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Basis for Determination of Chemical Stability and Compatibility of Solid Waste

Chemical Compatibility Technical Basis

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

Project Hanford Management Contractor for the
U.S. Department of Energy under Contract DE-AC06-96RL13200

Fluor Hanford

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**Basis for Determination of Chemical Stability and Compatibility of
Solid Waste**

Table of Contents

Basis for Determination of Chemical Stability and Compatibility of Solid Waste.....	i
1 Introduction.....	1
1.1 Background.....	1
1.2 Scope	1
2 Review of Literature and Data Sources	2
2.1 Chemical Incompatibility Schemes	2
2.1.1 Hazardous Waste Regulations – 40 CFR 264, Appendix V	2
2.1.2 Prudent Practices in the Laboratory: Handling and Disposal of Chemicals... ..	2
2.1.3 A Method for Determining the Compatibility of Hazardous Wastes	3
2.1.4 Chemical Hazards Response Information System Manual.....	3
2.2 Compatibility and Reactivity Data Sources.....	3
2.2.1 Material Safety Data Sheets.....	4
2.2.2 Handbook of Reactive Chemical Hazards	4
2.2.3 General Chemical Properties References.....	4
2.2.4 Material Compatibility References.....	4
2.3 Evaluation of Published Compatibility Segregation Schemes	5
3 Evaluation of Chemical Stability	5
3.1 Assumed Conditions of Waste Management.....	5
3.2 Stability of Various Classes of Potentially Unstable Waste.....	6
3.2.1 U.S. Department of Transportation Explosives and Desensitized Explosives	6
3.2.2 Organic Peroxides	7
3.2.3 Peroxidizable Compounds	8
3.2.4 Flammable Solids, Pyrophoric Materials, Flammable Water-Reactives, and Metal Powders.....	10
4 Compatibility Scheme for Multiple Wastes	12
4.1 Description of Incompatibility.....	12
4.2 Major Classes of Chemical Incompatibles	13
4.2.1 Reducer-Oxidizer Incompatibility	15
4.2.2 Acid-Base Incompatibility.....	16
4.2.3 Organic Acid-Inorganic Acid Incompatibility.....	16
4.2.4 Incompatibility of Inorganic Cyanides and Sulfides with Acids.....	16
4.2.5 Various Incompatibility Reactions of Metals and Related Compounds.....	16
4.2.6 Incompatibility of Acidic Water-Reactive Compounds	17
4.3 Incompatibility of other Potentially Unstable Mixtures	17
4.4 Compatibility Review Process.....	18
4.5 Compatibility Segregation Process for Lab Packs	18
4.6 Compatibility of Waste with Containers and Liners	18
5 Summary	19
6 References	20
Appendix A List of Common Chemical Compounds Organized by Stability Hazards and Compatibility Group.....	A-1
Appendix B Chemical Compatibility Scheme Charts.....	B-1

ACRONYMS

BHT	Butylated Hydroxytoluene
CFR	Code of Federal Regulations
CHRIS	Chemical Hazards Response Information System Manual
CWC	Central Waste Complex
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
MSDS	Material Safety Data Sheet
PVC	Polyvinyl chloride
RCRA	Resource Conservation and Recovery Act of 1976
TSD	Treatment, Storage and Disposal
WAC	Washington Administrative Code
WRAP	Waste Receiving and Processing
WSD	Waste Stabilization and Disposition Project
WSRd	Waste Specification Record

GLOSSARY

Chemical compatibility – The ability of two or more materials to exist in close and permanent association with no adverse reactions.

Container compatibility – Container materials selected to prevent significant chemical or galvanic reaction between the container and its contents so that the ability of the container to contain the waste is not impaired.

Dangerous waste – Solid waste designated in WAC 173-303 and regulated as dangerous and/or mixed waste by the Washington Department of Ecology.

Decomposes – Breaks down into simpler substances.

Hazardous waste – Solid waste designated by 40 CFR 261 and regulated as a hazardous waste and/or mixed waste by the U.S Environmental Protection Agency.

Incompatible waste – A dangerous waste that is unsuitable for placement in a particular device or facility because it might corrode or decay the containment materials or is unsuitable for mixing with another waste or material because the mixture might produce heat or pressure, fire or explosion, violent reactions, toxic dusts, fumes, mists, or gases, or flammable fumes or gases.

Inhibitor – A compound that retards or stops an undesired chemical reaction.

Mixed waste - A dangerous, extremely hazardous, or acutely hazardous waste that contains both a non-radioactive dangerous or hazardous component and as defined by 10 CFR 20.1003, source, special nuclear, or by-product material subject to the Atomic Energy Act of 1954 (42 U.S.C. 2011 et seq).

Oxidizer – Any compound that spontaneously evolves oxygen either at room temperature or under slight heating. Oxidizers promote the combustion of other materials. Includes peroxides, chlorates, perchlorates, nitrates and permanganates, hypochlorites, chromates, and halogens.

Peroxidizable – Chemical compounds that can spontaneously react with atmospheric oxygen to form organic peroxides.

Pyrophoric – Any liquid or solid that will ignite spontaneously in air at about 54.4 °C (130 °F).

Radioactive waste – Any garbage, refuse, sludge, and other discarded material, including solid, liquid, semisolid, or contained gaseous material that must be managed for its radioactive content according to DOE orders, NRC regulations or DOT regulations.

Reactivity – Measure of how readily a chemical or compound undergoes violent changes without detonating; reacts violently with water; forms potentially explosive mixtures with water; generates toxic gases, vapors or fumes when mixed with water.

Redox – Short form for the term oxidation-reduction reaction. See oxidizer or reducer.

Reducer – Any compound that will supply fuel in a redox reaction. Reducers are readily ignited in the presence of oxidizers. Includes all organic compounds, metal dusts and shavings, metal hydrides, carbon, ammonia, phosphorus, silica, sulfur.

Solid Waste – A discarded solid, semisolid, or gaseous material not exempted or excluded from regulation.

Stability – Measure of how prone a chemical or compound is to explode, spontaneously react, or to polymerize.

Sublimes – Direct passage of a substance from solid to vapor without appearing in the liquid state.

Unstable - A given chemical compound or solid waste which tends to explode or react violently (including spontaneous combustion) or may become explosive or prone to violent reaction when it degrades over time

Waste Specification Record – A document that identifies the anticipated treatment, storage, and disposal methods to be applied to a given class of waste managed at Hanford Site Treatment, Storage and Disposal units.

Waste Stream – A waste or group of wastes from a process or a facility with similar physical, chemical, or radiological properties.

1 Introduction

Solid wastes must be managed to prevent inadvertent reactions, explosion and degradation of waste containers per the *Washington State Department of Ecology Dangerous Waste Regulations* (WAC 173-303). An understanding of chemical compatibility principles and a consistent approach for implementing compatibility requirements is essential for complying with the regulations.

1.1 Background

A wide variety of solid wastes are generated and managed at the Hanford Site. These wastes may be managed at treatment, storage and disposal (TSD) units on the Hanford Site, and also can be transported to off-site TSD facilities. For each type of facility, the regulations require that waste be managed to prevent reactions, explosions, uncontrolled mixing of incompatible chemicals and degradation of containers by the waste.

Department of Energy (DOE) Order 435.1 requires that each TSD facility that manages mixed wastes maintain waste acceptance criteria. The criteria must address applicable safety and environmental requirements. The Waste Stabilization and Disposition (WSD) Project Acceptance service organization is responsible for incorporating DOE Order 435.1 requirements through HNF-EP-0063 Hanford Site Solid Waste Acceptance Criteria. HNF-EP-0063 sets the baseline criteria for waste acceptance, through a waste stream profile approval process, and through specific exceptions to the acceptance criteria. One of the specific criteria for waste acceptance at TSD facilities is a chemical compatibility review. The compatibility review covers compatibility between chemicals within a waste matrix, between the multiple containers within a lab pack, and between a waste container and the waste it contains.

Waste going to an off-site TSD facility is subject to the chemical compatibility and segregation requirements of WAC 173-303 and to the off-site TSD waste acceptance criteria. The waste is also subject to the transportation chemical compatibility and segregation requirements of 49 CFR.

1.2 Scope

This document explains the technical basis for ensuring chemical compatibility for solid wastes that are stored on site at on-site TSD facilities and for solid waste that will go to off-site TSD facilities. The document applies directly to the following aspects of chemical compatibility:

- Ensuring that hazardous waste is not chemically reactive or unstable such that it cannot be safely transported or stored;
- Ensuring that lab packs (i.e., drums containing multiple inner containers of differing types of hazardous waste) are packaged such that incompatible chemicals are not placed into the same drum;
- Selecting containers and liners that are compatible with the waste they contain.

This document does not cover individual TSD requirements, or specific offsite TSD requirements. This document does not cover chemical compatibility and segregation requirements for shipping wastes on-site or off-site. This document does not cover radiological hazards associated with radioactive waste or mixed wastes. Evaluation of compatibility for comingling and treating solid waste is beyond the scope of this document. In addition, heat generation and gas generation as they apply to the Hanford waste acceptance criteria are not covered in this document.

2 Review of Literature and Data Sources

While no comprehensive text exists on the subject of chemical compatibility, there are a number of valuable resources available to aid in compatibility evaluation. The texts discussed below have been used to varying extents in developing this technical basis.

2.1 Chemical Incompatibility Schemes

Several chemical incompatibility schemes have been published. These typically consist of lists of classes of chemicals that tend to react violently when mixed. These schemes have been developed from general knowledge of chemical reactions along with anecdotal information from chemical accidents. The following is a brief discussion of the major published chemical incompatibility schemes along with general notes on their influence on this document.

2.1.1 Hazardous Waste Regulations – 40 CFR 264, Appendix V

The general TSD facility standards section of the Resource Conservation and Recovery Act of 1976 (RCRA) regulations includes Appendix V to part 264 of Title 40 of the Code of Federal Regulations (40 CFR) that lists groups of incompatible wastes by general chemical class. For example, the appendix lists a group of basic wastes and a corresponding group of incompatible acidic wastes. There are six sets of incompatible wastes listed in the appendix. Appendix V states that it is not an exhaustive list of incompatibilities, and that incompatible chemicals can often be mixed in a manner that prevents uncontrolled or dangerous reactions from happening.

The compatibility segregation scheme developed in Section 4 draws heavily from this reference. In particular, the concept that the majority of chemical incompatibilities can be understood as either acid – base reactions or oxidizer – reducer reactions is fundamental to the approach developed here.

2.1.2 Prudent Practices in the Laboratory: Handling and Disposal of Chemicals

The National Research Council compiled a comprehensive reference on laboratory chemical waste management, *Prudent Practices in the Laboratory: Handling and Disposal of Chemicals* (National Research Council, 1995). This book includes several

useful chapters that identify classes of reactive chemicals and chemical mixtures. Chapter 3 of this reference includes two lists similar to the 40 CFR 264 Appendix V reference:

- Table 3.9 is a Partial list of Incompatible Chemicals
- Table 3.10 is a list of Classes of Incompatible Chemicals.

In addition, appendix B of Prudent Practices in the Laboratory provides Laboratory Chemical Safety Summaries for 88 specific chemicals (or chemical class). The Chemical Safety Summaries include information sections that cover: flammability and explosibility; reactivity and incompatibility; storage and handling.

The compatibility segregation scheme developed in Section 4 draws heavily from this reference. As Section 4 explains, simplifications have been incorporated, but the overall scheme is fully consistent with this reference.

2.1.3 A Method for Determining the Compatibility of Hazardous Wastes

The Environmental Protection Agency document *A Method for Determining the Compatibility of Hazardous Wastes* (Hatayama et al., 1980) is the most comprehensive and detailed reference on the subject of hazardous waste compatibility. It includes a compatibility chart with references to specific lists of chemicals belonging to each compatibility group, background on the type of reactions that occur between incompatible groups of chemicals, and provides references to supporting experimental and anecdotal data.

The compatibility segregation scheme developed in Section 4 draws heavily from this reference. As discussed in Section 3, a number of simplifying assumptions have been made, but the approach is consistent with this document.

2.1.4 Chemical Hazards Response Information System Manual

The U.S. Coast Guard maintains information for emergency responders through the Internet, including the *Chemical Hazards Response Information System Manual* (U. S. Coast Guard, 1999), more commonly known as the CHRIS Manual. The manual includes a compatibility chart for ship cargo and has an extensive list of specific chemical compounds ordered by compatibility group. While it is undoubtedly useful for its intended purpose, the CHRIS Manual has limited application to development of a comprehensive compatibility scheme for hazardous waste because it fails to address a number of important chemical classes, including oxidizers. In addition, its classification scheme is too complex for practical use in hazardous waste segregation.

2.2 Compatibility and Reactivity Data Sources

This section briefly discusses the most useful data sources for evaluation of chemical compatibility and reactivity of specific chemicals.

2.2.1 Material Safety Data Sheets

Material Safety Data Sheets (MSDS) can be a valuable source of information for understanding the reactive properties of a given chemical product and its incompatibilities with other chemical compounds. The vast majority of MSDSs provide at least some information about the reactivity (often under the term “stability”) and incompatibility with other chemicals. The quality and usability of MSDSs varies significantly among chemical manufacturers and suppliers. Two particular problems frequently arise when trying to use MSDSs to determine the compatibility of a mixture of chemicals:

- MSDSs often generalize and overstate the hazards of the product, presumably to avoid potential legal liabilities in the use of the product.
- MSDSs tend to oversimplify reactivity and compatibility hazards. The conditions under which a product might pose a reactivity or compatibility hazard are not always clearly defined. For example, an MSDS might say that a product “explodes when heated”. This statement is too general to be very useful for compatibility review. If the product must be heated to 700 degrees C, it clearly is not a reactivity hazard under normal conditions. On the other hand, if warming it to 40 degrees C causes it to explode, the product clearly poses a severe hazard under normal conditions.

Often, these problems can be minimized by reviewing MSDSs from several manufacturers to gain a broader perspective of the hazards. Some manufacturers produce high-quality MSDSs with consistent definition of the hazards of their products.

2.2.2 Handbook of Reactive Chemical Hazards

The *Handbook of Reactive Chemical Hazards* (Ref.) compiles anecdotal and experimental data on industrial and laboratory reactivity hazards. This is one of the most useful references available for evaluating specific chemicals and mixtures for potential reactivity.

2.2.3 General Chemical Properties References

General chemical references such as the *Merck Index* (Ref.) and the *Condensed Chemical Dictionary* (Ref.) can provide useful chemical property information, but rarely provide detailed reactivity and compatibility data.

2.2.4 Material Compatibility References

A number of manufacturers provide data on compatibility of plastics, metals and other materials with various chemical compounds. This data can be helpful in evaluating the compatibility of containers with different types of materials. Particularly useful references for compatibility of materials can be found on the Cole Parmer web site (<http://www.coleparmer.com/techinfo/ChemComp.asp>) and the Nalgene Company technical data web site (<http://nalgene.com>).

2.3 Evaluation of Published Compatibility Segregation Schemes

In general, the previously above listed literature and data sources provide useful general knowledge on chemical reactions. While there are many lists of hazardous chemicals, either the compatibility information is generalized and the hazards overstated or the reactivity information is oversimplified. Most chemical reactivity information is based on one-to-one chemical reactions, single chemicals or unused chemical products that are easily segregated. Reactivity information for containers appears to be based on short-term storage of single chemicals stored under laboratory conditions. No single one scheme covers the complexity of chemical compatibility as it applies to solid wastes managed on the Hanford Site.

3 Evaluation of Chemical Stability

Since no single published compatibility segregation scheme covers the wastes managed at Hanford, a compatibility segregation scheme has been developed through this document. Sections 3 and 4 of this document describe the rationale behind the compatibility review process used for solid waste storage and off-site transportation. There are three major components of the review process. First, waste must be determined to be sufficiently stable so that it would not explode or spontaneously react under the anticipated conditions of management of the waste. Second, when multiple wastes are packaged together (e.g., in a lab pack), the wastes must be determined to be compatible so that it would not undergo hazardous reactions should two or more wastes come in contact with one another. Third, the containers and liners used for packaging must be compatible with the waste.

The first portion of the compatibility review process evaluates whether the waste will be stable under the anticipated waste management conditions. In this section, we will discuss the assumed conditions of waste management and the types of solid waste that could pose stability problems. For each type of potentially unstable waste, the general criteria for determining acceptability are presented. Section 4 will cover compatibility of multiple wastes including lab packs and the compatibility of waste with containers and liners.

3.1 Assumed Conditions of Waste Management

There are two typical scenarios for management of solid waste prior to disposal. Non-radioactive solid waste typically is transported directly off-site to a commercial TSD facility. Often, the waste will be transloaded or commingled with other wastes and sent to another TSD facility for treatment and disposal. For the majority of solid waste, the Federal Land Disposal Restrictions regulations of 40 CFR 268 place a one-year storage time limit. Storage of non-radioactive hazardous waste beyond one year occurs only in the unusual case where there is inadequate treatment capacity for that type of waste. For non-radioactive solid waste, then, the waste must be shown to be stable during transportation and short-term storage.

Hanford mixed waste is transported from the generator to the CWC for extended storage until treatment capacity becomes available. Occasionally mixed waste may be

temporarily stored at T Plant or WRAP. There are many uncertainties regarding the availability of treatment capacity for the various mixed waste streams. As a result, we assume that storage could last for up to 20 years (see HNF-EP-0063) prior to either shipment to an off-site TSD facility or treatment at a Hanford Site facility.

The CWC provides indoor storage without temperature control. Temperatures inside the buildings can range from below 0 degrees F to over 120 degrees F. Under these conditions, it can be assumed any waste container that is not tightly sealed or is vented will "breathe," allowing volatile components of the waste out of the primary container as the temperature rises and allowing air into the primary container as the temperature falls. In some cases, tightly sealed inner containers (particularly glass containers) could rupture when the pressure increases due to high temperatures.

The assumed conditions of extended storage time and lack of temperature control for mixed waste stored on site requires a more rigorous stability evaluation process than for solid waste that is transported off-site for near-term treatment and disposal. In some cases, chemical products that can be transported off site for treatment near-term without any special measures to ensure stability might require treatment to ensure stability during extended storage at CWC. These situations will be discussed in more detail in the following sections.

NOTE: Most potentially unstable wastes are essentially pure discarded chemical products. Ordinarily, these products should have little or no radiological contamination and should be radiologically released (i.e., determined to be below radiological limits) in accordance with HNF-EP-0063. Due to the unusual hazards of potentially unstable chemical products, every reasonable effort should be made to radiologically release these products instead of placing them into extended storage at CWC.

3.2 Stability of Various Classes of Potentially Unstable Waste

This section discusses the reactivity hazards of the major classes of waste that could be unstable during transportation and storage conditions. The bases for evaluation of each class of waste are described.

For chemical compatibility use of the term "unstable" means that a given chemical compound or solid waste tends to explode or react violently (including spontaneous combustion) or may become explosive or prone to violent reaction when it degrades over time. The term "unstable" is not synonymous with the dangerous waste characteristic of reactivity in WAC 173-303. The characteristic of reactivity spans a broader range of hazards, which includes reactivity with water and release of toxic gases, vapors and fumes.

3.2.1 U.S. Department of Transportation Explosives and Desensitized Explosives

The group generically describes chemical compounds that meet the definition of Hazard Class 1 (49 CFR 173.50) and Class Division 4.1 – Desensitized Explosives (49 CFR 173.124(a)(1)). These materials are generally relatively pure chemical products used for their explosive properties or are laboratory reagent chemicals that happen to

possess explosive properties. An example of this type of material at the Hanford Site are the polynitroaromatic compounds used in very small amounts in Hanford laboratory facilities as reagents (e.g. Picric acid, 2,4-Dinitrophenylhydrazine).

The stability of an explosive or unstable compound refers to how strong an initiating force (i.e., activation energy) is required to cause it to react. Stable explosives require a strong initiating force, such as a blasting cap. Unstable explosives react with little or no initiating force. The stability of these compounds for direct shipment to off-site TSD facilities is ensured by meeting the specific U.S. Department of Transportation (DOT) shipment requirements provided in 49 CFR. In most cases, this involves desensitizing the materials by the addition of water or another wetting agent to meet the Division 4.1 definition. Under special conditions, a material might be shipped as Class 1 material using the specified packaging configurations required under 49 CFR. In no case may a DOT-Forbidden material be transported on-site or off-site. See the Hazardous Materials Table at 49 CFR 172.101 Column 3 to determine if a material is forbidden.

NOTE: Off-site TSD facilities might have additional requirements for desensitization or packaging of these materials.

Extended storage of DOT Explosives and Desensitized Explosives at CWC, WRAP or T Plant may not be authorized. Storage conditions at these facilities are not conducive to maintaining these materials in a stable form. For example, the temperature cycling at CWC could tend to allow desensitized explosives, such as wetted picric acid, to dry out to an unstable condition.

DOT Explosives and Desensitized Explosives may be present in a waste in a concentration sufficiently low to no longer meet the definition of Class 1 or Class Division 4.1. In these cases, extended storage could be allowed with an evaluation of the total quantity of the compound and the probability of the waste evaporating and leaving dry, concentrated explosive. For example, a liter of 0.2 weight percent picric acid would contain only 2 grams of picric acid, which would pose a minor hazard even in dry form. If stored in a tightly sealed, unbreakable plastic container, it is not credible to expect that the water could evaporate to dryness even under CWC storage conditions. Evaluation results shall be clearly documented in the acceptance review paperwork.

NOTE: See Appendix A.1 for a partial list of compounds classified by DOT as Class 1 or Class Division 4.1 that have been or are in products and wastes on the Hanford Site. Check 49 CRF for exact description.

3.2.2 Organic Peroxides

Organic peroxides are organic compounds containing oxygen in the chemical form R-O-O-R or R-O-O-H, where R represents any organic radical. Organic peroxides are produced commercially, primarily as catalysts for curing resins. Organic peroxides can also form spontaneously in certain chemicals due to exposure to oxygen. Such inadvertently formed organic peroxides are addressed in Section 3.2.3.

The DOT regulations group organic peroxides into Hazard Class Division 5.2, which is defined in 49 CFR 173.128. In most cases, organic peroxides must be mixed with a diluent such as water, silicone oil, or alcohol to meet Class Hazard Division 5.2; in the absence of diluent, they are DOT Forbidden materials. Organic peroxides that are DOT Forbidden should be considered potentially explosive. Appendix A.2 provides examples of organic peroxide found on the Hanford Site include Methyl ethyl ketone peroxide, Benzoyl peroxide and tert-Butyl hydroperoxide.

Evaluation of the stability for organic peroxides is almost identical to that for explosives and desensitized explosives. For shipment to off-site TSD facilities, stability evaluation consists of ensuring that the concentration of organic peroxide in the material and the packaging configuration meet the applicable requirements of 49 CFR 173.225.

Extended storage of organic peroxides at CWC, WRAP or T Plant is not appropriate. Under improper storage conditions, the concentration of organic peroxide can increase to a dangerous condition. Storage conditions are not conducive to maintaining these materials in a stable form. Organic peroxides are not generally found in low concentrations in waste streams, as they are ordinarily consumed as they are used to catalyze resins. In the event that a radioactive waste stream contained dilute organic peroxide, it is most appropriate to destroy the organic peroxide with a reducing agent prior to storage.

3.2.3 Peroxidizable Compounds

Certain classes of chemical compounds can spontaneously react with atmospheric oxygen to form organic peroxides as contaminants, a phenomenon known as autoxidation. These organic peroxides tend to be far less stable than commercially manufactured organic peroxides. Given sufficient time, some of these "peroxidizable" compounds can develop a sufficient concentration of organic peroxides to be dangerous. Two particular types of hazards have been observed (National Research Council, 1983):

- Certain volatile organic compounds (e.g., ethers) may form organic peroxides and subsequently evaporate, leaving a highly concentrated organic peroxide residue. These residues can be highly shock-sensitive and detonate with considerable force.
- Certain organic monomers (e.g., styrene) may form organic peroxides, which, when they reach some critical concentration, catalyze a polymerization reaction. Often such reactions are relatively harmless, slowly hardening the monomer. Occasionally, however, the polymerization may occur rapidly and with evolution of considerable heat. While these reactions do not result in fire or explosion, the heat and fumes released can be hazardous to human health or the environment.

There are a number of organic compounds that have been reported to form peroxides, but explosive or otherwise dangerous peroxides do not seem to form under normal conditions. Compounds included in this group include Methyl ethyl ketone, Methyl isobutyl ketone and Isopropyl alcohol.

Alkali metals and certain related water-reactive inorganic compounds also form potentially shock-sensitive peroxides. However, the greater hazard of these inorganic compounds lies in their flammability and water reactivity. Evaluation of the compatibility of these compounds is described in Section 3.2.4 below.

Appendix A.3 provides examples of common peroxidizable compounds that have been or are in products on the Hanford Site. The upper portion of the table includes compounds that form potentially explosive peroxides. The lower portion of the table includes compounds that can rapidly polymerize from peroxide formation.

A number of factors affect the rate at which organic peroxides may form in chemical compounds that are amenable to autoxidation and the relative hazards posed by those compounds. The following is a brief discussion of the most important of these factors.

- Chemical structure. *Prudent Practices* (Ref.) describes the chemical structures that are amenable to autoxidation, including the relative order of hazard. For example, cyclic ethers and those containing primary and secondary alkyl groups readily peroxidize, while secondary alcohols and certain ketones present a much lower hazard. Chemical structure also determines the type of hazard presented by peroxidization. As described previously, organic peroxides in some organic compounds catalyze a polymerization reaction before any explosive hazard can develop.
- Volatility. For those peroxidizable compounds that do not polymerize, volatility profoundly affects the level of hazard for extended storage. Highly volatile compounds, such as diethyl ether, can easily evaporate under storage conditions, especially at elevated temperatures with poorly sealed containers. Evaporation concentrates the non-volatile organic peroxides, eventually leaving an unstable solid organic peroxide residue. Conversely, low-volatility peroxidizable compounds and chemical products that contain low or non-volatile components pose a reduced hazard of formation of concentrated peroxide residues. An example of the latter is certain polyvinyl chloride (PVC) pipe glues that contain tetrahydrofuran as a primary solvent. The product also contains a large percentage of a non-volatile resin. Should the tetrahydrofuran completely evaporate, a substantial volume of solidified resin would remain without forming concentrated peroxide residues.
- Oxygen. Oxygen is required for autoxidation. Compounds that are stored in completely sealed bottles, such as ampoules, will not form peroxides. However, once a bottle is opened, air provides the required oxygen for peroxidization to begin. As a practical matter, few containers are completely air-tight, especially under fluctuating temperature conditions where the internal pressure increases and decreases, allowing air to enter the container as it cools.
- Light. Light apparently is effective in providing activation energy for the peroxidation reaction. Some of the most severe explosions involving peroxide formation have occurred when peroxidizable reagents were stored in clear glass bottles in bright sunlight. Peroxidizable compounds that have been stored under these conditions for an extended period of time should be considered potentially

unstable. Conversely, the normal condition for transportation and storage of hazardous waste excludes light, somewhat mitigating the hazard of autoperoxidation.

- **Inhibitors.** Many peroxidizable reagents are stabilized by the addition of antioxidant inhibitors, such as BHT (a generic name for compounds such as 2,6-di-*t*-butyl-4-methylphenol) and hydroquinone. These inhibitors retard the formation of organic peroxides until they are consumed by reaction with free oxygen. Large amounts of inhibitors can be added to peroxidizable chemicals to reduce the autoperoxidation hazard during extended storage.

To ensure the stability of waste for shipment to an off-site TSD facility, peroxidizable compounds should be evaluated for potential peroxide formation. At a minimum, a visual evaluation should be performed to identify whether solid residues are present in the material (which could indicate the presence of organic peroxides), and if the material has evaporated too much less than its original volume. If either solid residue is identified or evaporation (nominally to less than 10% of the original volume) has occurred, the container should be considered potentially explosive. In these cases, qualified personnel will perform testing of the material with peroxide test strips or another approved method to determine the stability of the material.

Extended storage of compounds that form explosive organic peroxides should be avoided whenever possible. The storage conditions at CWC could allow formation of significant peroxide concentrations and evaporation to dryness, leaving a shock-sensitive residue. When no other option is available, peroxidizable chemicals can be treated using a combination of reducing agents (e.g. ferrous sulfate), inhibitors (e.g. BHT), and low-volatility diluents (e.g. water, kerosene) to allow safe storage.

Compounds that may polymerize can be stored at CWC with treatment to inhibit peroxide formation. Addition of a large excess (gram quantities) of an organic inhibitor, such as BHT or hydroquinone, is considered sufficient to prevent a polymerization hazard even in extended storage.

3.2.4 Flammable Solids, Pyrophoric Materials, Flammable Water-Reactives, and Metal Powders

Flammable solids are a broad classification of material that include wetted explosives, pyrophoric materials, water reactive materials, metal compounds, certain reactive metals, and some non-metal materials. Explosives were covered in Sections 3.2.1.

Pyrophoric materials are liquids or solids that ignite spontaneously in air at 130 degrees F. The most common pyrophoric materials include phosphorus (white or yellow), and many organometallic compounds such as cobalt naphthenate and butyllithium. Phosphorus is generally packaged under water, which prevents ignition. Pyrophoric organometallic compounds are packaged either in metal cylinders under inert gas or dissolved in an organic solvent and capped with a septum to prevent intrusion of air and subsequent ignition. Organometallic compounds are extremely uncommon on the Hanford Site.

The alkali and alkaline earth metals, many other metal powders, and strong reducing compounds of metals (e.g., hydrides, amines) are ordinarily not considered to be pyrophoric, but can pose similar hazards depending on their physical form and method of storage. The alkali metals are typically packaged under oil to prevent oxidation and ignition while the alkaline earth metals can be packaged dry as large pieces or ribbon.

The hydrides (e.g. potassium hydride, lithium aluminum hydride, sodium borohydride), and amines of alkali metals pose similar hazards to the metals themselves, releasing hydrogen gas and often igniting when contacted with water.

Nearly all metals can be flammable when in very fine powder form. They are not truly pyrophoric when packaged in a dry state, but pose a severe flammability hazard. For example, both Aluminum and Titanium in wire, foil, shot or plate form do not burn. However, Aluminum dust could form flammable or explosive mixtures with air, especially when damp and Titanium dust in the absence of oxygen, such as under water, can ignite.

Non-metal materials with flammable properties are found in products used on the Hanford Site. Compounds of this type include camphor, naphthalene, nitrocellulose and calcium carbide. Camphor and naphthalene are organic solids that sublime slowly at room temperature and have flashpoints of 150 degrees F and 176 degrees F respectively. Nitrocellulose is a solid with a flashpoint of 55 degrees F. It is less flammable when kept wet. It can become explosive or form peroxides over time if it dries. Calcium carbide decomposes in water with formation of flammable acetylene gas, calcium hydroxide and heat, and thus poses an ignition hazard.

Any of these materials can be transported to off-site TSD facilities as long as they are packaged in accordance with the 49 CFR regulations and the TSD facility can accept these types of waste. The packaging configurations for these materials are specifically called out in the 49 CFR regulations, generally under DOT Division 4.2 or 4.3. Typically, packaging of pyrophoric materials requires an inert atmosphere and hermetically sealed packaging.

Long-term storage of these materials is undesirable and reasonable efforts should be made to radiologically release them instead of storage in the CWC or elsewhere. Inorganic peroxidizable compounds with apparent peroxide residues should be handled as if they are explosive. As a rule, the stability of these classes for extended storage is as follows.

- True pyrophoric compounds should not be accepted for extended storage. The safety of these compounds is entirely dependent on maintaining the integrity of the packaging over a long period of time, which cannot be reasonably assured.
- Alkali metals, alkaline earth metals, and metal hydrides and related water-reactive flammable compounds can be stored in the Alkali Metal Storage modules of CWC, which were designed for the specific hazards of these compounds. The

packaging of these materials must meet the specific requirements of 49 CFR for the applicable Division 4.2 or 4.3. Additionally, alkali metals should be packaged under oil, although other packaging configurations that prevent oxidation could be allowed on case-by-case review. Other materials must be stored in durable, tightly sealed packages. Additional packaging may be required depending on TSD acceptance procedures.

- Metal powders that are not water-reactive can be stored either in the Alkali Metal Storage modules or in the Low Flashpoint Flammable Liquid modules of CWC. They must be stored in durable, tightly sealed packages.

NOTE: Examples of pyrophoric materials and flammable solids that have been or are in Hanford wastes are listed in Appendix A.4. Appendix A.5 provides examples of water-reactive metals and related compounds that have been in or are on the Hanford Site.

4 Compatibility Scheme for Multiple Wastes

This section continues the evaluation of chemical stability started in Section 3 and describes the major types of incompatibility encountered during the management of solid waste and explains the basis for the compatibility review process described in Section 4.4.

4.1 Description of Incompatibility

Incompatibility is a somewhat subjective term that relates to undesirable reactions that could occur if two or more wastes are mixed together. WAC 173-303-040 defines incompatible waste as follows.

“Incompatible waste” means a dangerous waste which is unsuitable for placement in a particular device or facility because it may corrode or decay the containment materials, or is unsuitable for mixing with another waste or material because the mixture might produce heat or pressure, fire or explosion, violent reaction, toxic dusts, fumes, mists or gases, or flammable fumes or gases.

The first half of the definition refers to how waste interacts with containers, tanks, landfill liners, etc., which is not the subject of this section. The second half refers to the interaction between dissimilar waste types. These can be categorized into several broad groups of reaction outcomes that constitute incompatibility.

- Generation of heat or pressure
- Fire or explosion
- Violent reaction
- Generation of toxic dusts, fumes, mists or gases
- Generation of flammable fumes or gases.

Note that the first three classes generally refer to immediate, violent consequences of interaction. The last two classes involve generation of gaseous or other airborne products that pose a potential hazard, either due to toxicity or to flammability of the materials produced.

The qualitative nature of this definition raises significant difficulties in assessing whether two wastes are incompatible. Some mixtures, such as sodium metal and water, are violently reactive, unsuitable for mixing under essentially any circumstances. Other mixtures, however, may be unsuitable for mixing in certain situations, but pose little hazard in others. Concentrated sulfuric acid, for example, generates heat when mixed with water. This reaction ordinarily is not unacceptably violent. In an unvented containment vessel, however, sufficient pressure could be generated to cause a serious hazard. Professional judgment is required in assessing whether a mixture poses a significant hazard under the expected waste management conditions.

4.2 Major Classes of Chemical Incompatibles

The previous sections relate to individual chemical compounds that are potentially unstable. It is also possible for mixtures of incompatible chemical compounds to become unstable. The vast majority of chemical incompatibilities result from two types of exothermic chemical reactions: reducer-oxidizer (redox) reactions and acid-base reactions. A general understanding of redox reactions, acid-base reactions, and a handful of other chemical reactions provides the framework for the chemical compatibility evaluation process. The type and severity of the reaction is dependent on the strength of the oxidizer and reducer, the physical state of the mixture, and various other factors. These major reactions are summarized in Table 1 and discussed in the following subsections.

Under certain conditions, mixing incompatible chemicals may not produce any immediate reaction, but over time can form unstable byproducts. In a long-term storage situation slow decomposition may not be noticed. If the evolved heat and gases are confined, an explosive situation can develop. For instance, inorganic peroxides are generally stable but they may generate organic peroxides and hydroperoxides in contact with organic compounds. In another instance, the presence of catalyzing acids, bases or by-product contaminants in the waste can cause the explosive polymerization to occur.

Long-term storage of these materials is undesirable and every reasonable effort should be made to radiologically release them instead of storage in the CWC or elsewhere. Any of these materials can be transported to off-site TSD facilities as long as they are packaged in accordance with the 49 CFR regulations and the TSD facility can accept these types of waste. The packaging configurations for these materials are specifically called out in the 49 CFR regulations.

Table 1. Major Classes of Incompatible Chemicals

Type of Reaction	Potential Hazards	Group 1 is incompatible with...	Group 2
Oxidizer-reducer reaction	Fire, explosion, heat, shock-sensitive impurities	Oxidizers: <ul style="list-style-type: none"> • Oxidizing acids (e.g. nitric, perchloric acids) • Hydrogen peroxide (esp. >30%) • Oxidizing salts (e.g., nitrates, permanganates, chlorates) 	Reducers: <ul style="list-style-type: none"> • All organic compounds • Metals • Other inorganic reducing agents
Acid-base reaction	Heat, pressure	Strong acids: <ul style="list-style-type: none"> • Mineral acids (e.g., sulfuric, nitric, hydrochloric acids) • Organic acids (e.g., formic, acetic, oxalic acids) • Certain metal halides (e.g., ferric chloride, stannic chloride) 	Strong bases: <ul style="list-style-type: none"> • Alkali metal oxides and hydroxides • Amines (e.g., trimethylamine) • Ammonia and quaternary ammonium hydroxide compounds
Cyanide and sulfide-acid reaction	Toxic gases	Acids and acidic solutions (see examples above)	<ul style="list-style-type: none"> • Inorganic cyanides • Inorganic sulfides
Reactions of metals (various)	Heat, fire, flammable gas, explosion	<ul style="list-style-type: none"> • Reactive (alkali and alkaline earth metals) • Metal hydrides and similar compounds • Calcium carbide • Other metals in finely divided form 	<ul style="list-style-type: none"> • Water • Acids • Bases • Halogens • Halocarbons
Acidic water-reactive compounds	Heat, pressure, toxic gases	<ul style="list-style-type: none"> • Acid halides (e.g., thionyl chloride, acetyl chloride) • Acid anhydrides (e.g., acetic anhydride, phosphorus pentoxide) • Certain metal and non-metal halides (e.g., titanium tetrachloride, phosphorus trichloride) 	<ul style="list-style-type: none"> • Water • Bases

4.2.1 Reducer-Oxidizer Incompatibility

Reactions between reducing and oxidizing chemical compounds are probably the most common and dangerous of the chemical incompatibilities. Uncontrolled redox reactions can lead to ignition or explosion of waste mixtures. Many industrial and laboratory explosions have occurred from the inadvertent or uncontrolled mixing of reducers and oxidizers during waste management activities.

A variety of definitions of the term “oxidizer” exist. From a hazardous materials standpoint, the DOT definition in 49 CFR 173.127 is most useful:

Oxidizer means a material that may, generally by yielding oxygen, cause or enhance the combustion of other materials.

Oxidizers can react with any compound that can ignite or supply fuel in a reaction (which is a good working definition of a reducer). Reducers include all organic compounds, as well as metals (particularly when in powdered form) and other inorganic reducing agents. Several factors are important in assessing the compatibility and hazards of mixing oxidizers and reducers.

- Inherent strength of the oxidizer and reducer
- Concentration of the oxidizer and reducer
- The pH of aqueous solutions.

There is a spectrum of strengths of oxidizers, ranging from very powerful oxidizers such as perchloric acid to relatively mild oxidizers such as potassium persulfate. Even water can act as an oxidizer to very strong reducers (e.g., sodium metal). The DOT regulations include a series of engineering tests to assign packing groups according to the strength of oxidizers (49 CFR 173.127).

Concentration is the amount of the oxidizer or reducer in the mixture. Concentration has a major effect on all reaction rates. Concentrated oxidizing agents are incompatible with concentrated reducing agents. Either may pose a reactive hazard with chemicals that are not strongly oxidizing or reducing. The magnitude of the risk depends on the quantities of the oxidizer – reducer available. Mixtures that may react violently in concentrated form will be innocuous when sufficiently dilute. As a rule of thumb: most oxidizers in concentration of less than 10 % have little effect on reaction rates in organics.

The pH of aqueous solutions is the measure of the concentration of hydrogen ion or hydroxyl ion that results from ionization of a scale of 1 (acidic) to 14 (basic), with 7 being neutral. Strong acids such as hydrochloric, nitric and sulfuric acids highly ionize in water. Strong acid solutions have pH values from 1-3. Weak acids include acetic and carbonic acid because they do not ionize well in water. Weak acids have pH values of 4-6. Strong bases such as sodium or potassium hydroxide highly ionize in water. They have pH values between 12-14. Weak bases such as ammonium hydroxide have pH values from 8-12.

NOTE: Examples of oxidizers found on the Hanford Site are listed in Appendix A.6. Appendix A.7 provides examples of reducers.

4.2.2 Acid-Base Incompatibility

Acids-base reactions are exothermic. The reaction of concentrated acids and bases can generate a large amount of heat with consequent buildup of pressure when the mixture is confined. Acid-base reactions ordinarily are not explosive, nor do they result in ignition of the mixture.

The heat generated by acid-base reactions is directly proportional to the concentration of the acid and base. It is common among environmental professionals to think in terms of solution pH, with the general rule of thumb that solutions with a pH of 2 or less being strongly acidic and solutions with a pH of 12.5 or more being strongly basic. While this is generally true, it can be misleading with respect to the heat produced in reaction. For example, concentrated sulfuric acid (roughly 18 molar) and 2 molar sulfuric acid both have pH of < 2 , but the concentrated sulfuric acid is nearly 2000 times as concentrated as the 2 molar sulfuric acid solution. The heat of neutralization of the 2 molar solution is correspondingly much lower than that of the concentrated acid.

NOTE: Examples of acids or acidic compounds can be found on Appendix A.8. Appendix A.9 provides examples of bases.

4.2.3 Organic Acid-Inorganic Acid Incompatibility

The incompatibility between an inorganic acid and an organic acid should be evaluated on a case-by-case base. Weak inorganic acid will have little or no reaction hazards when mixed with an organic acid. However, the reaction of a strong metallic acid or oxidizing acid with an organic acid is quite different. The organic acid acts as a base or the reducing agent of a redox reaction. The result of mixing a strong acid with an organic acid may include heat generation, violent sputtering, and/or formation of toxic and flammable gases, fire or explosion.

4.2.4 Incompatibility of Inorganic Cyanides and Sulfides with Acids

Inorganic cyanides, inorganic sulfides, and certain chlorine-containing compounds release toxic gases under acidic conditions. When acidified, the cyanide ion is converted to hydrogen cyanide, a highly toxic gas. Similarly, the sulfide ion reacts with acid to form highly toxic hydrogen sulfide gas. Organic cyanide compounds (i.e., nitriles) and organic sulfide compounds (i.e., thiols or mercaptans) are quite stable and do not release hydrogen cyanide or hydrogen sulfide when mixed with acids.

NOTE: Appendix A.10 provides examples of inorganic cyanides and sulfides found in products used on the Hanford Site.

4.2.5 Various Incompatibility Reactions of Metals and Related Compounds

Metals in non-ionic form present a number of special incompatibilities. There is significant variation among metals in their general reactivity, ranging from the highly reactive alkali and alkaline earth metals to relatively inert metals. In general terms, the

more reactive metals pose compatibility problems in any physical form, while less-reactive metals present problems only when in a finely divided granular or powder form.

The alkali metals (most common are sodium, potassium, and lithium) and some of the alkaline earth metals (particularly barium, strontium and calcium) are very strong reducing agents. They vary in reactivity, with cesium, potassium, sodium and lithium being violently water-reactive, while strontium, calcium, magnesium and barium are relatively stable unless in a finely-divided powder or dust form. They are readily oxidized by a variety of materials including water. The reaction with water generates a large amount of heat and liberates hydrogen gas. With the alkali metals, the heat of reaction can cause the metal to ignite and sometimes causes it to explode.

There are varieties of other inorganic reducing agents that exhibit similar behavior. These include the following chemical classes.

- Metal hydrides (e.g., sodium hydride, lithium aluminum hydride) react with water in much the same manner as alkali metals, producing heat, hydrogen gas, fire and possible explosion.
- Borohydrides (e.g. sodium borohydride) are relatively stable in basic solution, but at neutral to acidic pH liberate hydrogen gas.
- Calcium carbide and metal acetylides liberate acetylene gas from contact with water.

4.2.6 Incompatibility of Acidic Water-Reactive Compounds

A relatively complex group of organic and inorganic compounds react violently with water, generating heat, pressure and, at times, toxic gases. This group of compounds includes the following.

- Anhydrous inorganic acids and acid halides, including aluminum trichloride, titanium tetrachloride, thionyl chloride, & phosphorus oxychloride
- Nonmetal halides, including boron trichloride and silicon tetrachloride
- Low molecular weight organic acid anhydrides and halides, including acetic anhydride & acetyl chloride
- Halosilane compounds, including dichlorosilane.

NOTE: Appendix A.11 provides examples of acidic water-reactive compounds that have been or are in products on the Hanford Site.

4.3 Incompatibility of other Potentially Unstable Mixtures

There are many potentially unstable mixtures covered in the *Prudent Practices in the Laboratory* (Ref.) and in *The Handbook of Reactive Chemical Hazards* (Ref.). Individual mixtures should be researched via these references and MSDSs for incompatibility, stability, polymerization, decomposition, and sublimation information.

4.4 Compatibility Review Process

As stated in Section 1 hazardous wastes must be managed to prevent inadvertent reactions, explosion and degradation of waste. This section attempts to provide a consistent approach for implementing the compatibility review process essential for complying with safe storage and transportation regulations.

The compatibility review process covers compatibility between chemicals within a waste matrix, compatibility of chemical products within a lab pack, and to determine compatibility of containers with the waste they contain. The two assumed conditions against which stability of chemical, product, and containers are measured is the possibility of storage lasting for 20 years and the lack of a temperature-controlled environment. The process should be applied to products prior to lab packing, and may help determine the appropriate Waste Specification Record application. This section covers the chemical waste. Section 4.5 covers the compatibility segregation process for lab packs. Section 4.6 covers the compatibility of waste with containers.

The compatibility review process starts once the waste has been designated per WAC-173-303. Wastes are separated by their characteristic dangerous waste codes. Individual waste products classified as DOT Explosives, Organic peroxides, and Pyrophoric or Flammable solids are handled according Sections 3.2.1, 3.2.2 and 3.2.4 respectively. Individual waste products designated with other characteristic dangerous waste codes are evaluated for stability, and peroxidizability (Section 3.2.3).

Waste mixtures are evaluated for stability within the waste matrix. The Chemical Compatibility Matrix Chart in Appendix B.1 is used to place matrix constituents into groupings to help determine reactions that might occur within the matrix. Additional information used in the review process includes the resources listed in Section 2, container inventory sheets, sampler logbooks, and process notes. Reaction considerations include the amount of material likely to peroxidize, oxidizer to reducer ratio, flammable constituent to non-flammable constituent ratio, and acid to base ratios.

4.5 Compatibility Segregation Process for Lab Packs

When a waste container holds several distinct waste types (e.g., a lab pack), each waste item must be compatible with the other waste items in the container so they do not react with one another or pose a hazard during transportation and storage. Each waste item is evaluated first per the compatibility review process in Section 4.4. Next, each pair of items is evaluated per the reaction pairs described in Section 4 and Table 1. An item found to be reactive is removed and packaged separately or with like material.

4.6 Compatibility of Waste with Containers and Liners

Under WAC 173-303 and HNF-EP-0063, containers must not be degraded by the waste they contain. Container compatibility includes inner containers in lab packs, liners, and outer containers. Inner containers, liners and outer containers can function individually or together to provide a compatible package. Liners and outer containers shall be consistent with HNF-EP-0063.

Ideally, containers supplied by chemical product manufacturers should be compatible with the materials they contain. This is not always the case. Manufacturers do not take into account that their product may be in the container for 20 years or that the material may be in an uncontrolled environment.

Some products are taken from their original container and placed in secondary containers for ease of use or to reduce contamination possibilities. These secondary containers work well for the short term but not necessarily for long-term waste disposal. For example solvents attack plastic containers; oxidizing acids (i.e. nitric acid) make plastic containers brittle. Acids and some bases attack metal containers.

The compatibility of the waste material with the container should be checked when used as inner containers in a lab pack. References for container compatibility include the Container Compatibility Matrix provided in Appendix B.2, manufacturer's compatibility tables, or in the corrosion resistance tables on the web sites provided in Section 2.2.4.

5 Summary

Hanford wastes must be managed to prevent inadvertent reactions, explosion and degradation of waste containers per WAC 173-303, DOE Order 435.1, and HNF-EP-0063. One of the specific criteria for managing waste is a chemical compatibility review. The compatibility review covers compatibility between chemicals within a waste matrix, between the multiple containers within a lab pack, and between a waste container and its contents.

There are a number of valuable resources available to aid in compatibility evaluation but no comprehensive text covers the wastes managed at Hanford. A compatibility segregation scheme has been developed through this document to provide a consistent approach for implementing the compatibility review process. There are three major components of the review process. First, the compatibility review process covered in Section 4.4 is used to determine if the waste is sufficiently stable so that it would not explode or spontaneously react under the anticipated conditions of management of the waste. Second, the compatibility segregation process for lab packs in Section 4.5 is used to determine when multiple wastes are compatible and can be packaged together. Third, Section 4.6 provides information for the compatibility of wastes with containers and liners.

6 References

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Appendix A
List of Common Chemical Compounds Organized by Stability Hazards
and Compatibility Group

A.1 Explosives

Example of DOT Class 1 and Division 4.1 compounds (See 49 CFR for details)		
Aluminum powder, coated Ammonium nitrate Ammonium perchlorate Ammonium picrate Cobalt naphthenate Dinitrophenol	Hafnium Powder, wetted Hexolite or Hexotol Mercury fulminate Naphthalene, molten Nitrocellulose Nitronaphthalene	Picric acid or Trinitrophenol Sulfur powder Titanium hydride Titanium powder Trinitrobenzene Trinitrotoluene Zirconium powder

A.2 Organic Peroxides

Examples of organic peroxides found in products on the Hanford Site	
Benzoyl peroxide tert-Butyl hydroperoxide tert-Butyl peroxybenzoate Chloroethylene Cumyl hydroperoxide Cyclopentadiene Di-tert-Butyl peroxide 1,1-Dichloroethylene Diethylether	6,6-Dimethylfulvene Lauroyl peroxide Methyl ethyl ketone peroxide Methyl methacrylate Peroxoacetic acid Styrene Tetrafluoroethylene Vinylacetate

A.3 Peroxidizable Compounds

Compounds that form potentially explosive peroxides:		
Diethylacetal	Dicyclopentadiene	Furan
1,3-Butadiene	Diethylether	Glycoldimethylether
Cumene	Diglyme	Methyl butyl ketone
Cyclohexene	Diisopropyl ether	Methylcyclopentane
Cyclopentene	Acrylaldehyde	
Decahydronaphthalene	1,4-Dioxane	Tetrahydrofuran
1,1-Dichloroethylene	Vinyl ether	Tetrahydronaphthalene
Monomers that can rapidly polymerize from peroxide formation:		
Acrylic acid	1,1-Dichloroethylene	Vinylacetate
Acrylonitrile	Methyl methacrylate	Chloroethylene
1,3-Butadiene	Styrene	4-Vinyl pyridine
Chloroprene	Tetrafluoroethylene	

A.4 Pyrophoric Materials, Flammable Solids

Pyrophoric Materials and Flammable Solids	
Aluminum dust	Iron (III) oxide
Ammonium picrate	Magnesium
Amorphous Carbon	Naphthalene
Beryllium	Nitrocellulose
Butyllithium	Phosphorus
Calcium	Phosphorus pentasulfide
Calcium resinate	Sodium sulfide
Camphor	Sulfur
Cobalt naphthenate	Titanium dihydride
2,4-Dinitrophenylhydrazine	Titanium dust
Hafnium	Zinc resinate

A.5 Water-Reactive Metals and Related Compounds

Water-Reactive Compounds	
Aluminum hydride	Potassium borohydride
Aluminum	Potassium hydride
Barium	Potassium
Calcium	Rubidium
Calcium carbide	Silicon
Calcium phosphide	Sodium borohydride
Cerium	Sodium
Cesium	Sodium methoxide
Hafnium	Sodium tetrahydroborohydrate
Lithium aluminum hydride	Strontium
Lithium hydride	Titanium
Lithium	Zinc
Magnesium	Zinc phosphide

A.6 Oxidizers

Examples of chemicals and compounds at Hanford that act as oxidizers	
Ammonium cerium (IV) nitrate	Mercury nitrate
Ammonium dichromate	Nickel (II) nitrate
Ammonium nitrate	Nitric acid
Ammonium nitrite	Nitric oxide
Ammonium perchlorate	Nitrogen dioxide
Ammonium peroxydisulfate	Nitrogen trifluoride
Barium nitrate	Oxygen
Barium perchlorate	Ozone
Barium peroxide	Perchloric acid
Calcium chlorate	Periodic acid
Calcium chlorite	Potassium bromate
Calcium hypochlorite	Potassium chlorate
Calcium nitrate	Potassium dichromate
Calcium permanganate	Potassium iodate
Calcium peroxide	Potassium nitrate
Cesium nitrate	Potassium nitrite
Chlorine dioxide	Potassium perchlorate
Chlorine trifluoride	Potassium periodate
Chloric acid	Potassium superoxide
Chromium trioxide	Silver oxide
Cobaltous nitrate	Silver nitrate
Copper nitrate	Silver perchlorate
Fluorine	Sodium chlorite
Hydrogen peroxide	Sodium dichloroisocyanurate
Iodine pentafluoride	Sodium permanganate
Iodine pentoxide	Sodium peroxydisulfate
Lead oxide	Strontium peroxide
Lead perchlorate	Tetranitromethane
Lithium nitrate	Trichloroisocyanuric acid
Lithium perchlorate	Uranyl nitrate
Magnesium perchlorate	Zinc nitrate
Manganese nitrate	Zinc peroxide

A.7 Reducers

Examples of chemicals and compounds at Hanford that act as reducers	
Ammonia	Lithium metal
Aluminum	Magnesium metal
Aluminum hydride	Methyl hydrazine
Barium	Phenyl hydrazine
Benzaldehyde	Phosphorus
Calcium	Potassium metal
Calcium carbide	Sodium chlorite
Calcium chlorite	Sodium hydrosulfite
Calcium cyanamide	Sodium hypophosphite
Calcium hydride	Sodium metabisulfite
Chromium (II) chloride	Sodium metal
Cobalt acetate	Sodium oxide
1,2-Dimethylhydrazine	Sodium tetrahydroborohydrate
Ethanedial	Stannous chloride
Formaldehyde	Strontium
Formic acid	Sulfur dioxide
Glucose	Tin (II) fluoride
Hydrazine	Titanium dihydride
Hydroquinone	Titanium trichloride
Hydroxylamine	Uranium (III) hydride
Hydroxylamine sulfate	Vanadium (III) chloride
Iron (II) chloride	Vanadium dichloride
Iron (II) sulfate	Zinc
Lithium Aluminum hydride	Zirconium hydride

A.8 Acids

Examples of acidic compounds	
Acetic anhydride	Hydroxylamine hydrochloride
Acetic acid	Hydroxylamine nitrate
Acrylic acid	Nitric acid
Aluminum trichloride	Oxalic acid
Antimony pentachloride	Perchloric acid
Benzene sulfonyl chloride	Periodic acid
Benzyl chloroformate	Phosphoric acid
Chlorosulfonic acid	Phosphorus acid
Chromium trioxide	Phosphorus pentachloride
Chromic acid	Phosphorus pentoxide
Citric acid	Pyruvic acid
Ferric chloride	Silicon tetrachloride
Formic acid	Sodium bisulfate
Glyoxylic acid	Stannic chloride
Hydriodic acid	Sulfuric acid
Hydrochloric acid	Sulfur trioxide
Hydrofluoric acid	Thionyl chloride

A.9 Bases

Examples of bases and compounds that act as bases	
Ammonia	Potassium carbonate
Ammonium hydroxide	Potassium hydroxide
Benzylamine	Propanediamine
Calcium oxide	Sodium
Cyclohexylamine	Sodium carbonate
Ethanolamine	Sodium hydroxide
Ethylene diamine	Sodium metasilicate
Lithium	Sodium methoxide
2-Methoxyethylamine	Sodium sulfide
Morpholine	Sodium tetrahydroborohydrate
Piperazine	Triethylenetetramine
Potassium	Trimethylamine

A.10 Inorganic Cyanides and Inorganic Sulfides

Inorganic Cyanides	Inorganic Sulfides
Ammonium thiocyanate Calcium cyanamide Copper (I) cyanide Cyanogen bromide Cyanogen chloride Hydrogen cyanide Iron (III) ferrocyanide Lead (II) thiocyanate Mercury (II) cyanide Mercury (II) thiocyanate Nickel (II) cyanide Potassium cyanate Potassium cyanide Potassium ferricyanide Potassium ferrocyanide Potassium thiocyanate Silver cyanide Sodium cyanide Sodium thiocyanate Zinc cyanide	Ammonium sulfide Arsenic trisulfide Carbon disulfide Copper (II) sulfide Hydrogen sulfide Iron (II) sulfide Mercury (II) sulfide Molybdenum (IV) sulfide Strontium sulfide Tin (IV) sulfide Phosphorus pentasulfide Sodium sulfide

A.11 Acidic Water-Reactive Compounds

Examples of Acidic Water-Reactive Compounds	
Acetic anhydride	Ferric chloride
Acetyl bromide	2,5-Furandione
Acetyl chloride	Germanium tetrachloride
Aluminum bromide	Methyl carbonochloridate
Aluminum trichloride	Phenyl dichlorophosphine oxide
Antimony trichloride	Phosgene
Benzene sulfonyl chloride	Phosphorus oxychloride
Benzoyl chloride	Phosphorus pentachloride
Benzyl chloroformate	Phosphorus pentoxide
Boron trichloride	Phosphorus trichloride
Boron trifluoride	Phthalic anhydride
Boron trifluoride diethyl etherate	Silicon tetrachloride
Calcium hydride	Sodium tetrahydroborohydrate
Carbon oxyfluoride	Stannic chloride
Chlorosulfonic acid	Sulfuryl chloride
Dichlorodimethylsilane	Tantalum pentachloride
Dichlorosilane	Thionyl chloride
Ethyl chloroformate	Titanium tetrachloride
Ethyl dichlorosilane	Trimethyl chlorosilane

Appendix B Chemical Compatibility Scheme Charts

B.1 Chemical Compatibility Matrix

	Ox	Fil	Ai	Ao	Bi	Bo	Mt	Oc	Ic	Aq	CR	WR	OR
Ox		X		X		X	X	X			X	X	X
Fl	X		?				?					X	X
Al	X	X	?	?	X	X	X	?			X	X	X
AO	X		?		X	X	X				X	X	X
Bi			X	X		X	X	?				X	X
Bo	X		X	X		X	X					X	X
Mt	X	?	X	X	X			?				X	X
Oc	X		?		?		?					X	X
Ic												X	X
Aq												X	X
CR	X		X	X								X	X
WR	X	X	X	X	X	X	X	X	X	X	X	X	X
OR	X	X	X	X	X	X	X	X	X	X	X	X	X

Legend
X – Probable Incompatibility
? – Occasional incompatibility, check specific compound compatibilities

B.2 Container Compatibility Matrix

	Steel ¹	Glass	High-density polyethylene (HDPE)	Low-density polyethylene (LDPE)	Polypropylene (PP)	Polyvinyl chloride (PVC)	Teflon
Oxidizers - Strong	X		X	X	X	X	
Oxidizers - Dilute	X		?	?	?	?	
Acids (except HF and Oxidizing acids)	X						
Bases	?						
Hydrofluoric acid and fluoride salts	X	X				?	
Solvents - Halogenated	?		X	X	X	X	
Solvents - Non-halogenated				?	?	X	
Aqueous solutions	?						

Legend
X – Probable Incompatibility
? – Occasional incompatibility, check specific compound compatibilities

Container Compatibility Matrix Materials:

- Steel (drums and cans) - generally incompatible with acids, oxidizers, and many aqueous solutions
 - Carbon steel - usually galvanized to reduce rust, galvanic action
 - Stainless steel – more corrosion resistant, rarely used for packaging
- Glass – not recommended for fluoride compounds
- Plastic (drums, carboys, bottles, liners, bags)
 - High-density polyethylene (HDPE)
 - Low-density polyethylene (LDPE)
 - Polypropylene (PP)
 - Polyvinyl chloride (PVC)
 - Teflon (fluorinated plastics)