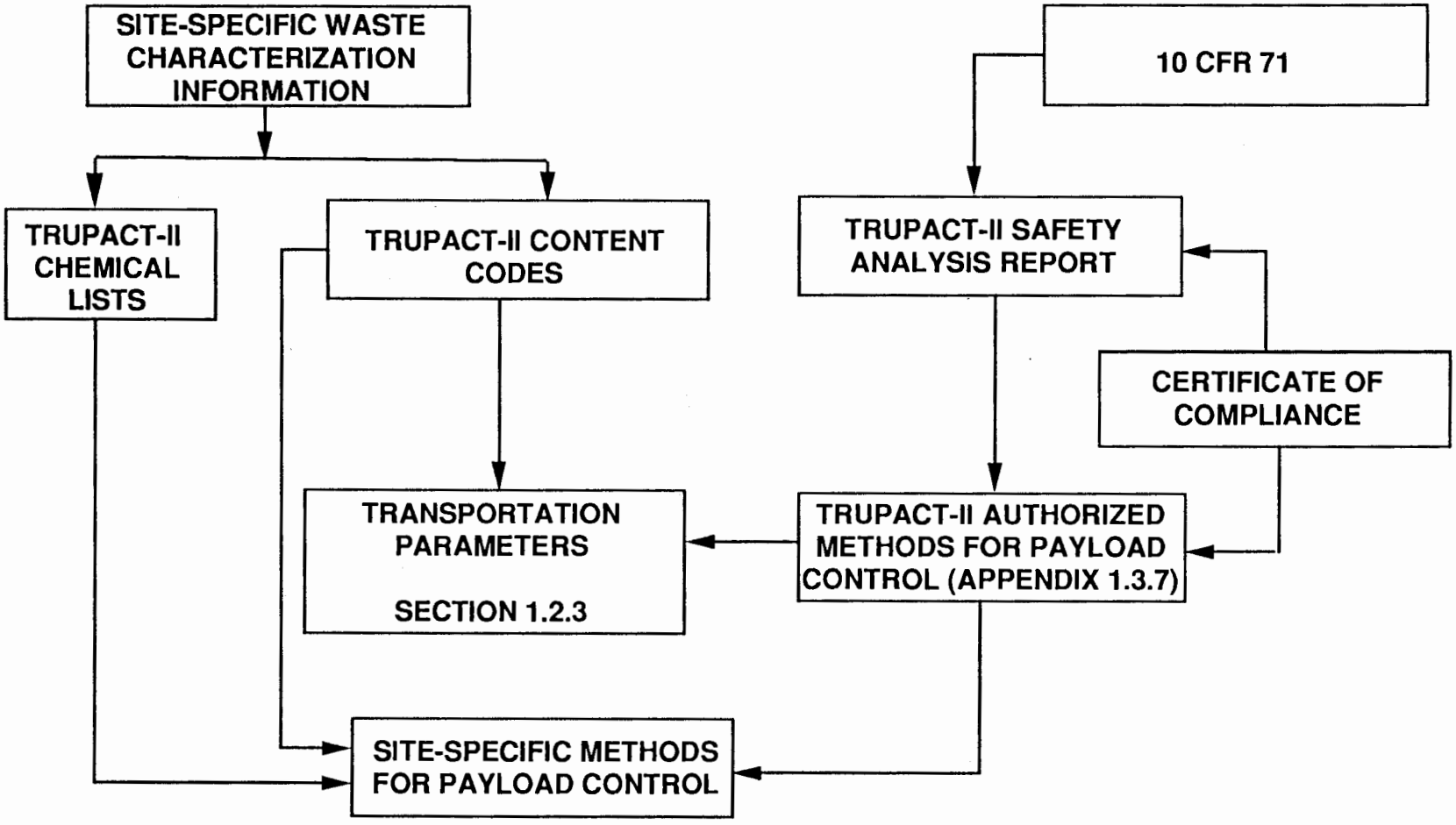



Figure 3-1. TRUPACT-II SAR and Related Documents

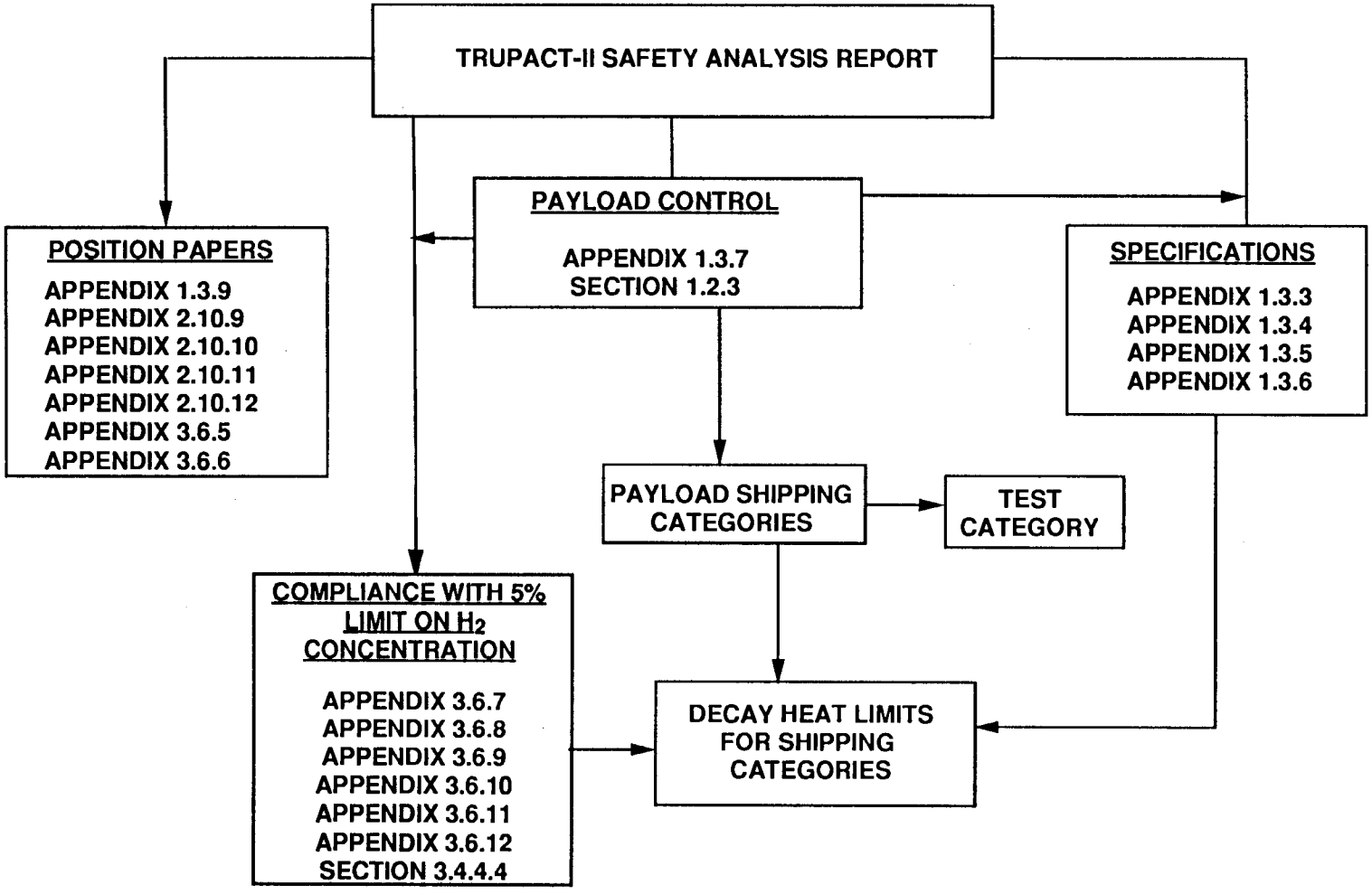



Figure 3-2. TRUPACT-II SAR Organization

## TABLE 3-2

## TRUPACT-II SAR PAYLOAD SECTIONS AND RELATED DOCUMENTS

| SECTION | TITLE |
|---|---|
| TRUCON | TRUPACT-II Content Codes |
| Chemical Lists | TRUPACT-II Chemical Lists Document |
| Section 1.2.3 | Contents of Packaging |
| Appendix 1.3.3 | Specification for 55-Gallon Drum and Liner |
| Appendix 1.3.4 | Specification for Standard Waste Box |
| Appendix 1.3.5 | Carbon Composite Filter Vent Specifications |
| Appendix 1.3.6 | Specification for Closure of Inner Confinement Layers |
| Appendix 1.3.7 | TRUPACT-II Authorized Methods for Payload Control (TRAMPAC) |
| Appendix 1.3.7-A1 | Real Time Radiography Procedures |
| Appendix 1.3.7-A2 | Gas Generation Test Procedure to Qualify CH-TRU Waste |
| Appendix 1.3.7-A3 | DOE Assay Methods Used for Determination of Fissile Material Content and Decay Heat Values of Contact-Handled Transuranic (CH-TRU) Wastes |
| Appendix 1.3.9 | Waste Sampling Programs at DOE Sites |
| Appendix 2.10.9 | Free Halides in the TRUPACT-II Payload - Source Term and Release Rate Estimates |
| Appendix 2.10.10 | Payload Compatibility with Butyl Rubber O-Ring Seals |
| Appendix 2.10.11 | Volatile Organic Compounds (VOCs) in the TRUPACT-II Payload - Source Term and Release Rate Estimates |
| Appendix 2.10.12 | Chemical Compatibility of Waste Forms |
| Section 3.4.4.4 | Flammable Gas Control |
| Appendix 3.6.5 | Biological Activity Assessment |

## TABLE 3-2

## TRUPACT-II SAR PAYLOAD SECTIONS AND RELATED DOCUMENTS (Continued)

| SECTION | TITLE |
|---|---|
| Appendix 3.6.6 | Thermal Stability of Payload Materials at Transport Temperatures |
| Appendix 3.6.7 | Effective G Values for TRUPACT-II Waste Types |
| Appendix 3.6.8 | Radiolytic G Values for Waste Materials |
| Appendix 3.6.9 | Gas Release Assessment |
| Appendix 3.6.10 | Gas Release Testing |
| Appendix 3.6.11 | Aspiration of Unvented Payload Containers of CH-TRU Waste |
| Appendix 3.6.12 | Temperature Dependence of Hydrogen Gas Generation and Release Rates |

### 3.3.1 Restrictions on Potentially Flammable Gases

This section summarizes the analyses performed to evaluate the presence of potentially flammable gases on CH-TRU waste transportation in the TRUPACT-II package. Resulting restrictions on the waste to ensure safe transportation conditions are described in the TRUPACT-II Safety Analysis Report (NuPac, 1989). The conservative factors and margins of safety used in these analyses and calculations, and the methodology and logic for the restrictions imposed on different parameters are highlighted in this section. Estimates of gas concentrations made from these analyses are also compared to results from sampling programs and waste analyses.

#### 3.3.1.1 Methodology for Restrictions on Potentially Flammable Gas Concentrations for Transportation Purposes - TRUPACT-II SAR Analyses

Potentially flammable gases can be generated in the waste, or be present as part of the initial waste inventory. Examples of potentially flammable gases that can be present in the waste include VOCs like methanol and other higher molecular weight alcohols. Examples of potentially flammable gases that can be generated in the waste include hydrogen and methane due to radiolysis of the waste materials. In Section 3.2, it is shown that the amount of potentially flammable gases in the initial waste inventory is very small, and is further restricted by controls on the waste composition before transportation. For waste forms that may contain significant amounts of potentially flammable gases in the initial waste inventory, adequate controls and restrictions exist to ensure that these are not transported without sufficient quantitative characterization of these gases under transportation conditions. The generation of potentially flammable gases in the waste is discussed in detail below.

The gas generation mechanisms that could be associated with TRU waste are the following:

- Chemical gas generation
- Biological gas generation
- Thermal gas generation
- Radiolytic gas generation.

Appendix 2.10.12 and Attachment B2 of the TRUPACT-II SAR discuss the relevance and potential of gas generation by chemical mechanisms in TRU waste containers under transportation conditions. Appendix 3.6.5 of the TRUPACT-II SAR discusses the potential for biological gas generation in the waste during transportation. Appendix 3.6.6 of the TRUPACT-II SAR discusses the potential for thermal gas generation in the waste during transportation.

These appendices show that gas generation by the three mechanisms (chemical, biological and thermal) is insignificant in a TRUPACT-II payload during a maximum sixty-day shipping period. While a normal TRUPACT-II shipment is expected to be three to five days, all analyses regarding flammable gas calculations in the TRUPACT-II SAR use a conservative period of sixty days (Appendix 3.6.4 of the TRUPACT-II SAR).

Appendix 2.10.12 (Table 3-2) shows that only chemically compatible waste forms are transported in the TRUPACT-II payload. Waste that is part of the TRUPACT-II payload is in a nonreactive form as either solid or solidified material, that has been safely stored and handled at the sites for a number of years. The TRUPACT-II payload restrictions further restrict the window of transportable waste properties to those that are safe under a series of conservative assumptions. Appendix 3.6.5 (Table 3-2) shows that given the waste forms and the conditions of transport in the TRUPACT-II package, microbial gas generation will be insignificant during a maximum sixty-day shipping period. The conditions in the waste during transportation are not conducive to microbial proliferation or gas generation. Appendix 3.6.6 (Table 3-2) shows that for the decay heat loadings to be transported in the TRUPACT-II package and resulting temperatures, thermal gas generation is not an issue. No thermal breakdown of any of the waste materials is expected under transportation conditions in the TRUPACT-II package. In summary, the only viable mechanism for flammable gas generation in the TRUPACT-II package, during a sixty-day shipping period, is radiolysis.

#### 3.3.1.2 Analyses for Radiolytic Gas Generation Estimates for CH-TRU Waste

For transportation purposes, CH-TRU waste materials can be classified into four waste types (NuPac, 1989), as follows:

I - Solidified Inorganics

II - Solid Inorganics

III - Solid Organics

IV - Solidified Organics

All of the CH-TRU waste materials at the different DOE TRU waste sites can be grouped into these four waste types. These waste types can be further sub-divided into waste material types based on their flammable gas generation potential. The flammable gas of concern is hydrogen, which can be produced by the radiolysis of hydrogenous waste materials (like water, paper, plastics, etc.). The potential for gas generation for each waste material type is quantified by bounding "G Values" (see Section 3.3.1.4). Table 3-3 lists the different waste material types and their applicable G values. As indicated in Table 3-3, the G value is defined as the number of molecules of gas (hydrogen, for example) produced per 100 eV of energy absorbed. As indicated in Table 3-3, a G value has not been established for Waste Type IV (Solidified Organics), and these wastes cannot be transported in the TRUPACT-II package unless individual containers are tested for their gas generation potential and shown to be within safe limits. It is expected that this testing will help establish a G value for this waste type. Appendix 3.6.8 of the TRUPACT-II SAR is a comprehensive literature survey of radiolytic G values for different materials. Appendix 3.6.7 of the TRUPACT-II SAR is a derivation of bounding G values for the different waste material types shown in Table 3-3.

TABLE 3-3

WASTE CLASSIFICATION INTO WASTE MATERIAL TYPES

| WASTE TYPE AND WASTE MATERIAL TYPE | G VALUE FOR HYDROGEN* | DESCRIPTION |
|---|---|---|
| I | | SOLIDIFIED AQUEOUS OR HOMOGENEOUS INORGANIC SOLIDS |
| I.1 | 1.6 | SOLIDIFIED INORGANIC LIQUIDS |
| I.2 | 1.3 | SOILS OR SLUDGES |
| I.3 | 0.4 | CONCRETED INORGANICS |
| II | | SOLID INORGANICS |
| II.1 | 1.7 | SOLID INORGANICS IN PLASTIC PACKAGING |
| II.2 | 0.0 | SOLID INORGANICS IN METAL CANS |
| III.1 | 3.4 | SOLID ORGANICS |
| IV | Not Established | SOLIDIFIED ORGANICS |

* Number of Molecules of $H_2$ Produced per 100 eV of Energy Absorbed; represent bounding "effective" G values.

The radiolytic gas generation rate is a product of the G value and the decay heat (watts or eV of energy) present in a waste container (with appropriate conversion factors). Hence, the maximum possible hydrogen generation rate for a waste container belonging to a certain waste material type can be calculated from its bounding G value for hydrogen and from a knowledge of its decay heat (watts per container). Conversely, a limit on the hydrogen concentration or hydrogen generation rate can be translated into a limit on the decay heat per payload container once the G values have been established. This calculational methodology for arriving at decay heat limits is discussed in further detail below.

3.3.1.3 Derivation of Decay Heat Limits for Payload Containers

One of the transportation requirements for the TRUPACT-II package is that the concentration of hydrogen remain below 5% in all layers of the payload and the package (NRC, 1984). The applicable regulation (NRC, 1984), however, states that the concentration of hydrogen or oxygen needs to be maintained below 5% in the secondary container cavity (the void volume in the TRUPACT-II cavity). As stated earlier, the restrictions for the TRUPACT-II package go beyond this regulation. No credit is taken for the potential absence of oxygen in the waste containers during transportation. In addition, the 5% limit on hydrogen concentration applies not only to the TRUPACT-II cavity, but also any layers of confinement (plastic bags, for example) that may be present within the waste containers in the TRUPACT-II cavity.

As described earlier, the hydrogen generation potential of a waste material depends on its G value, which has been quantified for each waste material type (Appendix 3.6.7 of the TRUPACT-II SAR, [NuPac, 1989]). The hydrogen concentration within a given void volume in the TRUPACT-II cavity depends on:

- The hydrogen generation rate
- The release of hydrogen through that void volume.

These release rates of hydrogen have been quantified for the different void volumes that can be present in the TRUPACT-II, and are summarized in Appendices 3.6.9 and 3.6.10 of the TRUPACT-II SAR (NuPac, 1989). For waste containers with different packaging configurations (but belonging to the same waste material type; that is, same bounding hydrogen generation rate), the release rates of hydrogen will be different. For example, a drum with two layers of plastic bags will have a higher overall release rate of hydrogen than a drum with four layers of plastic bags. In order to differentiate between different packaging configurations, "shipping categories" have been defined in the TRUPACT-II SAR as follows:

The shipping category consists of:

- The waste material type notation (e.g., II.1)
- An alpha code (A, B, C, D, etc.) denoting the type of payload container (drum [A], overpack of drums in a Standard Waste Box [B], Standard Waste Box [C], or an experimental bin overpacked in a Standard Waste Box [D])

- An integer denoting the maximum number of bags that can be present in the waste container.

For example, the shipping category:

II.1A4

denotes a drum of solid inorganic TRU waste packaged in a maximum of four layers of plastic bagging. A one-to-one correspondence exists between decay heats and shipping categories. Further discussions on shipping categories can be found in the TRUPACT-II SAR (NuPac, 1989). The classification of different content codes or internal description codes (IDCs) used at sites into the shipping categories is presented in the TRUCON document (DOE, 1989b). The controls in place to ensure that the shipping category requirements are met are described in Appendix 1.3.7 of the TRUPACT-II SAR (NuPac, 1989).

Figure 3-3 shows the hydrogen concentration profile with time in a drum with the waste in two layers of plastic inside the drum, a punctured rigid drum liner, and a carbon composite filter in the drum (as discussed in Section 3.3.1.4, all of the payload containers to be transported in the TRUPACT-II are required to be filtered). At time t=0, the waste is placed in the drum. The hydrogen concentration starts to build up in the different layers in the drum, and reaches a steady-state concentration after a certain period of time (time t=t1).

At steady-state conditions, the hydrogen generation rate is equal to the hydrogen release rate. At time t=t2, the drum is then placed in the TRUPACT-II (in this case, in a 14-drum payload configuration). The TRUPACT-II remains sealed during a maximum shipping period of sixty days, during which the concentrations of hydrogen in the different void volumes in the waste drums and the TRUPACT-II package increase. As shown in Figure 3-3, the allowable decay heat in the drum is controlled such that the concentration of hydrogen in the innermost layer of the drum is less than or equal to 5% at the end of the sixty-day shipping period. It should be noted that placing the drum in the TRUPACT-II package before steady-state concentrations are reached will result in lower concentrations of hydrogen in all layers of confinement. Hence, the assumption of steady-state condition for the waste containers is a conservative assumption.

#### 3.3.1.4 Input Parameters and Margins of Safety for Decay Heat Calculations

Hydrogen generation and release rates for each shipping category, along with other input parameters needed for the decay heat calculations, are described below. Conservative assumptions used in each of these input parameters are also indicated in this section.

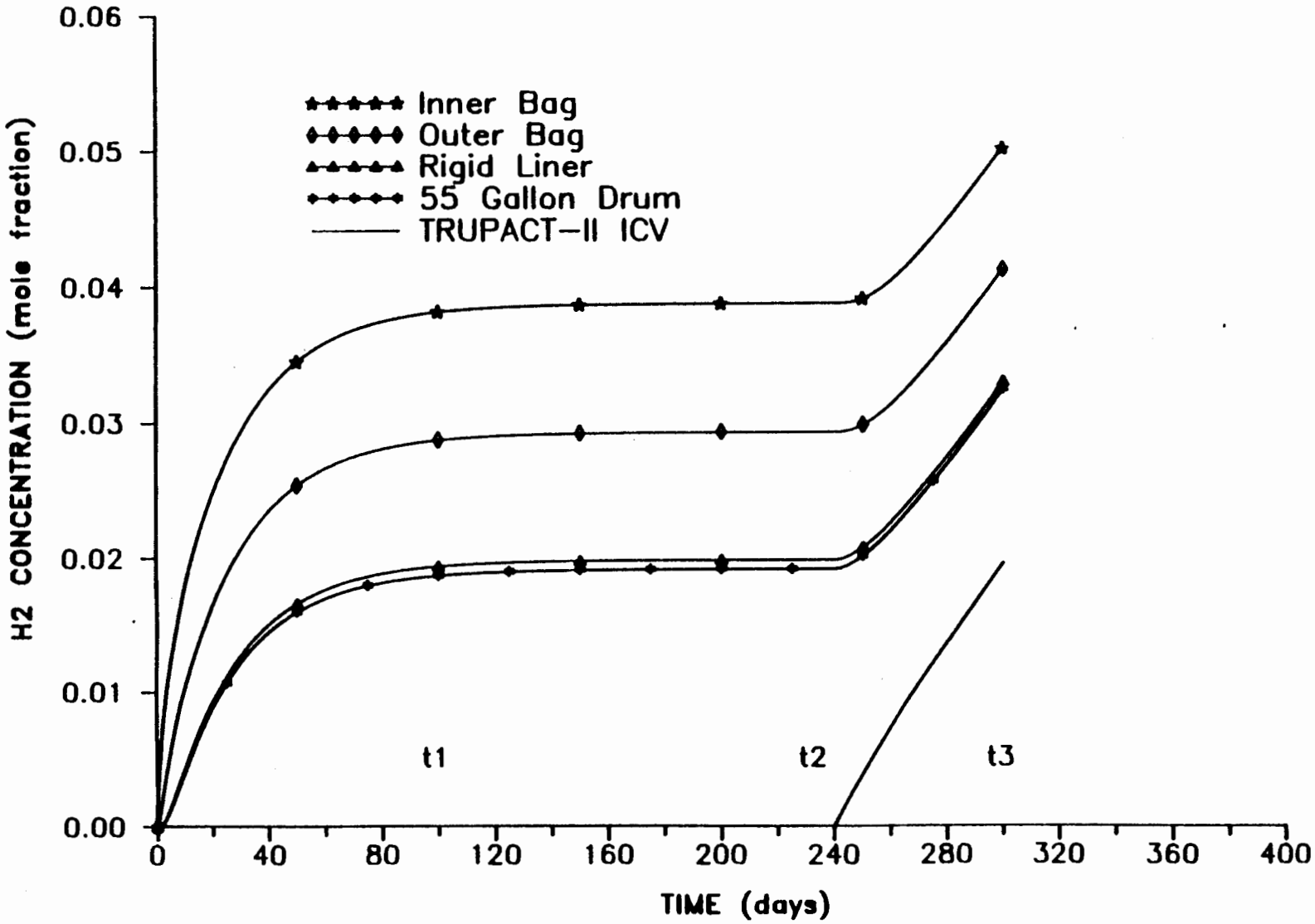



Figure 3-3. Hydrogen Concentration Profiles in a Drum that is part of a TRUPACT-II Payload

**Use of Bounding G Values**: The G values listed in Table 3-3 for the different waste material types are high estimates based on a number of conservative assumptions, as shown below.

- It is assumed that the bounding material (the material with the highest G value with respect to hydrogen generation) comprises 100% of the waste in the drum. For example, for Waste Material Type I.1 (Solidified Aqueous or Homogenous Inorganic Solids), it is assumed that all of the energy emitted by the alpha particle is absorbed by water, which has the highest G value of all materials that can be present in this waste material type. In reality, a fraction of this energy will be absorbed by waste materials (e.g., precipitated inorganic compounds) that do not produce any hydrogen. For Waste Material Type II.1 (Solid Inorganics), it is assumed that half of the alpha energy is absorbed by the packaging material. Further, this packaging material is assumed to be polyethylene, which has the highest G value among all packaging materials. Some of the waste in this waste material type is packaged in bags made of polyvinyl chloride (PVC), which has a much lower G value for hydrogen (0.7 compared to 4.0 for polyethylene). For Waste Material Type III.1, it is assumed that all of the energy from the alpha particles is absorbed by polyethylene, which has the highest G value among the constituents of this waste material type. This clearly overestimates the hydrogen generation potential of this waste, since polyethylene comprises only a fraction of the waste in this waste material type.

- No credit is taken for matrix depletion, which is a phenomenon that causes a sharp decrease in radiolytic gas generation with time. This is because the waste materials generating radiolytic gases become depleted with time around the radionuclides, and less gas is generated with increasing time. Some of the sampling programs conducted at the sites provide evidence that these theoretical G values are higher than would be actually seen in the waste (Clements and Kudera, 1985). Table 3-4 lists the average G values (by waste material type) for the drums sampled as part of the TRU Waste Sampling Program at the Idaho National Engineering Laboratory (Clements and Kudera, 1985). As can be seen from the Table, these G values are considerably lower than the theoretical G values listed in Table 3-3 and used in the TRUPACT-II SAR (NuPac, 1989).

It should be noted that the G values in Table 3-4 are presented only for comparative purposes. It is possible that any leakage from these drums that were sampled, the analytical techniques used, and any errors in measuring small quantities of energy from radioactive particles could have affected these G values.

Table 3-3 shows that a bounding G value has not yet been established for Waste Material Type IV, which consists of the organic sludges. As discussed earlier, these wastes cannot be transported in the TRUPACT-II package, unless it can be shown by actual testing and analyses that the hydrogen and total gas generation rates for these wastes are within safe limits. If sufficient data are collected by this testing, bounding G values will be established for these wastes in Waste Material Type IV.

## TABLE 3-4

## AVERAGE G VALUES FOR WASTE MATERIAL TYPES FROM TRU WASTE SAMPLING PROGRAM

| WASTE MATERIAL TYPE | AVERAGE G VALUE FOR HYDROGEN | NO. OF CONTAINERS |
|---|---|---|
| I.2 | 0.39 | 10 |
| II.1 | 0.17 | 66 |
| II.2 | 0.015 | 2 |
| III | 0.80 | 46 |
| IV | 3.2 | 11 |

Ref. - Clements and Kudera, 1985

**Packaging Configuration Assumptions**: For each shipping category, it is assumed that:

- The maximum possible layers of bagging (as defined by the shipping category) are present in all of the containers transported in the TRUPACT-II package.

- All of the alpha energy in a waste container is present in a single innermost bag.

Typically, the waste in a container is distributed among several inner bags, which tends to reduce the hydrogen concentration in these inner bags (compared to all of the waste being present in a single inner bag). These assumptions are, therefore, conservative with respect to the decay heat limits established for the shipping categories.

**Release Rates for Confinement Layers**: Under current restrictions of the TRUPACT-II Certificate of Compliance, all confinement layers (as defined in the TRUPACT-II SAR) in the payload containers must have sufficient release rates of hydrogen. Specifically, only a twist-and-tape closure is allowed on plastic bag layers, a filter or a punctured hole is required in rigid drum liners, and one or more filters are required in all payload containers. In other words, no sealed payload containers or confinement layers will be transported in the TRUPACT-II package. The release rates that have been used for these confinement layers are conservative because of the following assumptions used in the calculations:

- The lowest measured values from testing programs are used in the calculations (NuPac, 1989).

- In the case of large plastic bag liners, only diffusion and permeation are accounted for while computing the release rates; no flow component that may be present is accounted for.

- In the case of inner plastic bags, only diffusion is accounted for while computing release rates; no permeation from the bags is accounted for.

- Release rates for the bag closures were measured with simulated twist-and-tape closures which mimicked worst-case closure methods for the bags.

All of these factors ensure that release rates of hydrogen used for the different confinement layers are lower than actual release rates in the waste drums. This further limits the allowable decay heat in a given payload container.

**Maximum Shipping Period**: The shipping time used for calculating the decay heat limits is sixty days as described in Appendix 3.6.4 of the TRUPACT-II SAR (NuPac, 1989). As explained in this appendix, this time is twice the worst-case shipping time expected with a series of adverse hypothetical conditions. The normal shipping time for a shipment is expected to be three to five days (NuPac, 1989). The sixty-day shipping time restricts the decay heat limits calculated, since, it is assumed that the TRUPACT-II package remains sealed for this period of time. For example, for shipping category I.1A2, the decay heat limit with a sixty-day shipping time is 0.1594 watts. If the normal expected time of three days is used in the calculations, the decay heat limit for the same shipping category would be 0.2486

watts, an increase of approximately 56 percent. Conversely, using a sixty-day shipping time for shipping category I.1A2, it is predicted that a 5 percent hydrogen concentration is reached in the innermost bag with a decay heat limit of 0.1594 watts. If a three-day shipping time were used instead, the same decay heat limit would cause the hydrogen concentration in the innermost layer to be only 3.2 percent.

Temperature: In calculating the decay heat limits, the worst-case temperatures are used for each shipping category. Temperatures that yield minimum decay heat limits were used in each case.

It is shown in Section 3.4.4.4 of the TRUPACT-II SAR that a conservative pseudo steady-state analysis is used to calculate the hydrogen concentration in the payload as a function of time during the transportation period. In this analysis, no credit is taken for the void volume inside the payload containers in evaluating increases in hydrogen concentration (the steady-state hydrogen concentration in a vented payload container is independent of void volume). In addition, it is assumed that all of the hydrogen generated during the sixty-day shipping period is released into the TRUPACT-II cavity. This mole fraction of hydrogen is then added to the steady-state concentration of hydrogen in the payload container. This is equivalent to accounting for the hydrogen generated during transportation both within the payload container, as well as within the TRUPACT-II cavity. This clearly violates a mass balance on hydrogen on the conservative side. In reality, a fraction of the hydrogen generated during transportation will be released into the TRUPACT-II cavity, with the remainder being retained in the payload container.

### 3.3.2 Restrictions on Other Potentially Flammable Gases and VOCs

As discussed earlier, hydrogen is the only flammable gas of concern during transportation in the TRUPACT-II package. Potentially flammable compounds in the waste inventory are limited to only trace amounts. In addition, the total amount of potentially flammable VOCs in the headspace of payload containers is limited to 500 ppm for the TRUPACT-II package. The limit of 500 ppm is well below the flammability limit of all of these compounds. It is important to note that 500 ppm is not a flammability limit for any of these compounds. The purpose of this limit is to ensure that flammable mixtures of gases are not formed in the payload containers, while using a limit of 5% for the concentration of hydrogen. Waste types that may contain flammable VOCs in greater than trace amounts are not allowed to be transported in the TRUPACT-II, unless shown by actual testing that the concentrations of potentially flammable gases are within safe limits. This test procedure is described in Attachment 2.0 of Appendix 1.3.7 of the TRUPACT-II SAR (NuPac, 1989).

Appendix 3.6.8 of the TRUPACT-II SAR also addresses possible methane generation due to the radiolysis of solid organic materials (Waste Material Type III.1). Methane generation due to radiolysis is not expected to be significant for the TRUPACT-II payload materials. Biological generation of methane is also expected to be insignificant given the waste environment and a sixty-day shipping period. However, in the calculations for Waste Material Type III.1, the G value for hydrogen has been increased (from 4.0 to 4.1) to account for any possible methane generation in the payload during transportation.

### 3.3.3 Restrictions on Pyrophoric Materials

The restrictions on pyrophoric materials for transportation purposes are the same as those for operations safety purposes, listed under Section 3.2.1. The decay heat limits, and fissile limits for the waste containers, further restrict the presence of pyrophoric radionuclides in the waste, although it should be noted that the radionuclides are not present in a pyrophoric form in the TRU waste. For transportation in the TRUPACT-II package, the following fissile limits apply:

- 200g of Pu-239 Fissile Gram Equivalent per drum
- 325g of Pu-239 Fissile Gram Equivalent per SWB
- 325g of Pu-239 Fissile Gram Equivalent per TRUPACT-II

While the fissile limit per drum is 200 grams, the limit of 325 grams for the TRUPACT-II package reduces the average fissile loading per drum to 23 grams (since a payload consists of fourteen drums). The TRUPACT-II SAR also requires that two times the error be added to each fissile measurement.

### 3.3.4 Restrictions on Explosives and Compressed Gases

The restrictions on explosives and compressed gases for transportation purposes are the same as those for operations safety purposes, listed under Section 3.2.2.

### 3.3.5 Restrictions on Chemical Incompatibilities in the Waste

Only chemically compatible waste forms are allowed to be transported in the TRUPACT-II package. An analysis of chemical compatibility was performed for all waste to be transported in the TRUPACT-II, and is summarized in Appendix 2.10.12, and Attachment B2 of the TRUPACT-II SAR. The methodology used for this analysis was described earlier in Section 1.3.4. Wastes with potential incompatibilities are prohibited from being a part of the TRUPACT-II payload, unless these incompatibilities are resolved. These restrictions ensure that no adverse reactions occur in the TRUPACT-II payload transported to WIPP.

### 3.3.6 Restrictions on Free Liquids

The restrictions on free liquids for transportation purposes are the same as those for operations safety purposes, listed under Section 3.2.3

### 3.3.7 Summary of Transportation Requirements

The previous subsections under Section 3.3 have highlighted the assumptions and methodology involved in controlling potentially flammable gas concentrations in the TRUPACT-II payload during transportation. These controls and restrictions ensure that the payload must qualify for transportation under a series of extremely conservative assumptions. Waste forms that have the potential to contain or generate flammable gases (Waste Type IV or containers that exceed decay heat limits) are restricted from being transported in the TRUPACT-II unless

specifically tested for their gas generation potential, and shown to be within safe limits. The decay heat limits for shipping categories, based on considerations of gas concentrations, are limiting in almost all cases. While the design limit for decay heat for the TRUPACT-II package is 40 watts, most shipping category limits are at least an order of magnitude lower than this design limit. As shown in Table 1.2.3.3-1 of NuPac (1989), some of the decay heat limits (for a payload in the TRUPACT-II) also fall under 20 curies (of plutonium), below which double containment is not a requirement for transportation in a Type B package (DOT, 1989c) (the TRUPACT-II is a double-contained, Type B package). In summary, the TRUPACT-II transportation restrictions and authorized methods for payload control ensure safe transportation conditions for the TRUPACT-II package and payload.

## 3.4 CH-TRU MIXED WASTE NO-MIGRATION REQUIREMENTS FOR THE WIPP SITE

A major fraction of the CH-TRU waste destined for the WIPP site is both radioactive and hazardous, and is classified as "mixed waste". Mixed wastes are defined as a mixture of hazardous wastes regulated under Subtitle C of RCRA and radioactive wastes regulated under the Atomic Energy Act. Examples of the hazardous constituents in TRU waste are heavy metals like lead, and solvents like 1,1,1-Trichloroethane. The land disposal of hazardous wastes is regulated under RCRA, and the subsequent Hazardous and Solid Waste Amendments (HSWA), promulgated by the Environmental Protection Agency (EPA). These acts prohibit the land disposal of hazardous wastes, unless:

Option 1: The wastes meet treatment standards specified by the EPA or,

Option 2: It is determined that the prohibition is not required in order to protect human health and the environment.

The determination under Option 2 must be based on a demonstration that "there will be no migration of hazardous constituents from the disposal unit or injection zone as long the wastes remain hazardous."

The standards and procedures for the review (and subsequent finding) of no-migration petitions are codified under 40 CFR Part 268.6 (EPA, 1989b). The Department of Energy has chosen to exercise Option 2 (demonstration of no-migration) in complying with the land disposal restrictions. A No-Migration Variance Petition (NMVP) for the WIPP site was submitted to the EPA in 1989 (DOE, 1990c) under the requirements of 40 CFR 268.6. As part of the demonstration of no-migration, the NMVP includes a detailed Waste Analysis Plan that comprehensively summarizes all available waste characterization information for CH-TRU waste to be shipped to WIPP. This waste characterization is based primarily on process knowledge, and supplemented by limited sampling programs at the sites. Waste characterization is further discussed in Section 3.7.

In response to the NMVP submitted for the WIPP site, the EPA has issued a No-Migration Determination (NMD), granting a conditional variance for the land disposal of hazardous wastes at WIPP for the WIPP experimental phase (EPA, 1990). The NMD imposes several requirements and restrictions to ensure that the WIPP waste is safe for handling and operations during the test phase. The restrictions in the NMD addressing potential flammability concerns are discussed below.

### 3.4.1 Restrictions on Flammable Gas Concentrations in the NMD

The No-Migration Determination by the EPA requires that no waste containers be emplaced in the underground repository if it contains flammable mixtures of gases in any layer of confinement, or mixtures of gases that could become flammable when mixed with air. In addition, as an added margin of safety, the NMD defines any mixture as potentially flammable if it exceeds 50% of the lower explosive limit (LEL) of the mixture in air (EPA, 1990). In order to show compliance with this prohibition on flammable gases, the NMD requires that every waste container be tested for hydrogen, methane, and flammable VOCs as a class. The NMD further requires that all layers of confinement in a waste container be sampled and verified for the above criteria, until sufficient data are collected to show that sampling of all layers in a waste container is not necessary to demonstrate safety regarding the flammability concerns.

Specifically, the NMD requires that the following criteria be tested (for every layer of confinement, till sufficient data are gathered) and evaluated before a waste container is shipped to WIPP:

1. Sample and analyze the headspace gases of confinement layers containing waste, for hydrogen, methane, and flammable VOCs.

2. If the above analyses show that the concentration of flammable VOCs is insignificant (defined as less than 500 parts per million), the lower explosive limit of the gas mixture in the headspace can be calculated using Le Chatelier's Principle as described in Step 2a.

2a. If C1 and C2 are the measured concentrations of hydrogen and methane in the headspace (in volume percent), the sum of the fractions C1/LEL1 and C2/LEL2 (where LEL1 and LEL2 are the lower explosive limits of hydrogen and methane in volume percent) should be less than 0.5. The lower explosive limits to be used in these calculations are 4% for hydrogen (LEL1) and 5% for methane (LEL2). If the sum of the fractions (C1/LEL1 and C2/LEL2) exceeds 0.5, the waste container cannot be emplaced underground at WIPP. For example, if the measured concentrations of hydrogen and methane in a container headspace are 2% and 2.5%, respectively, the sum of C1/LEL1 and C2/LEL2 is 1.0 (0.5+0.5), and the container cannot be shipped to WIPP.

3. If a headspace analysis shows the concentration of flammable gases is significant (defined as being greater than or equal to 500 parts per million), an explicit flame test must be performed to determine if a flammable mixture of the headspace gases can be formed with air. This explicit flame test should be equivalent to ASTM method E681-85 "Concentration Limits of Flammability of Chemicals" (ASTM, 1985). If the headspace gas mixture fails the flame test, the gas mixture is considered flammable, and the waste container cannot be emplaced underground at WIPP.

Figure 3-4 is a flowchart that summarizes the NMD criteria listed in the steps above.

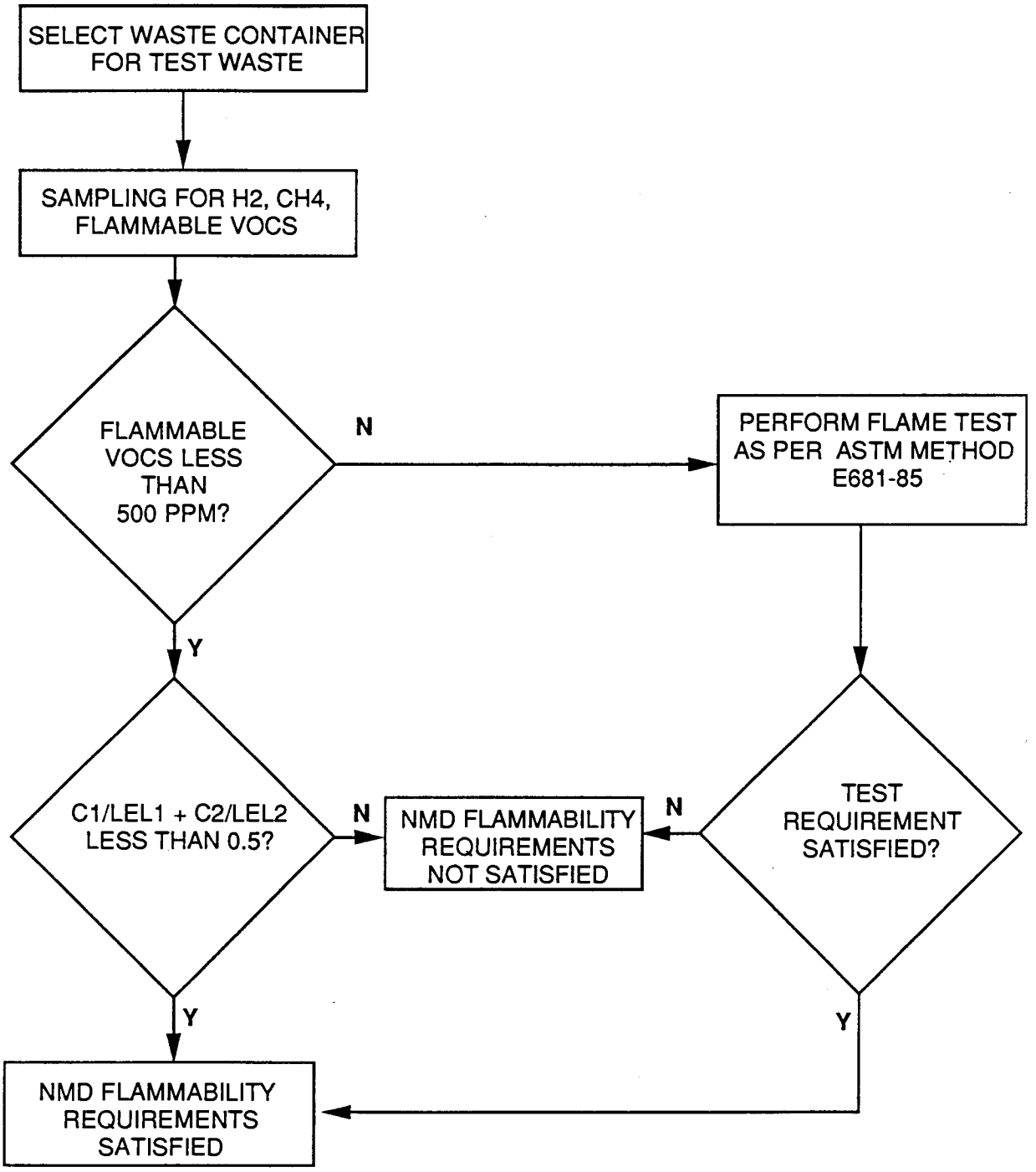



Figure 3-4. No-Migration Determination Flammability Requirements

The NMD also requires documentation of the time period after sampling, during which concentrations of headspace gases are expected to remain below flammable levels. This documentation is required to ensure that waste containers are emplaced at WIPP within this time period. For example, if a waste container is shown to meet the flammability criteria at time t=0, and it can be shown through conservative analysis that the container will meet the flammability criteria until time t=t1, the container must be placed underground before time t=t1. Time t=t1 is when the container becomes a part of the WIPP experimental program, and is monitored according to the test phase requirements (discussed in Section 3.5).

### 3.4.2 Summary of No-Migration Determination Requirements

The No-Migration Determination by the EPA applies to the WIPP Test Phase, and imposes several waste characterization requirements for this test waste. A significant portion of the NMD focuses on potential flammability concerns during the WIPP experimental program, even though the occurrence of any fire or explosion events is unlikely. Restrictions to control the concentrations of flammable gases in the waste include extensive sampling requirements, and compliance with limits with conservative margins of safety. Implementation procedures being developed to address these restrictions are discussed in Section 3.6.

## 3.5 TEST PLAN REQUIREMENTS FOR THE WIPP TEST PHASE

The first waste to be shipped to WIPP will be in support of the WIPP full-scale experiments. These experiments include the bin-scale and alcove experiments, and are described in two test plans and an addendum by Sandia National Laboratories (SNL) (Molecke, 1990a, 1990b; Molecke and Lappin, 1990). These experiments, along with other laboratory scale experiments, are expected to provide data in support of the Performance Assessment (PA) studies for the WIPP site. A primary purpose of these experiments is quantification of the short-term and long-term gas generation potential of the waste. The test plans for these experiments incorporate a number of control measures to ensure safe conditions during the experiments (Molecke, 1990a). A brief summary of these safety measures is provided below.

### 3.5.1 Pressure Relief Valves

The WIPP bin-scale experiments include a MODCOMP computer data acquisition system that periodically measures pressure within the bins, in order to keep the bin pressure within a narrow range of safe operating pressures. This is achieved by means of two solenoid-actuated pressure relief valves. In addition, the bin instrumentation systems will have a mechanical pressure relief valve, set to open at a bin gas pressure of greater than or equal to one pound per square inch gauge (psig). These pressure relief systems eliminate the potential of excess pressure build-up in the experimental bins.

### 3.5.2 On-line Oxygen Monitoring

The oxygen concentration within each test bin will be measured periodically, using an oxygen analyzer, to detect changes in the oxygen concentration in each bin, detect possible air leaks, and to evaluate the potential for the presence of a flammable gas mixture in a bin. The installation of an oxygen sensor system, to be used solely for providing safety information, is currently being evaluated. Data from these systems can be used to take corrective actions if there is a potential for the development of flammable gas mixtures in bins.

### 3.5.3 Periodic Monitoring of Potentially Flammable Gases

A major fraction of the test bins in the bin-scale experiments will be maintained under anaerobic conditions, and will be characterized by the absence of oxygen. A few of the bins are specified to be aerobic, and could contain high oxygen concentrations. As a safety precaution, one of the test requirements for these aerobic bins is that they be partially flushed with nitrogen to reduce the oxygen concentration to below 5%. As discussed in Section 2.0, at these oxygen concentrations (<5%), flammability of hydrogen is not a concern.

Another requirement for the test bins is the periodic sampling of the bin gases to evaluate safety concerns, in addition to the routine gas sampling and analysis as part of the bin-scale experiments. This periodic sampling will be used to evaluate and ensure safe operating conditions in the bins.

### 3.5.4 Summary of Requirements for the WIPP Test Phase

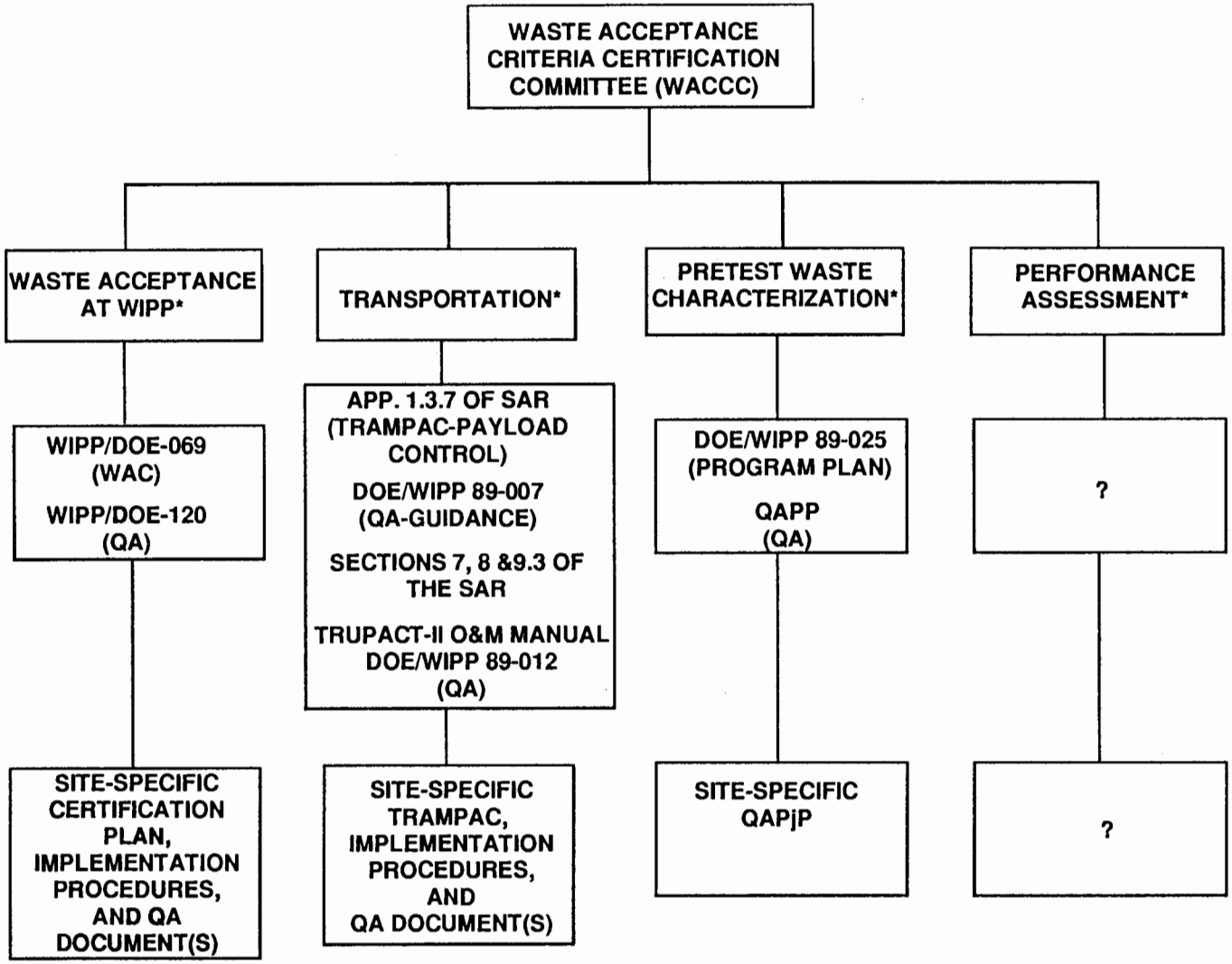
The initial shipments of TRU waste to the WIPP site will be in support of the WIPP test phase experiments. These experiments incorporate several safety measures to ensure proper operating conditions, and prevent the occurrence of potentially flammable gas mixtures in the experimental bins and other containers. Gas sampling is a vital part of these experiments, and the results obtained from these experiments are expected to provide input to the PA studies, and also the gas generation potential of different waste forms.

## 3.6 IMPLEMENTATION OF REGULATIONS AND REQUIREMENTS AT WASTE GENERATOR AND STORAGE SITES

Inherently, TRU waste generation processes and practices at the sites are geared towards meeting the regulations discussed above. For example, all TRU waste at all the sites is generated in either solid or solidified form, with only residual free liquids in the waste. Site waste generation practices require inventories and control over explosive, pyrophoric, and fissile materials. Specifically, the sites have implemented (or are in the process of implementing) procedures to show compliance with all governing regulations. The body responsible for enforcing the regulations, and auditing these specific procedures, is the Waste Acceptance Criteria Certification Committee (WACCC). Figure 3-5 shows the organizational structure of the regulations, and the governing document and site-specific documentation requirements for each of the regulations. Each of these is discussed below.

### 3.6.1 Implementation of Operations Safety Requirements and TRUPACT-II Transportation Requirements

The operations safety requirements for the WIPP site, and the TRUPACT-II transportation requirements, were discussed in Sections 3.2 and 3.3, respectively. As shown in Figure 3-5, each waste generator and storage site is required to write and implement a site certification plan, addressing the WIPP Operations Safety Requirements. Each site is also required to write and implement a compliance plan, addressing the transportation requirements specified in Appendix 1.3.7 of the TRUPACT-II SAR (TRAMPAC). These plans are approved by the WACCC, which also performs periodic audits on the implementation and Quality Assurance (QA) procedures of the sites.




* All criteria currently being consolidated into a revised version of WIPP/DOE-069

Figure 3-5. Documents Governing TRU Waste Transportation and Disposal

The following methods of determination and control are used by the sites to meet the WIPP Operations Safety Requirements and the TRUPACT-II transportation requirements:

- Knowledge of waste generation procedures (process knowledge)
- Procurement and Administrative Controls
- Nondestructive Assay and Nondestructive Examination (NDA/NDE) techniques
- Visual Examinations and Secondary Inspections
- Records and Database Information.

For example, decay heat and fissile content of waste containers are determined by means of NDA/NDE techniques that meet the requirements specified in TRAMPAC. Real-Time Radiography (RTR) is used to verify compliance with the free liquids criteria. Procurement and administrative controls are used to limit and control the use of explosives, pyrophorics, and other prohibited items in the waste. Process knowledge is used to characterize the waste composition (physical and chemical) and the packaging configurations of the waste, and is discussed in greater detail in Section 3.7. Visual examinations and secondary inspections are used to verify the absence of prohibited items in the waste (for newly generated waste), and to verify the presence of required items like filters in the waste containers. Records and database information are used for payload assembly and for characterizing the payload in the case of retrievably stored waste.

It should also be noted that in some cases, site-specific procedures extend beyond the regulations described in this section. For example, although the limit of free liquids is one percent by volume, some of the sites have more stringent requirements, and do not allow any visible free liquids in the waste.

As described in Section 3.3, the TRUCON document is a compilation of site-specific content codes allowed for transportation in the TRUPACT-II package. TRUCON also describes the transportation parameters and applicable methods of control for each content code. The TRUCON document is discussed further in Section 3.7.

### 3.6.2 Implementation of No-Migration Determination Requirements

The implementation of the No-Migration Determination requirements for the test waste will be a part of the protocols being developed to characterize the test waste before initiation of the WIPP full-scale experiments. Initial waste characterization requirements for the test waste are described in the program plan for waste characterization (DOE, 1991b). Applicable analytical protocols for these NMD requirements will be described in future revisions of the Quality Assurance Program Plan (QAPP) for the WIPP Waste Characterization Program (DOE, 1990d). Methods developed and used to meet the NMD requirements will also comply with the QA requirements and Data Quality Objectives specified in the NMD.

## 3.7 WASTE CHARACTERIZATION AND PROCESS KNOWLEDGE

Process knowledge is an integral part of the available information regarding the properties of TRU waste to be shipped to WIPP. It is required to show compliance with various aspects of the governing regulations discussed in Sections 3.1 through 3.5. TRU waste characterization at the DOE sites is primarily based on process knowledge, supplemented with limited sampling and analytical data. Process knowledge information has been gathered from the different DOE sites through questionnaires requesting specific information, and compiled into different databases and documents. This information is continually being updated to reflect the most current knowledge of the waste. In addition, available sampling and analytical data have been compiled and reported to supplement this process knowledge.

The databases and documents that have been used to collect and present waste characterization data are the following:

- TRUPACT-II Safety Analysis Report (TRUPACT-II SAR)
- TRUPACT-II Content Codes (TRUCON) Document
- TRUPACT-II Chemical Lists
- Waste Analysis Plan (WAP) of the WIPP No-Migration Variance Petition (NMVP)
- TRU Mixed Waste Characterization Database
- Nonradionuclide Inventory Database
- Documentation of Sampling Programs at the Sites

The information presented in some of these documents is discussed below, with particular reference to controls over potential flammability concerns.

### 3.7.1 TRUPACT-II Safety Analysis Report (TRUPACT-II SAR)

The TRUPACT-II SAR has been discussed in detail in Section 3.3.

### 3.7.2 TRUPACT-II Content Codes (TRUCON) Document

The TRUCON document is a compilation and classification of all CH-TRU waste in the DOE system that is eligible for transport in a TRUPACT-II package. TRUCON converts existing waste form numbers, content codes, and any other site-specific identification codes into a system (known as Content Codes) that is uniform for all of the DOE sites. Each content code provides characterization of the CH-TRU waste material in terms of transportation parameters like generation sources, waste description, processing and packaging history, assay method, descriptions of verification methods used to ensure the exclusion of prohibited items (i.e., corrosives, non-radioactive pyrophorics, explosives/compressed gases), decay heat limits for each payload content code, and correlation to any internal content codes used for the waste. The compilation of this waste characterization information in the TRUCON document effectively unifies the entire TRU waste system under a standard parametric description.

### 3.7.3 Waste Analysis Plan of the No-Migration Variance Petition (NMVP)

The NMVP was submitted to the EPA to address compliance with 40 CFR Part 268. The Waste Analysis Plan is Appendix B to the NMVP. It includes the most comprehensive waste characterization information available for CH-TRU waste and CH-TRU mixed waste generated

and/or stored at the ten major DOE sites. In addition to waste characterization information provided specifically for the NMVP, the Waste Analysis Plan compiles all other available information for the waste as Attachments. For example, the TRUCON document, TRUPACT-II Chemical Lists, the RCRA database, and available documentation of sampling programs at the sites, are Attachments to the Waste Analysis Plan.

Table 2-1 of the Waste Analysis Plan is a summary of the specific waste characterization for the CH-TRU wastes to be emplaced at the WIPP site. For each TRUPACT-II shipping content code, the table lists the corresponding site-specific identification codes, processes which generate the waste, waste descriptions, hazardous chemicals (if applicable) with semi-quantitative concentrations, and total waste quantities for each content code (storage and projected generation until the year 2013).

### 3.7.4 Sampling Programs

A summary of previous and ongoing sampling programs at the DOE sites is presented in Appendix 1.3.9 of the TRUPACT-II SAR. These programs include a comprehensive study done at the Idaho National Engineering Laboratory (INEL) (Clements and Kudera, 1985), and the Stored Waste Examination Pilot Plant (SWEPP) Sampling program in place at INEL to verify RTR as a compliance technique for the WIPP-WAC. These sampling programs provide real-time data regarding the chemical and physical properties of the stored waste at INEL. The primary conclusion that can be reached from these studies is that TRU waste that can qualify for transportation to WIPP and subsequent storage, has been handled, stored, and transported in a relatively safe manner at these sites over the years.

### 3.7.5 Summary of Waste Characterization and Process Knowledge

Process knowledge is a valuable tool in evaluating safety concerns associated with the handling, transportation, and storage of TRU waste. The best available process knowledge for TRU waste has been compiled and summarized in a number of documents. Process knowledge serves as a source to characterize the waste, and provide information on necessary parameters. For example, process knowledge is used to access the physical form of the waste, the chemical properties of the waste, chemical compatibility between the waste materials, the packaging configuration of the waste, and the absence of prohibited items from the waste. Since most of the DOE facilities act as production facilities for weapons, the waste generation processes (with respect to the composition of the waste) have essentially remained constant, and provide the basis for process knowledge. This information is supported by the sampling programs at the sites. As outlined in Section 3.6, other waste characterization techniques used in the TRU waste system (in addition to process knowledge and sampling programs) include:

- Procurement and Administrative Controls
- NDA/NDE techniques
- Visual Examinations and Secondary Inspections
- Records and Database Information

A detailed discussion of these techniques is beyond the scope of this report.

## 3.8 SUMMARY OF GOVERNING REGULATIONS

Safety is a prime concern in all stages of TRU waste transportation, handling, and eventual storage at the WIPP site (for test phase, as well as long-term disposal conditions). A number of regulations and requirements address these safety concerns, including those relating to flammability issues. This section provides a discussion of these regulations, and resulting controls over waste generation practices, transportation, waste characterization, and test phase requirements. Regulations that address the specific concerns of flammability outlined in Section 1.3 are listed below:

1. Presence or generation of potentially flammable gases in the waste

    - TRUPACT-II SAR
    - No-Migration Determination Requirements
    - Test Phase Controls

2. Presence or occurrence of potentially flammable VOCs in the waste

    - TRUPACT-II SAR
    - No-Migration Determination Requirements
    - Site-specific Procedures limiting the use of these compounds to trace amounts

3. Presence or occurrence of potentially explosive or pyrophoric materials in the waste

    - Operations and Safety Requirements
    - TRUPACT-II SAR Requirements
    - Site-specific Procedures

4. Presence or occurrence of potential chemical incompatibilities in the waste

    - Operations and Safety Requirements
    - TRUPACT-II SAR Requirements
    - No-Migration Determination Requirements

5. Presence or occurrence of free liquids in the waste

    - Operation and Safety Requirements
    - TRUPACT-II SAR Requirements
    - No-Migration Determination Requirements
    - Site-specific Procedures

# 4.0 HISTORY AND ANALYSIS OF UNUSUAL OCCURRENCES AT THE SITES

The purpose of this section is to evaluate past unusual occurrences at the DOE sites, based on available information from the sites. A discussion of the causes and events leading to these occurrences is presented in this section. These occurrences are also discussed with reference to the existing regulations applicable to the transportation and disposal of TRU waste at the WIPP site. Based upon descriptions of the incidents, the past events have been evaluated with respect to their relevance to the TRU waste to be shipped to WIPP. Wherever possible, the evaluations also provide a discussion of how the existing regulations would address these causes and prevent the occurrence of similar incidents for TRU waste to be shipped to the WIPP. It is important to note that the discussion of an incident in this section does not imply its relevance to TRU waste destined for WIPP. In fact, as noted under each incident, many of the incidents had no relevance to TRU waste, or conditions under which TRU waste will be transported and emplaced at WIPP. These incidents have, however, been included in this section for completeness.

Two approaches have been used to obtain descriptions of past unusual occurrences at the various waste generator and storage sites. The sites were contacted directly and requested to provide information about any unusual incidents relating to explosions, ignitions, or overpressurizations of waste drums and boxes. Information was provided by Argonne National Laboratory-East (ANL-E), Lawrence Livermore National Laboratory (LLNL), EG&G Rocky Flats Plant, and Los Alamos National Laboratory (LANL). Oak Ridge National Laboratory (ORNL) had no input, while no response was obtained from any of the other sites (Hunt, 1991). The second approach involved a search of a DOE database that keeps a record of all unusual occurrences at the sites since 1981. The incidents reported directly by the sites have been analyzed in detail in Sections 4.1 to 4.10. Wherever applicable, the original descriptions provided in the site reports have been retained in the analysis presented in this section. Also, if a report number was available, it has been listed along with the title of the report. A description of the database itself, together with incidents obtained from the databases and their analysis, are presented later in Section 4.11.

## 4.1 FAILURE OF 55-GALLON DRUM AT ARGONNE NATIONAL LABORATORY-EAST OCCURRENCE DATE - 12/02/76 Or 12/03/76

### 4.1.1 Description of the Event

As standard procedure for routine pickup, a 55-gallon drum of solid radioactive waste (SRW), also referred to as dry active waste (DAW), was located in a truck parked outside a building at ANL-E. The truck also contained eight other 55-gallon drums, and many fiber cartons of waste.

After an overnight off-shift period, at approximately 7:30 a.m. on December 3, 1976, an employee reporting for work discovered that the truck was slightly damaged. Upon closer examination, it was observed that the cover of the drum in question had been blown off through the aluminum roof of the truck, and had eventually come to rest on top of the truck. Approximately half of the original contents remained in the drum, with some of it hanging over the sides of the drum. Some expelled materials had adhered to the underside of the roof of the truck, while others were in the form of debris scattered within the truck.

### 4.1.2 Immediate Follow-Up Actions

Radiation surveys of the truck and premises were conducted using both dry smear and direct surveys, and revealed no contamination. The vehicle was then moved to the adjacent high-bay area dock, where the unaffected contents were removed and placed in SRW bins. Radiation surveys of the nearly empty truck and the unloading personnel, as well as direct surveys of the ruptured drum and its contents, also revealed no contamination. The half-filled drum and its expelled contents were transported for further investigation to a hot cell facility, for the remote handling of contents still inside the drum. The material which had adhered to the underside of the truck roof was put in an envelope, and the rest of the expelled contents were packaged in two fiber drums.

### 4.1.3 Examination of the Contents of the Ruptured Drum

The waste remaining in the drum, and the waste which had been expelled from the drum, consisted of similar materials. These included cardboard, shredded plastic bags, broken glass, glovebox components, bagged-out plastic pouches, hot plates, rubber hose, rubber gloves, and tissues. No alpha activity was detected. However, beta-gamma activity was detected in the plastic pouches that had been bagged out of the glovebox. Also, a strong odor of organic materials was detected in the first fiber drum to be inspected. Presumably, the source of this odor was an unbreached plastic pouch that contained xylene and petroleum ether, and provided a limited barrier to relatively free diffusion. The three pouches recovered from the drum and from the interior of the truck, were transported to a glovebox for further examination. These were suspected to contain alpha activity, and of being the possible source of flammable solvent vapor.

There was no evidence of smoke, char, explosive residues, or odors of explosives. The only signs of potentially high temperatures was a small area of blistered paint on the interior of the drum cover, and thermal effects on pieces of polyethylene. When a piece of damaged polyethylene was examined using a polarized microscope, it appeared to have melted. A tiny piece of glass (small enough to be removed by tweezers) was found adhering to the melted plastic. Also, a flocculent white material, which was noncrystalline in appearance, was extracted from the plastic and examined separately by trying to dissolve it in water. The substance was insoluble in water, indicating that it was unlikely to be a readily soluble inorganic salt. Other particles, such as dirt and iron oxide, were also visible.

Other materials found in the drum included an unlabeled white aerosol can without a spray nozzle, and an ultrasonic cleaner wrapped in polyethylene. The aerosol can appeared to be partially full, and by comparisons with a similar can found in the same laboratory complex, was hypothesized to contain Freon 12. Weight comparisons between the cans showed that 6.5 ounces of Freon 12 were missing from the unlabeled can. However, bubble tests of the inverted can did not reveal any leaks under the testing conditions.

### 4.1.4 Findings of the Committee of Inquiry

A committee was formed to investigate the incident. The committee investigation can be broadly classified into three areas:

- Pressurization of the drum
- Sources of flammable vapor
- Possible sources of ignition

**Pressurization of the Drum** - Close examination of the empty drum showed considerable and uniform bottom deformation, indicating a high pressure build-up over a very short time span. This caused the cover clamp to yield, and permitted the cover to be propelled through the aluminum roof of the truck. Measurements of the deformation of aluminum sphincter cans from the plastic pouches, characterized the incident as an explosion rather than a graduate overpressurization of the drum. However, the explosion was not attributed to an explosive device. Calculations, based on observations of the deformation of the lid and the bottom, indicated that the pressure source was located asymmetrically with respect to the drum cover.

Apparently, the presence of material in the drum below the ignition source, retarded the pressure wave sufficiently to produce the uniform bottom deformation. According to the committee report, this could have been caused by a solvent-vapor explosion.

The committee also estimated the internal pressure in the drum from evaporation of xylene, petroleum ether, and Freon 12. The estimates were about 55% of the drum design pressure, thereby indicating that there was no overpressurization solely due to solvent evaporation.

**Sources of Flammable Solvents** - The headspace of the drum was analyzed for organic vapors after the explosion from the open drum headspace, and this indicated the presence of two flammable solvents. The solvents identified were xylene and a petroleum ether fraction equivalent to n-pentane. The measured concentrations were 108 and 71 ppm by volume for xylene, and 120 and 79 ppm for the petroleum ether fraction. The committee agreed that since the source of the solvent had been removed for at least six hours prior to the measurements of the open drum headspace, it was safe to assume that much higher concentrations were originally present in the headspace before the explosion. The committee also agreed that the plastic pouch source did not offer much resistance to free diffusion. No other solvents were detected.

**Sources of Ignition** - Due to the lack of any signs of spontaneous heating, chemical reactions, or radiation effects, and also due to the lack of any contradictory evidence, the committee assumed that an electrical discharge within the sealed drum had initiated the explosion of n-pentane ether vapor inside it. The committee also listed several conditions existing between the time of drum closure and the discovery of drum failure, that could have enhanced the accumulation of static charges on plastic surfaces within the drum. These conditions are briefly described below:

- Low temperature and low relative humidity

- Extreme temperature variations resulting from moving the drum outdoors

- Solvent vapor evaporation/condensation due to temperature variations
- Friction between several square yards of polyethylene sheeting, and several square feet of polyvinyl chloride (PVC) sheeting contained in the drum
- Painted interior of the drum providing a dielectric barrier over most of the drum surface
- Low ambient temperature (-3°F) may have caused dimensional changes in drum and its contents, leading to shifting of packages and subsequent static charge accumulation
- Probable electrical discharge from the ultrasonic cleaner, which had two piezoelectric crystals as part of its circuitry.

### 4.1.5 Recommendations of the Committee of Inquiry

The committee recognized that this was the only authenticated instance of an explosion in a waste package until then, and conceded that the drum history and its contents were unique. In order to prevent the recurrence of such an incident, the committee recommended that flammable solvents and vapors must not be allowed to enter the waste stream. The committee also recommended the use of nonflammable solvents such as fluorinated hydrocarbons (e. g., Freon TF) as substitutes. When flammable solvents must be used, the committee recommended the use of safe evaporation techniques as a method of disposal.

Apart from flammable solvents, the committee also addressed personnel awareness, personnel training, and administrative policies regarding training activity.

### 4.1.6 Discussion of the Incident with Reference to Existing Regulations

At the onset it should be noted that there is no evidence to suggest that the drum involved in the incident contained TRU waste. Its contents were identified as dry active waste which normally refers (in the commercial power sector) to the dry fraction of low-level waste (LLW) (Thuot, 1991). As discussed below, governing regulations for WIPP waste effectively preclude the presence of a waste container with similar characteristics.

As mentioned in the committee report, it can be safely assumed that the concentrations of the n-pentane and xylene vapors at the time of the explosion were much higher than the low values measured in the open headspace of the drum after the explosion. In order to estimate the internal drum pressure from solvent evaporation, the committee assumed that before the explosion, both n-pentane and xylene vapors were present at concentrations equal to their upper explosive limits (roughly 10% by volume). Assuming this concentration of 10% by volume for each one of the two solvents, the total concentration of flammable solvent vapors in the drum was 200,000 ppm by volume. As discussed in Section 3.4.1, the No-Migration Determination and the TRUPACT-II SAR limit the total quantity of flammable volatile organic compounds (VOCs) in a drum headspace to only 500 ppm. Thus, the concentration of flammable solvents in the drum far exceeded (by three orders of magnitude) the limits imposed by the regulations applicable today.

For the WIPP test phase, the No-Migration Determination also requires that an explicit flame test be performed if a drum headspace contains greater than 500 ppm of flammable VOCs (see Figure 3-4). The drum in question would not qualify for shipment if it contained flammable gas mixtures (well over 500 ppm) in the headspace. Current waste generation and handling practices at the DOE sites preclude the disposal of large quantities of free, unstabilized, flammable VOCs. Adequate process knowledge (discussed in Section 3.7) exists for waste that qualifies for shipment to WIPP to support this conclusion. The TRUPACT-II Safety Analysis Report also stipulates that only content codes listed in the TRUCON document be shipped in the TRUPACT-II package. Specific waste characterization for these content codes is required and provided in the TRUCON document, including the installation of filters on waste containers to prevent the accumulation of pressure. In addition, waste containers with amounts of flammable VOCs in excess of 500 ppm in the headspace cannot be transported in the TRUPACT-II. Therefore, it appears that the drum in question at ANL-E would fail to qualify for transport or to meet the NMD requirements.

In summary, the regulations applicable today for transportation and subsequent storage and disposal of TRU waste have stringent compliance requirements, and involve margins of safety. These regulations provide a reasonable degree of assurance that such an event would not occur again.

## 4.2 BURIAL GROUND FIRE IN A DRUM (BARREL) OF WASTE FROM ROCKY FLATS OCCURRENCE DATE - 06/01/70

### 4.2.1 Description of the Event

During a routine evening patrol of a waste burial ground at Idaho Nuclear Corporation, a smoldering fire was discovered in the temporary above-ground storage area for waste from Rocky Flats. The drum on fire was in the top layer, but in the center of the plan area. Direct radiation monitoring and air sampling showed that the contamination spread was very low. Since all attempts to extinguish the fire in place failed, an equipment operator used a crane to lift the drum and isolate it from the remainder of the approximately 4500 drums in storage. The fire was extinguished by covering the drum in earth with the help of a bulldozer. No spread of contamination was detected.

### 4.2.2 Immediate Follow-Up Action

It was believed that the very hot sun shining on the black drums might have contributed to the ignition. So it was decided to cool the remainder of the drums with time-spaced fine water spray. Subsequently, a white paint was added to the water spray, and one application of the paint-mixed water spray eliminated any further need for external cooling.

### 4.2.3 Examination of Contents of the Burned Drum

After uncovering the drum from the earth and removing the lid, visual inspection revealed an extremely fine black powder which easily wafted in air. All other visible contents were extremely black. The lid had bulged during the fire, and had separated from the hold-down ring for approximately 1/4 to 1/3 of the outer periphery. The lid was taped back in its place, and the drum transported to a Hot Cell for further examination.

The material removed from the drum included broken glass, dirt, rocks, paper, plastic, glass jars, etc., of varied sizes and shapes. Most of the paper appeared to be ice cream cartons lined with plastic. The material in the top half of the drum was extremely moist, indicating that water had penetrated the lid during attempts to extinguish the fire. After removing the material in approximately the top half of the drum, a large solid object was found which felt like a piece of melted glass with somewhat sharp edges and projecting points. The debris surrounding this object were carefully removed, and the object was turned upside down for examination. Instantaneously it burst into flames. Although the flames were small (about 1 to 1.5 inches), the sparks were very white and bright. The object was turned over in its original position, and a Met-L-X extinguisher was used to extinguish the blaze. It was then packed in a 1-gallon tin container of Met-L-X, and removed from the Hot Cell. Samples were obtained from both sides of the object for analysis.

The remaining contents of the drum included numerous jars and bottles, some of which were still capped while others were broken. One of the jars was labeled $LiO_2$. Some metal shavings were also found, and were sampled for later analysis. The removed glass jars were separately packed in Met-L-X in individual tin containers for eventual analysis and disposal. The balance of the removed materials were placed in a new 55-gallon drum and sealed, while the old drum was covered with plastic and sealed with tuck tape. The drums, tin containers, and samples were transported back to the Burial Ground.

### 4.2.4 Findings of Idaho Nuclear Corporation

An analysis of all samples indicated the material to be mostly natural uranium with traces of beryllium, aluminum, copper, iron, magnesium, silicon, and manganese. This information matched well with the fact that the probable origin of the drum had been traced to an old natural uranium laboratory in Rocky Flats. Subsequently, numerous photographs which portrayed the sequence of emptying the drum, were taken to personnel at Rocky Flats for possible aid in identifying the cause of the fire. However, even though considerable effort has been expended at Rocky Flats to determine the cause of the fire, no conclusions have been drawn other than the spontaneous ignition of uranium.

### 4.2.5 Discussion with Reference to Existing Regulations

It appears from the report that the burned drum contained primarily uranium. The conclusions in the report attribute the cause of the fire to the spontaneous ignition of uranium. The description in the report of "extremely fine black powder", and also the "instantaneous" bursting into flames would indicate that the substance involved was very likely pyrophoric. The WIPP-WAC and the TRUPACT-II SAR restrict the presence of pyrophoric materials in the waste. Any radionuclide pyrophorics present in the waste are generally dispersed and passivated in the waste container. Waste generation practices and process knowledge are also well defined and controlled for the TRU waste to be shipped to WIPP. In fact, the TRUPACT-II SAR requires a sampling program to verify the transportation parameters for retrievably stored waste (waste generated prior to implementation of the WIPP-WAC), where the process knowledge and waste generation procedures are slightly less defined. A waste drum generated prior to 1970 (the drum in question, for example) would not be a part of the WIPP waste without adequate characterization. The buried waste at the sites is currently not part of the waste inventory that can be transported in the TRUPACT-II package. Therefore, given the existing regulations, a drum with similar contents, would not be a part of the TRU waste inventory or be allowed to be stored or disposed of at the WIPP.

## 4.3 DISTORTION OF STORAGE CONTAINERS AT HANFORD (Report #78-17) DISCOVERY DATE - 02/02/78

### 4.3.1 Description of the Event and Cause

On February 2, 1978, a technician observed an appearance change in a 55-gallon drum of TRU waste. Follow-up inspection by the management on February 8 confirmed the distortion, and also noted distortion in two other 55-gallon drums located on the third floor. All the drums were found to contain plutonium-contaminated waste; 220 grams of plutonium were contained in the first drum, 155 grams in the second drum, and 221 grams in the third drum. The possible cause was attributed to pressurization.

### 4.3.2 Corrective Actions

A meeting between representatives from Plutonium Operations, Research and Engineering, and Health, Safety, and Environment, determined that the potential hazard of unrelieved pressurization should be minimized by providing containment for any premature depressurization. The inspection frequency was increased to one inspection every day (compared to the earlier frequency of one inspection every month). The two most deformed drums were enclosed in a plastic bag fitted with a filter from a respirator mask. The third drum did not warrant similar action, because it was not sufficiently deformed at that time. However, the Plutonium Process Engineering Department was asked to develop a procedure for safe venting of all three drums.

### 4.3.3 Discussion with Reference to Existing Regulations

At the time of the incident, there were no requirements for waste drums to have filter vents. However, present-day regulations for transportation require carbon composite filter vents for all TRU waste containers, for continuous relief from overpressurization. Thus, under the present regulations, the TRU waste drums involved in this incident would not qualify for transportation to the WIPP.

The WIPP WAC and the TRUPACT-II requirements both impose a limit of 200 fissile gram equivalents of Pu-239 per 55-gallon drum. The report describing this incident does not mention the distribution of different isotopes of plutonium in the waste, and therefore it is not apparent if the quantities of plutonium in the drums exceeded the fissile gram equivalent limits imposed by the regulations applicable today. However, since Pu-239 does make up a significant portion of the plutonium inventory in typical weapons grade plutonium, it is quite likely that two of the three drums in question would have exceeded the limits applicable today. Besides, there is also a limit on the allowable decay heat per drum depending on the shipping category, as well as an upper limit of 40 watts for the TRUPACT-II package. As discussed in Section 3.0, decay heat and fissile limits for waste containers and the TRUPACT-II package eliminate the possibility of such high loaded drums being transported, unless they are tested for their gas generation potential. The quantities of plutonium reported in the three drums would most likely exceed these decay limits, especially if they were isotopes of Pu-238. As an example, based on Table 10.1 in Appendix 1.3.7 of the TRUPACT-II SAR (NuPac, 1989), 200 grams of Pu-238 in a drum would result in a decay heat value of approximately 114 watts, which would disqualify such a drum from shipment.

## 4.4 DISTORTION OF STORAGE CONTAINERS AT HANFORD (Report #78-87) DISCOVERY DATE - 08/17/78

### 4.4.1 Description of the Event and Cause

A tank farm operator observed appearance changes in two 55-gallon TRU waste drums located on waste storage pad. The drums were awaiting final stacking and recording prior to burial. One of the drums contained 60 grams of plutonium in 62 liters of solution, while the other contained 54 grams of plutonium in 70 liters of solution. The solutions were contained in Speedy dry packing material. The apparent cause for the changes in appearance was attributed to pressurization resulting from a chemical reaction between nitric acid and organics present in the drums.

### 4.4.2 Corrective Actions

The two drums were enclosed in plastic bags fitted with filter cartridges from respirator masks. Subsequently, they were vented by remotely punching a small hole in the side, while containment was being provided by the plastic bagging. A greenhouse fitted with a High Efficiency Particulate Air (HEPA) filtered exhaust system was also constructed over the drums. Sampling of the internal atmospheres of the two drums showed the presence of 18% and 42% $CO_2$, respectively, and relatively high concentrations of $N_2O$ and $NO_x$ (ranging from a combined total of approximately 17% and 45%, respectively, for the two drums). Apart from inert gases (argon and helium), other materials detected were nitrogen, oxygen, carbon monoxide, carbon dioxide, and low percentages (< 1%) of hydrogen. Unidentified organic compounds having the general formula $C_xH_yO_z$ were also present at concentrations of approximately 4% and 6%, respectively, in the two drums. The sampling confirmed what would be expected from a reaction between nitric acid and organics. It was decided that the contents of the two drums will be repackaged into drums with vent clips to prevent any future internal pressure build-up, and then the repackaged drums will be placed in retrievable storage.

### 4.4.3 Discussion with Reference to Existing Regulations

Any drum of TRU waste similar to the two drums involved in this incident would not qualify for transportation to the WIPP for two primary reasons. As mentioned earlier in the discussion of a similar incident at Hanford, the WIPP-WAC and TRUPACT-II limits require all drums to be fitted with carbon composite filter vents. The two drums would fail to satisfy this requirement, and therefore prevented from transportation to the WIPP. Acid solutions and other corrosives are prohibited from being a part of the TRUPACT-II payload unless neutralized and rendered non-corrosive. Also, both the drums contained more than 60 liters of solution (62 and 70 liters, respectively). The TRUPACT-II limits free liquids in a drum to less than 1% by volume. Based on a minimum of 60 liters of solution present in these 55-gallon drums, the free liquid concentration of approximately 29% by volume far exceeds the restrictions on free liquids imposed by the TRUPACT-II limits. In addition, buried waste does not qualify for transportation in the TRUPACT-II without adequate characterization or reprocessing. Therefore, given the regulations applicable today, these drums would fail to qualify for transportation to the WIPP.

## 4.5 PRESSURIZATION OF STORAGE CONTAINERS AT HANFORD (Report #75-122) DISCOVERY DATE - 10/21/75

### 4.5.1 Description of the Event and Cause

Routine monthly inspection of 303 storage containers of polystyrene cubes in early October, 1975, indicated possible pressurization, as evidenced by slight bulging. The inspection frequency was increased from monthly to weekly, and on October 21, definite bulging was detected in two cans. The cans were removed from storage for detailed examination, and there was a definite pressure release upon opening both of the containers. Another inspection of all the 303 containers in storage the following day, revealed definite bulging in 117 containers.

### 4.5.2 Corrective Actions

An action plan was developed to release the pressure in each one of the bulging containers by proper venting procedures. Each metal container of polystyrene cubes was punctured by a non-sparking tool, the vent was covered with a filter, and then the containers were returned to storage. Subsequently, the remainder of the 303 storage containers were also vented and installed with filters using the same procedures. Daily inspection of the storage rooms revealed no additional bulging containers, and therefore the inspection frequency was returned to the normal schedule on November 6.

### 4.5.3 Discussion with Reference to Existing Regulations

As explained earlier under discussion of similar incidents, the present day regulations make it mandatory for all waste containers to be fitted with carbon composite filter vents in order to prevent pressurization. In addition, only specific payload containers (drums and Standard Waste Boxes) are allowed for transportation in the TRUPACT-II package. Thus, the bulging containers reported in this incident would not have qualified for transportation to the WIPP under present regulations.

## 4.6 RUPTURE OF CHEMICAL STORAGE DRUM AT LAWRENCE LIVERMORE NATIONAL LABORATORY (Report # LLNL84-14-TWC612-84) OCCURRENCE DATE - 10/25/84

### 4.6.1 Description of the Event and Cause

The incident occurred in a chemical and storage handling area of Building 612 at LLNL. An employee reporting for work on the morning of October 25, 1984, observed a trail of liquid extending towards the west main gate of the facility. The employee followed this trail, and noticed a second liquid path which extended towards the southeast corner of Building 612. Further observation led him to a large wet area, about 15 feet in diameter, under and adjacent to an empty damaged pallet. An in-situ pH of the liquid was obtained, and the liquid was determined to be an acid. A search of the immediate vicinity led to the discovery of the bottom of a chemical drum. The search area was expanded, and an empty chemical drum with a belled top and without a bottom, was found outside the perimeter fence of the facility. The drum was marked "acid plating solutions". Subsequent measurements placed the drum about 60 feet to the south and its bottom about 50 feet to the east of the probable site of origin.

The Group Chemist later identified the drum as the one that he had used to accumulate small amounts of plating wastes. On October 22, when the chemist had noticed that the drum was full, he had tightened the closure bungs and moved the palletized drum to a staging area for transfer to drum storage.

The cause of the incident was attributed to pressurization resulting from chemical reaction. When the drum was being moved to the staging area, its chemical contents were agitated, thereby initiating a reaction with slow kinetics. The progressive increase in the temperature of the solution, exponentially accelerated the reaction producing gas rapidly, and pressurizing the sealed drum. The polyethylene liner acted as a bladder and expanded. This in turn pressurized the supportive steel drum shell at either end, until the distortion was severe enough to cause failure of the bottom seam. Once there was no bottom support, the polyethylene liner violently ruptured, and the contents escaped with enough force to propel the drum about 60 feet through the air.

### 4.6.2 Corrective Actions

The chemical solution dispersed on the asphalt surface of the yard was neutralized, absorbed, and packaged. The combining of plating waste within drums was discontinued. An analysis of the gas produced in the reaction identified it as oxygen. According to the report, this suggested that the reaction may have involved the decomposition of a peroxide. Tracing the contents of the drum to the probable initial waste generator indicated that one of the plating solutions used in the past did include hydrogen peroxide as one of its components.

### 4.6.3 Discussion with Reference to Existing Regulations

It should be noted that since there is no mention in the report of any radiation surveys after the discovery of the incident, it would appear that the waste drum in question did not involve radioactive waste. This inference is further strengthened by the fact that throughout the report, the drum is referred to as a "chemical drum" and belonged to the Toxic Waste Control (TWC) Group. The drum also appears to have contained high quantities of free liquids (acid plating solutions), prohibited under current regulations for TRU waste. Corrosive materials like acid solutions are also prohibited in the TRU waste to be shipped to WIPP.

The TRUPACT-II also imposes restrictions regarding the chemical compatibility of wastes within a container, between wastes in different containers in a TRUPACT-II, and between the waste and the TRUPACT-II package itself. The description provided in the report about the violent reaction within the drum, gives the impression that the materials in the drum were chemically incompatible. In summary, the drum reported in this incident would fail to comply with existing regulations, based on restrictions on the free liquid content and the chemical compatibility of the contents. The properties of the waste in this incident are not applicable to TRU waste to be shipped to WIPP.

## 4.7 FIRE IN BAGS OF DRY WASTE STORED IN THE TOXIC WASTE HOLDUP AREA AT LLNL, (Report # LLNL 83-2 B161-83-1) OCCURRENCE DATE - 06/30/83

### 4.7.1 Description of the Event and Cause

The refuse in waste bags piled in the toxic waste holdup area caught on fire. The Fire Department responded promptly to a report by a maintenance machinist, arrived at the scene within two minutes, and extinguished the fire with about 200 gallons of water. After the fire was extinguished, the remaining wastes were repackaged in plastic bags and disposed in metal drums. The area was brought back to normal working conditions within 3 hours after the onset of the fire.

According to the report, the precise cause of the fire was not determined. The probable cause was attributed to the ignition of dry wastes (primarily paper towels and rags) soaked in flammable liquids (acetone, ethanol, and laser dyes). The source of ignition was probably pyrophoric materials (cerium, neodymium, or uranium) that might have been disposed in the bags. Also, the ignition might have been influenced by continuous exposure to the hot summer sun for approximately three hours prior to the fire.

### 4.7.2 Corrective Actions

The waste drums are normally transferred into appropriate metal drums when transported to the waste holdup area. In this incident, empty metal drums had not been delivered on time, and therefore the waste was piled up in the area in the bags waiting to be placed in drums. In view of this procedural error, it was decided that waste bags will not be collected unless empty metal drums are available at the waste holdup area. A decision was also made to have an inventory sheet listing the types and quantities of toxic and flammable materials stored in the holdup area, to help the Fire Department determine a proper course of action in case of a fire in the future.

### 4.7.3 Discussion with Reference to Existing Regulations

As mentioned in the report, "the dry waste fire was probably the result of having pyrophoric metals seeded in the flammable waste." There are two restrictions that would prevent such an incident from occurring in a TRU waste drum. The WIPP-WAC and the TRUPACT-II SAR requirements do not allow pyrophorics to be packaged in a waste drum, unless they are stabilized or processed to render them non-pyrophoric. Radioactive pyrophorics are limited by fissile and decay heat limits, and are generally dispersed in the waste. In addition, the existing regulations on chemical incompatibility would prevent the packaging of pyrophorics and flammable materials in the same drum. Therefore, the properties of the waste in this incident are not representative of TRU waste to be shipped to WIPP. The limits on flammable VOCs such as acetone and ethanol (total of 500 ppm, which is well below the flammability limits of these compounds) preclude the presence of these VOCs in concentrations that could be flammable.

## 4.8 SMALL FIRE IN A WASTE CONTAINER AT LLNL, (Report # LLNL 89-6-B-241) OCCURRENCE DATE - 04/11/89

### 4.8.1 Description of the Event and Cause

A fire started in waste container shortly after a tissue paper wet with perspiration was discarded into the container. The addition of Lith-X to the open waste can did not completely extinguish the fire, so the can was dragged to a hood where more Lith-X was added and the hood exhaust fan was turned on. Shortly thereafter, the fire department arrived at the building and extinguished the fire. After the fire was extinguished, the container was enclosed in plastic and inerted with a flow of nitrogen. The surrounding areas were surveyed for radioactivity, but none was detected. However, fractions of micrograms of beryllium were detected from the analysis of smears taken of the area. The area was secured until it could be decontaminated.

The waste container was known to contain machine powders (a mixture of 50 mole% LiH and 50 mole% $BeH_2$). Presumably, this powder had reacted with moisture in the discarded paper tissue.

### 4.8.2 Corrective Actions

Large amounts of waste powders are no longer stored in standing waste containers. Special lids have been obtained for waste containers.

### 4.8.3 Discussion with Reference to Existing Regulations

It can be inferred from the report that this incident was the result of an operational error in discarding a moist tissue into the waste container containing machine powder. The reaction of the powder with the moisture from the tissue, shows that the two materials were chemically incompatible. In addition, as discussed in Section 3.2.5, powders and similar particulate waste materials are required to be immobilized under certain conditions according to the WIPP-WAC. It is not clear from the report whether any TRU waste was involved in the incident. The existing regulations would prevent such an incident occurring in a TRU waste drum, due to the restrictions on transporting chemically incompatible materials, and the requirements of characterizing the chemicals present within each waste type.

## 4.9 CHEMICAL REACTION DURING BULKING OF CONTAINERS AT LLNL (Report #LLNL 88-7-614) OCCURRENCE DATE - 04/26/88

### 4.9.1 Description of the Event and Cause

While bulking containers of acid in the Chemical Bulking Area in Building 614, a chemical reaction occurred with the release of a cloud of material. The cloud of material traveled to adjoining facilities, causing evacuation of facilities and subsequent medical evaluation. The cause was attributed to a chemical reaction due to mixing of acids from different containers.

### 4.9.2 Corrective Actions

The incident prompted a review of all types of bulking operations at the laboratory. This included a review of the chemical compatibility of acids to be bulked, review of the thermodynamic properties of the acids to be bulked, study of techniques for monitoring the temperature rise in a drum during acid bulking, recommendation of dilution procedures while working with acids, and documentation of other operational safety procedures.

### 4.9.3 Discussion with Reference to Existing Regulations

Since there were no radiation surveys done after the incident, this would indicate that the drums involved did not contain any radioactive waste. It is quite clear from the description of the incident, that the drums contained acids (corrosives and free liquids), and also were mixed without any attention to their chemical compatibility. As explained previously in Section 3.0, controls apply to TRU waste drums in order to restrict their free liquid content and the presence of corrosives, and also to eliminate chemical incompatibilities among different types of waste. The properties of the waste in this incident are not applicable to TRU waste to be shipped to WIPP.

## 4.10 RELEASE OF PLUTONIUM-238 (Pu-238) FROM A 55-GALLON DRUM AT LOS ALAMOS NATIONAL LABORATORY OCCURRENCE DATE - 09/19/84

### 4.10.1 Description of the Event and Cause

A modified 55-gallon drum, containing solid waste contaminated with Pu-238, had been tumbled in a drum tumbler for four hours. Subsequently, the drum was placed in a transfer van and transported to a building used for intermediate storage of retrievable transuranic solid waste. When a plug was removed from the top of the drum in order to install a valve and a pressure gauge, this resulted in the localized release of Pu-238 from the drum. The release was not detected until the driver of the transfer van left the site a few minutes later. The transfer van, the storage building, and two employees were contaminated as a result of the release, but personnel exposures appeared very low and probably under detection levels based on nose swipe test results.

Although no cause behind the incident was listed, it would seem from the description that overpressurization was a probable cause.

### 4.10.2 Corrective Actions

Initial personnel decontamination followed, and containment actions were taken and completed on the same day. Further evaluations and cleanup planning followed for the next couple of days, followed by the start of van and building cleanup work. The contaminated 55-gallon drum was bagged, and moved to an adjacent building for repackaging and final disposition.

### 4.10.3 Discussion with Reference to Existing Regulations

It can be inferred from the description of the incident that the drum in question most likely did not have a filtered vent for continuous pressure relief. As mentioned earlier under discussions of other instances of drum overpressurization, TRU waste drums to be transported to WIPP are required to be vented through a carbon composite filter in order to provide continuous pressure relief. Thus, under the existing regulations the drum involved in the incident would have failed to meet the requirements for transportation to WIPP. In addition, the decay heat limits applied for transportation purposes limit the amount of Pu-238 waste that can be shipped to WIPP in a waste container. For example, the decay heat limit for a drum containing solid inorganic waste in two layers of plastic packaging (Shipping Category II.1A2) is 0.0869 watt, which translates to approximately 0.159 gram of Pu-238. Therefore, containers with high loadings of Pu-238, capable of generating gases, cannot be transported in the TRUPACT-II package unless tested for their gas generation potential.

## 4.11 SUMMARY OF OTHER UNUSUAL OCCURRENCES

The DOE maintains a database known as the Safety Performance Measurement System (SPMS), which is a DOE-wide Environmental, Safety and Health (ES&H) information management system (DOE, 1990a). As subsets of the SPMS, there are two databases that contain information about unusual occurrences at waste generator and storage sites since 1981. These databases are the Computerized Accident/Incident Reporting System (CAIRS), and the Unusual Occurrence Reports System (UORS). A search of these databases was conducted using relevant keywords such as "fire", "container", "drum", "burn", "explosion", etc. (Eicher, 1991), in order to obtain a list of past occurrences that may be linked to the flammability of the waste. The diverse meaning of the keywords used in the search produced a list of the subject matter of a wide variety of cases, a majority of which are irrelevant to the topic of discussion in this paper. As an example, since the word "burn" was used in the search, a case entitled "Hot grease burned thumb while cleaning kitchen grille," was listed in the search output.

After scanning the titles of the cases in the search output, full unusual occurrence reports were obtained only for those cases where flammability or overpressurization could have been a probable cause. The Unusual Occurrence Report (UOR) for each of these cases was carefully studied to determine its relevance to the flammability concerns of TRU waste to be emplaced at WIPP. A number of these cases were found not to involve TRU waste, and were unrelated to the issue of flammability. All of these incidents are summarized below in the form of the subject matter, a description of the incident, the cause of the incident, the corrective action taken by the site personnel, and finally, a brief statement about the applicability of existing regulations to the incidents which were determined to be relevant to the issue of flammability. It should be emphasized that a discussion of these incidents does not reflect either applicability or a concern regarding TRU waste disposal at WIPP.

**Westinghouse Idaho Nuclear Co., Report No. 84733; File No. 1854**
**Occurrence Date 04/20/84**

Subject - Fire In A Radioactive Waste Container

Description and Cause - A heavy paper towel was used to absorb 15 ml of undiluted fuming nitric acid which had been spilled in the hood of a laboratory. A technician discarded the towel in a compactible radioactive waste container. The fire apparently resulted from the spontaneous combustion of the towel.

Corrective Action - The need for respirators was evaluated. Instructions were issued detailing proper cleanup for acids and spills. Spill kits were ordered for the laboratories.

Applicable Existing Regulation - The properties of the waste in this incident are not applicable to TRU waste. Restrictions on chemical incompatibilities, corrosives, pyrophorics, and free liquids, will prevent such an incident in a TRU waste drum.

**Los Alamos National Laboratory; Report No. 89819; File No. 4809**
**Occurrence Date 10/26/89**

Subject - Depleted Uranium Fire In a 30-Gallon Drum

Description and Cause - Personnel involved in the process of combining depleted uranium scrap for disposal opened a 30-gallon steel drum which contained 69 kg of depleted uranium and it started to burn. The lid was immediately placed back on the drum smothering the fire. Nose swipes of personnel involved showed no detectable contamination.

Uranium turnings require a protective liquid layer when stored or shipped from one location to another to prevent spontaneous combustion. In this shipment no liquid protective layer was used.

Corrective Action - Training needs for personnel were identified, and closer adherence to standard operating conditions were recommended. On-site procedures were modified to comply with the requirements of DOT Title 49, Part 173.418 which require pyrophoric materials to be placed in an inert atmosphere or in a matrix that precludes spontaneous combustion. It was also decided that future movements of uranium chips and turnings shall be made in diesel oil, rather than in water.

Applicable Existing Regulation - The quantities and constituents of the waste in this incident (69 kg of depleted uranium in a 30-gallon drum) are not representative of TRU waste. Restrictions on pyrophorics, and waste characterization based on RTR, will prevent such an incident in a TRU waste drum.

**EG&G Idaho, Inc.; Report No. 900216; File No. 5727**
**Occurrence Date 10/19/90**

Subject - Release to Environment

Description and Cause - Monthly environmental sampling of the sewer water effluent detected silver concentrations of greater than the 0.5 ppm limit as imposed by the city of Idaho Falls. The cause of the event has not been determined due to long turn-around times required with the laboratory sample process. The source of Ag not yet known and sampling is being performed on all Ag producing equipment located in the building.

Corrective Action - This is a relatively recent occurrence, and long-term corrective actions are being developed.

Applicable Existing Regulation - The incident is not relevant to TRU waste or to the issue of flammability.

**EG&G Idaho, Inc.; Report No. 89734; File No. 4352**
**Occurrence Date 07/20/89**

Subject - Multiple Occurrences of Contamination Events

Description and Cause - Low-level particles were found outside contamination control areas because of increased surveillance and monitoring sensitivity. The particles were generally less than 2000 cpm as measured with a pancake probe.

The cause was attributed to less than adequate sensitivity of earlier monitoring equipment. The contamination detection capability of the primary personnel contamination monitoring equipment was inadequate to detect low-level contamination. This resulted in low incidence of detection and lulled management and personnel into a false sense of security.

Corrective Action - A task force was organized to evaluate events and recommend appropriate corrective action. Highly sensitive Eberline PCM-1B Personnel Contamination Monitors were purchased and installed in key places.

Applicable Existing Regulation - The incident is not relevant to TRU waste or to the issue of flammability.

**EG&G Idaho, Inc.; Report No. 85733; File No. 1659**
**Occurrence Date 07/09/85**

Subject - Unexpected Contamination of Personnel

Description and Cause - During sampling of the Containment Vessel (CV) test chamber using a sample system within the Air Particulate Detector (APD) Glove Box, a sample hose leaked, slightly pressurizing the glove box. The resulting airborne activity contaminated two persons. The cause was loose tubing and inadequate ventilation.

Corrective Action - Repairs were performed on components within the glove box, and the vent/exhaust system was certified to be adequate. A leaking stainless steel flex hose inside the ADP box was replaced.

Applicable Existing Regulation - The incident is not relevant to the issue of flammability.

**Los Alamos National Laboratory; Report No. 87733; File No. 910**
**Occurrence Date 08/01/87**

Subject - Crates Containing TRU Wastes Partially Collapsed

Description and Cause - Three very large fiberglass reinforced polyester coated wooden crates containing TRU wastes stored on a pad collapsed. Only trace contamination observed. The cause was to due to considerable void space and inadequacy to hold the weight of overburden (6 ft). The packages were also subjected to side loadings.

Corrective Action - Damaged boxes and the wastes were being retrieved and reprocessed. It was decided that items which are not processed will be repackaged and stored.

Applicable Existing Regulation - The incident is not relevant to the issue of flammability. However, it is mentioned in the report that the current WIPP disposal requirements assure that future wastes will not be packaged and stored in the above manner. Waste containers to be shipped to WIPP are required to meet DOT, Type A container specifications (DOT, 1989d).

**Brookhaven National Laboratory; Report No. 89712; File No. 5465**
**Occurrence Date 06/29/89**

Subject - Release of Vehicle With Radiation Levels Above DOT Limits

Description and Cause - Five flatbed vehicles with a total of ten packages of non-TRU LLW destined for Westinghouse Hanford Company (WHC) burial were surveyed for contamination and radiation. Two vehicles were found to have 8 mrem/hr in the sleepers which exceeded the DOT limit (2 mrem/hr), with one of them also exceeding DOT limits at 2 m from the side of the vehicle (15 mrem/hr, limit 10 mrem/hr).

The cause was attributed to inadequate protocols for surveying, which failed to include specific instructions to survey all normally occupied positions of the transport vehicle.

Corrective Action - Procedures were revised to include specific radiation surveys of all vehicle positions that may be occupied.

Applicable Existing Regulation - The incident is not relevant to the issue of flammability.

**EG&G Idaho, Inc.; Report No. 85706; File No. 1632**
**Occurrence Date 02/21/85**

Subject - Waste Improperly Disposed In A LLW Soil Vault

Description and Cause - Violation of storage/disposal procedure occurred when a TRU waste container was incorrectly placed in a low-level waste soil vault instead of an Intermediate Level Transuranic Storage Facility (ILTSF). Criticality limits were not exceeded, and no hazards were presented to personnel nor the facility.

The cause was failure to follow and complete the receipt inspection checklist procedure. The required nanocurie/gram calculation section of the checklist had not been performed.

Corrective Action - The waste package was retrieved and properly stored. The procedure for sign-off was revised and the personnel involved were reprimanded.

Applicable Existing Regulation - The incident is not relevant to the issue of flammability.

**EG&G Idaho, Inc.; Report No. 87706; File No. 1711**
**Occurrence Date 06/04/87**

Subject - Improper Waste Drum Storage

Description and Cause - The Operational Safety Requirement (OSR) was violated when three TRU waste containers which had not been vented, were identified in the examination area and had been stored in the SWEPP. The SWEPP OSR prohibits the handling of unvented waste containers in the SWEPP storage or examination areas.

In evaluating the cause, detailed examination of dates resulted in change from 7/1/84 to 6/1/83 as the date after which all drums packaged at Rocky Flats Plant were equipped with semi-permeable gaskets. Therefore, the containers identified in this Unusual Occurrences Report were determined to be actually vented.

Corrective Action - The SWEPP OSR and Safety Analysis were revised to prohibit unvented waste containers from being stored or handled in the C&S building, or processed through the SWEPP examination area. All future transfers are verified by the Examination Supervisor.

Applicable Existing Regulation - The incident is not relevant to the issue of flammability.

**EG&G Idaho, Inc; Report No. 90701; File No. 4715**
**Discovery Date 01/09/90**

Subject - Storage of Transuranic Mixed Waste In A Non-Permitted Area

Description and Cause - Eleven DOT 17C containers (55-gallon drums) of TRU waste were stored in a non-permitted storage area for more than 90 days.

The delays encountered in meeting the scheduled shipping dates and exceeding the 90-day storage requirements were primarily caused by attempts to meet criteria that were unnecessarily restrictive since the conservative judgements were not balanced against the impacts they might cause.

Corrective Action - A closure plan was developed and transmitted to the EPA. A company wide "Lessons Learned" dissemination was completed.

Applicable Existing Regulation - The incident is not relevant to the issue of flammability.

**Westinghouse Materials Company of Ohio; Report No. 88702; File No. 2397**
**Occurrence Date 01/18/88**

Subject - Release of Uranyl Nitrate

Description and Cause - Approximately 100 pounds of uranyl nitrate flowed out of Sparge Tank to the floor sump during restart of the de-nitration boildown operation. The uranyl nitrate came out of the vent stack for the storage tank and less than 40 pounds was dispersed over the grounds.

The occurrence was caused by heating the uranyl nitrate in the tank too rapidly causing it to be released from the tank.

Corrective Action - The boildown operation was shut down by closing off the steam to the tanks. The area was roped off and cleaned. A training session was conducted and instruments were checked and calibrated.

Applicable Existing Regulation - The incident is not relevant to the issue of flammability.

**Oak Ridge National Laboratory; Report No. 84732; File No. 2548**
**Discovery Date 10/17/84**

Subject - Corrosion of Storage Drums

Description and Cause - Corrosion was noted on stainless steel and carbon steel 55-gallon drums containing packaged TRU waste. The surfaces of some drums were badly pitted and at least 4 drums had small holes (approximately 1/16-inch diameter) in the lids. No material was released and no drums required radioactive decontamination.

Condensate and/or rainwater leached the fire retarding chemicals from the plywood separators between drums. The resulting solutions probably contained chlorides or other agents corrosive to steel drums.

Corrective Action - 2100 drums were removed, inspected and cleaned. Drum lids with very deep pits and/or holes were replaced and patched using 20-mil stainless steel patches and metal bond. The fire retardant plywood separators were discarded.

Applicable Existing Regulation - The incident is not relevant to the issue of flammability.

**Oak Ridge National Laboratory; Report No. 86705; File No. 2583**
**Occurrence Date 01/15/86**

Subject - Contamination of Laboratory

Description and Cause - A highly radioactive sample containing curium was opened in an open port glovebox. Radioactive particles were released into the laboratory contaminating the area around the glove box and the individual involved.

The cause was the opening of an excessively concentrated and aged liquid sample of Cm-244 in the open port box in violation of written operating procedures. The release was believed to have occurred due to pressurization of the sample by radiolysis of the acidic solution.

Corrective Action - The laboratory was decontaminated. A whole body count was performed on the exposed technician who was provided with medical treatment. The recommendations of the ORNL Investigating Committee were incorporated into the procedures and quality assurance documentation.

Applicable Existing Regulation - The incident is not relevant to the issue of flammability.

**Oak Ridge National Laboratory; Report No. 86716; File No. 2592**
**Occurrence Date 10/16/86**

Subject - Contamination

Description and Cause - Alpha contamination was discovered in areas of the Waste Examination Assay Facility (WEAF).

The contamination was caused by failure of an employee to use a portable alpha probe. The procedures were inadequate to insure self checking. The bottom of a waste drum had been corroded by an internal agent causing leakage and contamination.

Corrective Action - The procedures were reviewed and modified to include personnel monitoring upon exiting the WEAF and for routine monitoring of RTR during normal operations. The facility was decontaminated and alpha and beta-gamma instruments were placed at the exits of the facility.

Applicable Existing Regulation - The incident is not relevant to the issue of flammability. However, under the existing payload control procedures for the TRUPACT-II, container integrity is a requirement for a drum to qualify for transportation to the WIPP. Therefore, the drum involved in the incident would be rejected from transportation due to container integrity failure. Besides, waste containers to be emplaced at WIPP should meet Type A specifications (DOT, 1989d), and are also measured for dose rates at the surface.

**Battelle Memorial Institute (PNL); Report No. 87706; File No. 4594**
**Occurrence Date 10/15/87**

Subject - Plutonium (Pu) Content of Waste Drum Exceeded Limit

Description and Cause - A package containing 254 grams of Pu was subdivided into 4 smaller packages. A quick-sort gamma counting indicated no package contained more than a 1/3 of the original material. One of the packages was placed with waste in drum already containing Pu. An NDA neutron measurement of the drum indicated 250 grams Pu, which exceeded the 230-gram Pu criticality safety mass limit.

Corrective Action - The procedures were revised to specify use of stronger transmission source for use in SGS assay.

Applicable Existing Regulation - Restrictions imposed by the TRUPACT-II SAR include a limit of 200 grams of Pu-239 fissile gram equivalent per drum. In addition, the amount of 200 grams is further limited by the 325-gram limit on the total TRUPACT-II payload of 14 drums, and the decay heat limits imposed on a drum.

**Westinghouse Hanford Co.; Report No. 84714; File No. 3113**
**Occurrence Date 02/27/84**

Subject - Transport of Burial Box With Unbolted Lid

Description and Cause - A burial box refurbished by a contractor was loaded with TRU waste and released for burial. When it was received at the burial grounds, it was noted that the lid was not properly secured. No release of contamination resulted from the shipment of the box.

The box was inadequately prepared for shipping because of overlapping responsibilities.

Corrective Action - The lid was secured on the box after development of a special procedure. The procedure and safety analysis report for packaging were updated and corrected to involve the Quality Assurance Department as an active party in burial box activities.

Applicable Existing Regulation - The incident is not relevant to the issue of flammability.

**Westinghouse Hanford Co.; Report No. 83708; File No. 3069**
**Occurrence Date 03/02/83**

Subject - Improper Control of Potentially Alpha Contaminated Equipment

Description and Cause - Two pieces of equipment (associated with TRU material) were being decontaminated when alpha contamination was discovered.

Routine surveys for beta-gamma contamination were performed but no alpha surveys were performed because no alpha presence was indicated on the Radioactive Shipment Record (RSR)

Corrective Action - The procedures were revised to ensure that equipment originating from or having history of being in an area where TRU material is present are appropriately surveyed and controlled.

Applicable Existing Regulation - The incident is not relevant to the issue of flammability.

**Westinghouse Hanford Co.; Report No. 86734; File No. 3305**
**Occurrence Date 04/11/86**

Subject - Failure of Computer Software Results In Burial of TRU Waste as Low-Level Waste

Description and Cause - A coding error in a software program resulted in low-level burial of 16 drums containing TRU waste. The empty drum weight was being added to the gross weight instead of being subtracted, thus the nanocuries/gram ratios were in error.

Corrective Action - New software was acquired, reviewed and verified. Other offices using the faulty software were notified. The drum locations were determined but are to be left in place.

Applicable Existing Regulation - The incident is not relevant to the issue of flammability.

**Westinghouse Hanford Co.; Report No. 89745; File No. 5035**
**Occurrence Date 08/24/89**

Subject - Free Liquids in TRU Waste Drums

Description and Cause - A drum was rejected at the TRU Storage and Assay Facility (TRUSAF) due to 590 mL of free liquid content. An additional 120 drums that were in storage were also rejected from TRUSAF due to free liquids.

The cause was attributed to personnel, who left free liquids in the original packaging due to carelessness and lack of knowledge.

Corrective Action - The controls were re-evaluated and revised to minimize improper packaging.

Applicable Existing Regulation - This is an example of site-specific restrictions being more stringent than regulations governing waste transportation and emplacement at WIPP.

**Westinghouse Hanford Co.; Report No. 89764; File No. 4810**
**Occurrence Date 12/20/89**

Subject - SARP Violation During Shipment of Mixed Waste Drums

Description and Cause - A violation of the Safety Analysis Report for Packaging (SARP) occurred by the installation of NUCFIL filters on TRU waste drums before the Engineering Change Notice (ECN) was completed.

Three causes were identified as contributing to the incident:

1) Lack of communication on the required revision to the SARP

2) The lack of availability of drum lids that meet the SARP requirements

3) No control placed on drums, or in the procedure to prevent shipment of the drums.

Corrective Action - It was decided that in the future, all SARP revisions will be sent in letter form to the Packaging Development personnel. A purchase request requirement form Clause will be placed on the Hanford Specification for Ordering DOT drums, which will require a configuration control number to be stenciled on the side and lid of the container.

Applicable Existing Regulation - The incident is not relevant to the issue of flammability.

**Westinghouse Hanford Co.; Report No. 82724; File No. 3584**
**Occurrence Date 09/14/82**

Subject - Inadvertently Disposed Radioactive Materials Shipping Casks

Description and Cause - The GE-8500 radioactive materials shipping casks containing TRU waste were disposed (buried) as low-level radioactive waste.

The drum in which the casks were transferred did not have the required tags and labels. When the drum was received at the Postirradiation Test Laboratory (PITL), the personnel were preoccupied with priority work and set the drum aside for later action. A Radioactive Shipment Record (RSR) was not provided to the PITL as required by procedures.

Corrective Action - The staff was admonished and reminded of the necessity to follow established procedures.

Applicable Existing Regulation - The incident is not relevant to the issue of flammability.

**Westinghouse Savannah River Co.; Report No. 89735; File No. 4696**
**Occurrence Date 11/13/89**

Subject - Fissile Material Movement Without NIM Coverage

Description and Cause - An operator moved three 5-gallon pails containing TRU waste while the Nuclear Incident Monitor (NIM) coverage for the area was out of service. The three pails contained a total of 3.66 grams of Pu-239.

The technical standard limit was violated due to personnel error. The pails were moved so that a plastic curtain could be hung along a wall.

Corrective Action - Operations were halted. The proper notifications were made. It was determined that the potential for nuclear criticality did not exist and activities were resumed. Appropriate disciplinary action was taken against the operator.

Applicable Existing Regulation - The incident is not relevant to the issue of flammability.

**Westinghouse Savannah River Co.; Report No. 89719; File No. 4357**
**Discovery Date 03/21/89**

Subject - Water Intrusion Into Transuranic Waste Drums

Description and Cause - Thirty-one 55-gallon drums of TRU waste were retrieved from interim storage in the burial ground. The drums were X-rayed and 26 of the containers were found to contain water ranging in volume from less than one gallon to a maximum of 14 gallons. Water was observed in both the drum and the 90-mil High Density Polyethylene liner.

The incident was caused by inadequate design and engineering evaluation of the carbon composite filter vent for the conditions under which the vent was to be used.

Corrective Action - Nylon-reinforced vinyl covers were installed over existing vented drums as a short-term measure to prevent further water intrusion. TRU pad sumps were monitored twice per week and after each rainfall to ensure no contamination. It was decided that upon resolution of regulatory issues, Waste Management shall be provided a detailed plan describing dewatering/processing of affected drums. Investigations of alternative filter design using a GoreTex cover over the filter media were also being performed.

Applicable Existing Regulation - The restrictions on free liquids imposed by the TRUPACT-II SAR requirements and the WIPP-WAC, along with RTR verification, will prevent such drums from being transported to the WIPP.

**Westinghouse Savannah River Co.; Report No. 89726; File No. 4435**
**Occurrence Date 07/27/89**

Subject - Pressurized Drum of 1,1,1-trichloroethane (TCE) Waste

Description and Cause - A drum containing nonradioactive TCE waste was being opened. When the drum's closure bolt was loosened and, upon attempting to remove the closure ring, both the drum and liner lids were propelled approximately 15 feet into the air due to pressurization.

The gas generation and subsequent pressurization were probably caused by a chemical reaction inside the drum. The waste appears to have reacted with the galvanized drum lid, possibly resulting in galvanic corrosion and the formation of a gas, possibly hydrogen.

Corrective Action - Drums were divided into one of three groups: 1) Drums with no lid deformation, 2) Drums with lid deformation less than 1 inch, and 3) Drums with lid deformation 1 inch or greater. It was decided that the drums in group two will be vented by puncturing with a nonsparking device. Drums in group three will be vented by gradually raising a 1000 pound pallet once the drums are unbolted, to provide protection against projectiles. The drums will be fitted with a vented lid.

Applicable Existing Regulation - The TRUPACT-II SAR requires all waste drums to be fitted with a filtered vent for continuous relief of pressure. This incident involved nonradioactive waste, which does not have similar venting requirements. In addition, the restrictions on free liquids and concentrations of VOCs such as TCE (specified in the NMD), restrict the amount of such compounds in TRU waste containers to trace levels.

**Westinghouse Savannah River Co.; Report No. 900234; File No. 5832**
**Occurrence Date 12/01/89**

Subject - Storage of Radioactive Waste Above Ground For Over Six Months

Description and Cause - Contaminated soil removed from the cleanup excavation near a tank was packaged and stored in the Savannah River Site Burial Ground. Due to the inability to have the samples pulled and analyzed (EP-toxicity tests) because of high radiation levels and due to the "lack of a task tracking system, the six-month time period allowed for temporary storage by the Technical Standard was exceeded.

Corrective Action - It was decided that in the future, contaminated soil will be disposed of as required either in an Engineered Low-Level Trench or in a Greater Confinement Disposal Facility. Upon completion of inventory, a Test Authorization will be issued covering the temporary storage (greater than six months) above ground of all waste awaiting permanent disposal. A basic oversight program was planned for a root cause analysis, and this was to be documented in the final Unusual Occurrences Report.

Applicable Existing Regulation - The incident is not relevant to the issue of flammability.

**Martin Marietta (Y-12); Report No. 85707; File No. 2679**
**Occurrence Date 11/07/85**

Subject - Uranium Scrap Fire

Description and Cause - A forklift was loading drums onto a salvage truck used to transport waste to the disposal site. A drum was being pushed forward to make room for more drums when a slat broke off the pallet allowing the fork to puncture the drum containing liquid coolant and saw fines. Liquid coolant started leaking from drum and a hissing noise ensued followed by steam spray coming from the top of the drum and the punctured area on the side of the drum. The intensity of the hissing and the spray increased which changed to a shower of sparks and flames. An explosion occurred and the lid was blown into the air and landed 60 feet from the salvage truck.

The saw fines were not separated from the other massive scrap.

Corrective Action - The fire was contained and the drum was disposed of. A procedure was developed for separating scrap and saw fines.

Applicable Existing Regulation - The properties of the waste in this incident are not applicable to TRU waste. Restrictions on pyrophorics, free liquids, particulates, and chemical incompatibility, will prevent such a drum from being shipped to the WIPP.

**Martin Marietta (Y-12); Report No. 85705; File No. 2677**
**Occurrence Date 07/20/85**

Subject - Fire Involving Thorium In A Scrapped Glove Box

Description and Cause - During sorting operations on the salvage yard a glove box which was being lifted by a forklift, fell from the forks, impacted with the ground, and ignited a one-gallon pail of thorium which was in the glove box.

The cause was impact which ignited the thorium. The reason for the presence of thorium in the glove box is not known.

Corrective Action - Thorium generators were advised not to send thorium to the salvage yard. The procedures were modified to not accept packages inside of other packages.

Applicable Existing Regulation - This incident does not involve waste in a configuration applicable to the TRU waste to be shipped to WIPP. Restrictions on pyrophorics will prevent such a drum from being shipped to the WIPP.

**Martin Marietta (Paducah); Report No. 90702; File No. 5026**
**Occurrence Date: 03/22/90**

Subject - Spill of Mixed Hazardous Waste

Description and Cause - The spill of mixed hazardous waste within the Hazardous Waste Storage Building was due to a forklift accidentally releasing a drum and dropping it approximately 12 inches to the ground.

The cause was incompatible use of an overpack drum constructed of steel while the primary drum contained an extremely acidic waste. Inappropriate use of the equipment to move the palletized drums was also cited as a cause.

Corrective Action - The procedures pertaining to the drum and overpack compatibility selection were re-evaluated.

Applicable Existing Regulations - The incident is not relevant to the issue of flammability.

**Westinghouse Hanford Co.; Report No. 82705; File No. 3397**
**Occurrence Date 03/13/82**

Subject - Uranium Concrete Billet Autoignition

Description and Cause - A pallet of concrete billet cans was observed to be on fire. Air samples and radiation surveys taken in the general area indicated no contamination release. However, two of the firefighters were contaminated on their face, hands, and clothes.

The cause was attributed to insufficient training, inadequate process specifications, and inadequate operating procedures. The use of wooden pallets was a deviation from procedures and standard practice.

Corrective Action - The remaining billets were placed on a metal pallet.

Applicable Existing Regulation - This incident does not involve waste in a configuration applicable to the TRU waste to be shipped to WIPP. Restrictions on pyrophorics will prevent such an incident involving TRU waste drums.

**Martin Marietta (Y-12); Report No. 88714; File No. 2723**
**Occurrence Date 06/02/88**

Subject - Chemical Fire

Description and Cause - Small samples of a reactive base were being collected in one container for eventual disposal. When material (assumed to be the same "base") was poured from an unlabeled bottle, it spontaneously ignited.

The unlabeled bottle contained maleic anhydride and not "base".

Corrective Action - Chemical containers were checked for proper labeling. The labeling requirements were reviewed with personnel. Chemicals that could react violently are to be stored separately, in safe, nonflammable containers.

Applicable Existing Regulation - This incident does not involve waste in a configuration applicable to the TRU waste to be shipped to WIPP. Restrictions on free liquids and chemical incompatibility will prevent such an incident in a TRU waste drum.

**Martin Marietta (Y-12); Report No. 85709; File No. 2681**
**Occurrence Date 12/27/85**

Subject - Ignition of Enriched Uranium Chips

Description and Cause - Enriched uranium chips ignited while being cleaned for processing in briquettes.

The cause was attributed to a faulty chip cleaning procedure, which was not removing all of the water from the chips prior to final drying.

Corrective Action - Personnel were checked for contamination. The cleaning and decontamination of the area was initiated. An inert gas purge through the chip basket was added to the procedure.

Applicable Existing Regulation - This incident does not involve waste in a configuration applicable to the TRU waste to be shipped to WIPP. Restrictions on pyrophorics will prevent such an incident in a TRU waste drum.

**Westinghouse Materials Co. of Ohio; Report No. 86704; File No. 2318**
**Occurrence Date 05/06/86**

Subject - Uranium Metal Fines Fire

Description and Cause - A 30-gallon drum, containing 150 pounds of depleted uranium metal fines immersed in water and ice, started to burn.

The cause was an exothermic reaction of uranium metal fines as a result of formation of uranium hydride.

Corrective Action - The uranium fines were limited to a net weight of 100 pounds per drum. It was decided that dry ice should be added, and the fines kept covered in water inside the 30-gallon drums. In addition, the 30-gallon drums were to be placed inside 55-gallon drums also filled with water and placed in a water sprinkler area.

Applicable Existing Regulation - The quantities and constituents of the waste in this incident (150 pounds of depleted uranium metal in a 30-gallon drum) are not applicable to TRU waste to be shipped to WIPP. Restrictions on pyrophorics, and verification by RTR, will prevent such an incident in a TRU waste drum.

**Westinghouse Materials Co. of Ohio; Report No. 85738; File No. 2313**
**Occurrence Date 08/20/85**

Subject - Explosion In The Mill

Description and Cause - Sparks generated in the mill triggered the explosion of hydrogen generated from the reaction of unoxidized uranium metal and moisture in the atmosphere.

The cause was the trapping of hydrogen in the "dead air" space in the uppermost portion of the cyclone.

Corrective Action - Repair work was completed. The nine explosion supervisor units and actuators were replaced, and valves for any hydrogen released were installed.

Applicable Existing Regulation - This incident relates to operational problems, and does not apply to TRU waste to be shipped to WIPP. The hydrogen concentration within the confinement layers of a drum is also restricted to levels below the lower explosive limit in a TRU waste drum.

**Du Pont Research; Report No. 90786; File No. 5442**
**Occurrence Date 08/09/90**

Subject - Fire In Radiologically Controlled Lab

Description and Cause - A fire was detected in the radiologically controlled area of Building 773-A in a laboratory module. The fire occurred in a plutonium glove box enclosure, and resulted in injury to personnel or breach of radiological containment. The actinide box is used by the Actinide Technology Section to perform dissolution and various testing of materials containing plutonium.

The fire was initiated by an energized hot plate/stirrer coming into contact with a polyethylene bottle.

Corrective Action - The fire was extinguished promptly and training lessons in emergency preparedness and response were completed.

Applicable Existing Regulation - The incident is not relevant to the issue of flammability of the waste, because the cause of the fire did not involve any waste.

**Lawrence Livermore National Laboratory; Report No. 84708; File No. 3745**
**Occurrence Date 07/12/84**

Subject - Fire Involving Anhydrous Nitric Acid

Description and Cause - Anhydrous nitric acid came into contact with wooden pallet, probably due to a leak because of thermal expansion at high ambient temperature of 109°F.

Corrective Action - The area was neutralized with lime. The material was placed in barrels and disposed of as toxic waste, and the area was washed down with water. Written Operational Safety Procedures were revised to improve communications.

Applicable Existing Regulation - This incident does not apply to TRU waste to be shipped to WIPP. Restrictions on the chemical incompatibility, as well as on the presence of corrosives like nitric acid, will prevent such an incident in a TRU waste drum.

**EG&G Rock Flats; Report No. 88733; File No. 985**
**Occurrence Date 05/23/88**

Subject - Spill of Low-Level Mixed Radioactive and Hazardous Waste

Description and Cause - Boxes of Pondcrete (low-level mixed radioactive and hazardous waste) are stacked in arrays three high by four wide by six long, containing 72 boxes total and covered by a plastic-lined canvas tarpaulin for protection from the weather. After heavy rain for several days, resulting in 2.7 inches of rainfall, a foreman observed apparently deformed boxes. In unstacking the boxes, one box fell from a forklift, spilling 0.25 cubic feet of Pondcrete onto the asphalt. No environmental impact or potential to human health occurred as a result of this incident. No significant impact on Plant productions was incurred.

Deformation of the waste boxes and slumping of the stacks were caused by a combination of fireboard waste box degradation, inadequate process control, and inadequate inspection procedures.

Corrective Action - The spilled material and the failed waste box were transferred to a new waste box with a plastic liner. The area was decontaminated and radiation surveys were conducted. Revised operating procedures for the Pondcrete mixing and packaging activities were prepared. Revised inspection procedures were prepared.

Applicable Existing Regulation - The incident is not relevant to the issue of flammability. In addition, waste containers used to ship waste to WIPP are required to meet DOT, Type A specifications.

**EG&G Rocky Flats; Report No. 85740; File No. 973**
**Occurrence Date 09/19/85**

Subject - Pressurization of Container and Release of Plutonium

Description and Cause - A sealed container containing floor sweepings from the button breakout line pressurized and released radioactive material contaminating personnel and facility.

An exothermic reaction was initiated between calcium metal and moisture present in the container which led to pressurization and failure of the container. Also, material inside the container was at less than atmospheric pressure, allowing air to enter the container and spontaneously igniting the plutonium fines. The storing of the container in the cold storage area led to the direct release of contamination to the room.

Corrective Action - Procedures were modified to require use of the cold storage area only for overflow storage, radiation monitors to be present when removing material, and all floor sweepings to be calcined twice. All material removed from the line is to be dried.

Applicable Existing Regulation - Restrictions on chemical incompatibilities, nonradioactive pyrophorics, together with the presence of filtered vents in each drum, will prevent such an incident (pressure build-up or chemical reactions) in a TRU waste drum.

**Battelle Memorial Institute (PNL); Report No. 83708; File No. 2872**
**Occurrence Date 05/18/83**

Subject - Localized Hydrogen Explosion

Description and Cause - A gas mixture was connected to an Infrared Spectrometer to purge residual carbon dioxide and water vapor; when the purging was started, an explosion occurred.

The staff member failed to recognize that a cylinder of 90% hydrogen and 10% nitrogen mixture instead of dry nitrogen was connected for the purge. When the mixture reached the instrument's globar (resistively heated ceramic) heat source, a localized explosion occurred.

Corrective Action - The spectrometer was returned to the manufacturer for examination. The reporting and safe handling procedures were reviewed and modified as necessary. Specific training on safe handling of compressed gases was provided. The spectrometer was transferred to another room where hydrogen bottles were not used. All hydrogen lines and valve connectors are now color-coded red.

Applicable Existing Regulation - The cause of the incident is not related to the flammability of the waste.

**EG&G Idaho, Inc.; Report No. 83753; File No. 1544**
**Occurrence Date 06/29/83**

Subject - Contamination Spread From Waste Box

Description and Cause - Two waste transport truck trailer units were found with radioactive contamination on the trailers and tires. Contamination was found on the ground, and on the forklift tines used to off load the waste packages.

Heavy rains washed radioactive contaminants from a leaking nonstandard waste box. The box was inadequately constructed, since the joint of the two-piece box lid was not sealed (caulked).

Corrective Action - The areas were surveyed and contaminated areas were located, marked and decontamination proceeded. Procedures were modified. Package design and quality inspection were evaluated. Inspection requirements were expanded to include documentation of box construction, closing, sealing, and labeling deficiencies.

Applicable Existing Regulation - The incident is not related to the flammability of the waste.

**Westinghouse Materials Co. of Ohio; Report No. 90704; File No. 4936**
**Occurrence Date 02/12/90**

Subject - Weight Loss From Drums of Hazardous/Radioactive Waste

Description and Cause - While the final records were being produced for a project of relocating 742 drums of waste declared hazardous, it was found that 222 of the drums had lost a total of 5,168 pounds of hazardous/radioactive material.

Due to the long outdoor storage of the drums (4-7 years), much of the water contained in the wastes leaked/evaporated. Some of the drums were deteriorated to the point that waste may have leaked out.

Corrective Action - The drums that showed the weight discrepancies were overpacked into larger drums, placed into approved indoor RCRA storage having secondary containment, and are being inspected weekly.

Applicable Existing Regulation - The incident is not related to the flammability of the waste. Waste containers to be shipped to WIPP are required to meet DOT, Type A specifications, or are required to be suitably overpacked.

**Westinghouse Materials Co. of Ohio; Report No. 86722; File No. 2335**
**Occurrence Date 09/05/86**

Subject - Uranium Metal Chips and Fines Fire

Description and Cause - A drum of uranium metal chips and fines caught on fire. There was no uranium spilled as a result of the fire.

An exothermic reaction of uranium metal fines occurred as a result of formation of uranium hydride.

Corrective Action - Sprinklers were activated and the drum was cooled to put out the fire. A sitewide Standard Operating Procedure (SOP) was issued on 3/10/88 "Guidelines for the Prevention of Uranium Metal Fires".

Applicable Existing Regulation - The properties of the waste in this incident are not applicable to TRU waste. Restrictions on the presence of pyrophorics and particulates will prevent such an incident in a TRU waste drum.

**Westinghouse Materials Co. of Ohio; Report No. 86713; File No. 2326**
**Occurrence Date 07/15/86**

Subject - Uranium Metal Chips and Fines Fire

Description and Cause - A 30-gallon drum of uranium metal chips and fines and water was placed inside a 55-gallon drum. The drum caught on fire while stored on a pad.

An exothermic reaction of uranium metal fines occurred as a result of formation of uranium hydride.

Corrective Action - The fire was extinguished. The 30-gallon drum was filled with water, placed in a 55-gallon drum, and shipped to a water sprinkler storage area. All uranium chip fines were limited to 100 pounds per drum. A change in the Standard Operating Procedure (SOP) was made. Dry ice was to be placed in all drums of uranium fines. Each day, the accumulated uranium metal fines and/or burned chips were to be checked for oxidation. A sitewide SOP was issued on 3/10/88 "Guidelines for the Prevention of Uranium Metal Fires".

Applicable Existing Regulation - The properties of the waste in this incident are not applicable to TRU waste. Restrictions on the presence of pyrophorics will prevent such an incident in a TRU waste drum.

**Westinghouse Materials Co. of Ohio; Report No. 86712; File No. 2325**
**Occurrence Date 06/01/86**

Subject - Uranium Metal Chips and Fines Fire

Description and Cause - A 30-gallon drum of uranium metal chips and fines was discovered on fire.

An exothermic reaction of uranium chips and fines and a delay in processing the chips and fines caused the fire.

Corrective Action - Identical to that for Occurrence Report No. 86713, File No. 2326.

Applicable Existing Regulation - The properties of the waste in this incident are not applicable to TRU waste. Restrictions on the presence of pyrophorics and particulates will prevent such an incident in a TRU waste drum.

**Westinghouse Materials Co. of Ohio; Report No. 86710; File No. 2323**
**Occurrence Date 06/30/86**

Subject - Uranium Metal Chips and Fines Fire

Description and Cause - Two 30-gallon drums of uranium metal fines were discovered on fire. An exothermic reaction of uranium metal fines and chips and a delay in processing the fines and chips caused the fire.

Corrective Action - Identical to that for Occurrence Report No. 86713; File No. 2326.

Applicable Existing Regulation - The properties of the waste in this incident are not applicable to TRU waste. Restrictions on the presence of pyrophorics and particulates will prevent such an incident in a TRU waste drum.

## 4.12 SUMMARY OF ANALYSIS OF PAST UNUSUAL OCCURRENCES

A history of past unusual occurrences at the sites, dating back to 1970, was obtained directly from some of the sites, as well as from the DOE SPMS database. These incidents are summarized in Table 4-1. The information in Table 4-1 is organized as follows:

- **Reporting Organization** - The DOE site where the unusual occurrence took place.
- **Report Number** - The reference number assigned to the occurrence by the DOE database.
- **Date** - The date that the occurrence took place, or was initially discovered.
- **Description** - Brief description of the occurrence.
- **Cause** - The reason for the occurrence as determined by investigation.
- **TRU-Related** - A statement reflecting whether the occurrence was TRU waste related, or not.
- **Applicable Existing Regulation** - An example of an existing regulation or criterion which would prevent another occurrence of this type.

Analysis of these incidents indicates that quite a few of them either did not involve TRU waste, were not representative of the waste characteristics typical of the TRU waste destined for WIPP, or were not caused by the flammability of the waste. A majority of these unrelated incidents seem to have involved personnel error, or faulty operational procedures, which have been accordingly rectified by appropriate corrective actions.

The cause of the incidents which did involve TRU waste, or were related to the issue of flammability or overpressurization, were attributed to one or more of the following reasons:

- Presence of pyrophorics in appreciable quantities
- Presence of free liquids in appreciable quantities
- Presence of flammable VOCs in appreciable quantities
- Presence of corrosives in appreciable quantities
- Lack of venting
- Chemical incompatibilities within the waste

The WIPP-WAC, the TRUPACT-II SAR, the No-Migration Determination, and other regulation discussions in Section 3.0, impose restrictions on each of the above, and all of these restrictions involve wide margins of safety. Proper implementation of these restrictions should provide an adequate degree of assurance, that the drums reported in past unusual occurrences would fail to comply with existing regulations governing the transportation and disposal of TRU waste at the WIPP. In summary, given the restrictions, it is unlikely that a TRU waste drum which qualifies for transportation and disposal will contribute to any incident related to overpressurization or the flammability of the waste.

TABLE 4-1

SUMMARY OF UNUSUAL OCCURRENCES AT DOE SITES

| Reporting[1] Organization | Report Number | Date | Description | Cause | TRU-Related | Applicable Existing Regulation |
|---|---|---|---|---|---|---|
| ANL-E | N/A[2] | 12/02/76 | Lid blown off of 55-gallon drum | Flammable VOCs, no vents | No | Restrictions on flammable VOCs |
| INC | N/A[2] | 06/01/70 | Burial ground fire in a 55-gallon drum | Pyrophorics | LLW[3] | Restrictions on pyrophorics |
| RHO | 78-17 | 02/02/78 | Distortion of storage containers | Pressurization | Yes | Vents, restrictions on fissile quantities, decay heat |
| RHO | 78-87 | 08/17/78 | Distortion of storage containers | Pressurization, chemical reaction | Yes | Vents, restrictions on free liquids, chemical incompatibility |
| ARHC | 75-122 | 10/21/75 | Pressurization of storage containers | Pressurization | Not known | Vents |
| LLNL | 84-14-TWC612-84 | 10/25/84 | Violent rupture of chemical drum | Chemical reaction | Not likely | Restrictions on free liquids, chemical incompatibility, vents |
| LLNL | 83-2-B161-83-1 | 06/30/83 | Fire in bags of dry waste | Pyrophorics, flammable VOCs | Not known | Restrictions on pyrophorics, flammable VOCs, chemical incompatibility |
| LLNL | 89-6-B-241 | 04/11/89 | Small fire in waste container | Chemical reaction | Not known | Restrictions on powders, chemical incompatibility |
| LANL | N/A[2] | 09/19/84 | Release of Pu-238 from a 55-gallon drum | Pressurization | Yes | Vents |
| LLNL | 88-7-614 | 04/26/88 | Chemical reaction during acid bulking | Chemical reaction | Not likely | Restrictions on free liquids, chemical incompatibility |
| WINC | 84733 | 4/20/84 | Fire in a radioactive waste container | Spontaneous combustion of nitric acid | Not known | Restrictions on corrosives, chemical incompatibility |
| LANL | 89819 | 10/26/89 | Depleted uranium fire in 30-gallon drum | Unstabilized pyrophorics | Not known | Chemical incompatibility, pyrophorics, free liquids |

TABLE 4-1

SUMMARY OF UNUSUAL OCCURRENCES AT DOE SITES
(Continued)

| Reporting[1] Organization | Report Number | Date | Description | Cause | TRU-Related | Applicable Existing Regulation |
|---|---|---|---|---|---|---|
| EG&GI | 900216 | 10/19/90 | Release to environment | Not determined | No | Not relevant |
| EG&GI | 89734 | 7/20/89 | Multiple occurrences of contamination events | Inadequate detection capability | No | Not relevant |
| EG&GI | 85733 | 07/09/85 | Unexpected contamination of personnel | Inadequate ventilation | No | Not relevant |
| LANL | 87733 | 08/01/87 | Crates containing TRU wastes partially collapsed | Faulty stacking procedure | Yes | Not relevant |
| BNL | 89712 | 06/29/89 | Release of vehicle with radiation levels above DOT limits | Inadequate personnel instruction | No, (LLW) | Not relevant |
| EG&GI | 85706 | 02/21/85 | Waste improperly disposed of in a low-level waste soil vault | Personnel error | Yes | Not relevant |
| EG&GI | 87706 | 06/09/87 | Improper waste drum storage | Later found to be proper | Yes | Not relevant |
| EG&GI | 90701 | 01/09/90 | Storage of transuranic mixed waste in a non-permitted area | Scheduling problems | Yes | Not relevant |
| WMCOO | 88702 | 01/18/88 | Release of uranyl nitrate | Operator error | No | Not relevant |
| ORNL | 84732 | 10/17/84 | Corrosion of storage drums | Corrosive agents | Yes | Prohibition of corrosives, WAC |
| ORNL | 86705 | 01/15/86 | Contamination of laboratory | Personnel error | No | Not relevant |
| ORNL | 86716 | 10/16/86 | Contamination | Personnel error | Yes | Not relevant |
| BMI (PNL) | 87706 | 10/15/87 | Pu content of waste drum exceeded limit | Personnel error | Yes | Decay heat limit; fissile shipping limit |
| WHC | 84714 | 02/27/84 | Transport of burial box with unbolted lid | Overlapping responsibilities | Yes | Not relevant |

TABLE 4-1

SUMMARY OF UNUSUAL OCCURRENCES AT DOE SITES
(Continued)

| Reporting[1] Organization | Report Number | Date | Description | Cause | TRU-Related | Applicable Existing Regulation |
|---|---|---|---|---|---|---|
| WHC | 83708 | 03/02/83 | Improper control of potentially alpha contaminated equipment | Faulty survey | No | Not relevant |
| WHC | 86734 | 04/11/86 | Failure of computer software results in burial of TRU waste as low-level | Faulty software | Yes | Not relevant |
| WHC | 89745 | 08/24/89 | Free liquids in TRU waste drums | Personnel error | Yes | Restrictions on free liquids |
| WHC | 89764 | 12/20/89 | SARP violation during shipment of mixed waste drums | Procedural error | Yes | Not relevant |
| WHC | 82724 | 09/14/82 | Inadvertently disposed radioactive materials shipping casks | Personnel error | Yes | Not relevant |
| WSRS | 89735 | 11/13/89 | Fissile material movement without Nuclear Incident Monitor coverage | Personnel error | Yes | Not relevant |
| WSRS | 89719 | 03/21/89 | Water intrusion into TRU waste drums | Inadequate Design | Yes | Restrictions on free liquids |
| WSRS | 89726 | 07/27/89 | Pressurized drum of TCE waste | No venting | No | Vents, restrictions on chemical incompatibilities |
| WSRS | 900234 | 12/01/89 | Storage of radioactive waste above ground over six months | Procedural error | Not known | Not relevant |
| MM(Y-12) | 85707 | 11/07/85 | Uranium scrap fire | Liquid coolant, uranium fines | LLW[3] | Restrictions on pyrophorics, free liquids, chemical incompatibility |
| MM(Y-12) | 85705 | 07/20/85 | Fire involving thorium in a scrapped glove box | Pyrophorics | LLW | Restrictions on pyrophorics |
| MM(P) | 90702 | 03/22/90 | Spill of mixed hazardous waste | Operational accident | Not known | Not relevant |

TABLE 4-1

SUMMARY OF UNUSUAL OCCURRENCES AT DOE SITES
(Continued)

| Reporting[1] Organization | Report Number | Date | Description | Cause | TRU-Related | Applicable Existing Regulation |
|---|---|---|---|---|---|---|
| WHC | 82705 | 03/13/82 | Uranium concrete billet autoignition | Pyrophorics | LLW[3] | Restrictions on pyrophorics |
| MM(Y-12) | 88714 | 06/02/88 | Chemical fire | Reaction between liquid chemicals | Not likely | Restrictions on free liquids, chemical incompatibility |
| MM(Y-12) | 85709 | 12/27/85 | Ignition of enriched uranium chips | Pyrophorics | LLW[3] | Restrictions on pyrophorics |
| WMCOO | 86704 | 05/06/86 | Uranium metal fines fire | Pyrophorics | LLW[3] | Restrictions on pyrophorics |
| WMCOO | 85738 | 08/20/85 | Explosion in the mill | Hydrogen | No | Hydrogen concentration restrictions |
| DPR | 90786 | 08/09/90 | Fire in radiologically-controlled lab | Plastic contacted with hot plate | No | Not relevant |
| LLNL | 84708 | 07/12/84 | Fire involving anhydrous nitric acid | Anhydrous nitric acid | Not known | Restrictions on chemical incompatibility, corrosives |
| EG&G RF | 88733 | 05/23/88 | Spill of low level mixed radioactive and hazardous waste | Operational accident | No, (LLW) | Not relevant |
| EG&G RF | 85740 | 09/19/85 | Pressurization of container and release of plutonium | Plutonium fines, calcium, moisture | Not known | Restrictions on chemical incompatibility, vents |
| BMI (PNL) | 83708 | 05/18/83 | Localized hydrogen explosion | Personnel error | No | Not relevant |
| EG&GI | 83753 | 06/29/83 | Contamination spread from waste box | Nonstandard waste box | Not known | Not relevant |
| WMCOO | 90704 | 02/12/90 | Weight loss from drums of hazardous/ radioactive waste | Evaporation of water | Not known | Not relevant |
| WMCOO | 86722 | 09/05/86 | Uranium metal chips and fines fire | Pyrophorics | LLW[3] | Restrictions on pyrophorics |

TABLE 4-1

SUMMARY OF UNUSUAL OCCURRENCES AT DOE SITES
(Continued)

| Reporting[1] Organization | Report Number | Date | Description | Cause | TRU-Related | Applicable Existing Regulation |
|---|---|---|---|---|---|---|
| WMCOO | 86713 | 07/15/86 | Uranium metal chips and fines fire | Pyrophorics | LLW[3] | Restrictions on pyrophorics |
| WMCOO | 86712 | 06/01/86 | Uranium metal chips and fines fire | Pyrophorics | LLW[3] | Restrictions on pyrophorics |
| WMCOO | 86710 | 06/30/86 | Uranium metal chips and fines fire | Pyrophorics | LLW[3] | Restrictions on pyrophorics |

[1] Explanation of Reporting Organization Abbreviations:

| | |
|---|---|
| ANL-E | Argonne National Laboratory-East |
| INC | Idaho Nuclear Corporation |
| RHO | Rockwell Hanford Operations |
| ARHC | ARCO Hanford Company |
| LLNL | Lawrence Livermore National Laboratory |
| WINC | Westinghouse Idaho Nuclear Co. |
| LANL | Los Alamos National Laboratory |
| EG&GI | EG&G Idaho, Inc. |
| BNL | Brookhaven National Laboratory |
| WMCOO | Westinghouse Materials Company of Ohio |
| ORNL | Oak Ridge National Laboratory |
| BMI (PNL) | Battelle Memorial Institute (PNL) |
| WHC | Westinghouse Hanford Co. |
| WSRS | Westinghouse Savannah River Co. |
| MM (Y-12) | Martin Marietta (Y-12) |
| MM (P) | Martin Marietta (Paducah) |
| DPR | DuPont Research |
| EG&G, RF | EG&G Rocky Flats Plant |

[2] Not Available

[3] Uranium, by definition, is not a transuranic element. Some of these incidents involved large amounts of uranium (more than a few kilograms) that were awaiting reprocessing into $U_3O_8$. Since these characteristics are typical of chunks of depleted uranium that are routinely disposed of as low-level waste after reprocessing, it is likely that the waste involved in the incidents would be classified as low-level waste (LLW).

# 5.0 SUMMARY

This paper has examined the issue of potential flammability concerns associated with CH-TRU waste to be transported for disposal at the WIPP. The potential flammability concerns from CH-TRU waste were discussed in Section 1.0, and the basic principles and mechanisms involved in the explosion of a flammable mixture were discussed in Section 2.0. The existing regulations which address the potential concerns, and procedures for implementing them were explained in Section 3.0. Section 3.0 also presented a summary of process knowledge gained from long-term practices at the sites. Section 4.0 examined a number of past unusual occurrences at the sites dating back to 1970, and analyzed whether these incidents might reoccur, given the restrictions applicable to TRU waste to be emplaced at WIPP.

The safety concerns associated with the flammability of the waste seem to be well addressed by regulations from agencies such as the EPA and the NRC, by the waste acceptance criteria formulated by the DOE for both transportation and disposal, and by the operational procedures at individual sites. The regulations and the waste acceptance criteria are based on conservative analysis, and thus involve a margin of safety for preventing any potential flammability-related incidents. As an example, the total quantity of flammable VOCs in the headspace of a TRU waste drum is limited to 500 ppm. The fact that this imposed limit is extremely conservative, is clearly evident upon comparison with the lower explosive limits for some typical flammable VOCs. One such flammable VOC, xylene, which was actually involved in one of the incidents summarized in Section 4.0, has a lower explosive limit in air of 1.1% (NFPA, 1986). Upon conversion of units, this value is equivalent to 11,000 ppm. Therefore a minimum of 11,000 ppm of xylene must be present in order to form a flammable mixture with air. By comparison, this is 22 times larger than the existing limit of 500 ppm of <u>total</u> amount of all flammable VOCs allowed per drum.

Similarly, while applying the Le Chatelier's principle to determine the flammability of gaseous mixtures in the headspace of a drum, the EPA mandates the use of a lower explosive limit of 50% of the actual value for each constituent in the mixture. As an example, the lower explosive limit for hydrogen is 4% (NFPA, 1986). However, when applying Le Chatelier's principle as mandated by the EPA, a value of 2% is used for calculations. This is conservative, since documented experiments have shown that explosions in simulated TRU waste drums do not occur below a hydrogen concentration of 15% in air (WSRC, 1990).

Existing regulations were also hypothetically applied to past unusual occurrences, as described in Section 4.0. The analysis in Section 4.0 shows that in all previous incidents related to the issue of flammability of the waste, the drums in question would have failed to qualify for transportation based on existing regulations. There are various existing requirements which, if implemented properly, would prevent incidents similar to past unusual occurrences. Some of these requirements are summarized below:

- <u>Presence of filtered vents</u> - The attributed cause for many of these incidents was overpressurization of the drums due to the absence of any vents. Presently, all TRU waste containers are <u>required</u> to be fitted with one or more carbon composite filter vent for transportation to WIPP. These vents provide continuous pressure relief, and thus prevent any pressure build-up within a drum.

- Prohibition of heat sealing of bags - Under the current transportation requirements, any bags used as confinement layers in waste containers are required to be closed only by a twist-and-tape closure. Heat sealing of bags is not allowed as per the TRUPACT-II SAR requirements. This prevents the possible accumulation of potentially flammable gases in inner confinement layers.

- Adequate waste characterization prior to transportation - A minimum amount of waste characterization on certain parameters is required before waste can be transported to WIPP. Examples of these parameters include verification of the absence of restricted items like free liquids (in excess of one volume percent), explosives, compressed gases, etc. This waste characterization information is summarized for each content code in the TRUCON document. This minimizes the potential of shipping a waste container with "unknown" properties, that could present a safety hazard.

- Restrictions on total amount of flammable VOCs - Under current transportation and EPA-NMD requirements, the total amount of flammable VOCs in the headspace of a CH-TRU waste container is restricted to 500 ppm. If the total exceeds this limit, then the EPA requires that a flame test be performed to assure the safety of the container.

- Restrictions on amount of flammable gases in the headspace - The concentration of a mixture of flammable gases in the headspace of a drum, is required to be below 50% of the lower explosive limit of the mixture as predicted by Le Chatelier's Law. Thus, a factor of safety of two is applied in determining flammability characteristics.

- Restrictions on hydrogen concentration - The decay heat limits on waste containers are controlled to the extent that the hydrogen concentration must remain below 5% in all layers of the payload and the TRUPACT-II package, irrespective of the oxygen concentration. Simulated experiments with 55-gallon drums have shown that an explosion did not occur as long as the concentration of hydrogen was below 15% (WSRC, 1990).

- Restrictions on pyrophorics - No non-radionuclide pyrophorics are allowed in the WIPP waste inventory, and radionuclide pyrophorics are limited to less than 1% by weight. The quantity of these materials is further limited by the criticality and wattage limits for the TRUPACT-II package.

  A vast majority of the incidents reported in Section 4.11 that were related to pyrophorics, were caused by the presence of uranium fines. It should be noted that uranium, by definition, is not a transuranic element. Unless contaminated with transuranic radionuclides, uranium fines would normally be disposed of as low-level waste (after their oxidation to $U_3O_8$). In fact, the uranium fines involved in all of these incidents were scheduled to be burned to $U_3O_8$ in an oxidation furnace, and the delay in their processing resulted in the fires. In addition, the quantities of uranium per drum reported in these incidents far exceeded the limits on radionuclide pyrophorics applicable today, and are therefore not representative of TRU waste drums. Operating procedures for handling uranium fines have considerably changed since the occurrence of these incidents, and uranium fines and/or burned chips are

sent for oxidation the same day without any processing delay. Thus, any uranium fines present in a TRU waste drum are preoxidized and dispersed in the waste, and therefore do not present a credible threat of ignition.

- Restrictions on free liquids - TRU waste containers for the WIPP Test Phase are not allowed to contain more than one volume percent free liquids. In addition, documentation is required to show that the liquids present will not compromise the integrity of the container. Waste for disposal at WIPP cannot be in free-liquid form. Only minor liquid residues remaining in well-drained bottles, cans, and other containers are acceptable.

  It should be noted that RTR procedures at the DOE sites are considerably more stringent than the one percent free liquids by volume allowed by the WIPP-WAC (DOE, 1990c) thereby allowing a margin of safety in addition to the regulations. As an example, when implementing RTR at INEL, any container with greater than 0.75 percent by volume of free liquids is rejected. Similarly, the criteria at Rocky Flats and ORNL reject drums with any detectable free liquid amounts.

- Restrictions on chemical incompatibility - The waste to be transported to the WIPP is required to be chemically compatible within each drum, between different drums in a payload, and between the payload and the TRUPACT-II package. The waste is also required to be in solid or solidified form.

In summary, adequate safety regulations exist for TRU waste to be shipped to WIPP. With proper implementation, these regulations should minimize any hazards with flammability concerns.

# 6.0 REFERENCES

ASTM - See American Society for Testing and Materials.

American Society for Testing and Materials, 1985, "Standard Test Method for Concentration Limits of Flammability of Chemicals", Designation E 681-85, American Society for Testing and Materials, Philadelphia, Pennsylvania.

Baker, W.E., P.A. Cox, P.S. Westine, J.J. Kulesz, and R.A. Strehlow, 1983, Explosion Hazards and Evaluation, Elsevier Scientific Publishing Company, Amsterdam, The Netherlands.

Bartknecht, W., 1981, Explosions: Course Prevention Protection, 2nd ed., Springer Verlag, Heidelberg.

Clements, T.L., Jr., and D.E. Kudera, 1985, "TRU-Waste Sampling Program: Volume I: Waste Characterization," EEG-WM-6503, Idaho National Engineering Laboratory, Idaho Falls, Idaho.

DOE - See U.S. Department of Energy.

DOT - See U.S. Department of Transportation.

Drysdale, D., 1985, "An Introduction to Fire Dynamics", John Wiley & Sons Ltd., New York, New York.

Eicher, R., U.S. Department of Energy, Office of Integration, 1991, Personal Communication with Joe Lippis of the U.S. Department of Energy, (WPO).

EPA - See U.S. Environmental Protection Agency.

Haessler, W.M., 1989, "Fire: Fundamentals and Control", Marcel Dekker, Inc., New York, New York.

Hord, J., 1976, "Is Hydrogen Safe", Note 690, National Bureau of Standards, U.S. Department of Commerce.

Hunt, A., U.S. Department of Energy (WPO), 1991, Personal Communication with Matthew Silva of the Environmental Evaluation Group (EEG).

Lappin, A.R., R.L. Hunter, eds., D.P. Garber, P.B. Davies, assoc. eds., 1989, "Systems Analysis, Long-Term Radionuclide Transport, and Dose Assessments, Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico; March 1989," SAND 89-2027, Sandia National Laboratories, Albuquerque, New Mexico.

Lewis, B., and von Elbe, G., 1961, Combustion, Flames, and Explosions of Gases", Academic Press, New York, New York.

Molecke, M. A., 1990a, "Bin-Scale Instruments and DAS Impacts on Safety/Control Issues", Memo of Record dated October 17, 1990, Sandia National Laboratories, Albuquerque, New Mexico.

Molecke, M. A., 1990b, "Test Plan: WIPP Bin-Scale CH-TRU Waste," Sandia National Laboratories, Albuquerque, New Mexico.

Molecke, M. A., 1990c, "Test Plan: WIPP In Situ Alcove CH-TRU Waste," Sandia National Laboratories, Albuquerque, New Mexico.

Molecke, M.A., and A.R. Lappin, 1990, "Test Plan Addendum #1: WIPP Bin-Scale CH TRU Waste Tests,", SAND 90-2082, Sandia National Laboratories, Albuquerque, New Mexico.

National Fire Protection Association, 1986, "Fire Protection Guide on Hazardous Materials, 9th edition", Batterymarch Park, Quincy, Massachusetts.

NFPA - See National Fire Protection Association.

NRC - See U.S. Nuclear Regulatory Commission.

NuPac, 1989, "Safety Analysis Report for the TRUPACT-II Shipping Package," Rev. 4, Nuclear Packaging, Inc., Federal Way, Washington.

Sax, N.I., and R.J. Lewis, Sr., 1987, "Hawley's Condensed Chemical Dictionary", Eleventh Edition, Van Nostrand Reinhold, New York, New York.

Schultz, N., 1985, "Fire and Flammability Handbook", Van Nostrand Reinhold Company, New York, New York.

Silva, M., 1990, "Preliminary Investigations into the Explosion Potential of Volatile Organic Compounds in WIPP CH-TRU Waste", EEG-45, Environmental Evaluation Group (EEG), Albuquerque, New Mexico, June 1990.

Thuot, J., Argonne National Laboratory-East, 1991, Personal Communication, February 21, 1991.

U.S. Department of Energy, 1988, "Integrated Data Base for 1988: Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics, DOE/RW-0006, Rev. 4, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

U.S. Department of Energy, 1989a, "Final Safety Analysis Report, Waste Isolation Pilot Plant," WP 02-9, U.S. Department of Energy, WIPP Project Office, Carlsbad, New Mexico.

U.S. Department of Energy, 1989b, "TRUPACT-II Content Codes (TRUCON)," DOE/WIPP 89-004, Rev. 3, U.S. Department of Energy, WIPP Project Office, Carlsbad, New Mexico.

U.S. Department of Energy, 1989c, "TRU Waste Acceptance Criteria for the Waste Isolation Pilot Plant," WIPP/DOE-069, Revision 3, Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, New Mexico.

U.S. Department of Energy, 1990a, "A DOE-Wide ES&H Information Management System SPMS", DOE/EH-0105, U.S. Department of Energy, Office of Environment, Safety, and Health, Washington, D.C.

U.S. Department of Energy, 1990b, "Final Supplemental Environmental Impact Statement," DOE/EIS-0026-DS, U.S. Department of Energy, Washington, D.C.

U.S. Department of Energy, 1990c, "Waste Isolation Pilot Plant No-Migration Variance Petition," DOE/WIPP 89-003, U.S. Department of Energy, WIPP Project Office, Carlsbad, New Mexico.

U.S. Department of Energy, 1990d, "Quality Assurance Program Plan for WIPP Waste Characterization Program," U.S. Department of Energy, Washington, D.C.

U.S. Department of Energy, 1991a, "Evaluation of the Effectiveness and Feasibility of the Waste Isolation Pilot Plant Engineered Alternatives: Final Report of the Engineered Alternatives Task Force", DOE/WIPP 91-007, U.S. Department of Energy, WIPP Project Office, Carlsbad, New Mexico.

U.S. Department of Energy, 1991b, "Waste Characterization Program Plan for WIPP Experimental Waste," DOE/WIPP 89-025, Revision 0, U.S. Department of Energy, Washington, D.C.

U.S. Department of Transportation, 1989a, "Explosives and Blasting Agents, Definitions and Preparation," Title 49, Code of Federal Regulations, Part 173, (49 CFR 173) Subpart C, U.S. Department of Transportation, Washington, D.C.

U.S. Department of Transportation, 1989b, "Gases, Definition and Preparation," Title 49, Code of Federal Regulations, Part 173, (49 CFR 173), Subpart G, U.S. Department of Transportation, Washington, D.C.

U.S. Department of Transportation, 1989c, "Packaging and Transportation of Radioactive Materials", Title 10, Code of Federal Regulations, Part 71, (10 CFR 71), U.S. Department of Transportation, Washington, D.C.

U.S. Department of Transportation, 1989d, "Type A Packaging Tests," Title 49, Code of Federal Regulations, Part 173.465, (49 CFR 173.465), U.S. Department of Transportation, Washington, D.C.

U.S. Environmental Protection Agency, 1980, "A Method for Determining the Compatibility of Hazardous Wastes", EPA-600/2-80-076, U.S. Environmental Protection Agency, Cincinnati, Ohio.

U.S. Environmental Protection Agency, 1989a, "Characteristics of Hazardous Waste," Title 40, Code of Federal Regulations, Part 261, (40 CFR 261), Subpart C, U.S. Environmental Protection Agency, Washington, D.C.

U.S. Environmental Protection Agency, 1989b, "Land Disposal Restrictions," Title 40, Code of Federal Regulations, Part 268 (40 CFR 268), U.S. Environmental Protection Agency, Washington, D.C.

U.S. Environmental Protection Agency, 1989c, "List of Hazardous Wastes," Title 40, Code of Federal Regulations, Part 261, (40 CFR 261), Subpart D, U.S. Environmental Protection Agency, Washington, D.C.

U.S. Environmental Protection Agency, 1990, "Conditional No-Migration Determination for the Department of Energy Waste Isolation Pilot Plant (WIPP)", Title 55, Federal Register, No. 47700 (55 FR 47700), November 14, 1990.

U.S. Nuclear Regulatory Commission, 1984, "Clarification of Conditions for Waste Shipments Subject to Hydrogen Generation," SSINS No. 6835, IE Information Notice No. 84-72, U.S. Nuclear Regulatory Commission, Washington D.C.

Westinghouse Savannah River Company, 1990, "TRU Drum Hydrogen Explosion Tests", Savannah River Company, Savannah River Laboratory, Aiken, SC.

WSRC - See Westinghouse Savannah River Company.

Zabetakis, M.G., 1965, "Flammability Characteristics of Combustible Gases and Vapors,", U.S. Bureau of Mines, Bulletin 627, U.S. Department of the Interior.

# 7.0 GLOSSARY

This section presents a glossary of different terminology used in this report. The glossary of the terms dealing with the behavior of flammable mixtures has been compiled from three different references (Sax and Lewis, 1987; NFPA, 1986; EPA, 1989a).

Aerosol - A suspension of liquid or solid particles in a gas, the particles often being in the colloidal size range. Fog and smoke are common examples of natural aerosols; fine sprays (perfumes, insecticides, inhalants, anti-perspirants, paints, etc.) are man-made.

Autoignition Temperature - The minimum temperature required to initiate or cause self-sustained combustion in any substance in the absence of a spark or flame. This varies with the test method. Also referred to as "autoignition point" or ignition temperature.

Boiling Point - The temperature of a liquid at which its vapor pressure is equal to or very slightly greater than the atmospheric pressure of the environment. For water at sea level it is 212°F (100°C)

Chemical Compatibility - A determination that specific wastes (chemical groups) can be mixed. A hazardous waste compatibility chart (EPA, 1980) is used for this purpose. At the intersection of two chemical groups is a listing of the possible consequences of mixing the two chemical groups. The consequences may be any one or a combination of the following: (1) Heat generation; (2) Fire; (3) Innocuous and nonflammable gas generation; (4) Toxic gas generation; (5) Flammable gas generation; (6) Explosion; (7) Violent polymerization; (8) Solubilization of toxic substances; (9) Consequence of mixing may be hazardous but unknown. If none of these consequences is listed at the intersection of the two chemical groups then chemical compatibility is ensured.

Chemical Incompatibility - A determination that specific wastes (chemical groups) cannot be mixed (see Chemical Compatibility).

Combustible Liquid - Any liquid having a flash point at or above 100°F (37.8°C) and below 200°F (93.3°C).

Combustible Material - Any substance that will burn, regardless of its autoignition temperature or whether it is a solid, liquid, or gas. Although this definition necessarily includes all flammable materials as well, this fact is disregarded in official classifications. Usually defined, the term "combustible" refers to solids that are relatively difficult to ignite and that burn relatively slowly, and to liquids having a flash point greater than 100°F (37.8°C). It is difficult to generalize about the combustibility of solids. The rate and ease of combustion may depend as much on their state of subdivision, as on their chemical nature. Many metals in powder or flake form will ignite and burn rapidly, whereas most are noncombustible as bulk solids. Cellulose is combustible as a textile fabric or as paper, and is flammable as fine fibers (cotton linters). Some polymers, such as nylon and polyvinylidene chloride will melt and burn but will not propagate flame; others, e.g., polyvinyl chloride and polyurethane, ignite at high temperature and evolve toxic fumes. Acrylics and cellulose-derived plastics, such as rayon and cellulose acetate, are readily combustible. This may be partially offset by use of fire-retardant chemicals. Glass is noncombustible in all forms.

Combustion - An exothermic oxidation reaction which may occur with any organic compound as well as with certain elements and inorganic compounds, e.g., hydrogen, sulfur, carbon monoxide, hydrogen sulfide, phosphorus, magnesium. The end products of combustion of elements and inorganic compounds are oxides; of organic compounds are carbon dioxide and water. Examples are (a) for an element: $2H_2 + O_2 \rightarrow 2H_2O$, (b) for an organic compound (carbohydrate): $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$. In this case, combustion is the reverse of photosynthesis. The heat of combustion is due to the rupture of chemical bonds and formation of new compounds. Substances differ greatly in their combustibility, that is, in their ignition points (solids and gases) or their flash points (liquids). Carbon disulfide burns almost explosively at 212°F (100°C), while rubber, hydrocarbons, and nylon are difficult to ignite at any temperature. Oxygen is not combustible but actively supports combustion; no oxygen is needed if another oxidizing agent is present, as in the combustion of a mixture of hydrogen and chlorine to form hydrogen chloride.

Spontaneous combustion may occur at, or even below, room temperature by any of the following mechanisms: (1) by exposure to air of substances that are highly sensitive to oxidation, (e.g., phosphorus); (2) by heat build-up from bacterial activity (compost, sewage sludge) or oxidation catalyzed by moisture, as in wet waste materials (paper, cotton, wool); (3) by internal heat accumulation due to autoxidation (fish oils, linseed oil).

Compressed Gas - Any material or mixture that, when enclosed in a container, has an absolute pressure exceeding 40 psi at 70°F (21.1°C) or, regardless of the pressure at 70°F (21.1°C), has an absolute pressure greater than 140 psi at 130°F (54.4°C), or any flammable material having a vapor pressure greater than 40 psi absolute at 100°F (37.8°C).

Corrosive - Liquid or solid that causes visible destruction or irreversible alterations in human skin tissue at the site of contact, including liquids that severely corrode steel. Examples of corrosives include nitric acid, bromine, soda lime, hydrochloric acid, sodium hydroxide solution.

Corrosivity - A waste exhibits the characteristic of corrosivity if a representative sample of the waste has either of the following properties: (1) It is aqueous and has a pH less than or equal to 2 or greater than or equal to 12.5, as determined by a pH meter using an EPA test method. The EPA test method for pH is specified as Method 5.2 in "Test Methods for the Evaluation of Solid Waste, Physical/Chemical Methods." (2) It is a liquid and corrodes steel (SAE 1020) at a rate greater than 6.35 mm (0.250 inch) per year at a test temperature of 130°F (55°C), as determined by the test method specified in NACE (National Association of Corrosion Engineers) Standard TM-01-69 and standardized in "Test Methods for the Evaluation of Solid Waste, Physical/Chemical Methods."

Deflagration - An exothermic chemical reaction or low-order explosion resulting from subsonic flame speed relative to the unburned mixture. A deflagration may be initiated by contact of a flame or spark but may be caused by impact or friction.

Detonation - An exothermic chemical reaction or high-order explosion resulting from supersonic flame speed relative to the unburned mixture. The energy in this reaction is transferred from the reaction zone to the unreacted zone by a reactive shock wave. A detonation may be initiated by mechanical impact, friction or heat.

Exothermic - A process or chemical reaction which is accomplished by evolution of heat, (e.g., combustion reactions).

Explosion - A violent bursting or expansion due to the pressure produced in a confined space by the sudden generation of gases in confinement, always accompanied by a fireball. The release of energy over a sufficiently small time and in a sufficiently small volume so as to generate a pressure wave of finite amplitude traveling away from the source. The release is not considered to be explosive unless it is rapid enough and concentrated enough to produce a pressure wave that one can hear.

Explosive - A chemical substance which reacts suddenly and violently on detonation by impact, friction, or heat, generating large volumes of gases, heat, etc.

Explosion Pressure - It is the pressure in excess of the initial pressure at which an explosive mixture is ignited.

Flame Propagation - See Propagation of Flame

Flame Temperature - The temperature of the flame produced by burning a compound in a normal atmosphere without any rate controls.

Flammable Liquid - Any liquid having a flash point less than 100°F (37.8°C) and a vapor pressure of not over 40 pounds per square inch absolute (psia) at 100 °F (37.8°C).

Flammable Gases - Gases that are ignited very easily; the flame and heat propagation rate is so great as to resemble an explosion, especially if the gas is confined. The most flammable gases are hydrogen, carbon monoxide, acetylene, and other hydrocarbon gases. Oxygen, though essential for the occurrence of combustion, is not itself either flammable or combustible; neither are the halogen gases, sulfur dioxide, or nitrogen.

Flammable Material - Any solid, liquid, vapor, or gas that will ignite easily and burn rapidly. The terms "flammable", "nonflammable", and "combustible" are difficult to delimit. Since any material that will burn at any temperature is combustible by definition, it follows that this word covers all such materials, irrespective of their ease of ignition. Thus, the term "flammable" actually applies to a special group of combustible materials that ignite easily and burn rapidly. Some materials (usually gases) classified in shipping and safety regulations as nonflammable are actually noncombustible. The distinction between these terms should not be overlooked. For example, sodium chloride, carbon tetrachloride, and carbon dioxide are noncombustible; sugar, cellulose, and ammonia are combustible but nonflammable.

Flammable Mixture - A homogeneous combustible mixture of a gas or vapor with either air or oxygen which can propagate a flame freely upon ignition.

Flammable Solid - Any solid material, other than an explosive, liable to cause fires through friction or retained heat from manufacturing or processing or which can be ignited readily, creating a serious transportation hazard because it burns vigorously and persistently. Flammable solids are of several types: (1) dusts or fine powders (metals or organic substances such as cellulose, flour, etc.); (2) those that ignite spontaneously at low temperatures (white

phosphorus); (3) those in which internal heat is built up by microbial or other degradation activity (fish meal, wet cellulosic materials); (4) films, fibers, and fabrics of low-ignition point materials.

Flammability - The ease with which a material (gas, liquid, or solid) will ignite either spontaneously (pyrophoric), from exposure to a high-temperature environment (autoignition) or from exposure to a spark or open flame. It also involves the rate of spreading of a flame once it has started. The more readily ignition occurs, the more flammable the material; less easily ignited materials are said to be combustible, but the line of demarcation is often indefinite and depends on the state of subdivision of the material as well as on its chemical nature.

Flammable (Explosive) Limits - In the case of gases or vapors which form flammable mixtures with air or oxygen, flammable limits are the boundary-line mixtures of vapor or gas with air or oxygen (usually expressed in terms of percentage by volume of gas or vapor in air or oxygen), which if ignited will just propagate a flame. The flammable limits usually listed in tables are based upon normal atmospheric temperatures and pressures, unless otherwise indicated. There will be considerable variation in flammable limits at pressures and temperatures above or below ambient. The general effect of increase in temperature or pressure is to lower the lower limit and raise the upper limit. Decrease in temperature or pressure has the opposite effect. Research has shown that the limits of flammability are not fundamental combustion parameters, but are dependent upon many variables which include, in part, the surface-to-volume ratio of reaction chamber, the flow direction, and velocity of the gas or vapor. In some experiments it appears that with laminar flow, the upper limit increases with increasing velocity, reaches a maximum value independent of the tube diameter and then decreases with turbulent flow. On the contrary, the lower limit remains unaffected by the flow rate. ASTM E681-85 is an existing standard method for the determination of flammable limits.

Flammable (Explosive) Range - The range of flammable vapor or gas-air mixture between the upper and lower flammable limits. For example, the lower limit of flammability of acrylonitrile at ordinary ambient temperature is approximately 3 percent vapor in air by volume, while the upper limit of flammability is about 17 percent. All concentrations by volume of acrylonitrile vapor in air falling between 3 percent and 17 percent are in the flammable or explosive range.

Flash Point - The temperature at which a liquid or volatile solid gives off suficient vapor to form an ignitable mixture with the air near the surface of the liquid or within the test vessel.

G Value - The G value for a material is defined as the number of molecules of gas (e.g., hydrogen) produced from the material per 100 eV of energy absorbed.

Hazardous Waste - Waste, or combination of wastes, which because of its quantity, concentration, or physical, chemical, or infectious characteristics may (1) cause, or significantly contribute to, an increase in mortality or an increase in serious irreversible or incapacitating reversible illness, or (2) pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, or disposed of.

**Hazardous Material** - Any material or substance which in normal use can be damaging to the health and well-being of humans. Such materials cover a broad range of types which may be classified as follows: (1) Toxic agents including drugs, chemicals, and natural or synthetic products that in normal use are in any way harmful, ranging from poisons to skin irritants and allergens. When improperly used, all materials can be hazardous to humans. (2) Corrosive chemicals such as sodium hydroxide or sulfuric acid that destroy or otherwise damage the skin and mucous membranes on external contact or inhalation. (3) Flammable materials including (a) organic solvents, (b) finely divided metals or powders, (c) some classes of fibers, textiles or plastics, and (d) chemicals that either evolve or absorb oxygen during storage, thus constituting a fire risk in contact with organic materials. (4) Explosives and strong oxidizers such as peroxides and nitrates. (5) Materials in which dangerous heat build-up occurs on storage, either by oxidation or microbiological action. Examples are fish meal, wet cellulosics, and other organic waste materials. (6) Radioactive chemicals that emit ionizing radiation.

**High-Level Waste (HLW)** - The highly radioactive material resulting from the reprocessing of spent nuclear fuel.

**Ignitability** - The characteristic used to define as hazardous those wastes that could cause a fire during transport, storage, or disposal. A waste exhibits the characteristic of ignitability if a representative sample of the waste has any of the following properties: (1) It is a liquid, other than aqueous solution containing less than 24% alcohol by volume, and has a flash point less than 140°F (60°C), as determined by a Pensky-Martens Closed Cup Tester (using the test method specified in ASTM Standard D-93-79 or D-93-80) or by a Setflash Closed Cup Tester (using the test method specified in ASTM Standard D-3278-78); (2) It is not a liquid and is capable, under standard temperature and pressure, of causing fire through friction, absorption of moisture, or spontaneous chemical changes and, when ignited, burns so vigorously and persistently that it creates a hazard; (3) It is an ignitable compressed gas as defined in the 49 CFR 173.300 DOT regulations; (4) It is an oxidizer as defined in the 49 CFR 173.151 DOT regulations.

**Ignition** - The process by which a rapid, exothermic reaction is initiated, which then propagates and causes the material involved to undergo change, producing temperatures greatly in excess of ambient.

**Ignition Energy** - The energy that is transferred from an ignition source to a flammable gas mixture to initiate the ignition process.

**Ignition Temperature** - The minimum temperature of a substance, whether solid, liquid, or gaseous, required to initiate or cause self-sustained combustion in the absence of any source of ignition or independently of the heating or heated element. Ignition temperatures observed under one set of conditions may be changed substantially by a change of conditions. For this reason, ignition temperatures should be looked upon only as approximations. Some of the variables known to affect ignition temperatures are percentage composition of the vapor or gas-air mixture, shape and size of the space in which the ignition occurs, rate and duration of heating and type of reactivity of other materials present in the space in which the ignition occurs. As there are many differences in ignition temperature test methods, such as size and shape of ignition chambers, composition of ignition chambers, method of heating, rate of heating, residence time and method of flame detection, it is not surprising that reported ignition temperatures are affected by the test methods employed.

Ignition Source - The mechanism by which an ignition is initiated. Typical ignition sources include mechanical sparks, mechanical heat (friction, shocks or impacts), open flames, hot surfaces, chemical reactions, and electrical sparks.

Le Chatelier's Law - The explosion (flammable) limits of a mixture of several flammable gases and vapors may be estimated if knowledge of the explosion limits of the components are known. If $P_i$ is the volume fraction of component "i" in the mixture, the lower explosion (flammable) limit (LEL) for the mixture is:

$$\text{LEL (mixture)} = \Sigma P_i / \Sigma (P_i / LEL_i)$$

and the upper explosion (flammable) limit (UEL) for the mixture is:

$$\text{UEL (mixture)} = \Sigma P_i / \Sigma (P_i / UEL_i)$$

Lower Explosion (Flammable) Limit [LEL] - For gases or vapors which form flammable mixtures with air or oxygen, it is the minimum concentration of vapor or gas in air or oxygen below which propagation of flame does not occur on contact with a source of ignition. The mixture below the lower explosive (flammable) limit is too "lean" to burn or explode.

Low-Level Waste (LLW) - Radioactive waste not classified as High-Level Waste (HLW), Transuranic (TRU) waste, spent nuclear fuel, or by-product material specified as uranium or thorium tailings and waste.

mJ - Unit of energy, milliJoules.

Mixed Waste - Any radioactive waste that is co-contaminated with RCRA-regulated hazardous wastes as defined in 40 CFR Part 261, Subparts C and D.

Nonflammable Gas - A gas other than a flammable gas.

Oxidizing Material (Oxidizer) - Any compound that spontaneously evolves oxygen either at room temperature or under slight heating. The term includes such chemicals as peroxides, chlorates, perchlorates, nitrates, and permanganates. These can react vigorously at ambient temperatures when stored near or in contact with reducing materials such as cellulosic and other organic compounds.

Propagation of Flame - The spread of flame from the source of ignition through a combustible mixture. A gas or vapor mixed with air in proportions below the lower limit of flammability may burn at the source of ignition, that is, in the zone immediately surrounding the source of ignition, without propagating (spreading) away from the source of ignition. However, if the mixture is within the flammable limits, the flame will spread through it when a source of ignition is supplied. The use of the term "flame propagation" is therefore convenient to distinguish between combustion which takes place only at the source of ignition, and that which travels (propagates) through the mixture.

**Pyrophoric Material** - Any liquid or solid that will ignite spontaneously in air at about 130°F (54.4°C). Titanium dichloride and phosphorus are examples of pyrophoric solids, tributylaluminum and related compounds are pyrophoric liquids. Sodium, butyllithium, and lithium hydride are spontaneously flammable in moist air, as they react exothermically with water. Such materials must be stored in an atmosphere of inert gas or under kerosene. Some alloys (misch metal) are called pyrophoric because they spark when slight friction is applied.

**Reactivity** - A waste exhibits the characteristic of reactivity if a representative sample of the waste has any of the following properties: (1) It is normally unstable and readily undergoes violent change without detonating. (2) It reacts violently with water. (3) It forms potentially explosive mixtures with water. (4) When mixed with water, it generates toxic gases, vapors, or fumes in a quantity sufficient to present a danger to human health or the environment. (5) It is a cyanide- or sulfide-bearing waste which, when exposed to pH conditions between 2 and 12.5, can generate toxic gases, vapors, or fumes in a quantity sufficient to present a danger to human health or the environment. (6) It is capable of detonation or explosive reaction if subjected to a strong initiating source or if heated under confinement. (7) It is readily capable of detonation or explosive decomposition or reaction at standard temperature and pressure. (8) It is a forbidden explosive as defined in the 49 CFR 173.51, or a Class A explosive as defined in the 49 CFR 173.53, or a Class B explosive as defined in the 49 CFR 173.88 DOT regulations.

**Shock Wave** - A compression wave produced by a sudden change in pressure and particle velocity. If the disturbance is small the result is an ordinary sound wave, but if the blow is severe, such as an explosion, the result is a definite atmospheric discontinuity which travels initially with a speed somewhat greater than that of sound.

**Transuranic (TRU) Waste** - Radioactive waste that contains more than 100 nanocuries/gram of alpha-emitting isotopes with atomic numbers greater than 92 and half-lives greater than 20 years. Such wastes result primarily from fuel reprocessing and from the fabrication of plutonium weapons and plutonium-bearing reactor fuel. Generally, little or no shielding is required for Contact-Handled (CH) TRU waste, but energetic gamma and neutron emissions from certain TRU nuclides and fission product contaminants may require shielding or that it be Remote-Handled (RH).

**Upper Explosion (Flammable) Limit [UEL]** - In the case of gases or vapors which form flammable mixtures with air or oxygen, it is the maximum concentration of vapor or gas in air or oxygen above which propagation of flame does not occur on contact with a source of ignition.

**Volatile Organic Compound (VOC)** - Any organic compound which participates in atmospheric photochemical reactions or that are measured by Method 18, 24, 25, or 25A or an equivalent or alternative method as defined in 40 CFR 60.2.