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of Transportation

Threat Assessment of Hazardous Materials Transportation in Aircraft Cargo Compartments

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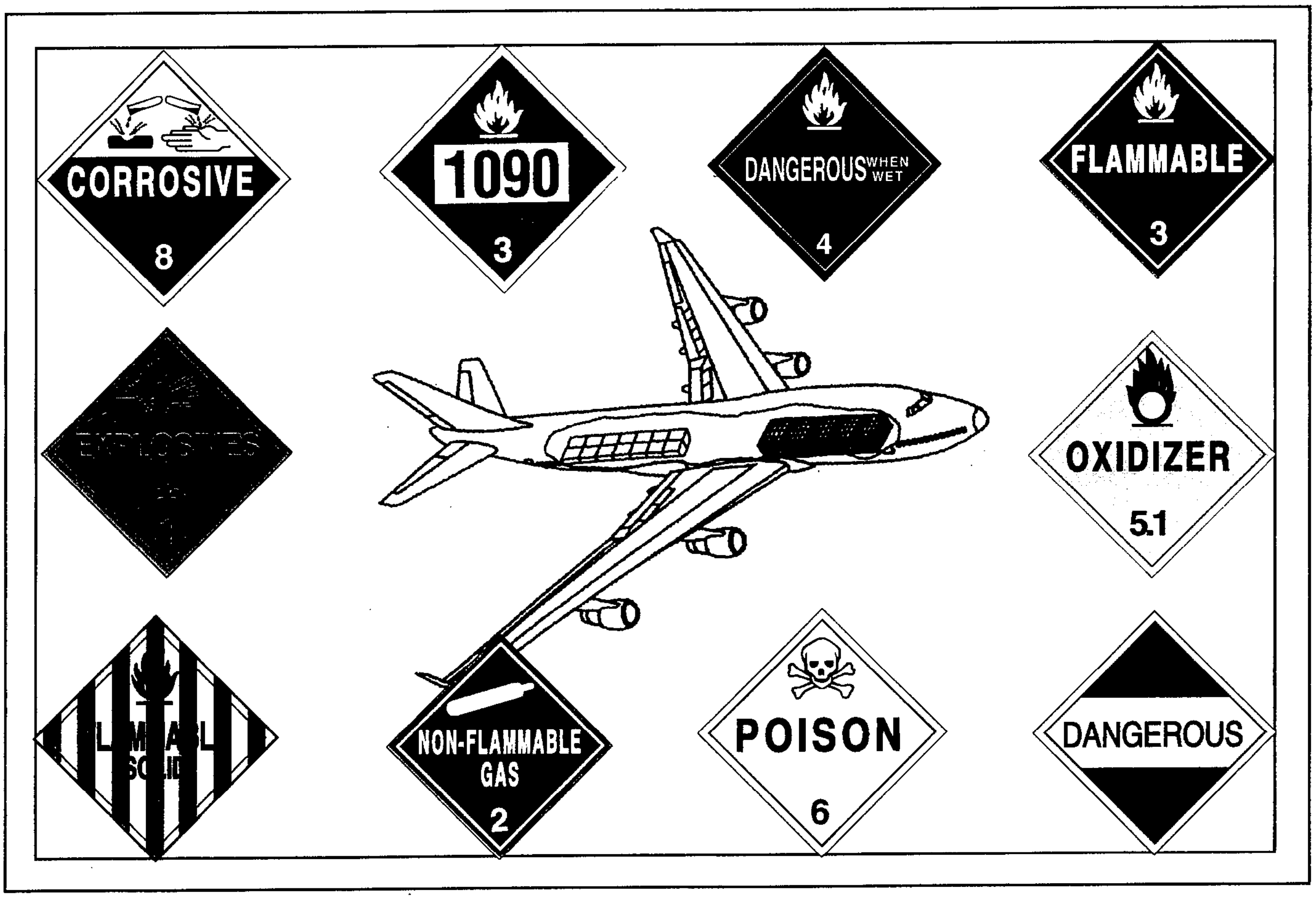

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The U.S. Department of Transportation's (DOT) John A. Volpe National Transportation Systems Center (Volpe Center) has conducted a quantitative threat assessment for the Office of Hazardous Materials Safety (OHMS) to determine the probability that a life-threatening incident would occur as a result of transporting hazardous materials in aircraft cargo compartments. The study team developed a threat assessment model and refined threat scenarios with the help of a panel of experts who contributed potential countermeasures, suggested experimental tests and provided input data for the model. The model calculated the likelihood of life-threatening incidents based on the presence of a package containing various selected ''worst likely'' hazardous materials, the specific cargo compartment type and the package's given state of compliance (or non-compliance) with current DOT hazardous materials regulations.

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	= 2.5 centimeters (cm)
1 foot (ft)	= 30 centimeters (cm)
1 yard (yd)	= 0.9 meter (m)
1 mile (mi)	= 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	= 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	= 0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	= 0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	= 2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	= 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	= 28 grams (gm)
1 pound (lb)	= 0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	= 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	= 5 milliliters (ml)
1 tablespoon (tbsp)	= 15 milliliters (ml)
1 fluid ounce (fl oz)	= 30 milliliters (ml)
1 cup (c)	= 0.24 liter (l)
1 pint (pt)	= 0.47 liter (l)
1 quart (qt)	= 0.96 liter (l)
1 gallon (gal)	= 3.8 liters (l)
1 cubic foot (cu ft, ft^3)	= 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	= 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	= 0.04 inch (in)
1 centimeter (cm)	= 0.4 inch (in)
1 meter (m)	= 3.3 feet (ft)
1 meter (m)	= 1.1 yards (yd)
1 kilometer (k)	= 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	= 0.16 square inch (sq in, in^2)
1 square meter (m^2)	= 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	= 0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	= 1 hectare (he) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	= 0.036 ounce (oz)
1 kilogram (kg)	= 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg)	= 1.1 short tons

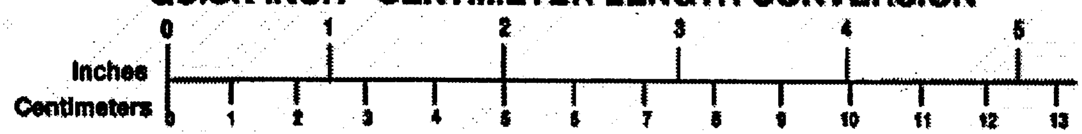
VOLUME (APPROXIMATE)

1 milliliter (ml)	= 0.03 fluid ounce (fl oz)
1 liter (l)	= 2.1 pints (pt)
1 liter (l)	= 1.06 quarts (qt)
1 liter (l)	= 0.26 gallon (gal)
1 cubic meter (m^3)	= 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	= 1.3 cubic yards (cu yd, yd^3)

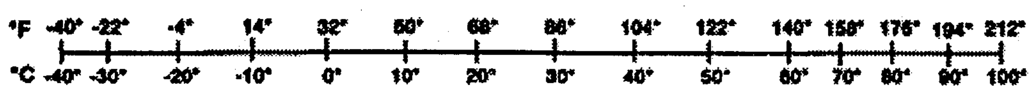
TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION



For more exact and or other conversion factors, see NBS Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

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Executive Summary

Introduction

The Research and Special Programs Administration's (RSPA) Volpe National Transportation Systems Center (Volpe Center) has conducted a quantitative threat assessment for RSPA's Office of Hazardous Materials Safety (OHMS) to determine the probability that a life-threatening incident would occur as the result of transporting hazardous materials in aircraft cargo compartments. This project was initiated following the tragic crash of ValuJet Flight 592 near Miami, Florida in May of 1996, which has been linked to hazardous material devices (chemical oxygen generators) shipped in violation of DOT regulations. Results of this effort will help DOT in determining the effectiveness of current regulatory activities, targeting specific threats for priority action, and developing effective means of reducing risk (that is, countermeasures). This report is also an effort to further implement Vice President Gore's plain language initiative.

Scope of Work

The study team developed a threat assessment model using an "event tree" methodology and refined threat scenarios with the help of a panel of experts who contributed potential countermeasures, suggested experimental tests and provided input data for the model. Additional inputs were developed from data collected by OHMS, the Volpe study team and support contractors. The threat scenarios were developed addressing three possible cases: 1) packages that comply with DOT regulations regarding shipment on passenger flights; 2) packages that comply with DOT regulations regarding shipment on cargo-only flights; and 3) packages that do not comply with DOT regulations for air transport. The specific materials chosen for each hazardous material class and division were the "worst likely" to be shipped by air (that is, these materials are among the more dangerous in their class/division, are commercially available, and are likely to be transported by air). This enabled the specific chemical, physical and toxicological properties of these materials to be used as inputs to the model. The model calculated the likelihood of life-threatening incidents based on the presence of a package containing the selected material, the specific cargo compartment type and the package's given state of compliance (passenger-compliant, cargo-compliant and non-compliant). For each case, the threat scenarios were then ranked and analyzed. Results for each case provide:

1) A relative ranking of the threat for the selected hazardous materials over all the cargo compartment types
2) A breakdown of the threat by the specific events (fire, explosion, toxic material release)
3) A relative ranking of the threat by cargo compartment type over all the hazardous materials selected for that case

Actions which could be taken to reduce the threat and potential experiments to verify the modeling results were also identified and ranked in order of effectiveness for future development.

Key Conclusions (General Trends)

The results of this assessment were reported in terms of the number of times a given material could be transported in a cargo compartment (a "cargo-compartment flight") before a catastrophe would be expected. The calculated likelihood (or probability) of life threatening events were grouped into three categories:

- ***High Threat*** - one catastrophe expected per ten thousand cargo compartment flights, or less;
- ***Medium Threat*** - one catastrophe expected for between ten thousand and ten million cargo compartment flights; and
- ***Low Threat*** - one catastrophe expected per ten million cargo compartment flights, or more.

Based on these groupings, the following results can be shown:

- All of the selected hazardous materials that had probabilities in the medium and high threat categories are already forbidden for air transport by DOT regulations.

- In the cargo-compliant and passenger-compliant cases, all the selected "worst likely" hazardous materials had probabilities in the low threat category.

Results based on cargo compartment type show that relative to the overall threat probabilities cargo compartment did not have a strong influence on the probability of a life-threatening incident in the non-compliance case. This is due to the fact that the worst likely hazardous materials chosen to represent the classes and divisions are such "bad actors." For the two compliant cases, the B1 cargo compartment stands out with probabilities two orders of magnitude higher than the next highest compartment. B1 cargo compartments were the highest risk for all cases due to the fact that they are protected by hand-held extinguishers only.

Key Recommendations

The most significant recommendations from this assessment were:

- Enhance public awareness of the hazards associated with air transportation of many commonly-used products through pamphlets, public notices and displays in airport check-in areas.

- Evaluate possible verbal querying of and written certifications by air passengers and shippers verifying they are NOT transporting hazardous materials in cargo packages or luggage.

- Evaluate the use of non-intrusive diagnostic screening of cargo packages by the newest X-ray or nuclear magnetic resonance densimetry scanning equipment developed for anti-terrorist baggage checking.

- Suggest that the United Nations Committee of Experts on Dangerous Goods examine simplifying the identification of dual hazard gaseous oxidizers (e.g., by creating a new category for oxidizing gases) and corrosive oxidizers (e.g., by identifying more oxidizing acids primarily as Division 5.1 hazards).

I Introduction

WHAT ARE HAZARDOUS MATERIALS?

Within the scope of this study, hazardous materials are defined as chemical substances or articles containing chemical substances which can pose a threat to public safety or to the environment during transport. Hazardous materials pose this threat through chemical, physical or nuclear properties which can make them dangerous in or near transporting conveyances when not properly identified and packaged. Hazardous materials can potentially lead to undesirable outcomes such as explosions, fires, or severely enhanced fires if they are accidentally released. There are also radioactive, toxic, infectious or corrosive hazardous materials which can have severe short or long term exposure effects on humans and the environment.

HOW ARE THEY DEFINED?

INTERNATIONALLY?

There is an internationally recognized system for classification, identification and ranking all types of hazardous materials created by the United Nations (UN) Committee of Experts on the Transport of Dangerous Goods within the former United Nations Economic and Social Council Organization (UNESCO) in the 1970's. This system has been accepted worldwide and is revised biennially and published as the "United Nations Recommendations on the Transport of Dangerous Goods" issued through the Geneva, Switzerland headquarters of the United Nations Economic Commission for Europe (UN/ECE)[1].

Under the United Nations (UN) classification system, all hazardous materials are divided into nine general classes according to physical, chemical and nuclear properties as shown below:

Class 1	Explosives and Pyrotechnics
Class 2	Compressed and Liquefied Gases
Class 3	Flammable Liquids
Class 4	Flammable Solids (Including Self-Reactive Liquids)
Class 5	Oxidizers and Peroxides
Class 6	Toxic and Infectious Materials
Class 7	Radioactive Materials
Class 8	Corrosive Material (acidic or basic)
Class 9	Miscellaneous Dangerous Substances and Articles

1 UN Recommendations on the Transport of Dangerous Goods Model Regulations, Eleventh Revised Edition (1999) published by the United Nations, New York and Geneva. ST/SG/AC.10/Rev.11, Sales No. E.98.VIII.1.

Within Classes 1, 2, 4, 5 and 6 there are more specifically defined subdivisions and within Class 1 there are Compatibility Group subdivisions as well. Also within Classes 3, 4, 5, 6 and 8 there are three different levels of packaging performance requirements (PG I, II and III) which are specified. These hazardous material classes and divisions are not mutually exclusive, since there are hazardous materials with multiple dangerous properties, each of which needs to be addressed according to their relative potential to do harm. In these cases, the UN system allows identification and communication of both the primary threat and any other subsidiary threats.

The United Nations Committee of Experts has created more than thirty-four hundred possible identification numbers, proper shipping descriptions and hazard classes to be assigned to various hazardous material compounds, mixtures, solutions and devices. There are also generic "n.o.s." (not otherwise specified) identification numbers and shipping descriptions which allow the material to be classed by its defined properties, for example, flammable solid, organic, n.o.s. The reader is referred to the UN Recommendations (1) for a fuller explanation of the Dangerous Goods classification system, the order of precedence each class and subdivision may have in the overall scheme and how the final identification and classification can be derived from the various definitions.

DOMESTICALLY?

The Department of Transportation's Office of Hazardous Materials Safety has the responsibility of managing the risks of hazardous materials transportation within the territorial boundaries of the U.S. essentially in harmony with the United Nation's Committee of Experts Recommendations on Transport of Dangerous Goods. In the interests of global harmonization of hazardous material transport between cooperating countries, DOT has essentially adopted the United Nations recommendations into their hazardous materials regulations.

HOW ARE THEY REGULATED?

INTERNATIONALLY?

Internationally, the transport of hazardous materials is regulated by mode of carriage. All cargo vessel carriage is governed by the United Nations International Maritime Organization (IMO) through the "International Maritime Dangerous Goods Code."[2] All aircraft carriage is governed by the United Nations International Civil Aviation Organization (ICAO) through the "Technical

[2] International Maritime Dangerous Goods (IMDG) Code, 1994 Consolidated Editions, as amended by Amendment 28 (1996) published by New York Nautical Instrument and Service Corporation, New York, NY 10013 for the International Maritime Organization (IMO), London, UK

Instructions for the Safe Transport of Dangerous Goods by Air," published biennially.[3] For international transportation by air, there is also the International Air Transport Association, an air carrier industry trade group, which publishes the "Dangerous Goods Regulations" annually.[4] For radioactive materials, the United Nations International Atomic Energy Agency's Safety Publications recommend certain aspects of transportation as well as storage of fissile and radioisotopic materials.[5-6]

DOMESTICALLY?

In the United States, hazardous materials are regulated under the Federal Hazardous Materials Transportation Law enacted by Congress, last amended by the Hazardous Materials Transportation Authorization Act of 1994. This is codified in Title 49 Parts 100 to 185, issued by the U.S. Department of Transportation's Research and Special Programs Administration with revisions and updates published in the Federal Register as they occur and annually reprinted by the Government Printing Office as well as other sources. DOT's hazardous material regulations can also be accessed on the Internet through the Office of Hazardous Materials Safety home page (http://hazmat.dot.gov). Parts 171, 172, 173 and 175 of the Code of Federal Regulations (CFR) cover specific material definitions as well as shipping, marking and labeling instructions and general regulations pertaining to transport of all hazardous material by air.

HOW OFTEN ARE HAZARDOUS MATERIALS PRESENT ON AIRCRAFT?

There are certain hazardous materials that are always present on aircraft. These company materials are essential to the aircraft's normal operation. This includes hazardous materials such as the Jet Fuel (Fuel, aviation, turbine engine in the fuel tanks which is a Class 3 flammable liquid) as well as compressed oxygen cylinders (Division 2.2 and 5.1) or chemical oxygen generators (Division 5.1) installed in the cockpit and passenger areas for emergency crew use or in the event of decompression. Also, there are lubricants, hydraulic fluids and pneumatic tires which are part of the essential construction of the aircraft. All these hazardous materials are specifically excluded from DOT hazardous materials regulations when they are included in the overall airworthiness certifications and re-inspections issued by the Federal Aviation Administration. These materials were

3 ICAO Technical Instructions published by INTEREG, International Regulations, Publishing and Distribution Organization, Chicago, IL 60660 for the International Civil Aviation Association, Montreal, Quebec, Canada.

4 IATA Dangerous Goods Regulations, 39th Edition, 1998 (ISBN 92-9035-984-6) published for the International Air Transport Association, Montreal, Quebec Canada.

5 IAEA Regulations for the Safe Transport of Radioactive Material, Safety Series 6, (1985 Edition), Second Edition, International Atomic Energy Agency, Vienna, Austria 1990.

6 IAEA Explanatory Material for the IAEA Regulations for the Safe Transport of Radioactive Material(1985 Edition), Safety Series 7, Second Edition, International Atomic Energy Agency, Vienna, Austria, 1987.

not directly considered in this assessment. Those company materials which are replacements (not installed on the aircraft), were considered in this assessment since they are typically transported in cargo compartments. The presence of undeclared COMAT is believed to be the cause of the ValuJet 592 crash.

RSPA believes hazardous materials represent a small percentage of overall cargo carried in both passenger and cargo aircraft, both domestically and internationally. The basis for this opinion is two-fold. Firstly, several large domestic cargo carriers have informed RSPA that hazardous material shipments roughly account for 0.2 to 0.5 percent of their daily operational shipments.

This estimate does not take into account the number of undeclared shipments of hazardous materials. The carrier cited above indicates 0.05% of their shipments (reported to be 10-25% of hazardous materials carried) are undeclared hazardous materials discovered because of incidents, leaks, or other inspection activities. The number of undeclared hazardous material shipments made without incident, and therefore not discovered, is not known.

Secondly, a 1996 analysis of Dangerous Goods movements in the UK by WS Atkins Safety and Reliability Co. for the UK Health and Safety Executive assumed from limited sampling at major UK airports that approximately 1-2 percent of all declared air shipments for both passenger and cargo aircraft were hazardous materials.[7] The export flow of dangerous goods through Heathrow Airport by British Airways for the 3-month audit period was found by Zarb[8] to be approximately 0.3 percent of the total number of packages and 0.8 percent of the total mass of packages. This average hazardous materials package volume estimate from one U.K. carrier fairly agrees with the estimates received by RSPA from domestic hazardous materials carriers.

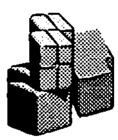
In the Zarb study the following breakdown by hazard material class was also reported:

7 Lines, I.G. *Review of the Major Hazards Associated with the Transport of Dangerous Goods at Airports.* Prepared by WS Atkins Safety & Reliability for the United Kingdom Health and Safety Executive, WS Atkins House, Birchwood Boulevard, Birchwood, Warrington, Cheshire, W3 7WA, UK. Report No. AM5101/430/R8000/WP1.00. November 1996.

8 Zarb, L.Y., "Quantification of the Carriage of Dangerous Goods by Air from/to/into EC Member States," DG VII/LYZCO Study Contract No. C4, B94, B2-7040, SIN 4439, 1995.

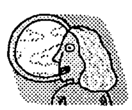
Table 1.1 Percent of Hazardous Material Packages Shipped by Class (Zarb Study)

Hazard Class/Division	Percentage of All Hazardous Material Packages	Percentage of Total Mass of Hazardous Materials Shipments
1.4S	2.4%	1.4%
2.1	1.8%	1.1%
2.2	3.6%	4.9%
3	26.1%	20.5%
4.1	0.5%	0.4%
4.2	0.9%	0.4%
4.3	0.1%	0.1%
5.1	0.3%	0.2%
5.2	0.03%	0.02%
6.1	7.5%	8.5%
7	20.7%	n/a
8	5.3%	9.5%
9	30.0%	52.7%



CARGO FLIGHTS?

Around 75 percent of hazardous material air shipments move by all-cargo aircraft according to the FAA.



PASSENGER FLIGHTS?

The remaining 25 percent of the dangerous good air shipments are transported in passenger aircraft.

UNDECLARED SHIPMENTS?

Of more concern are the undeclared hazardous materials that are carried aboard aircraft. There are no exact figures for the numbers of packages transported in non-compliance with air regulations. Unless a release occurs or a non-compliant package is reported upon delivery no record of the undeclared shipment is available. The carrier has no means of determining the package content except by questioning the sender. Some carriers X-ray packages, to identify bombs. While this technique can identify items such as aerosol cans and lighters, it is not a reliable means of detecting hazardous materials because x-ray cannot identify the contents of a container. FAA data for fiscal year 1998 reports 887 incidents of undeclared hazardous materials shipments. Of these 75 percent were cargo aboard cargo-only aircraft; 16 percent where in passenger baggage aboard passenger aircraft; and 8 percent were cargo aboard passenger aircraft.

WHAT THREATS DO HAZARDOUS MATERIALS PRESENT?

For this assessment, threats to the passengers and crew from hazardous materials transported by air were divided into two categories: "short-term," that is, those which may have an effect during the duration of the average flight which can result in serious illness, injury or a fatality, and "long-term," that is, those which may have an effect beyond the duration of the average flight.

IMMEDIATELY DURING THE FLIGHT?

In view of the properties of the materials being analyzed, "short term" vulnerabilities of the aircraft and occupants were concluded to be: 1) any explosion with sufficient over pressure to produce structural disruption or damage to critical aircraft systems (for example, flight controls, power, etc.); 2) severe fire; and 3) a lethally toxic material release into the atmosphere of the aircraft cabin or cockpit. These effects were generally attributed to hazard Classes 1-6.

Although not explicitly considered in this assessment Class 9 materials such as airbag inflators; machinery, equipment and apparatus containing hazardous materials; internal combustion engines; lithium batteries and sulfur (domestic) may under certain circumstances cause short term threats, and should be considered no less hazardous than comparable quantities of the materials they contain. For the purpose of this assessment items such as airbag inflators for example could nominally be 1.4S materials, but may also be transported as Class 9 provided additional testing and packaging criteria are met.

LONGER TERM?

"Long term" effects including radioactive exposure from Class 7 materials, infectious substance exposure from Division 6.2 materials and release of Class 9 environmentally hazardous substances to the atmosphere were considered beyond the scope of this study. However, significant corrosion effects on the aircraft from Class 8 materials could potentially have both short and long term effects. To resolve this question for the study, RSPA requested the FAA Technical Center to conduct a preliminary corrosion experiment on the effects of a powerful acid on the aluminum fuselage section of a commercial aircraft. Speitel[9] observed that the inner fuselage skin corrosion-resistant coating was sufficient, (if undamaged) to withstand this very acidic exposure for short durations. Based on this finding, Class 8 materials with no other hazard class assignment were deemed beyond the scope of this study. But release of corrosive materials could still cause long term structural damage to the aircraft.

WHAT ARE THE "WORST LIKELY" THREATS?

Given the primary focus of short term threats and a general understanding of the hazardous materials organizational system, it was concluded that the following fifteen "reactive chemical" classes and divisions are some of the "worst likely" threats to an aircraft in-flight:

Table 1.2 "Worst Likely" Hazardous Materials

Class	Division	General Description
1	1.1	Explosives with mass detonation hazard
1	1.2	Explosives with a projectile hazard
1	1.3	Explosives with a pyrotechnic hazard
1	1.4	Explosives with a minor blast hazard
1	1.5	Very insensitive blasting explosives
2	2.1	Flammable gases
2	2.2/5.1	Oxidizing gases
2	2.3	Toxic gases
3	--	Flammable liquids
4	4.1	Desensitized explosives, pyrotechnic solids and self-reactive solids and liquids
4	4.2	Spontaneously combustible and self-heating solids and liquids
4	4.3	"Dangerous When Wet" material producing flammable or toxic gases when contacting water
5	5.1	Oxidizing liquids and solids
5	5.2	Organic peroxides
6	6.1	Toxic liquids and solids

9 Speitel, L.C. "Effects of Concentrated Hydrochloric Acid Spills on Aircraft Aluminum Skin," U.S. Department of Transportation, Federal Aviation Administration, William J. Hughes Technical Center, Atlantic City, NJ. Report No. DOT/FAA/AR-TN97/108. 1998.

These fifteen possible hazardous material categories may have a combination of chemical and physical properties which could produce an explosion, cause or dangerously enhance a fire, or result in a lethal toxic incident to passengers or crew when not in compliance with the hazardous material regulations. This study also analyzed these specific types of threats by where they could be located on the aircraft.

WHAT CARGO COMPARTMENTS ARE WE TALKING ABOUT?

Cargo compartments are areas of the aircraft designated for the storage of baggage and cargo. There are five types of cargo compartments designated by the letters A through E. Overhead bins within the aircraft passenger cabin are not Type A compartments and are not included in this assessment. However, non-compliance materials (for example, aerosol hair spray) brought on-board in carry-on luggage and stored in overhead bins could present some of the same hazardous consequences as those materials moving in cargo compartments.

HOW ARE CARGO COMPARTMENTS DEFINED?

INTERNATIONALLY?

Cargo compartments are defined in terms of their size and construction, location and accessibility, as well as by their fire detection and suppression capabilities. The ICAO sets the standards internationally for cargo compartments. ICAO classifications are nearly identical to those used domestically as discussed below.

DOMESTICALLY?

Domestically the FAA sets the definition for cargo compartments. These cargo compartment classifications, which appear in 14 CFR 25.857, are presented in Appendix F (see page 113). The pertinent characteristics of each compartment are discussed below and are summarized in Table 1.3.

Type A - Type A cargo compartments are "easily accessible in flight" and, if a fire were to occur in one, it would be "easily discovered by a crew member." Hand held fire extinguishers are the only protective measure for fire in Type A compartments.

Type B - Type B cargo compartments are located on the main deck of the aircraft and are accessible in flight to a crewmember with a hand held fire extinguisher.

For the purposes of this evaluation B compartments have been divided into two categories, B1 and B2 based on their conformance to FAA Airworthiness Directive (AD) 93-07-16. This AD, which became effective in 1993, requires more stringent fire suppression requirements for certain larger aircraft. B1 compartments are AD non-applicable; typically these compartments rely on hand held extinguishers for fighting fires. B2 compartments are AD applicable, and rely mainly on the fire protection provided by the use of fire containment covers (FCC's) and fire resistant containers (FRC's).

Type C - Type C compartments are not accessible during flight. Unlike all other compartments, these have an approved built-in fire-extinguishing system in addition to an approved smoke detector or fire detector system, a means to control ventilation, and a means to exclude hazardous quantities of smoke, flames, or extinguishing agent from any compartment occupied by crew or passengers. Type C compartment suppression systems are typically designed to provide an initial extinguishing agent concentration of 5% and a second timed/metered agent to maintain the concentration at or above 3% for the remaining duration (up to 180 minutes) of the flight.

Type D - Type D cargo compartments are not accessible during flight. These compartments rely on passive oxygen starvation as a method of fire suppression. Ventilation is controlled so that any fire likely to occur will not progress beyond safe limits, the compartment volume does not exceed 1000 cubic feet, and there are means to exclude hazardous quantities of smoke, flames, or noxious gases from any compartment occupied by crew or passengers.

Type E - Type E cargo compartments are accessible and have an approved smoke or fire detection system, but rely on depressurization of the compartment for fire suppression. These compartments have a means to shut off ventilating airflow, and means to exclude hazardous quantities of smoke, flames, or noxious gases from the flight crew compartment.

Table 1.3 Characteristics of Aircraft Cargo Compartments

	Aircraft Cargo Compartment Type					
	A	B1 AD 93-07-16 Non-Applicable	B2 AD 93-07-16 Applicable	C	D✱	E
Fire Detection	Visual Only	Automatic Detection (Smoke/Fire) – Cockpit Indicator	Automatic Detection (Smoke/Fire) – Cockpit Indicator	Automatic Detection (Smoke/Fire) – Cockpit Indicator	None	Automatic Detection (Smoke/Fire) – Cockpit Indicator
Fire Protection/ Suppression	Active – Human Only (Hand Held Extinguisher)	Active – Human Only (Hand Held Extinguisher)	Passive -Fire Containment Covers and Fire Resistant Containers; and Active – Human Only (Hand Held Extinguisher)	Active Built-in – Automatic (if Activated)	None – Passive Only (Oxygen Starvation)	None – Passive Only (Depressurization)
Crew Accessible	Yes	Yes	Yes	No	No	Yes
Flight Type	Passenger and Cargo	Combi	Combi	Passenger and Cargo	Passenger and Cargo	Cargo Only
Location	Main Deck – Passenger Compartment (Adjacent To Cockpit)	Main Deck – Cargo Compartment	Main Deck – Cargo Compartment	Below Main Deck	Below Main Deck	Main Deck

✱ Note that Type D compartments are being phased out (converted to Type C's - see discussion below)

HOW ARE CARGO COMPARTMENTS REGULATED?

INTERNATIONALLY?

Cargo compartments are regulated internationally by the International Civil Aviation Organization (ICAO). ICAO policy on international airworthiness requires that each "contracting State" should establish (or adopt) its own compliance and detailed code of airworthiness. To this end ICAO has developed airworthiness technical guidance material relating to crash survival which has no mandatory status. ICAO provides guidance material on:

- Testing of flammability characteristics of interior materials
- Reporting of faults/malfunctions of systems/equipment to designers (included in these reportable items are incidences resulting in fire, smoke, fumes or explosion; and smoke, toxic or noxious fumes in the crew, passenger or freight compartments)
- Guidance for the analysis of failure effects
- Reliability assessment of cargo compartment fire suppression

These general requirements are supplemented by detailed specifications in the airworthiness codes and general operating regulations of the individual states. Comprehensive airworthiness regulations are published in a number of national and multinational codes such as the U.S. Federal Airworthiness Regulations (FARs). Table 1.4 is a list of references to the provisions relating to crash survival in some of the existing airworthiness codes. A large degree of uniformity already exists in the specifications appearing in these national and multinational codes and ICAO considers these to be representative of world standards.

Table 1.4 Cargo Compartment Regulations

	State Codes		**Multinational Codes**
	Canada	**U.S.**	**European Joint Airworthiness Requirements**
Stowage Compartments Requirements relating to compartments for the stowage of cargo, baggage, carry-on baggage and other equipment	525.787	FAR 25.787 121.285	JAR 25.787 ACJ 25.787
Cargo and Baggage Compartments Classification of compartments; requirements relating to fire resistance of lining materials; shielding of cables and controls	525.855 525.857	FAR 25.855 25.857 121.221 121.223	JAR 25.855 25.857

DOMESTICALLY?

In the United States aircraft cargo compartments are regulated by the FAA in the CFR. Cargo compartments must meet one of the four classification requirements defined in 14 CFR 25.857. This regulation controls several aspects of the cargo compartments:

- Accessibility in-flight
- Smoke, flame and noxious gas resistance
- Smoke/fire detection
- Fire extinguishing/suppression
- Compartment volume size

14 CFR §25.855 specifies requirements for:

- Construction and flammability of cargo compartment liner panels
- Protection of control or equipment whose damage or failure would affect safe operation of the aircraft
- Shielding and insulation of sources of heat to prevent ignition of cargo or baggage

In addition the FAA develops and implements policy, and manages information associated with aircraft airworthiness. They issue orders, advisory circulars, notices, and technical standard orders in the development of engineering, manufacturing, and maintenance policy. Airworthiness Directives (AD's) give guidance on how to maintain the safety of aircraft. Cargo compartments are part of the certification process of the aircraft, and are part of random ramp inspections.

Recent Changes

Since this assessment was initiated, several recent regulatory changes have added requirements for Type D cargo compartment fire detection/suppression and restricted certain hazardous materials on passenger aircraft. These are:

Compressed Oxygen Aboard Aircraft. In a final rule dated August 19, 1999 DOT put new limitations on the carriage of compressed oxygen in passenger aircraft or in inaccessible cargo compartments aboard cargo only aircraft. The regulations will require that compressed oxygen cylinders be placed in an overpack or outer packaging that satisfies the requirements of a new special provision (CFR 49 172.102, A-52). In addition this final rule forbids the loading or transport of any package (other than compressed oxygen) containing a hazardous material for which an OXIDIZER label is required, in an inaccessible cargo compartment that doesn't have a fire or smoke detection system and a fire suppression system. This rule does allow up to six cylinders of compressed oxygen in overpacks to be stowed horizontally on the floor in inaccessible cargo compartments with no fire detection or suppression systems.

Revised Standards for Cargo/Baggage Compartments (Type D Compartment Conversion to Type C) - In the cargo bays of larger airplanes, including the DC-10, MD-11, Boeing 747, 757, 767, and 777, the FAA requires fire-resistant compartment liners and smoke detectors, as well as extinguishers that disperse a fire-suppressing chemical and shut off air flow into the hold. But in smaller cargo holds such as the DC-9's, there is currently no requirement for fire detection and suppression equipment. On March 18, 1998 the FAA issued a Final Rule requiring fire detection and suppression systems in inaccessible aircraft cargo compartments by the year 2001.

Prohibition on the Transportation of Oxygen Generators and Oxidizers on Aircraft. In a final rule dated December 30, 1996, DOT prohibited oxygen generators (including spent devices) from being moved as cargo on passenger aircraft as well as in those inaccessible cargo compartments on cargo aircraft that lack fire or smoke detection and suppression systems (that is, Type D compartments). On August 21, 1998, the FAA issued a NPRM proposing regulations to ban chemical oxygen generator devices as cargo. This does not impact materials or devices that are required parts of the aircraft.

The DOT also issued a supplemental notice of proposed rulemaking on August 20, 1997 further analyzing the prohibition on the carriage of oxidizers aboard passenger carrying aircraft in Type B and C cargo compartments.

WHERE ARE CARGO COMPARTMENTS LOCATED AND HOW MANY OF EACH TYPE ARE THERE?

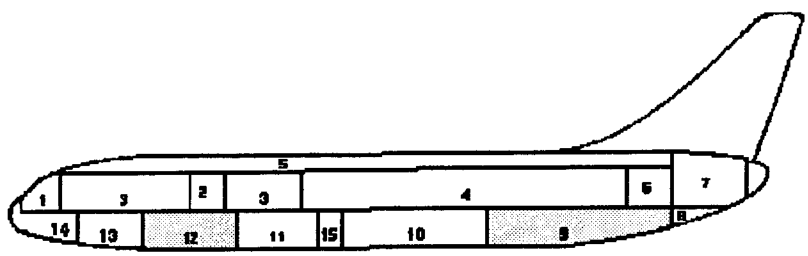
Type A – Typically Type A cargo compartments are crew luggage storage areas located in the cockpit, near the cockpit between the flight deck and the passenger cabin, adjacent to the galley area, or at the back of the aircraft. These compartments can be in proximity to numerous critical systems.

Type B – Type B cargo compartments are found only on "Combi" aircraft (one in which both cargo and passengers are carried on the main deck). Type B cargo compartments are usually much larger than Type A compartments. These are usually freight compartments on the main deck behind a partition with a locked door between the flight deck and the passenger cabin or behind the passenger cabin at the rear of the aircraft. These compartments can be in proximity to numerous critical systems.

Type C – The volume of Type C cargo compartments is usually larger than Type A or B and are generally found under the floor in wide-body aircraft and in a few instances can extend beneath the cockpit.

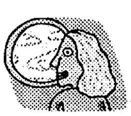
Type D – Type D compartments are found on most jet aircraft. They are usually found below the passenger cabin floor of the main fuselage, and in a few instances extend beneath the cockpit. Type D compartments are more common on older, narrow body aircraft.

Type E – Type E cargo compartments are located on cargo-only aircraft, on the main deck level, and normally comprises the entire main deck compartment. They are accessible by the flight crew. When a plane has a Type E cargo compartment, there may be non-revenue passengers within the compartment.



1	Cockpit
2 and 6	Lavatories
3 and 4	Cabin
5	Attic
7 and 8	Equipment Compartments
9 and 12	**Cargo Compartments**
10 and 13	Landing Gear/Hydraulics
11	Lower Galley
14 and 15	Avionics and Electrical

Figure 1.1 Typical Relative Locations of Aircraft Cargo Compartments



ON PASSENGER FLIGHTS?

Passenger aircraft are usually fitted with either Type C or Type D cargo compartments under the passenger cabin.

"Combi" aircraft are usually fitted with a Type B main deck cargo compartment, either in front or behind the passenger cabin and with a Type C or Type D cargo compartment under the floor.

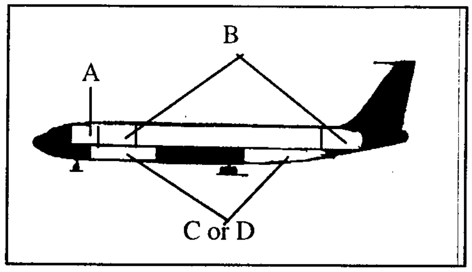


Figure 1.2 Typical Relative Locations of Cargo Compartments – Passenger/Combi Aircraft

ON CARGO FLIGHTS?

Cargo aircraft are usually fitted with a Type E main deck cargo compartment and with Type D or Type C under-floor cargo compartments.

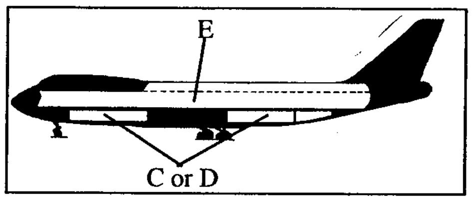


Figure 1.3 Typical Relative Locations of Cargo Compartments – Cargo Aircraft

The number of each type of cargo compartment varies depending on the type of aircraft.

HOW VULNERABLE ARE CARGO COMPARTMENTS?

TO FIRE?

An unsuppressed fire in a cargo compartment can lead to a dangerous situation where lives can be lost or the aircraft damaged or destroyed. If a fire is unsuppressed it can "breach" the cargo compartment and move into areas of the aircraft which might contain equipment necessary for flight or into areas occupied by crew or passengers.

Cargo compartment type has a definitive impact on the vulnerability of the aircraft to fire. Cargo compartments have varying degrees of protection against fires. Each has some form of active or passive fire protection ranging from automated fire detection and suppression systems to passive oxygen starvation and depressurization (see Table 1.4). The ability of a fire in a cargo compartment to be contained or suppressed depends on many factors including:

- The effectiveness and reliability of the fire detection and suppression systems

- How quickly the fire is detected and suppression begun
- The size of the fire (the amount of fuel available to the fire)
- The material involved
- If the material is containerized
- The material, condition and installation of cargo liners, and the presence of fire retardant covers

TO EXPLOSION?

Aircraft are highly susceptible to damage from an explosion. A major explosion could result in structural damage or hull breach, causing a sudden loss of pressure which could render the plane unflyable. Minor explosions could damage aircraft equipment or breach the cargo compartment allowing smoke, flames or toxic material to spread throughout the aircraft. Protection from damage due to explosion is provided by the aircraft structure itself, and to some extent by cargo containers, if used.

TO TOXIC MATERIAL MIGRATION?

Cargo compartment ceiling and sidewall liners offer some protection against migration of toxic materials into occupied areas. However, once a compartment is breached due to fire or explosion, there is little protection against toxic material escaping from the cargo compartment and being recirculated into the cabin (see Figure 1.4). Pressure within the cockpit offers some additional protection for the crew.

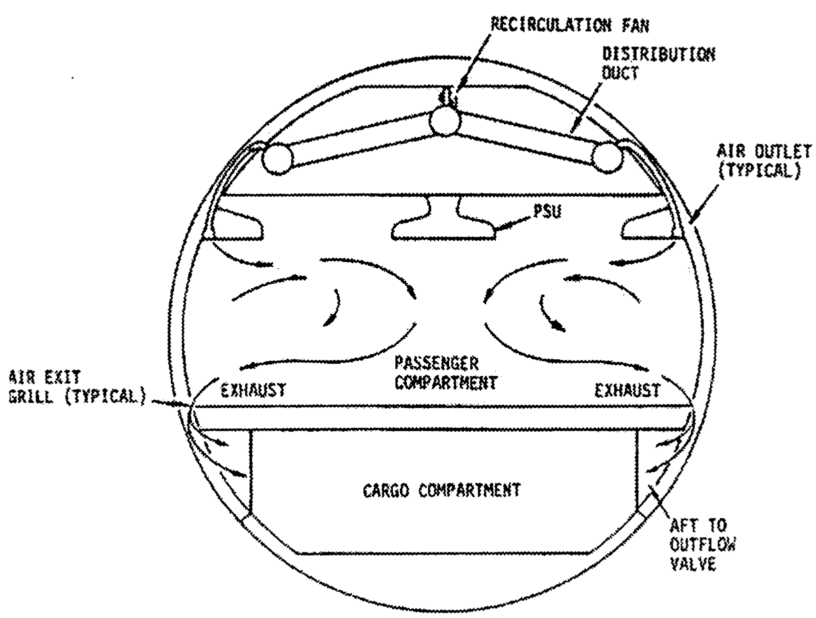


Figure 1.4 Aircraft Ventilation

Toxic material transfer also depends on the state of the material as well as the location of the cargo compartment. Toxic material incidents in accessible cargo compartments are more likely to be life threatening since any attempt to investigate a fire would allow the toxic material to escape into occupied areas. FAA Technical Center tests estimate that a fire in Type C or D cargo compartments will distribute smoke to the cabin in about one half of the cases of fire.

WHAT THREATS DO HAZARDOUS MATERIALS POSE IN EACH TYPE OF CARGO COMPARTMENT?

All compartments are vulnerable to fire, explosion or toxic material release events. However fire in certain material/compartments combinations are inherently more likely to end in life threatening events. For example, oxidizers in Type D or E cargo compartments are a particular problem since the manner of fire suppression used in these compartments, oxygen starvation, would be rendered ineffective in the presence of oxidizing materials. Type A and some Type B compartments rely solely on hand held extinguishers. Attempts at fire suppression in these compartments may be ineffective against fires involving oxidizing materials or any severe fire. Oxidizers can also render Type C flood systems inadequate.

WHAT HAZARDOUS MATERIAL SHIPMENTS ARE RESTRICTED IN AIRCRAFT?

The DOT hazardous materials regulations totally forbid the movement of certain materials in all modes of transportation These materials are generally characterized in Section 173.21 of the HMR as well as specifically cited in the HMR table. Of the more than 3,400 materials cited in DOT's hazardous materials regulations, about half are permitted both on cargo or passenger aircraft when shipped in compliance with the regulations. Approximately 30 percent are forbidden on passenger aircraft. And about 20 percent are forbidden on both passenger and cargo aircraft.

WHAT ARE THE HAZARDOUS MATERIAL RESTRICTIONS IN PASSENGER AIRCRAFT?

Hazardous materials are restricted on passenger aircraft in five ways, by:

- Name specifically
- Hazard class and subdivision
- Quantities contained per outer package
- Aggregate quantities per cargo compartment
- Packaging integrity

First, hazardous materials that have a known history of causing an aircraft fire or explosion, (for example, concentrated nitric acids, chemical oxygen generators and other substances or devices recognized as very highly reactive) are specifically forbidden by name. Second, with few exceptions, certain subdivisions of hazardous materials that are known to be highly reactive or toxic are excluded from passenger flights. For example, most explosives (except Division 1.4S), most flammable and toxic gases, all spontaneously combustible or "dangerous when wet" materials in Packing Group I, oxidizers in Packing Group I and all "temperature controlled" organic peroxides and self reactive substances are excluded from transport in passenger aircraft.

DOT and international regulations also restrict hazardous materials on board passenger aircraft by the quantity of substance or numbers of articles permitted in the outermost shipping containers. They also limit the quantity per package to smaller amounts than are permitted on corresponding cargo flights. For example, highly flammable liquids that may be allowed up to 30 liters per outer package in cargo-only aircraft are typically restricted to only 1 liter or less in passenger aircraft. Certain highly toxic solids that may be allowed up to 50 kg per outer package in cargo-only aircraft are likewise typically restricted to 5 kg or less in passenger aircraft.

Also, DOT regulations limit the aggregate quantities of many hazardous materials to 25 kg within an inaccessible cargo compartment (75 kg for Division 2.2 nonflammable gases) or within a freight container in an accessible compartment (for example on "combi" flights where there are passengers and freight both on the main deck). Aggregate limit restrictions apply to flights leaving or arriving into the United States and its territories and are not part of the ICAO or carrier regulations.

WHAT ARE THE HAZARDOUS MATERIAL RESTRICTIONS IN CARGO AIRCRAFT?

Hazardous materials are restricted on cargo aircraft in four ways, by:

- Name specifically
- Hazard class and subdivision
- Quantities contained per outer package
- Packaging integrity

Hazardous material restrictions for cargo-only aircraft are less stringent than for passenger aircraft in both number and quantity of material per outer package. DOT regulations also impose requirements for packaging integrity.

Division 1.1, 1.2, 1.5 and 1.6 materials with mass explosion hazards are still strictly forbidden. Most Division 1.3 materials with mass pyrotechnical hazards are also forbidden (except some rocket motors, power device cartridges, distress signals and flares). But most Division 1.4 explosive articles in all Compatibility Groups are permitted up to 75 kg per outer package.

Most Division 2.1 flammable gases, except those which are refrigerated liquids, are also permitted on cargo-only flights up to 150 kg per outer package in many cases. Also Division 2.2 and 5.1 oxidizing gases are permitted (except refrigerated liquids.) Most Division 2.3 toxic gases are forbidden on cargo-only aircraft (except up to 25 kg of selected materials such as ammonia, carbon monoxide, sulfur dioxide, ethylene oxide and sulfuryl fluoride.)

Most Class 3 flammable liquids are permitted on cargo-only aircraft except those which are also toxic by inhalation. Maximum quantities per outer package can range from 30 liters for highly volatile Packing Group I liquids to 220 liters for Packing Group III liquids with low volatility. Most Division 4.1 flammable solids are also permitted, except temperature-controlled self-reactive liquids. Most Division 4.2 spontaneously combustible materials and Division 4.3 dangerous when wet materials in Packing Group I are forbidden, but most materials in Divisions 4.2 and 4.3 Packing Group II and III are permitted in cargo-aircraft in quantities ranging from 50 to 100 kg per outer package.

Most Division 5.1 oxidizers are also permitted on cargo-only aircraft, except those which have one or more "subsidiary risks" (that is, they meet the definition of one or more other hazard classes). Quantities allowable per outer package typically range from 15 kg (2.5 liters for liquids) for highly reactive Packing Group I materials to 100 kg (30 liters for liquids) for Packing Group III materials of relatively low reactivity. All Division 5.2 temperature-controlled organic peroxides and Type B non-temperature-controlled organic peroxides are forbidden on cargo-only aircraft. Type C, D, E and F Division 5.2 liquids and solids which are not temperature-controlled may be transported in quantities from 10 to 50 kg (10 to 25 liters for liquids) per outer package.

Most Division 6.1 poisonous or toxic materials are permitted on cargo-only aircraft, except those which have one or more "subsidiary risks" or meet the definition of "toxic by inhalation (TIH)" substances (for example, acrolein, allyl chloroformate, arsenic trichloride, etc.) Division 6.1 toxic substance quantities per outer package on cargo aircraft typically range from 50 kg (30 liters for liquids) for Packing Group I materials to 200 kg (220 liters for liquids) for Packing Group III materials.

There are limited prohibitions of Class 7, 8 and 9 hazardous materials on cargo-only flights, except those which have one or more "subsidiary risks," for example, radioactive thorium metal, which is also a Division 4.2 pyrophoric solid. But quantities per outer package are generally limited by Packing Group according to their relative danger as with other hazard classes.

WHAT HAZARDOUS MATERIALS ARE NEVER PERMITTED ON AIRCRAFT?

The vast majority of these forbidden hazardous materials are in Classes 1 through 6. Typically they are the most highly explosive, flammable, oxidizing, self-reactive or toxic chemical substances or articles in their class. These include the Division 1.1, 1.2 and 1.3 mass explosion or fire threats as well as Division 5.2 organic peroxides which may decompose explosively. They also include the spontaneously combustible materials in Class 4, the powerful oxidizing materials in Class 5 and volatile toxic materials in Division 2.3 and Class 6.

Caution: Just because a hazardous material may be prohibited from air transportation by the regulations does not necessarily mean that they "never, ever fly" legally on commercial aircraft. DOT's hazardous materials regulations also permit "exemptions" to allow certain prohibited materials aboard either cargo or passenger aircraft. However, DOT requires that those exempted materials must be transported with "an equivalent level of safety" to the hazardous materials regulations in general. For example, the DOT has issued more than twenty-five exemptions to permit Division 1.1, 1.2 or 1.3 explosive material carriage on cargo-only aircraft. While these exemptions may allow cargo-airline holders to carry up to 2000 pounds of these explosives per flight, they must always be under strict operational controls for packaging, loading, unloading and routing. The exemptions to the hazardous materials regulations must be renewed biennially by the holders and may be revoked at any time for cause.

WHAT DOES IT MEAN WHEN AN AIR HAZARDOUS MATERIAL SHIPMENT IS NON-COMPLIANT (NC)?

A Non-Compliant shipment is one which does not meet DOT hazardous material regulations (either deliberately or unintentionally). A shipment can be Non-Compliant for any one or combination of the following reasons:

- Material is forbidden for all air transport
- It was not declared as hazardous material
- Package was not properly marked or labeled
- Quantity restrictions are exceeded for the type of flight (passenger or cargo)
- Inner or outer packaging does not meet DOT requirements (for example it is not in a DOT specification box, inadequate temperature control, etc.)

WHAT DOES IT MEAN WHEN AN AIR HAZARDOUS MATERIAL SHIPMENT IS CARGO-COMPLIANT (CC)?

For a shipment to be Cargo-Compliant it must meet the DOT requirements for a cargo flight but not necessarily those for a passenger flight:

- Material is not forbidden for cargo air transport
- It was declared as hazardous material
- Package was properly marked and labeled
- Quantity restrictions per outer package are not exceeded for cargo flights
- Inner or outer packaging meets or exceeds DOT requirements

WHAT DOES IT MEAN WHEN AN AIR HAZARDOUS MATERIAL SHIPMENT IS PASSENGER-COMPLIANT (PC)?

The shipment is Passenger-Compliant if it meets all of the DOT regulations for movement aboard passenger aircraft:

- Material is not forbidden for passenger air transport
- It was declared as hazardous material
- Package was properly marked and labeled
- Quantity restrictions per outer package are not exceeded for passenger flights
- Inner or outer packaging meets or exceeds DOT requirements
- Aggregate quantity limits per cargo compartment are not exceeded

II Methodology of the Assessment

CAN THIS METHODOLOGY BE ILLUSTRATED BY MEANS OF A STORY?

Here is a fictional analogy which illustrates the methodology of this study as it might be hypothetically applied in a commercial application:

Suppose there was a landlocked country of "Terra," where the discovery of large gold deposits brought promise of prosperity. The miners of Terra need to import many dangerous mining chemical supplies for the new mine, but they need to transport them all into the country by air.

The head of the Terra Airways, the only passenger and cargo airline to the rest of world wants to import all these new hazardous mining chemical products but the airlines insurance company, "Safety Insurance," has a problem. The airline's safety record has not been perfect and Safety Insurance wants to know the chances that these hazardous cargoes, when onboard, will cause the Terra Airways to have other accidents. Safety Insurance won't insure Terra Airways as a hazardous material carrier until they can estimate the increased risk of this new business to their stockholders. Terra Airways has been told what specific hazardous chemicals the gold mine will need but the gold mining operations haven't begun, so Safety Insurance doesn't know how many shipments will be needed over the normal insurance premium period.

The Safety Insurance risk management staff studies the list of potential hazards. There are explosives, flammable gases, oxygen, toxic gases, flammable liquids, flammable solids, oxidizers and catalysts as well as toxic and corrosive materials. They also study Terra Airway's current fleet of aircraft and their cargo compartments. They study the history of all the airplane accidents that might have been caused by one or more of these dangerous goods. Safety Insurance then develops a plan to bill the airline a surcharge for every flight containing these hazardous materials on board, depending on what threats to the aircraft are presented by those materials while being carried to Terra.

Safety Insurance's risk managers say to the president of Terra Airways: "we need to make estimates of 'threat factors'; that is the chance for each possible way in which each dangerous material could bring harm to the plane or its occupants. Each hazardous substance or article must first be classed by its potential danger to humans, whether it is explosive, flammable, toxic, corrosive, radioactive or unstable when heated, either by itself or when mixed with air, water or another hazardous chemical. Shipments that contain potentially dangerous chemicals always need special packaging to prevent accidental spills. In some cases they also must be refrigerated during transport to keep them from reacting within their packagings."

The airline's president wanted to know why this was necessary. Safety Insurance explained: "Suppose there was a fire onboard the plane somewhere in the same compartment? Or suppose an electrical short-circuit causes a spark nearby? Or suppose the package containing the hazardous chemical material was dropped or fell just before being put on the plane and began leaking? Or suppose there was a loose piece of metal rubbing on the package during a bumpy ride through rough air over the mountains? What would happen to the hazardous material in those packages exposed to that condition? Would they then cause a chain reaction, spreading from package to package?"

The president of Terra Airways replied: "But how would I know these things?" And Safety Insurance responded: "No one exactly knows what the chances of hazardous material accidents happening on aircraft are. But insurance companies must take that risk when they insure your airline and we want to know how big that risk is so we know what premium to charge you per flight, according to what you carry, how much you carry and where you put it on the plane."

The airline president asked: "But will we then have to make this calculation every time we want to fly any hazardous material to Terra?" Safety Insurance replied: "we probably can generalize from these specific materials to whole classes and quantity ranges. Once your gold mine is underway, we can establish the frequency of shipments which would finally allow us to estimate the overall risk of all flights of dangerous goods on Terra Airways and arrive at an overall insurance premium per year instead of per flight."

Thus by using this quantitative risk management approach, Safety Insurance and Terra Airways were able to create a workable policy arrangement which protected both insurer and client, and allowed the gold mine operation to proceed in Terra.

WHAT ARE THE DIFFERENCES BETWEEN A "RISK ANALYSIS" AND A "THREAT ASSESSMENT"?

WHAT IS MEANT BY EACH?

"Risk" is understood as a function of the frequency of an undesired outcome and its severity. A risk analysis quantitatively evaluates both to a degree appropriate to the nature of the problem, available resources and the objectives of the study. A threat assessment identifies the possible sources of an undesirable outcome and seeks to quantitatively evaluate the probability of a life threatening situation and the level of severity. A threat assessment is often a precursor of a risk analysis.

WHY WASN'T A TOTAL RISK ANALYSIS POSSIBLE?

The hypothetical events that are being addressed in this study - life-threatening events on an in-flight aircraft related to the carriage of hazardous materials – turn out to be extremely rare. The data required for a more substantive risk analysis is currently unavailable. Some of the most significant areas where data is lacking include, but are not limited to, shipping frequencies for hazardous materials by class and division, the frequency of hazardous material related incidents, and the volume and nature of air-borne hazardous materials which are undeclared. A more complete risk analysis could also address a broader range of outcomes including injuries and property damage.

The results of this assessment reflect this lack of frequency data. A frequently shipped material will be under represented even though in actuality, the movement frequency may cause the overall risk of the material to be greater than that of a very rarely shipped material which is more likely to cause a life threatening situation.

WHAT WILL A "THREAT ASSESSMENT" TELL US?

A threat assessment can identify the individual pathways leading up to an undesirable event and, as far as possible, determine the likelihood of each individual pathway. This information can be used to identify and prioritize potential countermeasures, as well as serve as a departure point for further study.

This threat assessment investigates life-threatening incidents onboard an in-flight aircraft due to the carriage of hazardous material in a cargo compartment. By limiting the consequence to potentially life-threatening incidents (such as explosions, severe fires and toxic material releases) and diagramming the logic flows from the hazardous materials present to those consequences, the numerical inputs (referred to hereafter as "Factors") required to calculate the likelihood of each pathway can be identified.

This assessment assumes the existence of a selected hazardous material in a particular packaging state (Non-Compliant, Cargo-Compliant or Passenger-Compliant) on an aircraft in a designated cargo compartment. In this study all possible combinations of hazardous material type, packaging state and cargo compartment type are evaluated to determine the probability of a life-threatening incident occurring.

This assessment identifies the sources of threat and roughly quantifies the probability of each per flight. Because it assumes that a hazardous material is onboard the aircraft in a particular cargo compartment, rather than utilizing true shipping frequencies, it is not a true measure of risk, but rather of relative hazard, vulnerability, or threat ranking of specific combinations of hazardous material and cargo compartments. It evaluates the various life-threatening pathways which contribute to the risk and the extent to which they contribute to the overall risk. We can say that a particular hazardous material may likely lead to a life-threatening event, but not how often the material is shipped and therefore not how often the event will occur per time unit or per number of flights.

WHAT IS AN "EVENT TREE"?

The key analytical tool used in conducting this study is the quantitative event tree. The event tree is a method for representing sequential pathways which could lead to potentially life-threatening situations due to the presence of a hazardous material and provide a method for calculating the likelihood of each pathway.

Once the logical flow of events (from the presence of a given hazardous material to the consequential life-threatening situation) has been determined for each set of assumptions, an event tree analysis can be used to determine the likelihood of all possible outcomes for a given threat. For example, a fire on an aircraft may have many outcomes ranging from a very small fire which self-extinguishes, up to a very large life-threatening fire with catastrophic consequences. Event trees model these "falling domino" sequences and determine their probability of occurrence.

To estimate the probability of basic events, reasonable "worst likely" situations are assumed. For example, any given class of hazardous material is typified by one of the most hazardous specific chemicals within that class that is likely to be shipped on an aircraft.

HOW DOES AN EVENT TREE WORK?

An event tree is made up of multiple branches, all of which eventually end in either a life-threatening event or a non-event. A separate event tree is used for each major pathway leading to a calamitous event. In the case of this assessment there are event trees for flammable, oxidizer, and dangerous-when-wet threats, as well as toxic material releases. For each tree, probabilities are calculated for these outcome events which indicate the likelihood that they will occur. Each tree is used to compute these probabilities for various applicable combinations of hazardous material types, cargo compartment type and compliance with current DOT regulations.

Each of the four event trees used in this assessment is composed of a series of yes-no decision points. Each decision point relates to a factor that contributes to, or is necessary for, the resulting life-threatening event to occur. There are 22 factors used in this assessment. These factors differ for each of the event tree types. These factors can include: the probability of an independent (non-hazardous material related) fire, the probability of a package release, the probability that released material will ignite, the probability that the fire will be suppressed, etc. The weight assigned to the "Yes"(Y) or "No"(N) branches for each decision point depends on the probability associated with that factor. The factors used in this assessment and the probabilities assigned to them are presented in Appendix A.

Figure 2.1 shows a sample event tree for a Division 2.2/5.1 Oxygen, compressed in a type D cargo compartment. Following the first line in the event tree shown (Row 1, marked by the first arrow), a life threatening severe hazardous material outcome (explosion) occurs if six conditions are met: (1) there is an independent fire, (2) the fire continues after attempt at suppression, (3) there is an independent package release; (4) the fire causes initiation of the released material, (5) there is an explosion, and (6) the explosion is severe. Row 65 (marked by the second arrow) also ends in a "Severe Explosion." This scenario contains conditions for an event similar to the first except that it does not involve an independent fire, but instead the material is initiated by a source other than a fire. In 36 of the 84 scenarios, the outcomes are non-events. Total probabilities for each category or outcome are presented in the far right column of the table (see number three arrow). The calculation model constructed for this assessment was built to be easily modified as additional data becomes available and is structured to incorporate information on shipping frequencies once such information becomes available.

The logic flow for the event trees used in this assessment are presented graphically in Appendix A of this report.

HOW IS AN EVENT TREE USED?

Event trees are used to both graphically represent pathways that could lead to life threatening events due to the presence of a hazardous material, and provide a calculation mechanism which ensures that all possible pathways are considered and prevents the total probability of a life-threatening event from exceeding one.

The event tree methodology is useful in identifying and evaluating proposed countermeasures. Through analysis of the trees it is possible to determine specific locations within the causal chain of events leading to a life threatening event where interventions can change the likelihood of source events (for example, explosion) to accomplish a reduction in the probability of occurrence for a given scenario.

WHAT CAN AN EVENT TREE TELL US?

This threat assessment provides a ranked list of probabilities that a life-threatening event occurs for each combination of hazardous material and cargo compartment and is further broken down by other factors such as event type, such as fire or explosion.

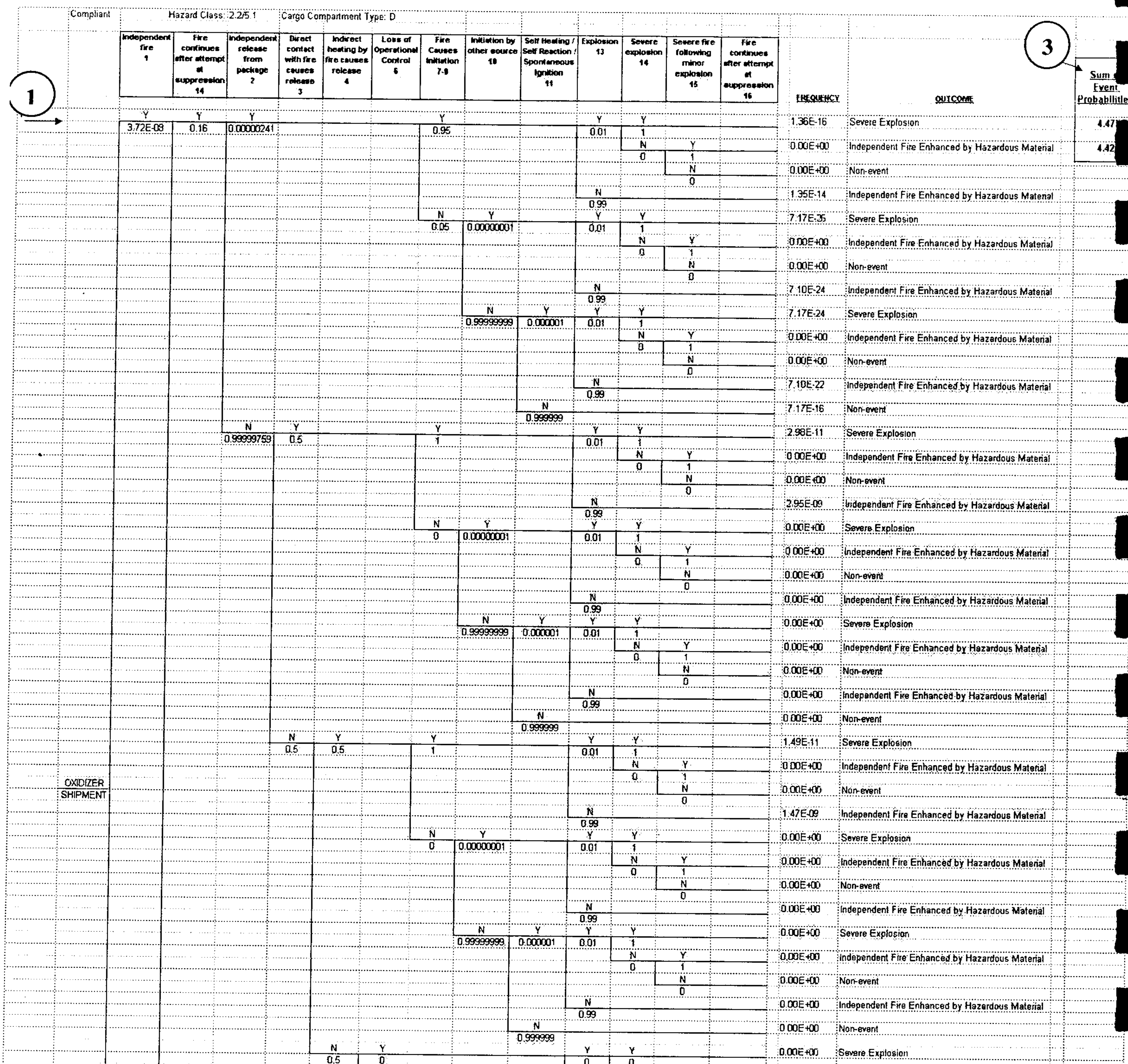


Figure 2.1 Sample Event Tree for Division 2.2/5.1 Oxygen, compressed in a Type D Cargo Compartment

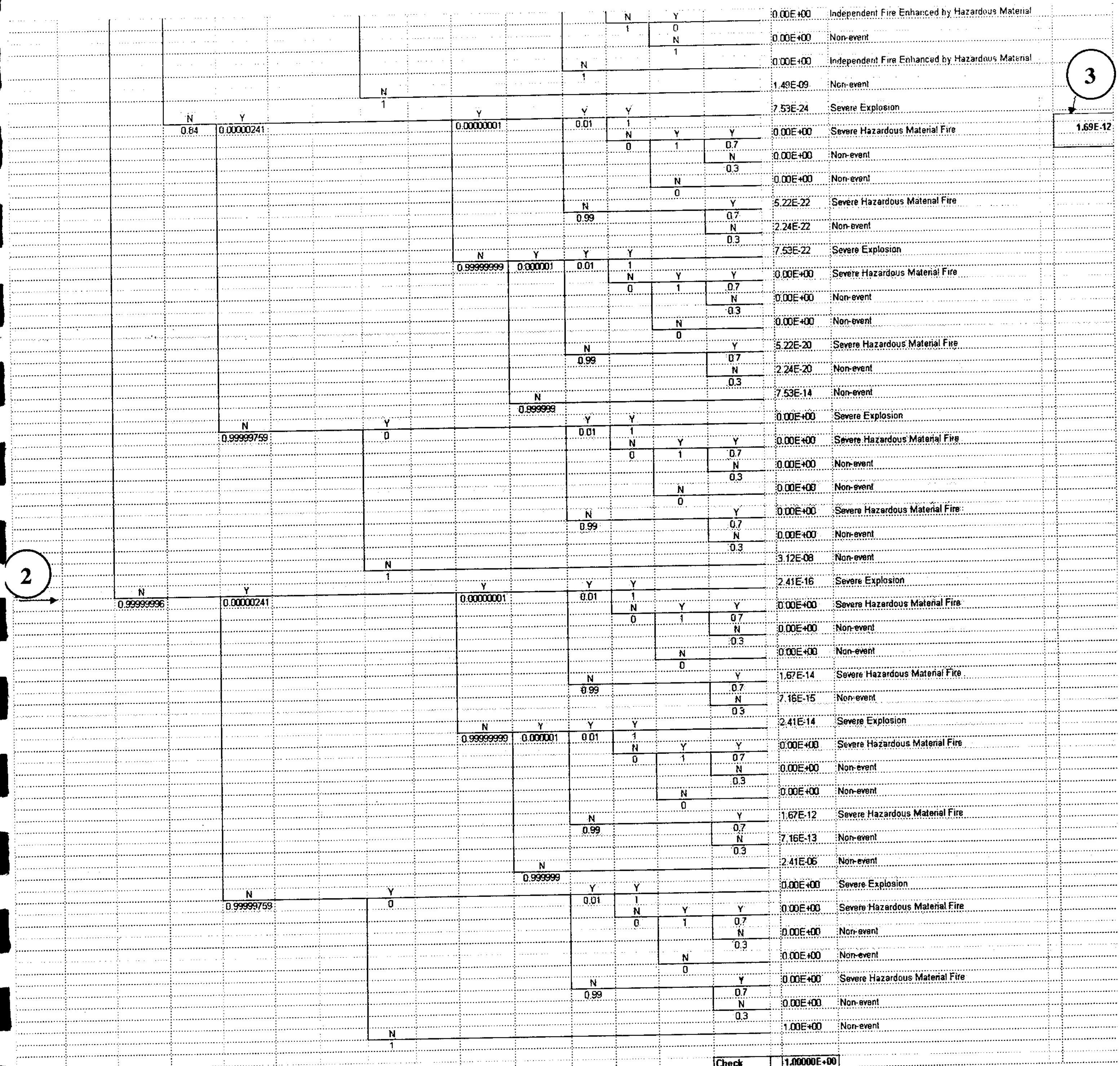


Figure 2.1 Sample Event Tree for Division 2.2/5.1 Oxygen, compressed in a Type D Cargo Compartment, continued

WHAT WERE THE SPECIFIC HAZARDOUS MATERIALS CHOSEN FOR THIS ASSESSMENT?

The problem: how to evaluate "threat factors" for an entire class or division of hazardous chemicals which can contain many different substances and/or articles? For example, there are 535 different flammable liquid entries in the hazardous material table and more than 700 toxic material entries! It was concluded that the ranges of chemical, physical, and toxicological properties in the hazard class subdivisions were too broad to be able to make meaningful "representative composites" for this assessment.

The solution: to review all the table entries in each hazardous material class and division and choose one to represent the "worst likely" threat among the classes and subdivisions to pose immediate danger to an in-flight aircraft. It was assumed that the hazardous material selected to represent its class and division could be compliant or non-compliant with DOT regulations. Since the compliant assumption is different for a hazardous material transported on passenger aircraft vs. cargo-only aircraft, separate cases were created for each.

In order to have a range of hazardous materials to choose from for the individual cases, different "worst likely" hazardous materials were made to represent the same class and division, depending on the degree of compliance. So it is not possible to make direct comparisons between each hazardous material class and division among the cases, since they are typically represented by different chemical substances and/or articles. See Table B.1 in Appendix B for more comprehensive information for all the materials chosen for all three cases.

FOR THE NON-COMPLIANT CASE?

Table 2.1 Selected Materials – Non-Compliant Case

Represents Class/Division	"Worst Likely" Hazardous Material		Compatibility Group	Packing Group
1.1	UN0129	Lead azide, wetted	1.1A	n/a
1.2	UN0293	Hand grenades	1.2F	n/a
1.3	UN0335	Fireworks(display)	1.3G	n/a
1.4	UN0371	Warheads, rocket	1.4F	n/a
1.5	NA0331	ANFO (ammonium nitrate-fuel oil mixture)	1.5D	n/a
2.1	UN1966	Hydrogen, refrigerated liquid		n/a
2.2 / 5.1	UN1073	Oxygen, refrigerated liquid		n/a
2.3	UN1017	Chlorine (TIH*-Zone B)		n/a
3	UN1155	Diethyl ether		n/a
4.1	UN1347	Silver picrate, wetted		n/a
4.2	UN1381	Phosphorus, white, dry		n/a
4.3	UN1410	Lithium aluminum hydride		n/a
5.1	UN2014	Hydrogen peroxide, aqueous solution (50%)		n/a
5.2	UN3113	Organic peroxide, Type C, liquid, temperature controlled		n/a
6.1	UN1259	Nickel carbonyl (TIH*-Zone A)		n/a

* Toxic Inhalation Hazard

FOR THE CARGO-COMPLIANT CASE?

Table 2.2 Selected Materials – Cargo-Compliant Case

Represents Class/Division	"Worst Likely" Hazardous Material	Compatibility Group	Packing Group
1.1	None permitted		n/a
1.2	None permitted		n/a
1.3	None permitted		n/a
1.4	UN0412 Cartridges for weapons	1.4E	II
1.5	None permitted		n/a
2.1	UN1049 Hydrogen, compressed		n/a
2.2 /5.1	UN2451 Nitrogen trifluoride		n/a
2.3	UN1017 Methyl bromide (TIH*-Zone C)		n/a
3	UN1155 Diethyl ether		I
4.1	UN1571 Barium azide, wetted		I
4.2	UN2008 Zirconium powder, dry		I
4.3	UN1410 Lithium aluminum hydride		I
5.1	UN2466 Potassium superoxide		I
5.2	UN3103 Organic peroxide, Type C, liquid		II
6.1	UN2740 n-propyl chloroformate (TIH*-Zone B)		I

* Toxic Inhalation Hazard

FOR THE PASSENGER-COMPLIANT CASE?

Table 2.3 Selected Materials – Passenger-Compliant Case

Represents Class/Division	"Worst Likely" Hazardous Material	Compatibility Group	Packing Group
1.1	None permitted		n/a
1.2	None permitted		n/a
1.3	None permitted		n/a
1.4	UN0404 Flares, aerial	1.4S	II
1.5	None permitted		n/a
2.1	UN1950 Aerosols, flammable		n/a
2.2 /5.1	UN1072 Oxygen, compressed		n/a
2.3	None permitted		n/a
3	UN1155 Diethyl ether		I
4.1	UN3223 Self-reactive liquid, Type C		II
4.2	UN2008 Zirconium powder, dry		I
4.3	UN1400 Barium (metal)		II
5.1	UN1442 Ammonium perchlorate		II
5.2	UN3106 Organic peroxide, Type D, liquid		II
6.1	UN2295 Methyl chloroacetate		I

WHY WERE THESE MATERIALS CHOSEN FOR ASSESSMENT?

These specific hazardous materials were selected for the threat assessment according to the following criteria:

1. Is the chemical substance or article representative of some of the "worst likely" materials in its hazard class and division for a given compliance case?

2. Is the chemical substance or article commercially available and reasonably prevalent?

3. Is the chemical substance or article of sufficient commercial value to justify air transportation?

After evaluating these questions for a wide number of materials in each class and division, the selected materials were recommended by RSPA's Office of Hazardous Materials Safety (OHMS) for the representative material in an entire class and division of hazardous material in each of the compliance cases.

Caution: These selections were made on the best information, experience and technical judgment available to this assessment but should not be interpreted as a wide consensus for the ten or fifteen "most dangerous" chemicals that could be placed in an aircraft cargo compartment.

HOW WERE THE PROBABILITY FACTORS ASSIGNED FOR EACH MATERIAL?

BY PHYSICAL PROPERTIES (PHYSICAL STATE, MELTING POINT, BOILING POINT, ETC.)?

Once the choice of a specific hazardous material for each of the non-compliant and compliant cases was made, the physical properties of each chemical substance or article containing a chemical substance was analyzed. Was it a gas, a liquid or a solid? This determined how fast a given material would migrate from the cargo compartment atmosphere. If it was a liquid, then the boiling point and viscosity became an important indicator of its relative volatility and overall mobility.

BY CHEMICAL PROPERTIES (REACTIVITY, STABILITY, ETC.)?

The chemical properties of the hazardous material chosen for each case were reviewed and ranked. How reactive is it to fire, impact, friction and electrostatic discharge, etc.? How thermally stable is it? And will it decompose, react with water, itself or its packaging violently or explosively? These questions largely determined how (that is, along what 'threat event' tree branches) the deteriorating condition would develop.

BY TOXICOLOGICAL PROPERTIES?

The toxicological properties of the hazardous material chosen for each case were reviewed and ranked. Data were used for inhalation toxicity in laboratory animals (LC_{50} values) when human toxicity data was not directly available. Also the rates of evaporation at reduced pressures such as would occur in flight were analyzed. These two properties together can determine whether material escaping from a damaged or leaking package could follow threat event tree branches producing a lethal atmosphere for human occupants somewhere in the aircraft.

HOW WERE PROBABILITY FACTORS ASSIGNED FOR EACH CARGO COMPARTMENT?

Probability factors related to cargo compartment type include: independent fire, fire suppression, cargo compartment breach, and toxic material transfer. Independent fire numbers were calculated based on the number of past instances of independent fires in cargo compartments and the number of departures for Part 121 flights. Fire suppression, compartment breach and toxic material transfer numbers were based on the results of fire tests performed at the FAA Technical Center.

WHAT WERE THE SOURCES FOR THE PROBABILITY FACTORS?

The individual probabilities assigned to the basic events are strongly based on available data. The OHMS, Volpe Center, support contractors, and a group of stakeholder experts all contributed significantly to the identification and acquisition of data for this study. OHMS provided data on material properties, and initiation probabilities; the Volpe/Arthur D. Little (ADL) team provided packaging failure probabilities; the FAA Tech Center provided data on fire suppression; independent fire numbers came from the FAA and the airlines. Emphasis was placed on maximizing consistency and coherence among the probability estimates. The probabilities should be considered reasonable starting estimates to be refined as additional data becomes available. Even if these estimates are later revised, it is anticipated that the general trends and relative standing between scenarios will remain the same.

WHAT DO THE "FACTORS" MEAN IN PRACTICAL TERMS?

The factors used in the four event trees can be categorized as follows:

Independent Fire (Factor 1)	Relating to the probability that a fire not involving hazardous materials will occur.
Package Release (Factors 2-6)	Relating to the probability that a hazardous material will be released from its packaging
Initiation (Factors 7-12)	Relating to the probability that a released hazardous material will initiate
Explosion (Factors 13-15)	Relating to the probability that a hazardous material will explode
Fire Suppression (Factors 16-17)	Relating to the probability that a fire will be suppressed
Toxic Material Transfer (Factors 18-22)	Relating to the probability that a toxic material will be released and transferred to the cabin or cockpit

Following are the definitions and assigned values for each of the factors. A table containing all values for these factors is also presented in Appendix C (see page 95).

Independent Fire

♦ Factor 1: Independent Cargo Compartment Fire

This factor represents the probability that a fire which starts in a cargo compartment is unrelated to hazardous materials. This could include a fire caused by a malfunctioning cargo heating blanket, a broken cargo compartment light fixture, a lit cigarette, etc.

Independent fire probabilities are derived from estimates of cargo compartment departures (1970 to present) and historical instances of independent fires reported to the FAA (see Appendix E). These probabilities are shown in the table below.

Table 2.4 Factor 1 - Independent Fire Probabilities

Cargo Compartment Type	Cargo Compartment Departures*	Independent Fire in Cargo Compartment**
A	94 million	7.45E-08
B1	7.1 million	5.80E-07
B2	734,000	5.80E-07
C	57 million	5.26E-08
D	242 million	3.72E-08
E	6.9 million	5.80E-07

*Source: RSPA Census of Passenger-Carrying Aircraft
**Source: FAA

Package Release

♦ Factor 2: Package Release – Independent Release

This factor represents the probability that a hazardous material package fails and its contents are released – unrelated to a fire. The package failure and content release could be due to defective packaging, mishandling (dropped or punctured), shifting en-route (improper stowage), etc. Note that this factor applies to cases where the package is not near a fire.

The failure rate for compliant packages and cylinders is assumed to be less than for non-compliant packages. Thus, this value varies depending on the packaging assumptions.

Table 2.5 Factor 2 - Independent Package Release Probabilities

Hazardous Material Class/Division*	Compliance Case			Independent Release from Package
	Non-	Cargo	Pssngr	
2.1	✓			1**
2.2/5.1	✓			
1.4E		✓		1.00E-05***
1.5S			✓	
2.1			✓	
3		✓	✓	
4.1		✓	✓	
4.2		✓	✓	
4.3		✓	✓	
5.1		✓	✓	
5.2		✓	✓	
6.1		✓	✓	
2.1		✓		2.41E-06****
2.2/5.1		✓	✓	
2.3		✓		
1.1A	✓			3.00E-04***
1.2F	✓			
1.3G	✓			
1.4F	✓			
1.5D	✓			
2.3	✓			
3	✓			
4.1	✓			
4.2	✓			
4.3	✓			
5.1	✓			
5.2	✓			
6.1	✓			

*See Table B-1 for selected materials and packaging assumptions.
** Cryogenic liquids whose containers are designed to vent.
***Source: ADL. The compliance package failure rate of 1.00E-05 was established from reported release rates of select airlines. Engineering judgement was used to estimate an increase in risk for non-compliant packages by a factor of 30 over the compliance case rate (or 3.00E-04).
**** Source: OHMS. Release rates for cylinders.

♦ Factor 3: Package Release -- Direct Contact with Fire Causes Release

This factor represents the probability that a hazardous material package fails and its contents are released – <u>because it is in direct contact with a fire</u>. The package failure and content release could be due to the packaging burning, melting, expanding, bursting, etc. This probability has two parts:

Proximity -The probability the package is in contact with the fire – where applicable, the assumption used was 50% since the location of the fire within the cargo compartment is unknown.

Release - The probability the package fails and releases its contents if it is in direct contact with the fire. This depends on the type of hazardous material, packaging material, and specific assumptions made about non-compliant packages.

These two components are multiplied to achieve the overall probability for this factor.

Table 2.6 Factor 3 - Direct Contact with Fire Causes Release Probabilities

Hazardous Material Class/Division*	Compliance Case			Direct Contact with Fire Causes Release		
	Non-	Cargo	Pssngr	Proximity	Release***	Overall Probability
2.3	✓			0.50	1.00E-03	5.00E-04
4.1		✓		0.50	2.00E-02	1.00E-02
4.1	✓			0.50	0.10	5.00E-02
1.1A	✓			0.50	1	0.50
1.2F	✓					
1.3G	✓					
1.4F	✓					
1.4E		✓				
1.4S			✓			
1.5D	✓					
2.1		✓	✓			
2.2/5.1		✓	✓			
2.3		✓				
3	✓	✓	✓			
4.1			✓			
4.2	✓	✓	✓			
5.1	✓	✓	✓			
5.2		✓	✓			
6.1	✓	✓	✓			
2.1	✓			n/a**	1	1
2.2/5.1	✓					
5.2	✓					
4.3	✓	✓	✓	n/a**	n/a**	n/a**

*See Table B-1 for selected materials and packaging assumptions.
**Release due to venting/breathing is assumed for refrigerated liquids in non-compliant packaging
***Source: OHMS

♦ Factor 4: Package Release -- Indirect Heating by Fire Causes Release

This factor represents the probability that a hazardous material package fails and its contents are released – because it is indirectly heated by a fire in close proximity to the package. The release could be due to the packaging burning, melting, expanding, bursting, venting or breathing.

This probability has two parts:

Proximity - The probability the package is close enough to the fire to cause content release – where applicable, the assumption used was 50% since the location of the fire within the cargo compartment is unknown.

Release - The probability that the package fails and releases its contents when the package is indirectly heated by a fire. This depends on the type of hazardous material, packaging material, and specific assumptions made about non-compliant packages.

These two components are multiplied to achieve the overall probability for this factor.

Table 2.7 Factor 4 - Indirect Heating by Fire Causes Release Probabilities

Hazardous Material Class/Division*	Compliance Case			Indirect Heating by Fire Causes Release		
	Non-	Cargo	Pssngr	Proximity	Release****	Overall Probability
1.4E		✓		0.50	0	0
1.4S			✓			
2.3	✓			0.50	1.00E-04	5.00E-05
4.1		✓		0.50	1.00E-02	5.00E-03
4.1	✓			0.50	0.10	5.00E-02
1.1A	✓			0.50	0.50	0.25
1.2F	✓					
1.3G	✓					
1.4F	✓					
1.5D	✓					
2.1		✓	✓			
2.2/5.1		✓				
2.3		✓				
3	✓	✓	✓			
4.1			✓			
4.2	✓	✓	✓			
5.1	✓	✓	✓			
5.2		✓	✓			
6.1	✓	✓	✓			
2.2/5.1			✓	0.50	1	0.5
2.1	✓			n/a**	1	1
2.2/5.1	✓					
5.2	✓					
4.3***	✓	✓	✓	n/a	n/a	n/a

* See Table B-1 for selected materials and packaging assumptions.
**Release due to venting/breathing is assumed for refrigerated liquids in non-compliant packaging
***Division 4.3 material is a special case and is treated in Factor 5
****Source: OHMS

♦ Factor 5: Package Release – Release Via Breathing / Venting

This factor is the probability that a package containing Division 4.3 materials vents or breathes in the absence of a fire. This probability has two parts:

Source - The probability a heat source (non-fire) exists in the cargo compartment.

Exposure - The probability that the exposure to the heat source is sufficient to cause the package to vent or breathe.

Table 2.8 Factor 5 - Package Release Via Venting/Breathing (No Fire) Probabilities

Hazardous Material Class/Division*	Compliance Case			Package Release via Venting/Breathing		
	Non-	Cargo	Pssngr	Heat Source**	Sufficient Exposure ***	Overall Probability
4.3	✓			9.77E-07	1	9.77E-07
		✓		9.77E-07	0.10	9.77E-08
			✓	9.77E-07	1.00E-03	9.77E-10

Note: This does not apply to any other material Class/Division
* See Table B-1 for selected materials and packaging assumptions.
** Source: ADL. Derived from FAA incident data.
*** Source: OHMS

♦ Factor 6: Package Release – Loss of Operational Control

The probability that temperature or other operational control devices are inadequate. This covers the case where cryogenic or other materials requiring refrigeration initiate upon package failure due to rise in temperature to the cargo compartment level.

Table 2.9 Factor 6 - Loss of Operational Control Probabilities

Hazardous Material Class/Division*	Compliance Case			Loss of Operational Control**
	Non-	Cargo	Pssngr	
2.1	✓			1.00E-03
2.2/5.1	✓			
5.2	✓			0.10

Note: This does not apply to any other material Class/Division
* See Table B-1 for selected materials and packaging assumptions.
**Source: OHMS

Initiation

♦ Factor 7: Initiation – With Independent Release

This factor represents the probability that an independently released hazardous material in the same compartment as an independent fire is initiated indirectly by that fire. This factor assumes migration to the fire is necessary for initiation – otherwise it would be covered under Factor 8 or 9. This factor does not apply if the material is released directly by a fire – this case would be covered by Factor 2.

This probability has two parts:

Migration - The probability that the independently released material migrates close enough to an independent fire for initiation. This value depends on the physical state of the material – 5% for solid material; 50% for liquid material; and 95% for gases.

Initiation - The probability that the released material initiates or enhances burning if exposed to fire. This is dependent on the chemical properties of the material involved.

These two components are multiplied to achieve the overall probability for this factor.

Table 2.10 Factor 7 - Initiation with Independent Release Probabilities

Hazardous Material Class/Division*	Compliance Case			Initiation with Independent Release		
	Non-	Cargo	Pssngr	Migration **	Initiation **	Overall Probability
4.1		✓		5.00E-02	0.50	2.50E-02
1.1A	✓			5.00E-02	1	5.00E-02
1.2F	✓					
1.3G	✓					
1.4F	✓					
1.4E		✓				
1.4S			✓			
1.5D	✓					
4.1	✓		✓			
4.2	✓	✓	✓			
5.1		✓	✓			
3	✓	✓	✓	0.50	1	0.50
5.1	✓					
5.2	✓	✓	✓			
2.1	✓	✓	✓	0.95	1	0.95
2.2/5.1	✓	✓	✓			
2.3	✓	✓		n/a	n/a	n/a
4.3	✓	✓	✓			
6.1	✓	✓	✓			

* See Table B-1 for selected materials and packaging assumptions.
**Source: OHMS

♦ Factor 8: Initiation - In Direct Contact with Fire

This factor applies where the hazardous material is released due to direct contact with fire; that is, only to those cases where Factor 3 'Package Release -- Direct Contact with Fire Causes Release' applies. This factor represents the probability that a hazardous material initiates or enhances burning once released directly into the fire. This is dependent on the chemical properties of the material. *Note that direct contact between the material and the fire is assumed.*

Table 2.11 Factor 8 - Initiation – Direct Contact with Fire Probabilities

Hazardous Material Class/Division*	Compliance Case			Initiation - Direct Contact with Fire**
	Non-	Cargo	Pssngr	
4.1		✓		0.50
1.1A	✓			1
1.2F	✓			
1.3G	✓			
1.4F	✓			
1.4E		✓		
1.5S			✓	
1.5D	✓			
2.1	✓	✓	✓	
2.2/5.1	✓	✓	✓	
3	✓	✓	✓	
4.1	✓		✓	
4.2	✓	✓	✓	
5.1	✓	✓	✓	
5.2	✓	✓	✓	
2.3	✓	✓		n/a
4.3	✓	✓	✓	
6.1	✓	✓	✓	

* See Table B-1 for selected materials and packaging assumptions.
** Source: OHMS

♦ Factor 9: Initiation – Not in Direct Contact with Fire (Indirect Heating)

This factor applies where the hazardous material is released due to indirect heating by fire; that is, only to those cases where Factor 4 'Package Release -- Indirect Heating by Fire Causes Release' applies. This factor represents the probability that a hazardous material, once released <u>due to indirect heating by fire,</u> initiates or enhances burning. This is dependent on the chemical properties of the material. *Note that heating sufficient to cause material release is assumed.*

Table 2.12 Factor 9 - Initiation – Indirect Heating by Fire Probabilities

Hazardous Material Class/Division*	Compliance Case			Initiation - Indirect Heating by Fire **
	Non-	Cargo	Pssngr	
1.5D	✓			0
5.2			✓	5.00E-03
1.2F	✓			1.00E-02
1.3G	✓			
1.4F	✓			
1.4E		✓		
1.4S			✓	
5.2		✓		
3			✓	2.50E-02
4.1		✓		0.10
5.1	✓			
5.2	✓			
4.1	✓			0.25
4.2			✓	
1.1A	✓			0.50
4.1			✓	
4.2		✓		
5.1			✓	
3	✓	✓		0.75
2.1	✓	✓	✓	1
2.2/5.1	✓	✓	✓	
4.1			✓	
4.2	✓			
5.1		✓		
2.3	✓	✓		n/a
4.3	✓	✓	✓	
6.1	✓	✓	✓	

* See Table B-1 for selected materials and packaging assumptions.
** Source: OHMS

♦ Factor 10: Initiation by Other Source

This factor represents the probability that a hazardous material (which has been released by any means but not ignited by fire) initiates – because it is exposed to an initiating source other than fire. The predominant source of initiation (heat, impact, friction or electrostatic discharge (ESD)) for each material is identified. This probability has three parts:

Source - The probability that an initiating source occurs in the cargo compartment. This includes component overheating, shock, friction, and electrostatic discharge.

Exposure - The probability the released material is exposed to an initiating source in the cargo compartment. Heat and ESD sources are assumed to be location specific, requiring the material to migrate in order to be exposed. Therefore, this value differs by the physical state of the material: 5% for solids, 50% for liquids, and 95% for gases. Sources of shock or friction are assumed to occur throughout the cargo compartment, exposing all packages. In these cases, a value of 100% is assigned.

Initiation - The probability that the released material initiates or enhances burning if it is exposed to any of the initiating sources listed above. This depends on the chemical and physical properties of the material.

These three components are multiplied to achieve the overall probability for this factor.

Table 2.13 Factor 10 - Initiation – Other Source (Heat/Impact/Friction/ESD) Probabilities

Hazardous Material Class/ Division*	Compliance Case			Initiation by Other Source (Heat/Impact/ Friction/ESD)				
	Non-	Cargo	Pssngr	Source Type	Source ***	Migration/ Exposure **	Initiation **	Overall Probability
1.5D	✓			Impact/ Shock	1.00E-03	1	1.00E-09	1.00E-12
5.1		✓		Heat	9.77E-07	5.00E-02	1.00E-04	4.89E-12
4.1			✓	Heat	9.77E-07	5.00E-02	1.00E-03	4.89E-11
1.3G	✓			Friction	1.00E-04	1	1.00E-06	1.00E-10
1.4S			✓					
1.2F	✓			Impact/ Shock	1.00E-03	1	1.00E-06	1.00E-09
1.4F	✓							
1.4E		✓						
5.1			✓					
4.2		✓	✓	ESD	9.77E-07	5.00E-02	1.00E-02	4.89E-10
5.2		✓	✓	Heat	9.77E-07	0.50	1.00E-03	
2.2/5.1		✓		Heat	9.77E-07	0.95	1.00E-03	9.29E-10
5.2	✓			Heat	9.77E-07	0.50	1.00E-02	4.89E-09
2.2/5.1	✓		✓	Friction	1.00E-04	1	1.00E-04	1.00E-08
4.1		✓		Friction	1.00E-04	1	1.00E-03	1.00E-07
3	✓	✓	✓	ESD	9.77E-07	0.50	0.33	1.61E-07
5.1	✓			Heat	9.77E-07	0.50	0.50	2.44E-07
2.1			✓	ESD	9.77E-07	0.95	0.50	4.64E-07
2.1	✓	✓		ESD	9.77E-07	0.95	0.99	9.19E-07
4.1	✓			Friction	1.00E-04	1	1.00E-02	1.00E-06
1.1A	✓			Friction	1.00E-04	1	0.50	5.00E-05
4.2	✓			n/a	n/a	1	1	1
2.3	✓	✓		n/a	n/a	n/a	n/a	n/a
4.3	✓	✓	✓					
6.1	✓	✓	✓					

* See Table B-1 for selected materials and packaging assumptions
** Source: OHMS
*** Source: ADL

♦ Factor 11: Spontaneous Ignition/Self Reaction/Self-Heating / Reaction with Packaging Material

This factor represents the probability that a released hazardous material, initiates via spontaneous ignition in air, self reaction, self-heating, or reaction with packaging material, that is, without any other means of initiation being present (such as fire, heat, impact, friction, or electrostatic discharge). The value for this factor depends on the chemical properties of the material.

Table 2.14 Factor 11 - Initiation – Self Heating/Self Reaction/Spontaneous Ignition/Reaction with Packing Materials Probabilities

Hazardous Material Class/ Division*	Compliance Case			Initiation - Self Heating/ Self Reaction/ Spontaneous Ignition/ Reaction with Packing Materials		
	Non-	Cargo	Pssngr	Self Heating/ Self Reaction**	Spontaneous Ignition/ Reaction with Packing Materials**	Overall Probability
1.1A	✓			0	0	0
1.2F	✓					
1.3G	✓					
1.4F	✓					
1.4E		✓				
1.4S			✓			
1.5D	✓					
2.1	✓	✓	✓			
3	✓	✓	✓			
4.1	✓	✓				
4.2		✓	✓			
5.1		✓				
2.2/5.1	✓	✓	✓	0	1.00E-06	1.00E-06
5.2		✓	✓	1.00E-06	1.00E-09	1.00E-06
4.1			✓	0	1.00E-03	1.00E-03
5.1			✓			
5.2	✓			1.00E-02	1.00E-04	1.00E-02
5.1	✓			0	0.25	0.25
4.2	✓			0	1	1
2.3	✓	✓		n/a	n/a	n/a
4.3	✓	✓	✓			
6.1	✓	✓	✓			

* See Table B-1 for selected materials and packaging assumptions.
** Source: OHMS

♦ Factor 12: Sufficient Water for Severe Reaction

This factor represents the probability that a released Dangerous-When-Wet material encounters enough water in the cargo compartment to initiate. The value for this factor is dependent on the chemical properties of the material.

Table 2.15 Factor 12 - Initiation – Sufficient Water for Severe Reaction Probabilities

Hazardous Material Class/Division*	Compliance Case			Initiation - Sufficient Water for Severe Reaction**
	Non-	Cargo	Pssngr	
4.3			✓	5.00E-04
4.3	✓	✓		1.00E-02

* See Table B-1 for selected materials and packaging assumptions.
** Source: OHMS

Explosion

♦ Factor 13: Any Explosion

This factor represents the probability that the material explodes if initiated by any source or if there is a loss of operational control. The value for this factor is dependent on the chemical properties of the material.

Table 2.16 Factor 13 - Explosion Probabilities

Hazardous Material Class/Division*	Compliance Case			Explosion**
	Non-	Cargo	Pssngr	
4.1			✓	0
4.2	✓	✓	✓	
1.5D	✓			1.00E-09
5.1			✓	
5.2		✓	✓	
5.2	✓			1.00E-04
2.2/5.1		✓		1.00E-03
5.1	✓			
2.2/5.1			✓	1.00E-02
5.1		✓		
1.4E		✓		0.10
3	✓	✓	✓	0.50
1.1A	✓			1
1.2F	✓			
1.3G	✓			
1.4F	✓			
1.4S			✓	
2.1	✓	✓	✓	
2.2/5.1	✓			
4.1	✓	✓		
2.3	✓	✓		n/a
4.3	✓	✓	✓	
6.1	✓	✓	✓	

* See Table B-1 for selected materials and packaging assumptions.
** Source: OHMS

♦ Factor 14: Severe Explosion

This factor represents the probability that the explosion in Factor 13 is severe (that is, the aircraft is assumed to be destroyed). The value for this factor is dependent on both the physical and chemical properties of the material.

Table 2.17 Factor 14 - Severe Explosion Probabilities

Hazardous Material Class/Division*	Compliance Case			Severe Explosion**
	Non-	Cargo	Pssngr	
1.4F	✓			0
1.4E		✓		
1.4S			✓	
2.1			✓	
4.1			✓	
4.2	✓	✓	✓	
5.2		✓	✓	1.00E-12
5.2	✓			1.00E-06
5.1	✓	✓		1.00E-05
3	✓	✓	✓	0.50
4.1		✓		
1.1A	✓			1
1.2F				
1.3G				
1.5D	✓			
2.1	✓	✓		
2.2/5.1	✓	✓	✓	
4.1	✓			
5.1			✓	
2.3	✓	✓		n/a
4.3	✓	✓	✓	
6.1	✓	✓	✓	

* See Table B-1 for selected materials and packaging assumptions.
** Source: OHMS

♦ Factor 15: Severe Fire Alone or Following Minor Explosion

This represents the probability that a cargo compartment fire (either hazardous material fire or independent fire enhanced by hazardous material) becomes severe (life threatening). This can be after a minor explosion or alone, depending on the event tree being used. The value for this factor is dependent on both the physical and chemical properties of the material.

Table 2.18 Factor 15 - Severe Fire Alone or Following Minor Explosion Probabilities

Hazardous Material Class/Division*	Compliance Case			Severe Fire Alone or Following Minor Explosion***
	Non-	Cargo	Pssngr	
1.1A	✓			0**
1.2F	✓			
1.3G	✓			
1.5D	✓			
2.1	✓	✓		
1.4F	✓			1.00E-02
1.4S			✓	
5.2		✓	✓	
1.4E		✓		0.50
4.1		✓	✓	
2.1			✓	1
2.2/5.1	✓	✓	✓	
3	✓	✓	✓	
4.1	✓			
4.2	✓	✓	✓	
5.1	✓	✓	✓	
5.2	✓			
2.3	✓	✓		n/a
4.3	✓	✓	✓	
6.1	✓	✓	✓	

* See Table B-1 for selected materials and packaging assumptions.
** Materials assumed to have been involved in severe explosions
*** Source: OHMS

Fire Suppression

♦ Factor 16: Fire Not Suppressed (Non-Oxidizer)

This factor represents the probability that a hazardous material (non-oxidizer) cargo compartment fire is suppressed. The value for this factor depends on cargo compartment type (that is, type of fire suppression available). Note that type D cargo compartments have no fire detection.

Table 2.19 Factor 16 - Fire Not Suppressed (Non-Oxidizer) Probabilities

Cargo Compartment Type	Fire Not Detected*	Fire Suppression Not Working*	Fire Suppression has Insufficient Chemicals*	Overall Fire Not Suppressed*
A	0.05	0.01	0.10	0.16
B1	0.01	0.01	0.58	0.60
B2	0.01	0.04	n/a	0.05
C	0.01	0.01	0.02	0.04
D	n/a	0.16	n/a	0.16
E	0.01	0.14	n/a	0.15

* Source: FAA Tech Center

♦ Factor 17: Fire Not Suppressed (Oxidizer)

This represents the probability that a cargo compartment fire involving oxidizers is suppressed. The value for this factor depends on cargo compartment type (that is, type of fire suppression available). This factor applies to Divisions 5.1, 5.2, 2.2/5.1 and 1.5D hazardous materials.

Table 2.20 Factor 17 - Fire Not Suppressed (Oxidizer) Probabilities

Cargo Compartment Type	Fire Not Suppressed (Oxidizer)*
A	1
B1	1
B2	1
C	0.5
D	0.7
E	0.8

* Source: FAA Tech Center

Toxic Material Transfer

♦ Factor 18: Cargo Compartment Breached

This factor represents the probability that a cargo compartment is breached by a fire.

Table 2.21 Factor 18 - Cargo Compartment Breached Probabilities

Cargo Compartment Type	Cargo Compartment Breached*
A	0.95
B1	0.99
B2	0.99
C	0.04
D	0.16
E	0.99

* Source: FAA Tech Center

♦ Factor 19: Toxic Material Transfer to Cabin / Cockpit - Fire and Cargo Compartment Breached

This factor represents the probability that released toxic material is transferred to the cabin or cockpit in the event there is a fire and the cargo compartment is breached. This factor is cargo compartment dependent.

Table 2.22 Factor 19 - Toxic Material Transfer (Fire and Cargo Compartment Breached) Probabilities

Cargo Compartment Type	Toxic Material Transfer (Fire and Breach)*
A	0.95
B1	0.99
B2	0.99
C	0.50
D	0.50
E	0.99

* Source: FAA Tech Center

♦ Factor 20: Toxic Material Transfer to Cabin / Cockpit – Fire and Cargo Compartment Intact

This factor represents the probability that a released toxic material is transferred to the cabin or cockpit in the event there is a fire but the cargo compartment is not breached. This factor is cargo compartment dependent.

Table 2.23 Factor 20 - Toxic Material Transfer (Fire and Cargo Compartment Intact) Probabilities

Cargo Compartment Type	Toxic Material Transfer (Fire and Cargo Compartment Intact)*
A	0.95
B1	0.99
B2	0.99
C	0.10
D	0.10
E	0.99

* Source: FAA Tech Center

♦ Factor 21: Toxic Material Transfer to Cabin / Cockpit - No Fire and Cargo Compartment Intact

This factor represents the probability that a released toxic material is transferred to the cabin or cockpit in the event there is no fire and the cargo compartment is not breached. This factor is cargo compartment dependent.

Table 2.24 Factor 21 - Toxic Material Transfer (No Fire and Cargo Compartment Intact) Probabilities

Cargo Compartment Type	Toxic Material Transfer (No Fire and Cargo Compartment Intact)*
A	0.01
B1	0.01
B2	0.01
C	0.01
D	0.01
E	0.01

* Source: FAA Tech Center

♦ Factor 22: Toxic Material Transfer Is Life Threatening

This factor represents the probability that a released toxic material in occupied areas of the aircraft results in a life-threatening event. The probability for this factor is based on the toxicity and volatility of the material involved.

Table 2.25 Factor 22 - Toxic Material Transfer is Life Threatening Probabilities

Hazardous Material Class/Division*	Compliance Case	Toxic Material Transfer is Life Threatening**
2.3 (TIH Zone B) 6.1 (TIH one B)	Non-Compliant Cargo-Compliant	0.50
2.3 (TIH Zone C)	Cargo-Compliant	0.10
6.1 (TIH Zone A)	Non-Compliant	0.95
6.1 (No TIH Zone)	Passenger-Compliant	1.00E-02

* See Table B-1 for selected materials and packaging assumptions.
** Source: OHMS

III Results of the Assessment

WHAT DOES THE TOTAL PROBABILITY FOR EACH EVENT REPRESENT?

The outputs from each of the event trees are calculated probabilities which represent the likelihood that a particular life threatening event will occur if a selected material is moved, under a given regulatory assumption, in a specified cargo compartment.

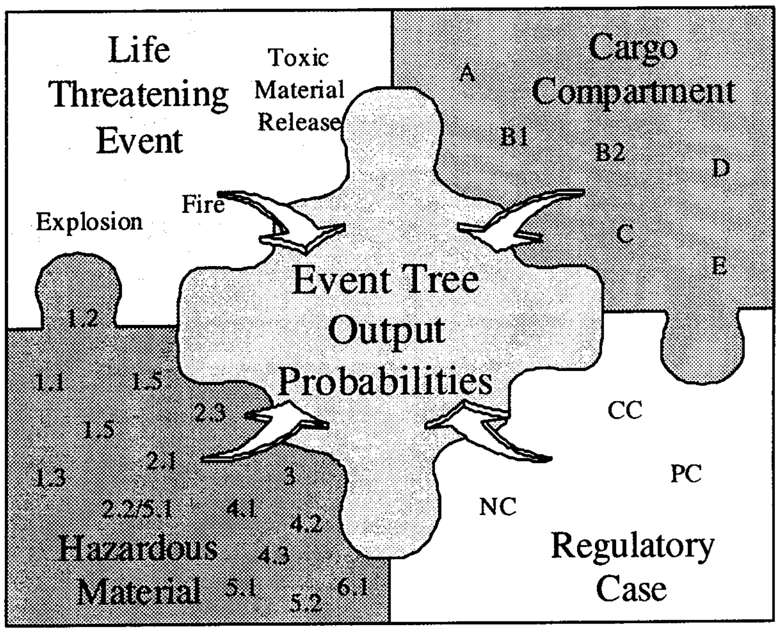


Figure 3.1 Probability Inputs

The results of this assessment were reported in terms of the number of times a given material could be transported in a cargo compartment (a "cargo-compartment flight") before a catastrophe would be expected. The probabilities were grouped into three categories:

- ***High Threat*** - one catastrophe expected per ten thousand cargo compartment flights, or less;
- ***Medium Threat*** - one catastrophe expected for between ten thousand and ten million cargo compartment flights; and
- ***Low Threat*** - one catastrophe expected per ten million cargo compartment flights, or more.

The results are presented by compliance case.

FOR THE NON-COMPLIANT CASE

WHAT ARE THE RELATIVE RANKINGS OF SELECTED "WORST LIKELY" HAZARDOUS MATERIALS FOR THREAT TO AIRCRAFT?

Figure 3.2 shows the relative rankings of the non-compliant materials selected for this assessment. The probabilities are averaged over all cargo compartment types.

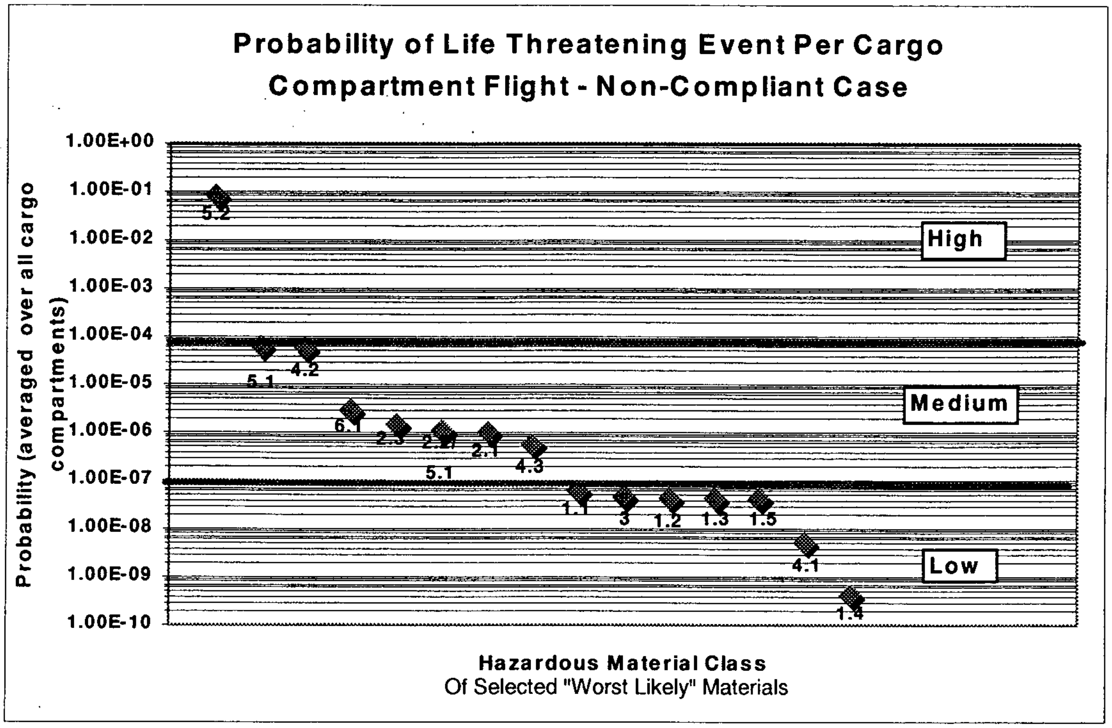


Figure 3.2 Probability of Life Threatening Event – Non-Compliant (NC) Case

- Selected Division 5.2 (Organic Peroxide) material, 'Organic peroxide, type C, liquid, temperature controlled (Disecbutyl peroxy dicarbonate 98%)', stands out as the most likely to cause a life-threatening situation. The result for this material is about three orders of magnitude greater than that for the next highest result.

- The medium threat group includes Divisions 5.1, 4.2, 6.1, 2.3, 2.2/5.1, 2.1 and 4.3, the most reactive oxidizing, flammable and toxic hazardous materials. The selected material for Divisions 2.2/5.1 and 4.3 were Oxygen, refrigerated liquid, and Hydrogen, refrigerated liquid, respectively. These are cryogenic liquids which, if released, create a potentially explosive atmosphere.

- The third group of relatively low threat is comprised of Class 1 explosives, Division 4.1 desensitized explosives, and Class 3 volatile flammable liquids. That many categories of explosives appear to be less a threat than other hazardous materials analyzed can be explained by their relative insensitivity to initiations leading to detonation. Most common explosives are designed to have high thresholds of initiation for safety reasons.

WHAT IS THE EVENT CONTRIBUTION TO THE THREAT PROBABILITY?

Table 3.1 Event Contribution to Life-threatening Event Probability – Non-Compliant (NC) Case

Hazardous Material Class/Division	Selected Hazardous Material	Severe Explosion	Severe Hazardous Material Fire	Independent Fire Enhanced	Toxic Material Release: No Fire	Toxic Material Release: Fire Breach	Toxic Material Release: Fire Intact	Total Average Probability of Life-Threatening Event	Threat Rank
5.2 Organic Peroxide	Organic peroxide, type C, liquid, temperature controled	0% 1.00E-11	100% 8.33E-02	0% 8.07E-08				8.33E-02	1
5.1 Oxidizer	Hyrogen peroxide, aqueous solution (50%)	0% 7.50E-13	100% 6.25E-05	0% 4.36E-08				6.25E-05	2
4.2 Flammable (Spontaneously Combustable)	Phosphorous, white, dry		100% 5.80E-05	0.1% 5.04E-08				5.81E-05	3
6.1 Toxic	Nickel carbonyl				98.4% 2.85E-06	1.6% 4.61E-08	0% 5.80E-10	2.90E-06	4
2.3 Toxic	Chlorine				100% 1.50E-06	0% 3.30E-11	0% 4.15E-13	1.50E-06	5
2.2 / 5.1 Oxidizer	Oxygen, refrigerated liquid	100% 1.09E-06						1.09E-06	6
2.1 Flammable Gas	Hydrogen, refrigerated liquid	100% 9.96E-07						9.96E-07	7
4.3 Dangerous When	Lithium aluminum hydride		100% 5.82E-07					5.82E-07	8
1.1A Explosive	Lead azide, wetted	100% 6.04E-08						6.04E-08	9
3 Flammable Liquid	Diethyl ether	25% 1.20E-08	0% 7.02E-12	75% 3.59E-08				4.79E-08	10
1.2F Explosive	Hand grenades	100% 4.04E-08						4.04E-08	11
1.3G Explosive	Fireworks (display)	100% 4.04E-08						4.04E-08	12
1.5 Oxidizer	ANFO	0% 4.03E-17	0% 2.50E-16	100% 4.03E-08				4.03E-08	13
4.1 Flammable Solid	Silver picrate, wetted	100% 5.29E-09						5.29E-09	14
1.4F Explosive	Warheads, rocket		0% 5.80E-16	100% 4.04E-10				4.04E-10	15

- Of the fifteen materials selected, six lead exclusively to life threatening explosions (Divisions 2.2/5.1, 2.1, 1.1A, 1.2F, 1.3G and 4.1). All six of these materials are classed in classes or divisions which are not permitted onboard aircraft. The two most likely materials to cause an explosion (Divisions 2.2/5.1 and 2.1) require operational temperature controlling features. In addition, for Class 3 materials, the chance of explosion accounts for 25% of the likelihood of a life-threatening situation occurring.

- Toxic material releases appear fourth (Division - 6.1 Nickel carbonyl) and fifth (Division 2.3 - Chlorine) most likely to lead to a life threatening situation. Given the severe toxicity of the materials selected, this finding was not surprising.

- The three materials contributing the most to fire probability are Division 5.2 Organic peroxide, Division 5.1 Hydrogen peroxide, and Division 4.2 Phosphorous, white. Division 5.2 materials, although explosive, are more likely to burn. Division 1.4F and 1.5 materials enhance fires rather than explode.

HOW DOES CARGO COMPARTMENT TYPE AFFECT VULNERABILITY TO THE HAZARDOUS MATERIAL THREAT?

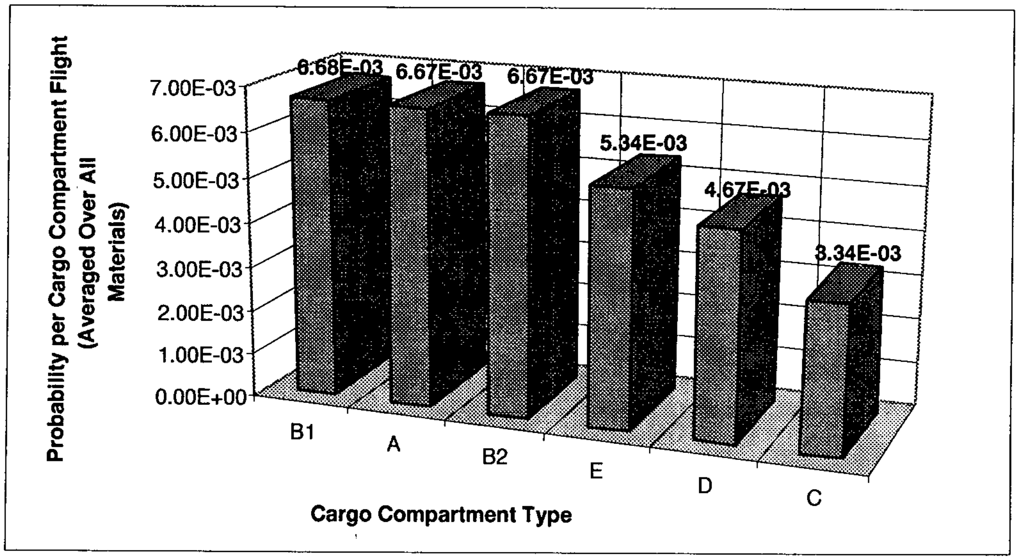


Figure 3.3 Graph of the Probabilities of Threat by Cargo Compartment Type (Averaged Over Sub-events and Hazardous Material Classes) – Non-Compliant (NC) Case

- Although the ranking of the cargo compartments make logical sense, with B1, A and B2 compartments most likely involved in a scenario leading to a life-threatening situation and C compartments least likely, the differences in the probabilities involved are minor.

FOR THE CARGO-COMPLIANT CASE

WHAT ARE THE RELATIVE RANKINGS OF SELECTED "WORST LIKELY" HAZARDOUS MATERIALS FOR THREAT TO AIRCRAFT?

Figure 3.4 shows the relative rankings of the cargo-compliant materials selected for this assessment. The probabilities are averaged over all cargo compartment types.

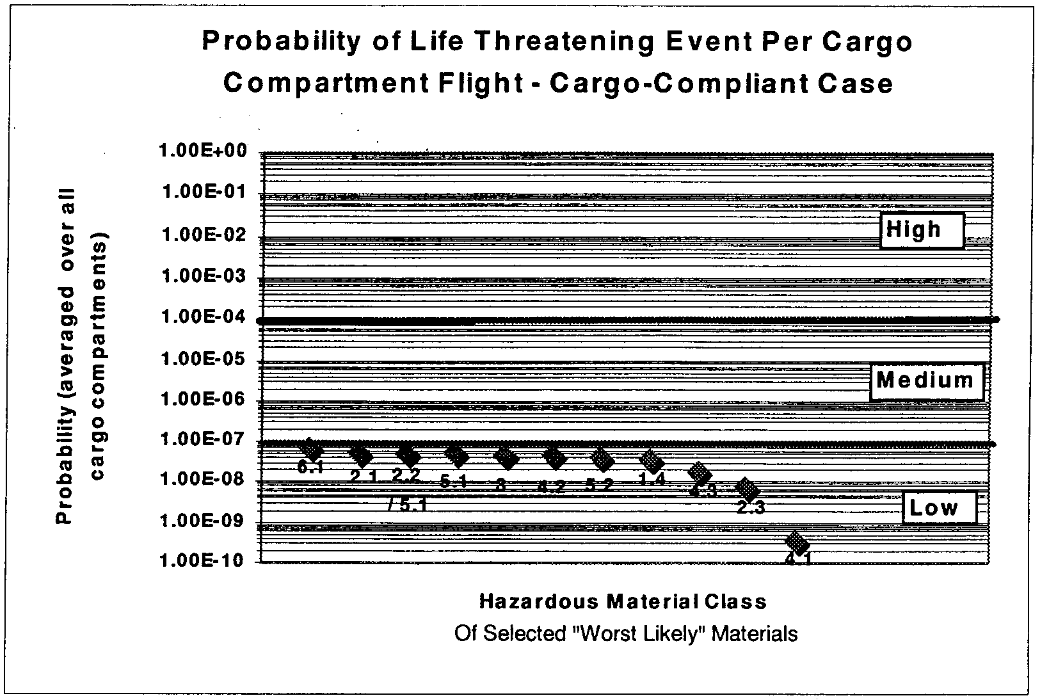


Figure 3.4 Probability of Life Threatening Event – Cargo-Compliant (CC) Case

- As might be expected for regulatory compliant packages, all materials fall into the low threat category. This tends to confirm that current regulations are providing adequate protection.
- The selected Division 6.1 toxic material, 'n-propyl chloroformate' ranks as the most likely to cause a life-threatening situation, but still only at the low threat level.

WHAT IS THE EVENT CONTRIBUTION TO THE THREAT PROBABILITY?

Table 3.2 Event Contribution to Life-threatening Event Probability – Cargo-Compliant (CC) Case

Hazardous Material Class/Division	Selected Hazardous Material	Severe Explosion	Severe Hazardous Material Fire	Independent Fire Enhanced	Toxic Material Release			Total Average Probability of Life-Threatening Event	Threat Rank
					No Fire	Fire Breach	Fire Intact		
6.1 Toxic	n-propyl chloroformate				67.0% 5.00E-08	32.5% 2.43E-08	0% 3.05E-10	7.46E-08	1
2.1 Flammable Gas	Hydrogen, compressed	100% 5.04E-08						5.04E-08	2
2.2 / 5.1 Oxidizer	Nitrogen trifloride	0% 5.04E-11	0% 2.01E-12	99.9% 5.04E-08				5.04E-08	3
5.1 Oxidizer	Potassium superoxide	0% 5.04E-15	0% 4.07E-17	100% 5.04E-08				5.04E-08	4
3 Flammable Liquid	Diethyl ether	25% 1.20E-08	0% 2.34E-13	75% 3.59E-08				4.79E-08	5
4.2 Flammable (Spontaneously Combustable)	Zirconium powder, dry		0% 9.45E-16	100.0% 4.54E-08				4.54E-08	6
5.2 Organic Peroxide	Organic peroxide, type C, liquid	0% 4.04E-29	0% 8.35E-12	100% 4.04E-08				4.04E-08	7
1.4E Explosive	Cartridges for weapons		0% 1.84E-15	100% 3.83E-08				3.83E-08	8
4.3 Dangerous When	Lithium aluminum hydride		100% 1.95E-08					1.95E-08	9
2.3 Toxic	Methyl bromide				33% 2.41E-09	66% 4.85E-09	1% 6.11E-11	7.33E-09	10
4.1 Flammable Solid	Barium azide, wetted	67% 2.22E-10	0% 4.83E-14	33% 1.11E-10				3.33E-10	11

- The top-rated threat is a toxic material release from a Division 6.1 material.
- Six of the eleven hazardous materials leading to life threatening events involve an independent fire enhanced by a hazardous material as the primary event (Divisions 1.4E, 2.2/5.1, 3, 4.2, 5.1, and 5.2). Fire started by the presence of hazardous material is the life-threatening event linked to Division 4.3 materials.
- Two materials including the second ranked (Divisions 2.1 and 4.1), lead primarily to severe explosion events.

HOW DOES CARGO COMPARTMENT TYPE AFFECT VULNERABILITY TO THE HAZARDOUS MATERIAL THREAT?

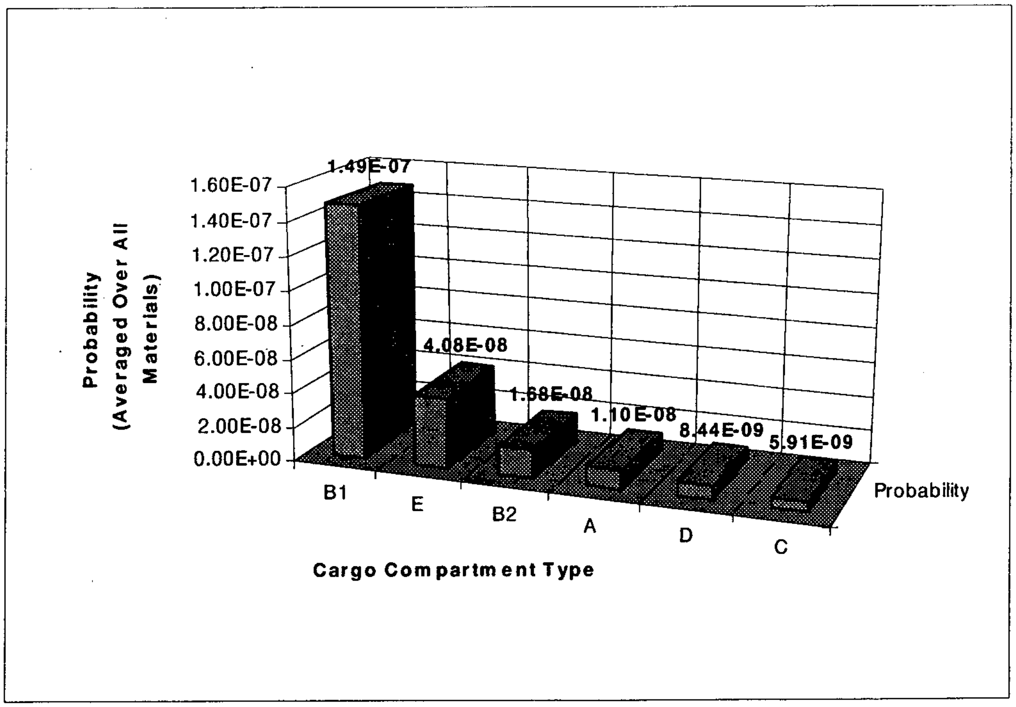


Figure 3.5 Graph of the Probabilities of Threat by Cargo Compartment Type (Averaged Over Sub-events and Hazardous Material Classes) – Cargo-Compliant (CC) Case

- The ranking of the cargo compartments show B1 compartments most likely involved in a scenario leading to a life-threatening situation and C compartments least likely.
- For the high threat hazardous materials chosen, the cargo compartment probabilities are within two orders of magnitude.

FOR THE PASSENGER-COMPLIANT CASE

WHAT ARE THE RELATIVE RANKINGS OF SELECTED "WORST LIKELY" HAZARDOUS MATERIALS FOR THREAT TO AIRCRAFT?

Figure 3.6 shows the relative rankings of the passenger-compliant materials selected for this assessment. The probabilities are averaged over all cargo compartment types.

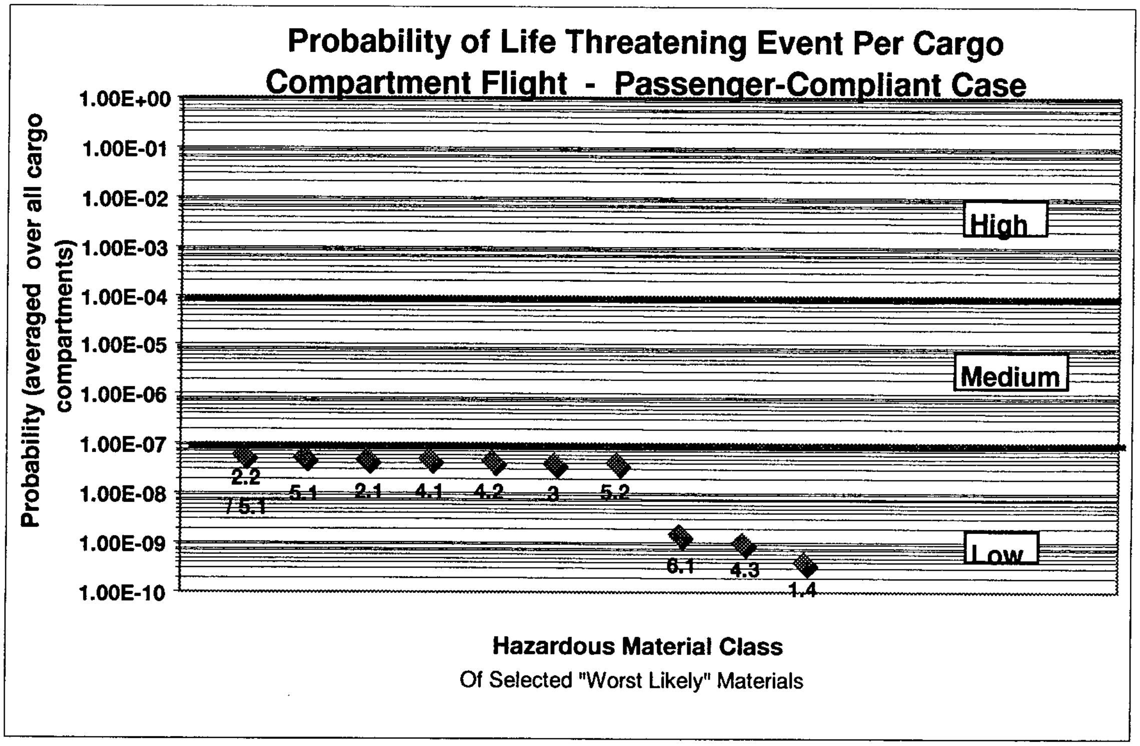


Figure 3.6 Probability of Life Threatening Event – Passenger-Compliant (PC) Case

- Selected Division 2.2/5.1 (Oxidizing gases) material, 'Oxygen, compressed' ranks as the most likely to cause a life-threatening situation. It was still in the "low threat" category.
- Selected Division 1.4S (Explosive) material, 'Flares, aerial,' is the least likely of the materials in the passenger-compliant case to lead to a life-threatening incident. The material selected to represent this division for the non-compliance case also resulted in a very low probability.

WHAT IS THE EVENT CONTRIBUTION TO THE THREAT PROBABILITY?

- Of the ten passenger-compliant cases, the most likely scenario for Division 2.2/5.1 is an independent fire enhanced by hazardous materials. Eight of the ten pathways lead to a life-threatening event involving independent fires enhanced by hazardous materials.

- For the other hazardous materials, a pathway leading to a toxic material release (Division 6.1 - Methyl chloroacetate) ranked eighth, and one leading to a fire due directly to a hazardous material (Division 4.3 - Barium (metal)) ranked ninth.

Table 3.3 Event Contribution to Life-threatening Event Probability - Passenger-Compliant (PC) Case

Hazardous Material Class/Division	Selected Hazardous Material	Severe Explosion	Severe Hazardous Material Fire	Independent Fire Enhanced	Toxic Material Release: No Fire	Toxic Material Release: Fire Breach	Toxic Material Release: Fire Intact	Total Average Probability of Life-Threatening Event	Threat Rank
2.2 / 5.1 Oxidizer	Oxygen, compressed	1% 6.05E-10	0% 2.01E-12	99.0% 5.99E-08				6.05E-08	1
5.1 Oxidizer	Ammonium perchlorate	0% 5.54E-17	16% 8.33E-09	84% 4.54E-08				5.37E-08	2
2.1 Flammable gas	Aerosols, flammble		0% 8.98E-13	100% 5.04E-08				5.04E-08	3
4.1 Flammable Solid	Self-reactive solid type C		4% 1.93E-09	96% 4.54E-08				4.73E-08	4
4.2 Flammable (Spontaneously Combustable)	Zirconium powder, dry		0% 9.45E-16	100.0% 4.29E-08				4.29E-08	5
3 Flammable Liquid	Diethyl ether	25% 1.01E-08	0% 2.34E-13	75% 3.04E-08				4.06E-08	6
5.2 Organic Peroxide	Organic peroxide, type D, liquid	0% 4.04E-29	0% 8.35E-12	100% 4.04E-08				4.04E-08	7
6.1 Toxic	Methyl chloroacetate				67.0% 1.00E-09	32.5% 4.85E-10	0% 6.11E-12	1.49E-09	8
4.3 Dangerous When Wet	Barium (metal)		100% 9.67E-10					9.67E-10	9
1.4S Explosive	Flares, aerial		0% 1.93E-18	100% 4.03E-10				4.03E-10	10

HOW DOES CARGO COMPARTMENT TYPE AFFECT VULNERABILITY TO THE HAZARDOUS MATERIAL THREAT?

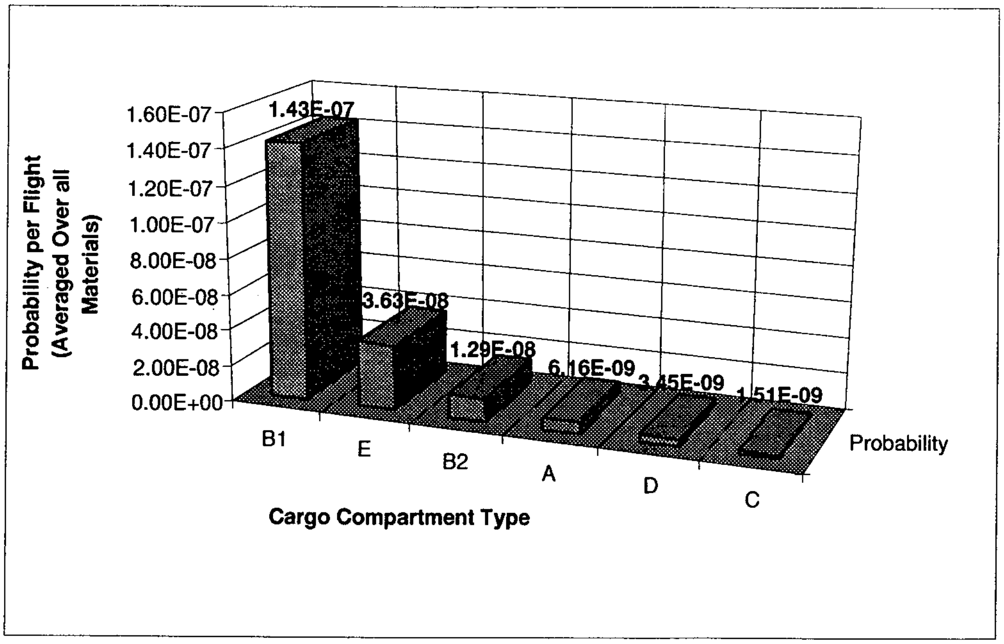


Figure 3.7 Graph of the Probabilities of Threat by Cargo Compartment Type (Averaged Over Sub-events and Hazardous Material Classes) – Passenger-Compliant (PC) Case

- The ranking of the cargo compartments show B1 compartments most likely involved in a scenario leading to a life-threatening situation and C compartments least likely.
- For the high threat hazardous materials chosen, the cargo compartment probabilities are within two orders of magnitude.

WHAT GENERAL TRENDS DO THE RESULTS SHOW?

- The vast majority of the scenarios have probabilities that fall into the 'medium threat' level or below (see Table 3.4). The only scenario with a probability in the 'high threat' level occurs in the non-compliant case. Seven more scenarios in the non-compliant case have probabilities which fall into the 'medium threat' level. The threat levels should be understood as a measure of the likelihood a life-threatening scenario involving that material, for the indicated compliance condition.

Table 3.4 Summary of Probabilities for All Selected Materials

High Threat — one catastrophe per ten thousand cargo compartment flights, or less; $>10^{-4}$ >1/10,000

Medium Threat — one catastrophe per ten thousand to ten million cargo compartment flights; 10^{-4}-10^{-7} 1/10,000–1/10,000,000

Low Threat — one catastrophe per ten million cargo compartment flights, or more; $<10^{-7}$ <1/10,000,000

Non-Compliant (NC)

Threat	Probability	Class	Material
High Threat	8.33E-02	5.2	**Organic Peroxide, type C, liquid, temperature controlled (Disecbutyl peroxy dicarbonate 98%)***
Medium Threat	[illegible]		
Low Threat	6.04E-08	1.1	Lead azide, wetted*
	4.79E-08	3	Diethyl ether
	4.04E-08	1.2	Hand grenades*
	4.04E-08	1.3	Fireworks (display)*
	4.03E-08	1.5	Ammonium Nitrate-Fuel Oil Mixture (ANFO)*
	5.29E-09	4.1	Silver picrate, wetted*
	4.04E-10	1.4	Warheads, rocket*

Cargo-Compliant (CC)

Threat	Probability	Class	Material
High Threat			
Medium Threat	[illegible]		
Low Threat	7.46E-08	6.1	n-propyl chloroformate**
	5.04E-08	2.1	Hydrogen, compressed**
	5.04E-08	2.2 / 5.1	Nitrogen trifluoride**
	5.04E-08	5.1	Potassium superoxide**
	4.79E-08	3	Diethyl ether
	4.54E-08	4.2	Zirconium powder, dry
	4.04E-08	5.2	Organic peroxide, type C, liquid (t-Butyl peroxy benzoate 77%)
	3.83E-08	1.4	Cartridges for weapons**
	1.95E-08	4.3	Lithium aluminum hydride**
	7.33E-09	2.3	Methyl bromide**
	3.33E-10	4.1	Barium azide, wetted**

Passenger-Compliant (PC)

Threat	Probability	Class	Material
High Threat			
Medium Threat	[illegible]		
Low Threat	6.05E-08	2.2 / 5.1	Oxygen, compressed
	5.37E-08	5.1	Ammonuim perchlorate
	5.04E-08	2.1	Aerosols, flammable
	4.73E-08	4.1	Self-reactive solid, type C (azodicarbonamide formulation)
	4.29E-08	4.2	Zirconium powder, dry
	4.06E-08	3	Diethyl ether
	4.04E-08	5.2	Organic Peroxide, type D, liquid (2,5-Dimethyl - 2,5-dibutyl peroxyhexane 95%)
	1.49E-09	6.1	Methyl choroacetate
	9.67E-10	4.3	Barium (metal)
	4.03E-10	1.4	Flares, aerial

*** Forbidden Cargo & Passenger**
**** Forbidden Passenger (Permitted on Cargo)**

Probabilities are the likelihood of life-threatening incidents based on the presence of a package containing the selected hazardous material and the package's given state of compliance, summed across all cargo compartment types.

- The probabilities for scenarios in the cargo-compliant and passenger-compliant cases show a similarity in range and distribution and are, overall, lower than those for the non-compliant case. This is a rough example of the effectiveness of current regulations when they are followed.

- The selection of different specific materials to represent each hazardous material class and division for the non-compliant, cargo-compliant and passenger-compliant cases renders comparison across compliance case by class or division difficult. There is only one instance of a class or division in which the same material recurs in all three cases, Class 3 (Diethyl ether), and one where the same material is used in two compliance cases, Division 4.2 (Zirconium powder, dry). For these materials there is little to no variation in the probabilities by compliance case and all of the related probabilities fall into the 'low threat' level.

WHAT ARE THE KEY CONCLUSIONS?

The results of this assessment were reported in terms of the number of times a given material could be transported in a cargo compartment (a "cargo-compartment flight") before a catastrophe would be expected. The probabilities were grouped into three categories:

- ***High Threat*** - one catastrophe expected per ten thousand cargo compartment flights, or less;
- ***Medium Threat*** - one catastrophe expected for between ten thousand and ten million cargo compartment flights; and
- ***Low Threat*** - one catastrophe expected per ten million cargo-compartment flights, or more.

Based on these groupings, the following results can be shown:

- All of the selected hazardous materials that had probabilities in the medium and high threat categories are forbidden in passenger aircraft and all but one in cargo aircraft as well.

- In the cargo-compliant and passenger-compliant cases, all the selected "worst likely" hazardous materials had probabilities in the low threat category.

- The selected Division 5.2 (Organic Peroxide) material in the non-compliant case has, by far, the greatest probability of causing a life-threatening situation and, as such, is the only scenario classified as 'high threat.' The presence of the "worst likely" non-compliant material in the 'high threat' category suggests that this division is the greatest potential threat in commercial aircraft transportation.

- Seven materials in the non-compliant case fell into the medium threat category: Divisions 5.1, 4.2, 6.1, 2.3, 2.2/5.1, 2.1, and 4.3.

- The medium threat category was populated solely by scenarios in the Non-Compliant case and included very reactive or volatile and very toxic solids, liquids and gases.

- For the cargo-compliant and passenger-compliant cases, all fell into the low threat category. This is an indication of the effectiveness of current regulations. The most probable scenarios involved selected materials from Division 6.1 in the cargo compliant case, and Division 2.2/5.1 in the passenger compliant case.

- Even in the non-compliant case, all but one of the scenarios resulted in threats in the medium and low ranges.

Results based on cargo compartment type show:

- Relative to the overall threat probabilities, in the non-compliant case cargo compartment type did not have a strong influence on the probability of a life-threatening incident. This result is possibly because the worst likely materials chosen to represent the classes and divisions for this assessment are such "bad actors" that the location of the package did not matter greatly.

- For the cargo-compliant and passenger-compliant cases, the B1 cargo compartment stands out with probabilities two orders of magnitude higher than the next highest compartment.

- In all three cases B1 cargo compartments were the highest risk due to the fact that they are protected by hand-held extinguishers only.

- Class C cargo compartments present the lowest threat probability in all three compliance cases, however only marginally less at risk than the E, B2, A and D compartments.

WHAT COMPARISONS CAN BE MADE WITH ACCIDENT/INCIDENT DATA INVOLVING HAZARDOUS MATERIAL ON OR EN ROUTE TO AIRCRAFT?

Significant accident/incident occurrence data from 1970 to the present is shown in Appendix D for hazardous materials on or en route to an aircraft, either as cargo or as part of the airworthiness systems. The data has been collected from various RSPA and FAA hazardous material reports as well as FAA fire and accident investigations. There are thirty-one entries in this survey. Eight incidents involve Division 2.2/5.1, compressed oxygen gas, and five involve chemical oxygen generators, either as part of the emergency breathing systems or as cargo. There are another three occurrences involving Division 8 nitric acid or Division 5.1 hydrogen peroxide shipped as undeclared cargoes. Compliant and non-compliant oxygen and oxidizing chemicals appear as the most frequently recurring hazardous material threats to aircraft safety.

The second recurring threat (with six occurrences) is Division 4.1 flammable solids, specifically from kitchen or safety matches transported as cargo or in passenger baggage. Since matches contain a mixture of oxidizing chemicals (typically sodium chlorate) and various solid fuels (sulfur and dextrin) that are designed to be friction-sensitive incendiary articles.

Shipments of compressed oxygen and matches aboard passenger and cargo-only aircraft are assumed to be frequent, but recent tightening of RSPA regulatory restrictions on the transport of chemical oxygen generators should eliminate these devices being carried as cargo aboard passenger flights.

Other hazardous materials which have been involved in serious but random, non-recurring incidents aboard or en route to aircraft include:

- Division 4.3 dangerous when wet metal (lithium)
- Division 8/4.3 organophorphorus compound (methyl phosphorodichlorodite)
- Division 2.1 cigarette lighters (filled with liquefied petroleum gas)
- Division 1.4 consumer fireworks
- ORM-D "blank" cartridges for weapons

These incidents mostly involved undeclared hazardous materials, highlighting the need for greater screening of cargo and passenger cargoes for unidentified or misidentified hazardous substances or articles.

The results of the passenger-compliant case for Division 2.2/5.1 compressed oxygen cylinders from the event tree analysis suggest that if every aircraft flight carried oxygen there would be a catastrophic event for approximately one in every 17 million flights.

Domestically, flight statistics for a twenty-year period from 1977 to 1996 indicate a total of about 135.5 million departures. Since compressed oxygen is installed in every aircraft as part of the emergency equipment it may be noteworthy to compare the frequency of domestic catastrophic in-flight accidents directly caused or seriously exacerbated by the presence of compressed oxygen during that same period.

The incident data base for the same twenty year period indicates that there was one catastrophic incident, the US Airways-Skywest collision at Los Angeles on February 1, 1991, in which compressed oxygen appeared to play an exacerbating role in increasing the number of fatalities from the collision.

While this comparison of the actual "one in 135 million flights" from the incident database vs. the event tree prediction of "one in 17 million flights" is tenuous, it does suggest that the event tree model predicted results are at least within an order of magnitude of actual experience.

IV Threat Countermeasures

WHAT AFFECT MIGHT THREAT COUNTERMEASURES HAVE?

If we view the level of threat as a continuum where movement to the left is in the direction of lower threat, and movement to the right is in the direction of higher threat, then we can visualize that as below:

A	[C]	B
Lesser Threat		**Greater Threat**

where:

A = Compliant (passenger and cargo only regulations)
B = Non-compliant
[C] = Actual Current Situation

In evaluating the anticipated results of implementing countermeasures, three categories of results became apparent:

1. Increased compliance with current regulations (Moves [C] to the left, closer to A);
2. Improved safety/handling/reliability of known hazardous material packages (Moves A to the left); and
3. Reduced vulnerability of the aircraft to damage (Moves A {some} and B {more} to the left).

Countermeasures expected to increase compliance with regulations – Since it was not within the scope of this study to measure current levels of compliance, the implementation of countermeasures expected to increase levels of compliance cannot be quantitatively evaluated. However, these countermeasures would have the overall affect of moving our current situation closer to the compliance cases where even the most serious threat is low level.

Countermeasures expected to reduce threat for known hazardous material packages – Implementing countermeasures which are expected to improve the safety, handling or reliability of known hazardous material packages will necessarily only affect the passenger-compliant and cargo-compliant cases. The results of this study show that the compliant cases are already in the low range of threat and it may be difficult to significantly improve that.

Countermeasures expected to reduce the threat to the aircraft – Implementing countermeasures that are expected to reduce the threat to the aircraft would affect both the compliant case and the non-compliant case, although the threat reduction would likely be greater in the non-compliant case since the compliant cases are, by their natures, less of a threat. These countermeasures are the most concrete and largely involve fire detection and suppression abilities for aircraft cargo compartments. Implementation of some of these countermeasures has begun since this list was originally established.

WHAT THREAT COUNTERMEASURES HAVE ALREADY BEEN IMPLEMENTED?

Certain threat countermeasures have already been implemented. In a step toward education and outreach, RSPA and the Federal Aviation Administration (FAA) have distributed more than ten million pamphlets entitled "These Fly...These May Not" informing the public what is permitted on aircraft and what is forbidden. The latest FAA and RSPA warning advisories on batteries and blowtorches can be found on the RSPA website under the "What's New" icon. Also in the area of education and outreach, there are inserts from ICAO inside airline tickets and new luggage regarding the carriage of hazardous materials on-board aircraft.

The FAA has also developed and distributed a Company Materials brochure to air carriers and repair stations. A hazardous materials display case has been prepared and is being demonstration tested at O'Hare International Airport in Chicago. The FAA has also instituted a program to issue press releases about pending enforcement cases when recommended hazardous materials civil penalties exceed $50,000. Approximately 100 such press releases have already been issued. The FAA has also increased the number of hazardous materials inspectors and is resolving pending cases more quickly. The FAA's Civil Penalty Sanction Guidance Policies have also been published in the Federal Register.

WHAT ADDITIONAL THREAT COUNTERMEASURES HAVE HIGH POTENTIAL?

In the early stages of the project, the first panel of experts meeting was held to get industry and stakeholder input into the assessment. At that time participants generated a list of almost seventy potential countermeasures which might reduce the threats associated with the transport of hazardous materials in aircraft cargo compartments. This original list was reviewed and consolidated by the project team, then grouped into subject categories (aircraft, detection and scanning, education and outreach, packaging, procedures, and other). The twenty-five consolidated countermeasures were then evaluated by the expected results of implementation. The entire list of consolidated countermeasures is presented in Appendix G, organized by the anticipated results of implementation. Ten countermeasure alternatives with significant potential to reduce risk were selected for presentation here:

1. Enhance public awareness of the hazards associated with air transportation of many commonly used products through pamphlets, public notices and displays in airport check-in areas.

2. Evaluate possible verbal querying of and written certifications by air passengers and shippers verifying they are NOT transporting hazardous materials in cargo packages or luggage.
3. Evaluate the use of non-intrusive diagnostic screening of cargo packages by the newest X-ray or nuclear magnetic resonance densimetry scanning equipment developed for anti-terrorist baggage checking.
4. Better identify strong oxidizing materials when shipping as cargo that presently require two separate hazard labels (for example, compressed oxygen and nitric acids).
5. Transport all hazardous material shipments in specially designed, tightly sealed fire, corrosion and explosion resistant containers (unit load devices).
6. Improve fire detection capabilities in all cargo compartments to Type C standards and improve fire suppression capabilities in Type D compartments to Type C standards in Part 121 passenger aircraft.
7. Improve smoke barriers in all Type B and E cargo compartments to ensure minimal migration of potentially toxic fumes.
8. Require all cargo compartment ceiling and wall liner attachment systems to meet the same cargo liner panel flammability requirements in the FAA regulations.
9. Increase the frequency and number of inspections of all aircraft cargo compartments to determine if they still meet all appropriate FAA Flight Standard Requirements for the type for which they have been certified.
10. Improve the frequency and search authority of airline inspections of both passenger baggage and cargo packages.

In addition to the countermeasures proposed by the panel of experts, the NTSB, in response to a September 5, 1996 fire onboard a FedEx DC-10 cargo plane, offered the following recommendation to DOT/RSPA:

- Require, within 2 years, that a person offering any shipment for air transportation provide written responses, on shipping papers, to inquiries about hazardous characteristics of the shipment, and develop other procedures and technologies to improve the detection of undeclared hazardous materials offered for transportation.
- Require, within two years, that air carriers transporting hazardous materials have the means 24 hours per day, to quickly retrieve and provide consolidated specific information about the identity (including proper shipping name), hazard class, quantity, number of packages, and location of all hazardous materials on an airplane in a timely manner to emergency responders.

HOW DO THE RESULTS OF THIS ASSESSMENT INFLUENCE PROPOSED THREAT COUNTERMEASURES?

The occurrence of a fire on-board an aircraft, whether as an event initiating a hazardous material incident or as the consequence of a hazardous material incident, plays a major role in the development of a life-threatening situation. Countermeasures which address fire safety issues, thus reducing the threat to the aircraft, and the hazardous materials most likely involved in these scenarios should be carefully reviewed for cost-benefit considerations. The hazardous material divisions involved in the most probable events related to fire are (in descending order): Division 5.2, Division 5.1, Division 4.2, and Division 4.3 materials. The selected materials in these divisions, especially when shipped without regard to regulations, were found likely to cause a life-threatening situation, often independent of cargo compartment type. This would indicate that for these scenarios it is overwhelmingly the material, and not the material-cargo compartment combination, which is the important factor. Assuming confirmation of the findings of this assessment, these materials should not be permitted onboard aircraft unless there are well-demonstrated mitigating circumstances.

Exceptions to current DOT regulations exist for certain items and can be granted for others. The methodology used in this study makes it possible to more accurately estimate the threat from these excepted hazardous materials. For example, passenger exceptions for carriage of aerosol cans could undermine the safety of fire suppression systems. The technical justifications behind such exceptions should be re-evaluated in light of the findings of this study.

Finally, it must be stressed that this assessment finds a significant difference in the probability that a life threatening situation occurs due to a hazardous material shipment that is shipped in accordance with regulations versus a shipment in which regulations are violated. Countermeasures intended to increase compliance, identified above and in Appendix G should be reviewed for cost-benefit considerations and those which are most cost effective should be implemented. For example, the danger posed by undeclared shipments, in particular, may be reduced through increased education and training efforts. Longer term, new non-invasive bomb-detection equipment for checked baggage may be developed to identify at least some types of hazardous materials as well.

V Future Work

WHY IS DATA ON AIR SHIPMENT FREQUENCIES OF HAZARDOUS MATERIALS SHIPMENTS IMPORTANT?

The current effort analyzes the probability of a life-threatening incident for various combinations of hazardous material and aircraft cargo compartment types. The assessment assumes that the particular hazardous material being investigated is on board the aircraft. The estimated probabilities are developed assuming that a given hazardous material has been placed in a given cargo compartment. Actual shipping rates for the materials are not addressed. The current results therefore do not represent a true measure of the total risk for all combinations of hazardous material and compartment types, but rather a relative hazard, vulnerability, or threat ranking of each particular combination. This leads to results which can be misleading if not interpreted properly. For example, certain Division 5.2 Organic peroxides may show a very high risk probability, however, the material are rarely shipped by air, therefore their overall risk may be low. Conversely, Division 2.2/5.1 Compressed Oxygen may show a relatively low level of risk, but as these materials are frequently shipped, their overall risk may be relatively high. In order to effectively allocate resources to minimize risks, further work will require that better data be obtained.

HOW CAN SHIPPING FREQUENCY DATA BE OBTAINED?

FOR COMPLIANT SHIPMENTS?

Industry figures on declared hazardous material movements, although not readily available, could be compiled. Air carrier records such as Notices to Aircraft Commanders (NOTACs) which indicate the presence of hazardous material on a flight could be evaluated to determine how often and what types of hazardous material are being transported by air. Incidents involving hazardous materials reported by handlers of the packages such as airline baggage handlers or package sorters, freight forwarders, freight terminals, trucking companies, or shippers themselves could be evaluated to determine the frequency of problems with compliant packages, and lead to better data on package failure rates and modes.

Although this study did not address hazardous materials in aircraft system components such as fuel, oxygen, and COMAT, such materials are present on every flight and could be considered in a future analysis.

FOR NON-COMPLIANT SHIPMENTS?

The total number of non-compliant (undeclared or improperly packaged or labeled) shipments is not known. For undeclared hazardous material shipments, there is no record of movement unless the package is detected via an inspection (refused), leak or other incident. These known instances, although not the entire picture, may be useful in estimating the extent of the problem.

Incidents involving hazardous materials reported by handlers of the packages such as airline baggage handlers or package sorters, freight forwarders, freight terminals, trucking companies, or shippers themselves could be evaluated to gain insight into the frequency of problems with non-compliant packages.

The FAA Technical Center in Atlantic City, NJ is presently developing a research project with the direction of the Office of Civil Aviation Security to identify methods to screen cargo shipments for illegal and potentially dangerous goods and devices. This could also present an opportunity for the FAA and RSPA to explore the type and frequency of undeclared or non-compliant hazardous materials shipments. The identification of cargo shipments relating to different types of terrorist or illegal drug activity has much in common with the identification of improperly identified dangerous goods, either unintentional or intentional. Many of the same materials are involved for both cases (for example, detonators, ammunition, cartridges for weapons, illegal drug intermediates that are poisonous or flammable, etc.). In several past instances, DOT's hazardous material regulation violations with criminal intent have been effectively used to convict persons involved in transporting terrorist paraphernalia, when conviction under various Department of Justice anti-terrorism statutes was more difficult to prove beyond a reasonable doubt.

CAN BETTER THREAT FACTORS FOR SPECIFIC HAZARDOUS MATERIALS BE OBTAINED?

FROM EXPERIMENTAL TESTING SUGGESTED BY THE PANEL OF EXPERTS?

Prior to completion of the final event tree model for this threat assessment, the panel of experts, convened in October 1996 and June 1997, were asked to make suggestions on any experimental testing programs which the FAA and RSPA could undertake, jointly or separately. Testing programs would be designed to provide new or more quantitative data on the threat factors to aircraft posed by specific hazardous materials in various types of compartments. All suggestions received from the panel at that time were then consolidated into eleven specific proposals. These proposals are presented in Appendix G.

WHAT PRIORITIES SHOULD BE GIVEN TO THESE EXPERIMENTAL PROPOSALS BASED ON THE RESULTS OF THE THREAT ASSESSMENT?

Hazardous materials identified in the "high threat" and "medium threat" categories by the methodology employed in this assessment should receive greater priority in any future experimental programs to further quantify threat factors. This would include:

- Division 5.2 organic peroxides, particularly those which present a threat of thermal explosion as well as self-heating when exposed to prolonged periods of elevated temperature.
- Division 8/5.1 strong oxidizing acids (for example, nitric, chloric, perchloric and chromic acids) which present the threat of combining with packaging or baggage material adjacent to a leaking container to form a spontaneously combustible mass.
- Spontaneously combustible Division 4.2 hazardous materials (for example, white phosphorus). **Caution**: Certain Division 4.1 friction-sensitive materials (for example, matches) could self-ignite under "rough handling" conditions and may pose a level of threat similar to Division 4.2 materials.

All other experimental proposals could be ranked according to the probabilities given in the results section of this report for the most reactive hazardous materials classes and sub-divisions in either the non-compliant or the compliant cases. Proposals which evaluate longer-term toxicity or corrosion effects or "rocketing cylinder" effects on the aircraft cargo compartments should not be given immediate consideration.

WHAT ARE THE KEY RECOMMENDATIONS?

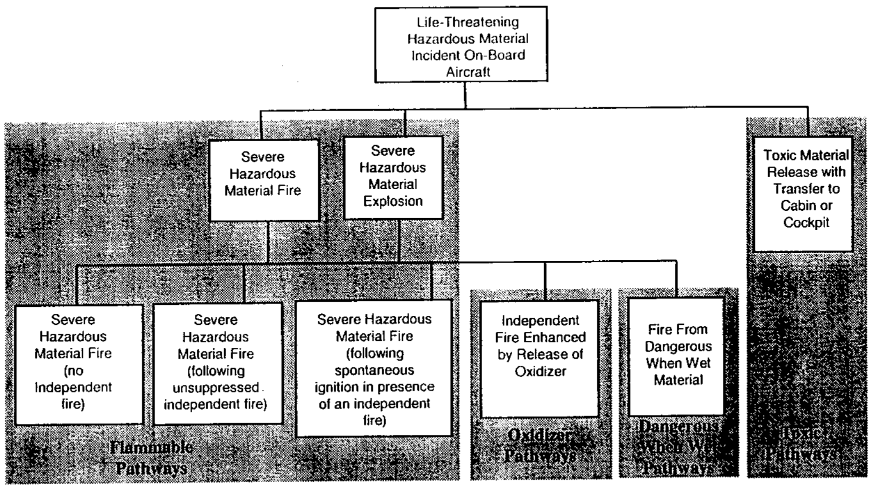
- RSPA and the FAA should explore any possible ways in which the newer, non-invasive, diagnostic screening technologies (3-dimensional X-ray densimetry, nuclear magnetic resonance or other similar equipment) being developed for rapid inspection of random or suspicious checked baggage might be applied additionally to the search for mis-identified or undeclared hazardous material cargo shipments.
- RSPA should consider petitioning the United Nations Committee of Experts on Dangerous Goods to simplify identification of dual hazard gaseous oxidizers (for example, by creating a new category for oxidizing gases) and corrosive oxidizers (for example, by identifying more oxidizing acids primarily as Division 5.1 hazards) – See Appendix G for details.
- RSPA and the FAA should consider, for future implementation, the threat countermeasure proposals in this assessment which have a high likelihood of increasing a shipper's hazardous material awareness and improving the levels of shipper regulatory compliance.

APPENDIX A - EVENT TREE LOGIC FLOWS

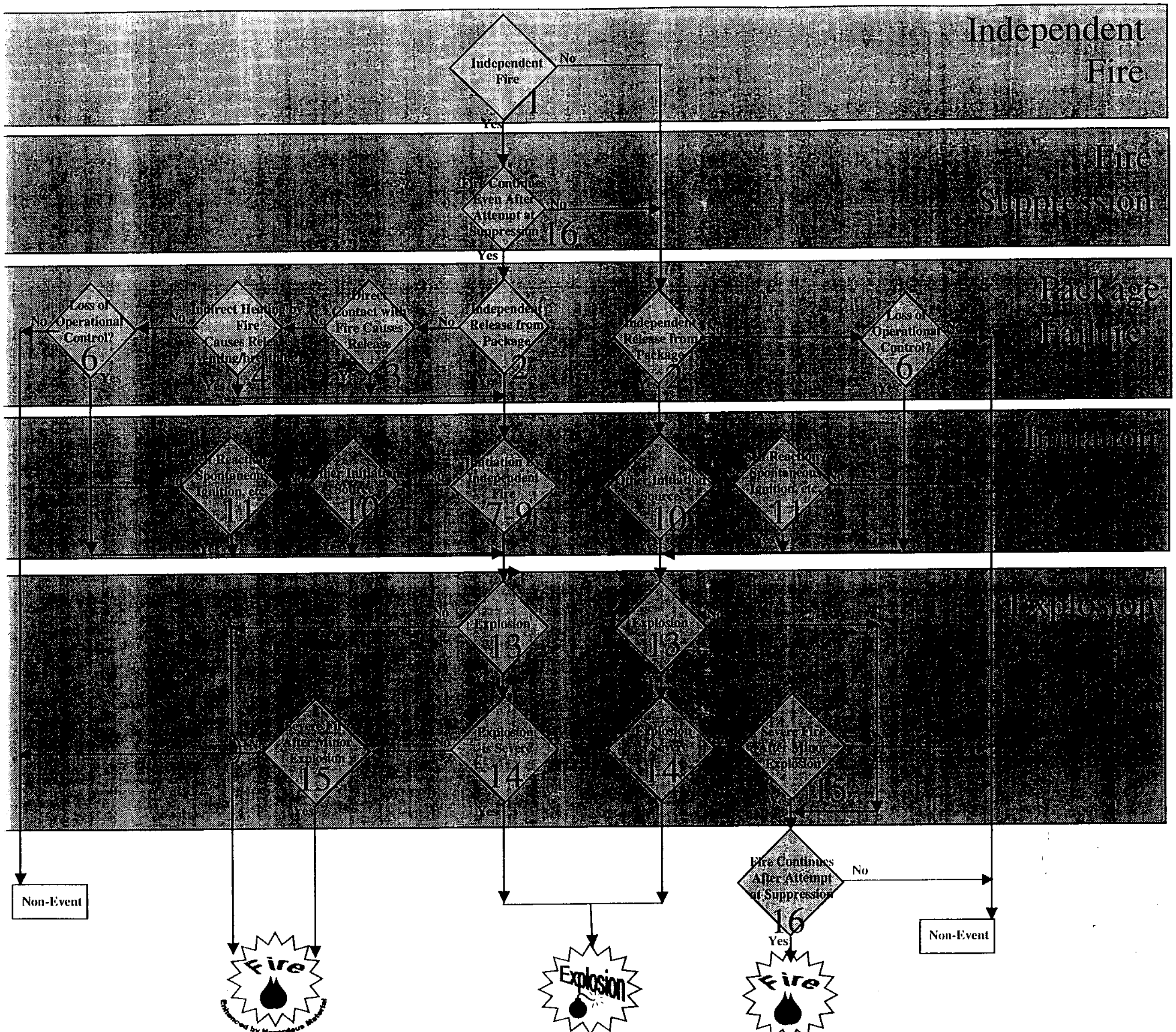
This appendix contains diagrams depicting the logic flows of the event trees used in this assessment. Within each tree decision points (diamonds) are marked with the number of the factor they relate to. The actual probabilities for these factors for all of the selected materials can be found in Appendix C, Table C-1.

TOP LEVEL EVENTS LEADING TO LIFE-THREATENING INCIDENTS ON-BOARD AIRCRAFT

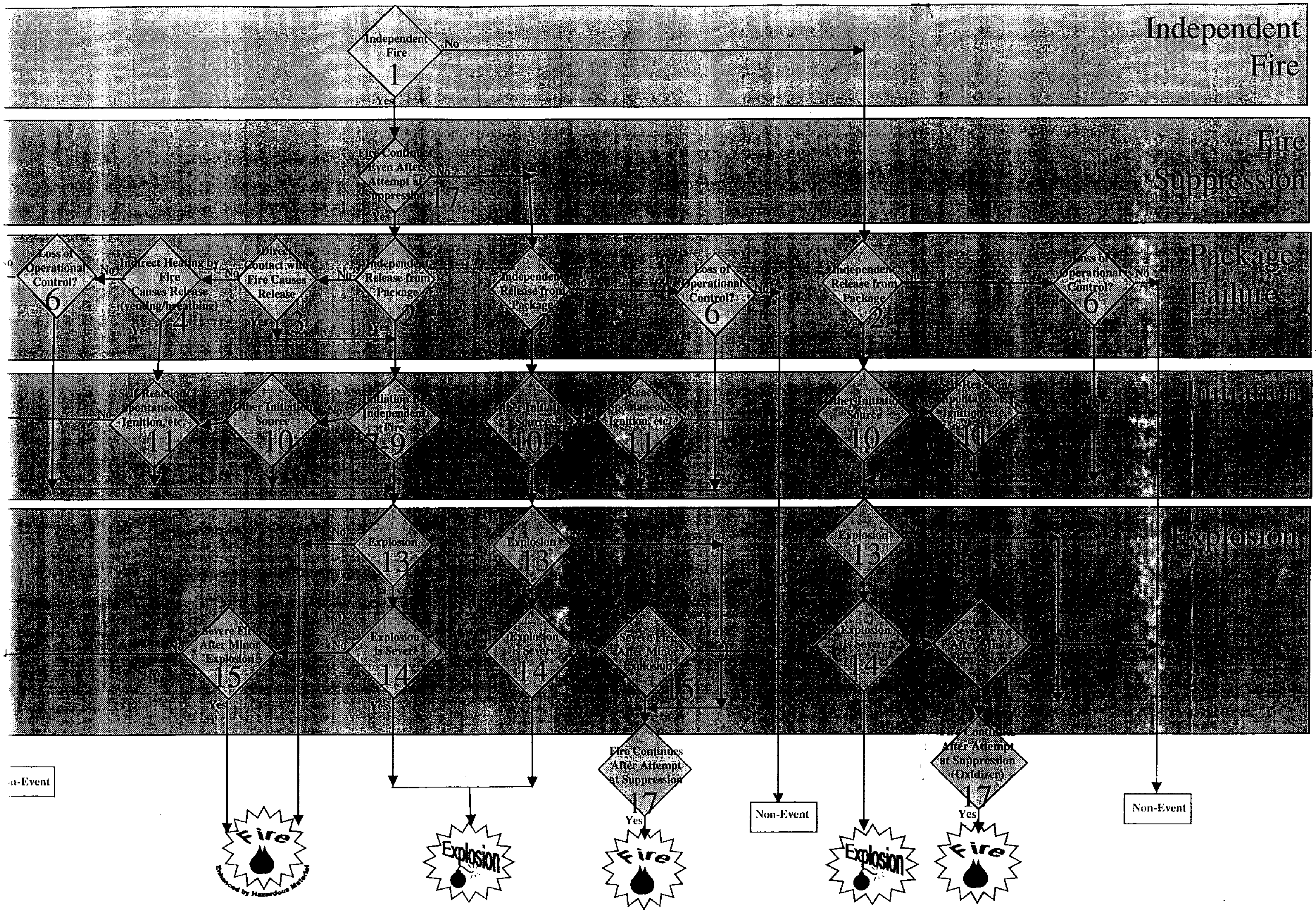
Hazardous Materials Transportation in Aircraft Cargo Compartments

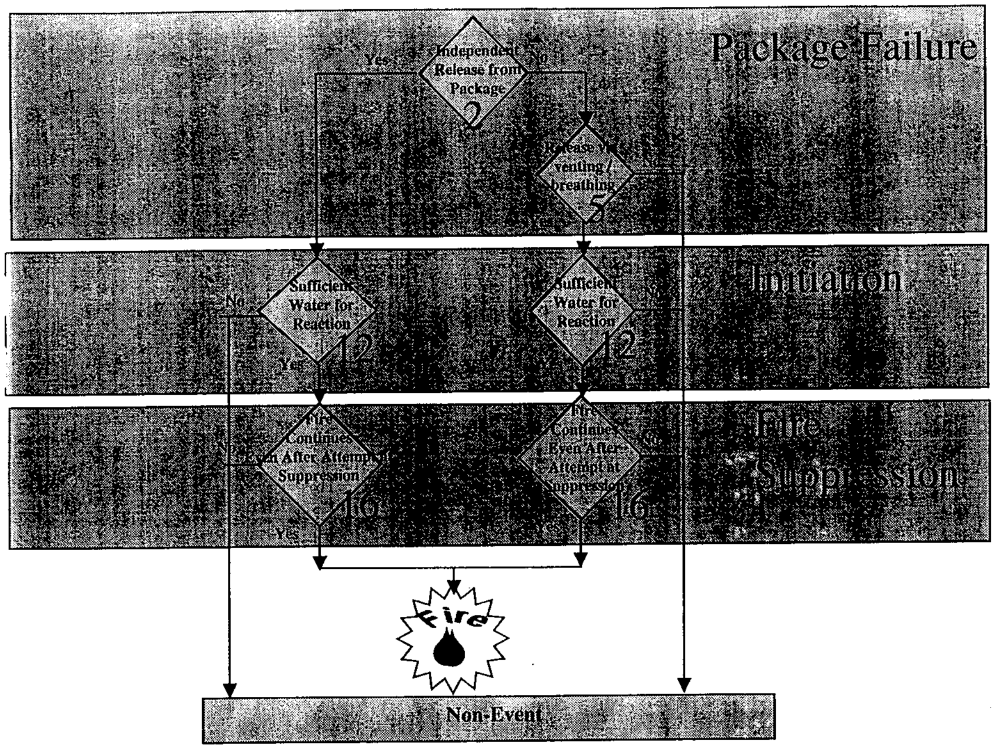


FLAMMABLE PATHWAYS LEADING TO LIFE-THREATENING INCIDENTS ON-BOARD AIRCRAFT



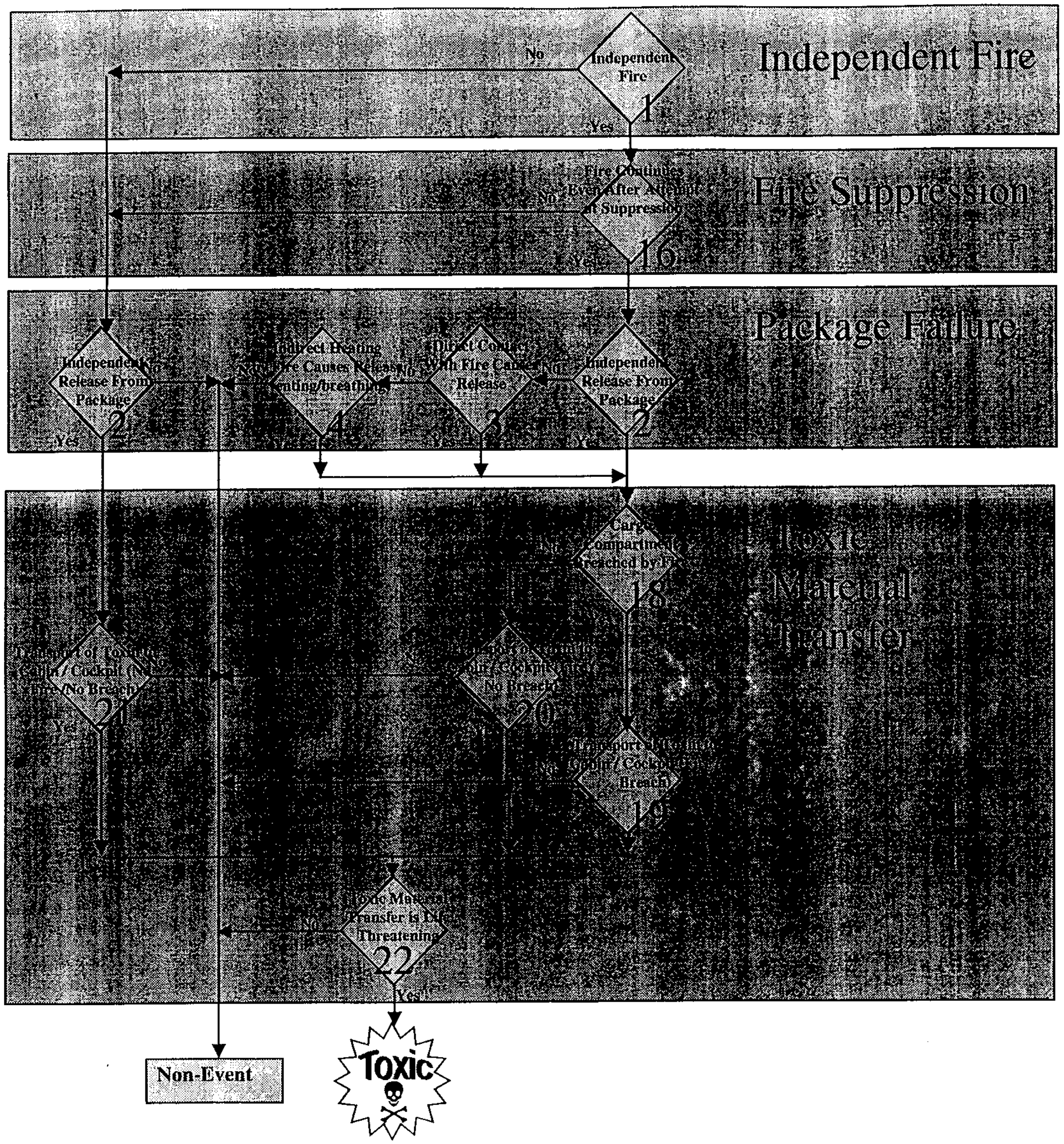
OXIDIZER PATHWAYS LEADING TO LIFE-THREATENING INCIDENTS ON-BOARD AIRCRAFT





Dangerous When Wet (DWW) Pathways Leading to Life-Threatening Incidents On-Board Aircraft

Toxic Pathways Leading to Life-Threatening Incidents On-Board Aircraft



APPENDIX B - SELECTED "WORST LIKELY CASE" MATERIALS AND PACKAGING ASSUMPTIONS

Table B.1 Selected "Worst Likely Case" Hazardous Materials Treated in this Assessment

Class/Division of Hazardous Material	Packaging Group (I, II, III)	Maximum Quantity per Package (when not forbidden): Cargo Aircraft	Maximum Quantity per Package (when not forbidden): Passenger Aircraft	Examples of "Worst Likely Case" Compliant and Non-compliant Materials Potentially Carried on Aircraft	Selected Compliant and Non-compliant Materials and Packaging Assumptions: Case	Name	UN Number	Packing Group	Maximum Quantity per Package: Cargo	Maximum Quantity per Package: Passenger	State	Packaging Assumptions NC = Non-Compliant CC = Cargo-Compliant PC = Passenger-Compliant
Division 1.1: Explosives with a mass explosion hazard	II	Forbidden	Forbidden	Lead azide, detonators, black powder, nitroglycerin, bombs, torpedo warheads, TNT blasting explosives, flash powder	NC	1.1A - Lead azide, wetted	UN0129	II	Forbidden	Forbidden	S	NC - Package of lead azide misidentified. Lead azide is wetted, but in otherwise non-compliant packagings.
Division 1.2: Explosives with a projection hazard	II	Forbidden	Forbidden	Hand grenades, rocket warheads, explosive projectiles, detonating fuzes, high explosive-incendiary (HEI) ammunition	NC	1.2F - Hand grenades	UN0293	II	Forbidden	Forbidden	S	NC - Box of grenades misidentified as practice grenades (1.4S). Packaged with protective features, but non-specification box.
Division 1.3: Explosives with predominant fire hazard	II	Forbidden (except for certain few articles)	Forbidden	Smokeless powders, rocket motors, illuminating ammunition, igniters, tracers, incendiary cartridges, aerial flares, display fireworks	NC	1.3G - Fireworks (display)	UN0335	II	Forbidden	Forbidden	S	NC - Display fireworks for professional outdoor use misidentified as consumer fireworks (1.4G) in non-specification box.
Division 1.4: Explosives with minor blast hazard	II	75-100 kg for most articles (except for Division 1.4F articles which are Forbidden)	Forbidden (except for 1.4S)	Ammunition primers, power device cartridges, cartridges for weapons, rocket warheads, small model rocket motors, bird scaring cartridges, signal cartridges, consumer fireworks, aerial flares, smoke signals, small arms ammunition, toy caps	NC CC PC	1.4F - Warheads, rocket 1.4E - Cartridges for weapons 1.4S - Flares, aerial	UN0371 UN0412 UN0404	II II II	Forbidden 75 kg 100 kg	Forbidden Forbidden 25 kg	S S S	NC - Rocket warheads misidentified as inert projectiles. Packaged with protective features, but in non-specification box. CC - Cartridges for weapons in compliant packagings. PC - Aerial flares in compliant packagings in quantity permitted on passenger aircraft.
Division 1.5: Very insensitive explosives	II	Forbidden	Forbidden	ANFO, insensitive blasting explosives	NC	1.5D - Ammonium Nitrate-Fuel Oil Mixture (ANFO)	NA0331	II	Forbidden	Forbidden	S	NC - ANFO misidentified as ammonium nitrate and in non-compliant packagings.
Division 2.1: Flammable gases	n/a	15-150 kg	1-75 kg	Propane, butane, acetylene, refrigerated liquid hydrogen, compressed hydrogen, silane, lighters, aerosols	NC CC PC	2.1 - Hydrogen, refrigerated liquid 2.1 - Hydrogen, compressed 2.1 - Aerosols, flammable	UN1966 UN1049 UN1950	n/a	Forbidden 150 kg 150 kg	Forbidden Forbidden 75 kg	G G G	NC - Hydrogen (refrigerated liquid) in a cryogenic cylinder misidentified as nitrogen. The cylinder is not designed to hold gas in a compressed state, therefore, in transport as the liquified gas evaporates, the cylinder continuously releases its contents. CC - Hydrogen, compressed in a DOT specification cylinder. PC - Aerosols, flammable - a fiberboard box of DOT specification cans.
Division 2.2 / 5.1: Oxidizing gases	n/a	25-150 kg	75 kg	Refrigerated liquid oxygen, compressed oxygen, nitrous oxide, nitrogen trifluoride	NC CC PC	2.2 - Oxygen, refrigerated liquid 2.2 - Nitrogen trifluoride 2.2 - Oxygen, compressed	UN1073 UN2451 UN1072	n/a	Forbidden 25 kg 150 kg	Forbidden Forbidden 75 kg	G G G	NC - Oxygen (refrigerated liquid) in a cryogenic cylinder misidentified as nitrogen. The cylinder is not designed to hold gas in a compressed state, therefore, in transport as the liquified gas evaporates, the cylinder continuously releases its contents. CC - Nitrogen trifluoride - DOT specification cylinder in strong outer packaging PC - Oxygen, compressed - DOT specification cylinder in strong outer packaging

Table B.1 Selected "Worst Likely Case" Hazardous Materials Treated in this Assessment

Class/Division of Hazardous Material	Packaging Group	Maximum Quantity per Package (when not forbidden)		Examples of "Worst Likely Case" Compliant and Non-compliant Materials Potentially Carried on Aircraft	Selected Compliant and Non-compliant Materials and Packaging Assumptions							
	(I, II, III)	Cargo Aircraft	Passenger Aircraft		Case	Name	UN Number	Packing Group	Maximum Quantity per Package: Cargo	Maximum Quantity per Package: Passenger	State	Packaging Assumptions NC = Non-Compliant CC = Cargo-Compliant PC = Passenger-Compliant
Division 2.3: Gases poisonous by inhalation	n/a	Forbidden (except some materials up to 25 kg)	Forbidden	Chlorine, arsine, hydrogen cyanide, fluorine, hydrogen fluoride, hydrogen chloride, dinitrogen tetroxide, phosgene, phosphine, sulfur dioxide, methyl bromide	NC CC	2.3 - Chlorine (TIH-Zone B) 2.3 - Methyl bromide (TIH-Zone C)	UN1017 UN1062	n/a	Forbidden 25 kg	Forbidden Forbidden	G G	NC - Chlorine misidentified and transported in a non DOT-specification cylinder with no pressure release valve. CC - Methyl bromide in a DOT specification cylinder with a pressure relief valve PC - Not applicable (None Permitted)
Class 3: Flammable liquids	I (L) II (L) III (L)	2.5-60 L 1-60 L 5-220 L	0.5-1 L 1-5 L 5-60 L	Diethyl ether, acetone, lighter fluid, toluene, methanol, ethanol, isopropanol, paints, acrylonitrile, turpentine, printing inks	NC CC PC	3 - Diethyl ether 3 - Diethyl ether 3 - Diethyl ether	UN1155	I	30 L	1 L	L	NC - Diethyl ether in non-specification packaging for packing group I. PC - DOT specification package containing 1L.
Division 4.1: Flammable solids (includes self-heating and self-reactive solids and liquids)	I (S) II (S) II (L) III (S)	0.5-15 kg 10-50 kg 10-25 L 50-100 kg	0.5 kg 1-15 kg 1-10 L 15-25 kg	Smokeless powders for small arms (100 pounds or less), wetted nitrocellulose, black powders for small arms, picric acid, wetted TNT, powdered aluminum, highway fusee, titanium, phosphorus trisulfide, self reactive solids types C-F	NC CC PC	4.1 - Silver picrate, wetted 4.1 - Barium azide, wetted 4.1 - Self-reactive solid, type C (Azodicarbonamide formulation)	UN1347 UN1571 UN3224	I I II	Forbidden 0.5 kg 10 kg	Forbidden Forbidden 5 kg	S S S	NC - Package of silver picrate misidentified. Silver picrate is wetted, but in otherwise non-specification packagings. CC - Barium azide, wetted, in specification packaging for packing group I. PC - Self reactive solid, type C, in specification packagings for packing group II.
Division 4.2: Spontaneously combustible materials	I (S/L) II (L) II (S) III (L) III (S)	Forbidden 5 L 50 kg 60 L 0.5-100 kg	Forbidden 1 L 15 kg 5 L 0.5-25 kg	White phosphorus, aluminum triethyl, butyl-lithium, zinc dimethyl, magnesium diphenyl, titanium trichloride, sodium hydrosulfite, powdered titanium or zirconium	NC CC PC	4.2 - Phosphorus, white, dry 4.2 - Zirconium powder, dry 4.2 - Zirconium powder, dry	UN1381 UN2008 UN2008	I I I	Forbidden 50 kg 50 kg	Forbidden 15 kg 15 kg	S S S	NC - White phosphorus, misidentified and in non-compliant packagings (e.g., plastic or glass inner and fiberboard outer packagings). CC - Zirconium powder, dry in DOT specification packagings (e.g., plastic inner and fiberboard outer PC - Zirconium powder, dry in DOT specification packagings (e.g., plastic inner and fiberboard outer packagings). Outer packaging limited to 15 kg.
Division 4.3: Dangerous when wet materials	I (L) I (S) II (L) II (S) III (L) III (S)	1 L 15 kg 5 L 50 kg 60 L 100 kg	Forbidden Forbidden 1 L 15 kg 5 L 25 kg	Metallic lithium, sodium or potassium, aluminum hydrides, lithium aluminum hydride, cesium (metal), barium (metal), powdered magnesium, lithium or sodium borohydride, trichlorosilane, zinc dust	NC CC PC	4.3 - Lithium aluminum hydride 4.3 - Lithium aluminum hydride 4.3 - Barium (metal)	UN1410 UN1410 UN1400	I I II	15 kg 15 kg 50 kg	Forbidden Forbidden 15 kg	S S S	NC - Lithium aluminum hydride in non-specification packagings (e.g., glass inner, fiberboard outer packagings) CC - Lithium aluminum hydride in compliant PC - Barium (metal) in compliant package, packing group II. Up to 15 kg. per outer.

Table B.1 Selected "Worst Likely Case" Hazardous Materials Treated in this Assessment

Class/Division of Hazardous Material	Packaging Group	Maximum Quantity per Package (when not forbidden)		Examples of "Worst Likely Case" Compliant and Non-compliant Materials Potentially Carried on Aircraft	Selected Compliant and Non-compliant Materials and Packaging Assumptions							
	(I, II, III)	Cargo Aircraft	Passenger Aircraft		Case	Name	UN Number	Packing Group	Maximum Quantity per Package: Cargo	Maximum Quantity per Package: Passenger	State	Packaging Assumptions NC = Non-Compliant CC = Cargo-Compliant PC = Passenger-Compliant
Division 5.1: Oxidizing materials (includes Division 5.1 materials that have a Class 8 subsidiary risk)	I (L)	2.5 L	Forbidden	Nitrate salts, chloric acid and chlorate salts, perchloric acid and perchlorate salts, hydrogen peroxide, potassium superoxide, ammonium perchlorate, hyochlorite bleaches and swimming pool chemicals, bromic acid and bromate salts, nitric acid, chromic acid and chromate salts, permanganate salts.								
	I (S)	15 kg	1 kg		NC	5.1 - Hydrogen peroxide, aqueous solution (with more than40percent but not more than 60 percent, stabilized as necessary)	UN2014	II	Forbidden	Forbidden	L	NC - Hydrogen peroide, aqueous solution (50%) misidentified as a more dilute Hydrogen peroxide, aqueous solution (20%), and in otherwise non-specification packagings.
	II (L)	5 L	1 L		CC	5.1 - Potassium superoxide	UN2466	I	15 kg	Forbidden	S	CC - Potasium superoxide in DOT specification packagings (e.g., glass inner, fiberboard outer)
	II (S)	25 kg	5 kg [1]		PC	5.1 - Ammonium perchlorate	UN1442	II	25 kg	5 kg	S	PC - Ammonium perchlorate in DOT specification packagings (e.g., glass inner, fiberboard outer)
	III (L)	30 L	2.5 L									
	III (S)	100 kg	25 kg									
Division 5.2: Organic peroxides[2]	II(L)	10-25 L	5-10 L	Organic peroxide catalysts	NC	5.2 - Organic peroxide, type C, liquid, temperature controlled (Disecbutyl peroxy dicarbonate 98%)	UN3113	II	Forbidden	Forbidden	L	NC - Organic peroxide, type C, liquid, temperature controlled (Disecbutyl peroxy dicarbonate 98%), misidentified as non-temperature controlled in non-compliant (sub-standard) packaging. Compliant quantity per outer package.
	II(S)	10-25 kg	5-10 kg		CC	5.2 - Organic peroxide, type C, liquid (t-Butyl peroxy Benzoate 77%)	UN3103	II	10 L	5 L	L	CC - Organic peroxide, type C, liquid (t-Butyl peroxy Benzoate 77%) in DOT specification
	II(S)	10-25 kg	5-10 kg		PC	5.2 - Organic peroxide, type D, liquid (2,5-Dimethyl - 2,5-dibutyl peroxyhexane 95%)	UN3106	II	10 L	5 L	L	PC - Organic peroxide, type D, liquid (2,5-Dimethyl - 2,5-dibutyl peroxyhexane 95%) in DOT specification composite packagings with plastic inner recepticle.
Division 6.1: Toxic materials	I (L)	30 L	1 L	Acrolein, allyl alcohol, arsenical pesticides, cyanide salts and solutions, carbamate pesticides, methyl chloroacetate, ethyl chloroformate, n-propyl chloroformate, ethylphosphorus dichloride, ethylene chlorohydrin, iron pentacarbonyl, methyl isocyanate, nickel carbonyl, parathion, tear gas devices, hydrofluoric acids								
	I (S)	15-50 kg	1-5 kg		NC	6.1 - Nickel carbonyl (TIH-Zone A)	UN1259	I	Forbidden	Forbidden	L	NC - Nickel carbonyl misidentified as nickel cynanide, in DOT non-specification packagings
	II (L)	30-60 L	1-5 L		CC	6.1 - n-propyl chloroformate (TIH-Zone B)	UN2740	I	2.5 L	Forbidden	L	CC - n-propyl chloroformate in DOT specification packagings for packing group I (e.g., plastic or metal drum with plastic liner)
	II (S)	50-100 kg	0.5-25 kg		PC	6.1 - Methyl chloroacetate	UN2295	I	30 L	1 L	L	PC - Methyl chloroacetate in DOT specification packagings for packing group I (e.g., plastic or metal drum with plastic liner)
	III (L)	5-220 L	5-60 L									
	III (S)	5-200 kg	5-100 kg									

Reference: Code of Federal Regulations: CFR:49:172.101

Packing Groups I, II, III indicate the degree of danger presented by the materials is great, medium or minor respectively

'L' indicates liquid; 'S' indicates solid

[1] Material generally forbidden if subsidiary risk is corrosive or flammable (except isobutyl cloroformate)

[2] Source of Selected Division 5.2 Materials: Society for the Plastics Industry

APPENDIX C - PROBABILITY FACTORS FOR SELECTED "WORST LIKELY" HAZARDOUS MATERIALS IN EACH COMPLIANCE CASE AND CLASS/DIVISION

Table C.1 Probability Factors for Selected "Worst Likely" Hazardous Materials

Hazardous Material Class / Division	Selected Representative Material (Worst Likely Case) Proper Shipping Name	UN Number	Case	Independent Release from Package 2	Direct Contact with Fire Causes Release 3: Proximity	3: Release	3: Combined	Indirect Heating by Fire Causes Release 4: Proximity	4: Release	4: Combined	Release via Venting / Breathing (No Fire) [DWW only] 5 (Heat Source / Sufficient Exposure)	Loss of Operational Control 6	Contact Between Independently Released Material and Fire Causes Initiation 7: Migration	7: Initiation	7: Combined	Direct Contact with Fire Causes Initiation 8	Indirect Heating by Fire Causes Initiation 9	Initiation by Other Source (Heat / Impact / Friction / ESD) 10: Worst Case Source	10: Source	10: Migration / Exposure	10: Initiation	10: Combined	Self Heating / Self Reaction / Spontaneous Ignition / Reaction with Packaging Materials 11: Self-heating / Self-reaction	11: Spont. Ign./ Reaction with Pack. Matl.	11: Combined	Sufficient Water for Severe Reaction 12	Explosion, Given Ignition: Any Explosion 13	Severe Explosion 14	Severe Fire Following Minor Explosion 15	Toxic Material Transfer is Life Threatening 22
1.1 Explosives with mass explosion hazard																														
1.1 A	Lead azide, wetted	UN0129	Non-Compliant Cargo & Passenger	3.00E-04	0.50	1	0.50	0.50	0.50	0.25	n/a	n/a	5.00E-02	1	5.00E-02	1	0.50	Friction	1.00E-04	1	0.50	5.00E-05	0	0	0	n/a	1	1	0	n/a
1.2 Explosives with a projection hazard																														
1.2 F	Hand grenades	UN0293	Non-Compliant Cargo & Passenger	3.00E-04	0.50	1	0.50	0.50	0.50	0.25	n/a	n/a	5.00E-02	1	5.00E-02	1	1.00E-02	Impact/ Shock	1.00E-03	1	1.00E-06	1.00E-09	0	0	0	n/a	1	1	0	n/a
1.3 Explosives with predominant fire hazard																														
1.3 G	Fireworks (display)	UN0335	Non-Compliant Cargo & Passenger	3.00E-04	0.50	1	0.50	0.50	0.50	0.25	n/a	n/a	5.00E-02	1	5.00E-02	1	1.00E-02	Friction	1.00E-04	1	1.00E-06	1.00E-10	0	0	0	n/a	1	1	0	n/a
1.4 Explosives with minor blast hazard																														
1.4F	Warheads, rocket	UN0371	Non-Compliant Cargo & Passenger	3.00E-04	0.50	1	0.50	0.50	0.50	0.25	n/a	n/a	5.00E-02	1	5.00E-02	1	1.00E-02	Impact/ Shock	1.00E-03	1	1.00E-06	1.00E-09	0	0	0	n/a	1	0	1.00E-02	n/a
1.4E	Cartridges for Weapons	UN0412	Cargo Compliant	1.00E-05	0.50	1	0.50	0.50	0	0	n/a	n/a	5.00E-02	1	5.00E-02	1	1.00E-02	Impact/ Shock	1.00E-03	1	1.00E-06	1.00E-09	0	0	0	n/a	0.10	0	0.50	n/a
1.4S	Flares, aerial	UN0404	Passenger Compliant	1.00E-05	0.50	1	0.50	0.50	0	0	n/a	n/a	5.00E-02	1	5.00E-02	1	1.00E-02	Friction	1.00E-04	1	1.00E-06	1.00E-10	0	0	0	n/a	1	0	1.00E-02	n/a
1.5 Very insensitive explosives																														
1.5D	Ammonium nitrate fuel oil mixture (ANFO)	NA0331	Non-Compliant Cargo & Passenger	3.00E-04	0.50	1	0.50	0.50	0.50	0.25	n/a	n/a	5.00E-02	1	5.00E-02	1	0	Impact/ Shock	1.00E-03	1	1.00E-09	1.00E-12	0	0	0	n/a	1.00E-09	1	0	n/a
2.1 Flammable Gases																														
2.1	Hydrogen, refrigerated liquid	UN1966	Non-Compliant Cargo & Passenger	1	n/a	1	1	n/a	1	1	n/a	1.00E-03	0.95	1	0.95	1	1	ESD	9.77E-07	0.95	0.99	9.19E-07	0	0	0	n/a	1	1	0	n/a
2.1	Hydrogen, compressed	UN1049	Cargo Compliant	2.41E-06	0.50	1	0.50	0.50	0.50	0.25	n/a	n/a	0.95	1	0.95	1	1	ESD	9.77E-07	0.95	0.99	9.19E-07	0	0	0	n/a	1	1	0	n/a
2.1	Aerosols, flammable	UN1950	Passenger Compliant	1.00E-05	0.50	1.00	0.50	0.50	0.50	0.25	n/a	n/a	0.95	1	0.95	1	1	ESD	9.77E-07	0.95	0.50	4.64E-07	0	0	0	n/a	1	0	1	n/a
2.2 & 5.1 Oxidizing Gases																														
2.2 / 5.1	Oxygen, refrigerated liquid	UN1073	Non-Compliant Cargo & Passenger	1	n/a	1	1	n/a	1	1	n/a	1.00E-03	0.95	1	0.95	1	1	Friction	1.00E-04	1	1.00E-04	1.00E-08	0	1.00E-06	1.00E-06	n/a	1	1	1	n/a
2.2 / 5.1	Nitrogen trifluoride	UN2451	Cargo Compliant	2.41E-06	0.50	1	0.50	0.50	0.50	0.25	n/a	n/a	0.95	1	0.95	1	1	Heat	9.77E-07	0.95	1.00E-03	9.29E-10	0	1.00E-06	1.00E-06	n/a	1.00E-03	1	1	n/a
2.2 / 5.1	Oxygen, compressed	UN1072	Passenger Compliant	2.41E-06	0.50	1	0.50	0.50	1.00	0.50	n/a	n/a	0.95	1	0.95	1	1	Friction	1.00E-04	1	1.00E-04	1.00E-08	0	1.00E-06	1.00E-06	n/a	1.00E-02	1	1	n/a
2.3 Gases Poisonous by Inhalation																														
2.3	Chlorine	UN1017	Non-Compliant Cargo & Passenger	3.00E-04	0.5	1.00E-03	5.00E-04	0.5	1.00E-04	5.00E-05	n/a	n/a			n/a	n/a	n/a	n/a				n/a			n/a	n/a	n/a	n/a	n/a	0.50
2.3	Methyl bromide	UN1062	Cargo Compliant	2.41E-06	0.50	1	0.50	0.50	0.50	0.25	n/a	n/a			n/a	n/a	n/a	n/a				n/a			n/a	n/a	n/a	n/a	n/a	0.10

Table C.1 Probability Factors for Selected "Worst Likely" Hazardous Materials, Continued

Hazardous Material Class / Division	Selected Representative Material (Worst Likely Case) Proper Shipping Name	UN Number	Case	Package Failure / Release: Independent Release from Package 2	Direct Contact with Fire Causes Release 3			Indirect Heating by Fire Causes Release 4			Release via Venting / Breathing (No Fire) [DWW only] 5			Loss of Operational Control 6	Initiation / Enhancement by Independent Fire: Contact Between Independently Released Material and Fire Causes Initiation 7			Direct Contact with Fire Causes Initiation 8	Indirect Heating by Fire Causes Initiation 9	Other Initiation: Initiation by Other Source (Heat / Impact / Friction / ESD) 10					Self Heating / Self Reaction / Spontaneous Ignition / Reaction with Packaging Materials 11			Sufficient Water for Severe Reaction 12	Explosion, Given Ignition: Any Explosion 13	Severe Explosion 14	Severe Fire Following Minor Explosion 15	Toxic Material Transfer is Life Threatening 22
					Proximity	Release		Proximity	Release		Heat Source	Sufficient Exposure			Migration	Initiation				Worst Case Source	Source	Migration / Exposure	Initiation		Self-heating / Self-reaction	Spont. Ign./ Reaction with Pack. Matl.						
3 Flammable Liquids																																
3	Diethyl ether	UN1155	Non-Compliant Cargo & Passenger	3.00E-04	0.50	1	0.50	0.50	0.50	0.25			n/a	n/a	0.50	1	0.50	1	0.75	ESD	9.77E-07	0.50	0.33	1.61E-07	0	0	0	n/a	0.50	0.50	1	n/a
3	Diethyl ether	UN1155	Cargo Compliant	1.00E-05	0.50	1	0.50	0.50	0.50	0.25			n/a	n/a	0.50	1	0.50	1	0.75	ESD	9.77E-07	0.50	0.33	1.61E-07	0	0	0	n/a	0.50	0.50	1	n/a
3	Diethyl ether	UN1155	Passenger Compliant	1.00E-05	0.50	1	0.50	0.50	0.50	0.25			n/a	n/a	0.50	1	0.50	1	2.50E-02	ESD	9.77E-07	0.50	0.33	1.61E-07	0	0	0	n/a	0.50	0.50	1	n/a
4.1 Flammable Solids (including self-reactive liquids)																																
4.1	Silver picrate, wetted	UN1347	Non-Compliant Cargo & Passenger	3.00E-04	0.50	0.10	5.00E-02	0.50	0.10	5.00E-02			n/a	n/a	5.00E-02	1	5.00E-02	1	0.25	Friction	1.00E-04	1	1.00E-02	1.00E-06	0	0	0	n/a	1	1	1	n/a
4.1	Barium azide, wetted	UN1571	Cargo Compliant	1.00E-05	0.50	2.00E-02	1.00E-02	0.50	1.00E-02	5.00E-03			n/a	n/a	5.00E-02	0.50	2.50E-02	0.50	0.10	Friction	1.00E-04	1	1.00E-03	1.00E-07	0	0	0	n/a	1	0.50	0.50	n/a
4.1	Self-reactive solid, type C (azodicarbonamide formulation)	UN3224	Passenger Compliant	1.00E-05	0.50	1	0.50	0.50	0.50	0.25			n/a	n/a	5.00E-02	1	5.00E-02	1	0.50	Heat	9.77E-07	5.00E-02	1.00E-03	4.89E-11	0	1.00E-03	1.00E-03	n/a	0	0	0.50	n/a
4.2 Spontaneously Combustable Materials																																
4.2	Phosphorus, white, dry	UN1381	Non-Compliant Cargo & Passenger	3.00E-04	0.50	1	0.50	0.50	0.50	0.25			n/a	n/a	5.00E-02	1	5.00E-02	1	1	n/a	n/a	1	1	1	0	1	1	n/a	0	0	1	n/a
4.2	Zirconium powder, dry	UN2008	Cargo Compliant	1.00E-05	0.50	1	0.50	0.50	0.50	0.25			n/a	n/a	5.00E-02	1	5.00E-02	1	0.50	ESD	9.77E-07	5.00E-02	1.00E-02	4.89E-10	0	0	0	n/a	0	0	1	n/a
4.2	Zirconium powder, dry	UN2008	Passenger Compliant	1.00E-05	0.50	1	0.50	0.50	0.50	0.25			n/a	n/a	5.00E-02	1	5.00E-02	1	0.25	ESD	9.77E-07	5.00E-02	1.00E-02	4.89E-10	0	0	0	n/a	0	0	1	n/a
4.3 Dangerous When Wet Materials																																
4.3	Lithium aluminum hydride	UN1410	Non-Compliant Cargo & Passenger	3.00E-04			n/a			n/a	9.77E-07	1	9.77E-07	n/a			n/a	n/a	n/a	n/a				n/a			n/a	1.00E-02	n/a	n/a	n/a	n/a
4.3	Lithium aluminum hydride	UN1410	Cargo Compliant	1.00E-05			n/a			n/a	9.77E-07	0.10	9.77E-08	n/a			n/a	n/a	n/a	n/a				n/a			n/a	1.00E-02	n/a	n/a	n/a	n/a
4.3	Barium (metal)	UN1400	Passenger Compliant	1.00E-05			n/a			n/a	9.77E-07	1.00E-03	9.77E-10	n/a			n/a	n/a	n/a	n/a				n/a			n/a	5.00E-04	n/a	n/a	n/a	n/a
5.1 Liquid and Solid Oxidizers (includes Division 5.1 mterials that have a Class 8 subsidiary risk)																																
5.1	Hydrogen peroxide, aqueous solutions (50%)	UN2014	Non-Compliant Cargo & Passenger	3.00E-04	0.50	1	0.50	0.50	0.50	0.25			n/a	n/a	0.50	1	0.50	1	0.10	Heat	9.77E-07	0.50	0.50	2.44E-07	0	0.25	0.25	n/a	1.00E-03	1.00E-05	1	n/a
5.1	Potassium superoxide	UN2466	Cargo Compliant	1.00E-05	0.50	1	0.50	0.50	0.50	0.25			n/a	n/a	5.00E-02	1	5.00E-02	1	1	Heat	9.77E-07	5.00E-02	1.00E-04	4.89E-12	0	0	0	n/a	1.00E-02	1.00E-05	1	n/a
5.1	Ammonium perchlorate	UN1442	Passenger Compliant	1.00E-05	0.50	1	0.50	0.50	0.50	0.25			n/a	n/a	5.00E-02	1	5.00E-02	1	0.50	Impact/ Shock	1.00E-03	1	1.00E-06	1.00E-09	0	1.00E-03	1.00E-03	n/a	1.00E-09	1	1	n/a

Table C.1 Probability Factors for Selected "Worst Likely" Hazardous Materials, Continued

Hazardous Material Class / Division	Selected Representative Material (Worst Likely Case) Proper Shipping Name	UN Number	Case	Package Failure / Release: Independent Release from Package 2	Direct Contact with Fire Causes Release 3: Proximity	3: Release	Indirect Heating by Fire Causes Release 4: Proximity	4: Release	Release via Venting / Breathing (No Fire) [DWW only] 5: Heat Source	5: Sufficient Exposure	Loss of Operational Control 6	Initiation / Enhancement by Independent Fire: Contact Between Independently Released Material and Fire Causes Initiation 7: Migration	7: Initiation	Direct Contact with Fire Causes Initiation 8	Indirect Heating by Fire Causes Initiation 9	Other Initiation: Initiation by Other Source (Heat / Impact / Friction / ESD) 10: Worst Case Source	10: Source	10: Migration / Exposure	10: Initiation	Self Heating / Self Reaction / Spontaneous Ignition / Reaction with Packaging Materials 11: Self-heating / Self-reaction	11: Spont. Ign./ Reaction with Pack. Matl.	Sufficient Water for Severe Reaction 12	Explosion, Given Ignition: Any Explosion 13	Severe Explosion 14	Severe Fire Following Minor Explosion 15	Toxic Material Transfer is Life Threatening 22
5.2 Organic Peroxides (Liquid)																										
					n/a	1	n/a	1				0.50	1			Heat	9.77E-07	0.50	1.00E-02	1.00E-02	1.00E-04					
5.2	Organic peroxide, type C, liquid, temperature controlled (Disecbutyl peroxy dicarbonate 98%)	UN3113	**Non-Compliant** Cargo & Passenger	3.00E-04	1		1		n/a		0.1	0.50		1	0.1		4.89E-09			1.01E-02		n/a	1.00E-04	1.00E-06	1	n/a
					0.50	1	0.50	0.50				0.50	1			Heat	9.77E-07	0.50	1.00E-03	1.00E-06	1.00E-09					
5.2	Organic peroxide, type C, liquid (t-Butyl peroxy Benzoate 77%)	UN3103	**Cargo Compliant**	1.00E-05	0.50		0.25		n/a		n/a	0.50		1	1.00E-02		4.89E-10			1.00E-06		n/a	1.00E-09	1.00E-12	1.00E-02	n/a
					0.50	1	0.50	0.50				0.50	1			Heat	9.77E-07	0.50	1.00E-03	1.00E-06	1.00E-09					
5.2	Organic peroxide, type D, liquid (2,5-Dimethyl - 2,5-dibutyl peroxyhexane 95%)	UN3106	**Passenger Compliant**	1.00E-05	0.50		0.25		n/a		n/a	0.50		1	5.00E-03		4.89E-10			1.00E-06		n/a	1.00E-09	1.00E-12	1.00E-02	n/a
6.1 Poisonous Materials																										
					0.50	1	0.50	0.50																		
6.1	Nickel carbonyl	UN1259	**Non-Compliant** Cargo & Passenger	3.00E-04	0.50		0.25		n/a		n/a	n/a		n/a	n/a	n/a	n/a			n/a		n/a	n/a	n/a	n/a	0.95
					0.50	1	0.50	0.50																		
6.1	n-propyl chloroformate	UN2740	**Cargo Compliant**	1.00E-05	0.50		0.25		n/a		n/a	n/a		n/a	n/a	n/a	n/a			n/a		n/a	n/a	n/a	n/a	0.50
					0.50	1	0.50	0.50																		
6.1	Methyl chloroacetate	UN2295	**Passenger Compliant**	1.00E-05	0.50		0.25		n/a		n/a	n/a		n/a	n/a	n/a	n/a			n/a		n/a	n/a	n/a	n/a	1.00E-02

aded Areas are Prohibited Materials or Non Applicable

Table C.1 Probability Factors for Selected "Worst Likely" Hazardous Materials, Continued

		Fire Suppression		Toxic Material Release/Transfer			
Cargo Compartment Type	Independent Fire 1	Fire Not Suppressed 16	Fire Not Suppressed (oxidizer) 17	Cargo Compartment Breached 18	Transfer to Cabin/Cockpit (fire and breach) 19	Transfer to Cabin/Cockpit (fire, cargo compartment intact) 20	Transfer to Cabin/Cockpit (no fire, cargo compartment intact) 21
A	7.45E-08	0.16	1	0.95	0.95	0.95	0.01
B1	5.80E-07	0.60	1	0.99	0.99	0.99	0.01
B2	5.80E-07	0.05	1	0.99	0.99	0.99	0.01
C	5.26E-08	0.04	0.50	0.04	0.50	0.10	0.01
D	3.72E-08	0.16	0.70	0.16	0.50	0.10	0.01
E	5.80E-07	0.15	0.80	0.99	0.99	0.99	0.01

APPENDIX D - HAZARDOUS CARGO FIRE INCIDENTS

Hazard Class/ Division	Substances or Articles Involved	Fire/Near Fire Incident Date and Location	Carrier/ Shipper/ Aircraft	Location of Fire/Near Fire	Description
2.2/5.1	oxygen gas	12/31/70 Washington DC--National	United Airlines Boeing 737	Forward cargo compartment	Fire during routine turn-around servicing causing cylinder to vent 162 cu. feet of oxygen and a severe fire resulted which burned through the outer fuselage. No passengers aboard.
2.2/5.1	oxygen gas	05/01/73	American Airlines B- 707	passenger cabin	Explosion of portable oxygen cylinder while administering oxygen to passenger.
2.2/5.1	oxygen gas	07/07/73	American Airlines DC-10	passenger cabin	Portable oxygen cylinder ignited while administering oxygen to passenger
2.2/5.1	oxygen gas	04/10/81	Saudi Arabian Airlines L-1011	Unknown	Fire after take-off believed the result of improperly handled oxygen cylinder
2.2/5.1	oxygen gas	11/12/82	Scandinavian Air Swearingen SA Metro II	cockpit area	Electrical short/fire, 70 psi leak, left side cockpit console.
2.2/5.1	oxygen gas	10/14/89 Salt Lake City Airport	Delta Airlines Boeing 727	forward service compartment	Maintenance was being performed on the oxygen system when a violent fire erupted as the plane was being boarded. Everyone evacuated safely. Aircraft totally destroyed.
2.2/5.1	oxygen gas	02/01/91Los Angeles Intl.	US Airways Boeing 737 and Skywest Airways Fairchild Metroliner	Forward cargo compartment	The US Air 737 collided with the Fairchild Metroliner while landing killing all 12 occupants in the Metroliner immediately. The 737 veered off the runway and into a building crushing the top and left side of the cockpit. The impacts ruptured the oxygen system in the 737 and greatly accelerated the fire and reduced the survival time in the cabin. 22 passengers and 2 crewmembers died in the 737.
2.2/5.1	oxygen gas	10/29/91 New Delhi, India	Indian Airlines Boeing 737	Forward cargo compartment	Fire broke out during a "D" maintenance check of the oxygen system which damaged regulators, lines and burned a small hole through the fuselage. No injuries or fatalities.
5.1	sodium chlorate oxygen generator	08/10/86 Chicago-O'Hare	American Trans Air DC-10	Forward cargo compartment	While aircraft was parked at the gate, a mechanic unknowingly activated an oxygen container in an aluminum LD-3 service container filled with seatbacks, engine oil and hydraulic. Aircraft destroyed by fire. No injuries or fatalities.

Hazard Class/ Division	Substances or Articles Involved	Fire/Near Fire Incident Date and Location	Carrier/ Shipper/ Aircraft	Location of Fire/Near Fire	Description
5.1	sodium chlorate oxygen generator	10/06/92 Los Angeles Intl.	Qantas Unit Load Device for B-747	Freight consolidation area	The ULD was loaded at a freight forwarder with a solid oxygen generator being shipped as a replacement part and awaiting delivery to Qantas for a flight to Brisbane. No injuries or fatalities.
5.1	sodium chlorate oxygen generator	09/23/93 Oakland, CA	FedEx Boeing 727	Plane-side aft cargo compartment	During the off load of the aft cargo compartment into a ULD, a fire erupted in the ULD. The fire originated in a Passenger service unit containing a sodium chlorate oxygen generator which was improperly labeled and packaged. No injuries or fatalities.
5.1	sodium chlorate oxygen generator	10/20/94 Los Angeles	Emery Air	Package sorting area	Fire was observed in a box as a truck was unloaded. Contents of truck were destined for an Emery Air flight. Box on fire contained 37 sodium chlorate oxygen generators individually wrapped in bubble plastic. Fire started when one retainer pin came out and the spring hammer released on the percussion cap. No safety caps to prevent firing pin from hitting the cap were installed.
5.1	sodium chlorate oxygen generator	05/11/96 Near Miami Airport	ValuJet Airlines DC-9	Forward cargo compartment	Five cardboard boxes filled with as many as 144 out of service sodium chlorate oxygen generators which had not been equipped with safety caps and misrepresented by the shipper, SabreTech as "empty oxygen canisters" were loaded in the forward cargo compartment. A severe fire broke out shortly after take-off from Miami and the plane crashed before it could complete an emergency landing. All 110 passengers and crew aboard were fatally injured.
8/5.1	concentrated nitric acid	11/03/73 near Boston	Pan Am Cargo Boeing 707	E compartment	Heavy smoke in cockpit led to a crash that resulted in the death of all three crewmembers. Cause of the smoke was from leaking concentrated nitric acid bottle improperly packed in sawdust in the main deck cargo compartment.
8/5.1	concentrated nitric acid	07/19/93 near Cleveland - Hopkins	FedEx Package sorting operation in Brooklyn Heights, OH	off site building	During package inspection a discrepancy was noted in the documentation and set aside. It subsequently made a "popping" sound, rocked back and forth. Package was wheeled outside where it gave off a strong odor and burst into flames. Package contained a one-liter bottle of concentrated nitric acid.

Hazard Class/ Division	Substances or Articles Involved	Fire/Near Fire Incident Date and Location	Carrier/ Shipper/ Aircraft	Location of Fire/Near Fire	Description
5.1/8	hydrogen peroxide and sodium hydroxide	02/03/88 Nashville, TN	American Airlines MD-80	Type D cargo compartment	Crew noticed a "hot cabin floor" over the cargo compartment and smoke in the cabin during final approach but the aircraft landed safely. Investigation showed that the fire was most probably originated in a fiberdrum containing an undeclared and improperly packaged quantity of concentrated hydrogen peroxide shipped together with sodium hydroxide and other textile treatment chemicals.
8/4.3	"methyl phosphorodic hlorodite" (not a proper shipping name-- chemical structure unknown--- possibly CH_3OPCl_2or CH_3OPOCl_2)	04/18/94 Los Angeles, CA	FedEx Package Sorting facilities	Off site building	During package sort, package was removed because of leakage and smoke emitted. Package contained three-1 liter glass bottles of substance which may have been a Division 4.3 dangerous when wet material (and possibly a PIH as well) mis-identified as just a Class 8 Corrosive liquid, n.o.s. No fire resulted. Product was said to have reacted with packaging but it may have been reacting with the moisture in the air and in the packaging also or instead.
2.1	propane gas	04/23/78 San Diego, CA	Pacific Southwest Boeing 727	Cargo compartment	While unloading, a cardboard box containing a leaking propane cylinder ignited.
4.1	kitchen matches	08/22/90 Denver -- Stapleton	Trans World	baggage loading area	A piece of checked baggage was observed to be smoking during the loading process and left on the ramp. A box of kitchen matches was found to have ignited within it.
4.1	100% Rayon bales	10/18/90 Chicago, IL	United Airlines Boeing 727	Aft Cargo compartment	Ramp personnel reported burning smell in aft compartment. Found burned spot on sidewall liner caused by smoldering bales of rayon sheeting. Not known if it was spontaneous combustion in the rayon bale or a prior ignition and slow burn before being loaded in the aircraft.
4.1	matches, strike anywhere UN1331	09/06/91 Anchorage, AK	Alaska Airlines	baggage compartment cart, plane-side	Strike Anywhere Matches (200) ignited in a passenger backpack while being offloaded into baggage cart.

Hazard Class/ Division	Substances or Articles Involved	Fire/Near Fire Incident Date and Location	Carrier/ Shipper/ Aircraft	Location of Fire/Near Fire	Description
4.1	matches, safety	011/07/95 Panama City, Panama	Continential Airlines Boeing 727	Plane-side-- during cargo loading into aft compartments	Ramp crew was loading 2800 pounds of product identified as safety matches but in fact were actually large, bundled uncovered match "combs" without covers. Cargo ignited during loading and before the fire could be extinguished most of the plane cargo area and above was severely damaged. Only the crew and cleaning personnel were on board when the fire broke out and all evacuated safely. One fireman and one ground handler were slightly burned trying to remove burning boxes from the plane.
4.1	matches, safety	04/03/97 Anchorage, AK	Alaska Airlines	planeside -- during loading into aft cargo compartment	While loading baggage into Flight 20, ramp service agent smelled smoke. All baggage was unloaded and re-checked on the ramp. A bag smelling of burnt material was opened and four books of matches were found, one of which had self- ignited.
4.1	matches, kitchen	01/22/98 Miami, FL	American Airlines	baggage transfer belt from ticket counter	Passenger bag travelling along belt contained matches. At some point during the transfer, about 20 matches fell out of the original box in the bag and ignited causing the interior of the bag to be slightly scorched.
4.3 (3)	lithium metal (flammable inks)	05/10/91 Aqualilla, Puerto Rico	Four Starr Aviation (FedEx sub-contractor)	cargo compartment	There was an emergency landing of the aircraft and an on-board hazmat fire subsequent to that emergency. NTSB couldn't confirm the fire had begun to the emergency landing. The lithium metal was also being shipped with some flammable printing inks in the same compartment.
1.4 & 2.1	Butane lighters and fireworks	07/10/94 Chicago-O'Hare Airport	United Boeing 737	planeside, cargo compartment	As checked baggage was being off-loaded a bag exploded containing about 200 BIC lighters and some consumer-type fireworks. The ramp service baggage handler received minor burns.
1.4/ ORM-D	cartridges for weapons, blank	03/25/98 Moonachie, NJ	FedEX	freight consolidation terminal	A box of ammunition was being loaded into a truck when the inner contents shifted, causing all 200 rounds to discharge, manifesting a loud report and a puff of smoke and charring inside the box. The truck was bound for Newark airport to be loaded on a FedEx cargo flight.
1.4	fireworks	07/19/97 Abbotsford, Canada airport	Southwest Airlines Flight 594	forward cargo compartment	Baggage handler began loading the forward bin when he noticed a small smoldering hole in the front pocket of a backpack. As he lifted it out, it caught fire and the handler patted it out and transferred it to the ramp where it was extinguished. Subsequent examination and investigation revealed that the passenger was transporting fireworks articles in the backpack.

Hazard Class/ Division	Substances or Articles Involved	Fire/Near Fire Incident Date and Location	Carrier/ Shipper/ Aircraft	Location of Fire/Near Fire	Description
6.2	human infectious substances	12/15/97 Philadelphia airport	FedEx	freight consolidation area	The shipment had been inspected and refused for several discrepancies. When the inspector placed the box on the floor and turned his back, the box "exploded." Debris was scattered and the box was shredded. Explosion may have been due to pressure buildup from temperature-controlling substances (liquid CO2 or liquid nitrogen?)
Unkown	"leaking chemicals"	08/29/71	Air Carrier unidentified Boeing 707	aft cargo compartment	Aircraft was diverted to Shannon due to a fire in the aft cargo compartment resulting from "spontaneous ignitions of leaking chemicals." No information on the carrier or the leaking chemicals is available.
Unkown	Div 4.3 flammable metal powders, Div. 4.1 flammable solids, organic and Class 3 flammable liquids	08/01/97-New York - Newark Airport	FedEx Flight 14	Unkown	Flight 14 crashed and burned upon landing in EWR airport. All freight was lost, consumed by the fire and was unrecoverable. No conclusions reached on whether hazmat contributed to the crash severity.

Source: FAA

APPENDIX E - INDEPENDENT CARGO COMPARTMENT FIRE INCIDENTS

Summary of Reported Independent Cargo Fires Incidents Not Caused by Hazardous Material - 1970 To Present

DATE	CARRIER	INCIDENT
08/02/77	Texas Intl DC-9	Mailbag fire in forward cargo compartment.
08/19/80	Saudia L-1011	Ignition source in aft compartment undetermined. 301 fatalities.
12/11/86	MRKA 382G	Electrical fault in power jack in cargo compartment. Caused hydraulic fluid to smoke.
12/21/86	RMAA DHC7	Electrical short in back bulkhead caused smoke in compartment.
11/28/87	So. African 747	Ignition source in forward right pallet position in main deck compartment undetermined. No survivors
08/24/88	Northwest 727	Mailbag was in contact with compartment light and was smoldering.
11/04/88	Flying Tigers 747	Electrical short in pallet drive wheels in deck floor. Burnt wires.
12/30/88	Delta 727	Localized burn spot on a cargo heating blanket.
05/05/89	Lufthansa 747	"Drain mast" heater caused ignition of cargo.
02/23/90	United DC-10	Electrical short inside connector leading to powered ULD rollers caused sparks under the floor.
05/22/90	Delta 727	Cargo heater blanket shorted out causing burned spot on cargo liner.
12/14/90	Eastern 727	Cargo heater blanket short caused smoldering suitcase.
12/19/90	SRAA 382G	Cargo loading light contacting insulation caused B cargo compartment to fill with smoke.
02/01/91	U.S. Air DC-9	Fire in cargo compartment upon arrival involving 5 pieces of luggage. No ignition source was found.
05/05/91	Northwest 747	Power drive unit in main cargo compartment found smoking.
07/25/94	Northwest 747	Fire broke out in aft compartment attributed to broken electromechanical equipment and damaged electrical wiring.
12/05/95	Inter-Canadian F28	Inflight fire in B compartment from canvas mail bags contacting compartment light fixture.

Total Independent Fire Incidents Since 1970: 13

Compartment Type	Instances of Independent Fire	Departures	Probability of Independent Fire		
A	7	94,000,000	7:94,000,000	1:13M	7.45E-08
B1	0 (Assume 1)	7,100,000	1:7,100,000	1:7M	5.80E-07*
B2	0 (Assume 1)	734,000	1:734,000	1:734K	5.80E-07*
C	3	57,000,000	3:57,000,000	1:19M	5.26E-08
D	9	242,000,000	9:242,000,000	1:27M	3.72E-08
E	4	6,900,000	4:6,900,000	1:2M	5.80E-07

* Based on FAA estimates of departures and incidents

APPENDIX F - CARGO COMPARTMENT CLASSIFICATIONS

FAR Section 25.857 - Cargo Compartment Classification

(a) **Type A.** A Type A cargo or baggage compartment is one in which--

(1) The presence of a fire would be easily discovered by a crew member while at his station; and
(2) Each part of the compartment is easily accessible in flight.

(b) **Type B.** A Type B cargo or baggage compartment is one in which --

(1) There is sufficient access in flight to enable a crew member to effectively reach any part of the compartment with the contents of a hand fire extinguisher;
(2) When the access provisions are being used, no hazardous quantity of smoke, flames, or extinguishing agent will enter any compartment occupied by the crew or passengers; and
(3) There is a separate approved smoke detector or fire detector system to give warning at the pilot or flight engineer station.

(c) **Type C.** A Type C cargo or baggage compartment is one not meeting the requirements for either a Class A or B compartment but in which--

(1) There is a separate approved smoke detector or fire detector system to give warning at the pilot or flight engineer station;
(2) There is an approved built-in fire-extinguishing system controllable from the pilot or flight engineer stations;
(3) There are means to exclude hazardous quantities of smoke, flames, or extinguishing agent, from any compartment by the crew or passengers;
(4) There are means to control ventilation and drafts within the compartment so that the extinguishing agent used can control any fire that may start within the compartment.

(d) **Type D.** A Type D cargo or baggage compartment is one in which--

(1) A fire occurring in it will be completely confined without endangering the safety of the airplane or the occupants;
(2) There are means to exclude hazardous quantities of smoke, flames, or other noxious gases, from any compartment occupied by the crew or passengers;
(3) Ventilation and drafts in the compartment will not progress beyond safe limits; and
(4) Reserved
(5) Consideration is given to the effect of heat within the compartment on adjacent critical parts of the airplane. For compartments of 500 cu.ft. or less, an airflow of 1500 cu. ft. per hour is acceptable.
(6) The compartment volume does not exceed 1,000 cubic feet

(e) **Type E.** A Type E cargo compartment is one on airplanes used only for the carriage of cargo and in which --

(1) [Reserved]
(2) There is a separate approved smoke or fire detector system to give warming at the pilot or flight engineer station;
(3) There are means to shut off the ventilating airflow to, or within, the compartment, and the controls for these means are accessible to the flight crew in the crew compartment;
(4) There are means to exclude hazardous quantities of smoke, flames, or noxious gases from the flight crew compartment; and
(5) The required crew emergency exits are accessible under any cargo loading condition.

APPENDIX G - PANEL OF EXPERTS

In the early stages of the project, the first panel of experts meeting was held to get industry and stakeholder input into the assessment. At that time participants generated a list of almost seventy potential countermeasures which might reduce the threats associated with the transport of hazardous materials in aircraft cargo compartments. This original list was reviewed and consolidated by the project team, then grouped into subject categories (aircraft, detection and scanning, education and outreach, packaging, procedures, and other).

The twenty-five consolidated countermeasures were then evaluated by the expected results of implementation. Below is the complete consolidated list of countermeasures, organized by the anticipated results of implementation.

COUNTERMEASURES EXPECTED TO INCREASE COMPLIANCE WITH REGULATIONS

Table G.1 Countermeasures Expected to Increase Compliance With Regulations

Countermeasure	Result/Comments
Education and Outreach	
Publicize hazardous material regulations and penalties (e.g., airport TV/video, posters, display cases, pamphlets, instructions for passengers, public service announcements, warning signs at airports, signs on cargo compartments, expand FAA penalty announcements, etc.).	Improves compliance with regulations, toward the 'compliance' environment. Comment: FAA is deploying hazardous materials display at O'Hare. FAA's Civil Penalty Sanction Guidance Policies have been published in the Federal Register. Comment: FAA has issued press releases concerning enforcement cases with civil penalties greater than $50,000.
Train or educate groups regarding relevant areas of hazardous material shipping (e.g., carriers on COMAT, manufacturers/packaging engineers and shippers on packaging (a), rescue workers on response techniques (b), etc.).	Improves compliance with regulations, toward the 'compliance' environment. Possibly reduce packaging failures (a). Possibly reduce consequences of a situation once an aircraft has made an emergency landing due to hazardous material (b). Comment: FAA has distributed COMAT brochure.
Procedures	
Certify hazardous material employees/handlers.	Improves compliance with regulations, toward the 'compliance' environment; possibly reduces some package failures.
Query passengers and shippers about presence of hazardous material.	Increase compliance.
Detection and Scanning	
Screen for hazardous material before they get on the plane (e.g., x-ray, neutron scanning)	Improves compliance with regulations, toward the 'compliance' environment.
Improve inspections of passenger baggage and cargo; increase inspection authority; increase number of inspectors; quicker resolution to FAA enforcement cases.	Improves compliance with regulations, toward the 'compliance' environment. Comment: FAA has increased the number of hazardous materials safety inspectors and is resolving pending cases more quickly.

Other

Global harmonization of standards.	Might increase ease of enforcement, reduce confusion among shippers and lead to an increase in compliance. Comment: Largely Accomplished.
Simplify the International system of identifying multi-hazard oxidizing materials.	Reduce confusion and mis-identification of strong oxidizers that are also compressed gasses or corrosive liquids (e.g., oxygen or nitric acids).

COUNTERMEASURES EXPECTED TO REDUCE RISK FOR KNOWN HAZARDOUS MATERIAL PACKAGES

Table G.2 Countermeasures Expected to Reduce Risk for Known Hazardous Material Packages

Countermeasure	Result/Comments
Education and Outreach	
Train or educate groups regarding relevant areas of hazardous material shipping (e.g., carriers on COMAT, manufacturers/packaging engineers and shippers on packaging (a), rescue workers on response techniques (b), etc.).	Improves compliance with regulations, toward the 'compliance' environment. Possibly reduce packaging failures (a). Possibly reduce consequences of a situation once an aircraft has made an emergency landing due to hazardous material (b). Comments: RSPA has distributed more than 10 million "What Can Fly" pamphlets. ICAO and possibly IATA have warning signs issued with tickets and new luggage.
Packaging	
Ship hazardous material in specialized (unit load) containers.	Effectively reduces the chance of package failure of known hazardous material by providing another level of containment. For a disastrous situation to occur, the container would also have to fail.
Require dynamic testing for package strength.	Reduce some package failures primarily in the regulated environment.
Stricter packaging requirements.	Reduce regulated package failures; possibly no effect, or an increase if more packages are shipped to avoid regulations, on packages which do not meet regulations.
Procedures	
Certify hazardous material employees/handlers.	Improves compliance with regulations, toward the 'compliance' environment; possibly reduces some package failures.
Prohibit high risk hazardous material from passenger flights.	Reduces dangers to passengers from packages that meet regulations. May eliminate some hazardous material packages that meet regulations from some cargo compartment types. Comment: Done for oxygen generators on passenger aircraft and being considered for oxidizers.
Examine the placement of hazardous materials within the aircraft.	Possibly lower damage to aircraft and critical systems; reduce possibility of someone being exposed to toxic materials.
Re-examine exemptions to hazardous material regulations, including passenger exemptions.	Reduce risk in the cases where packages meet regulations.
Revisit the classification of materials.	No immediate impact; possible that it could lead to improved procedures for various classes. Comment: Low Priority.
Re-examine aggregate quantity limits, possibly quantify with empirical data.	Reduce risk in situations where regulations are followed. Comment: Medium priority.
Forbid materials that negate cargo compartment safety features (e.g., oxidizers in environments which use oxygen starvation as fire suppression.	Eliminate certain risks when regulations are followed.

COUNTERMEASURES EXPECTED TO REDUCE THE THREAT TO THE AIRCRAFT

Table G.3 Countermeasures Expected to Reduce the Threat to the Aircraft

Countermeasure	Result / Comments
Aircraft	
Improve fire detection/ monitoring (e.g. heat trend monitoring).	Increased likelihood that a fire would be detected for cargo compartments with improved equipment. Comment: On-going
Improve fire suppression (e.g. active extinguishing agents sufficient to control oxidized fire) and Upgrade cargo compartments to Type C standards or better.	All cargo compartments would be equipped with active fire suppression systems and the likelihood that the amount of suppression chemical available is insufficient would be reduced where this countermeasure is applied. In upgraded compartments the likelihood that fire penetrates the cargo compartment, a fire is not detected, no active suppression system is present, or an insufficient amount of suppression chemical is present would all be reduced. Comment: D" to "C" conversions on-going.
Improve smoke barriers in Type B and E compartments.	Reduction in the likelihood of fumes or gases reaching occupied areas.
Require cargo compartment liner attachments meet liner flammability requirements	Reduce risk of failure of cargo compartment safety features. Comment: Aluminum in use in an estimated 70% of fleet.
Upgrade air cargo compartment appliance and wiring (lights, heating blankets, etc.) to meet explosion-proof standards for flammable vapors similar to marine cargo holds.	Reduce or eliminate the likelihood of a flammable liquid or gas spill induced explosion in the cargo compartment.
Procedures	
Ensure cargo compartments meet flammability requirements (compliance and/or recertification).	Reduce risk of failure of cargo compartment safety features.

IDEAS FOR FUTURE HAZARDOUS MATERIALS EXPLORATION BY RSPA AND THE FAA

Panel of Experts Proposals

1. Evaluate the relative ignitability and/or of various Class 3 consumer flammable liquids as well as volatile flammables used in illegal drug manufacture.
2. Evaluate the relative ignitability and corrosion damage capable of being caused by Class 8 batteries, installed in consumer devices, handicapped conveyances or shipped separately.
3. Evaluate the relative explosivity of a malfunctioning Class 9 air bag inflators or airbag modules and their possible contributory effects to or from an independent cargo fire.

4. Evaluate the threat from "spontaneous rupture" of an aluminum cylinder of Division 2.2 compressed air used, for example, in self-contained underwater breathing devices.
5. Evaluate the effects of package failures involving substantial quantities of Division 5.2 liquid organic peroxides and the effects of self-heating.
6. Evaluate the longer term effects of Class 8 mercury metal on embrittlement of aluminum aircraft structures and surfaces.
7. Evaluate the threat of miscellaneous residual hazardous solvents and/or reagents conveyed in chemical, and biomedical preparatory equipment or analytical instruments (in response to the FEDEX Flight 1406 cargo fire en route to Boston, September 5, 1996 believed to be caused by such solvents or reagents contained in "DNA synthesis equipment.")
8. Evaluate the threat of packaging failures in conjunction with an independent cargo fire in a simulated cargo compartment of significant quantities of the following Division 5.1 gases, liquids and solids: compressed oxygen, concentrated hydrogen peroxide, chemical oxygen generators, sodium or potassium chlorates and sodium hypochlorite (swimming pool chemicals).
9. Evaluate the conditions under which Division 4.1 safety matches and strike-anywhere kitchen matches could self-ignite during air transport (for recent multiple incidents in both passenger baggage and cargo transport of these items see Appendix D.)
10. Evaluate the likelihood of leaks and spontaneous ruptures during air transport of Division 2.1 liquified petroleum gas canisters used in camp stores, lanterns and ski equipment.
11. Evaluate the cargo compartment conditions of leakage, airflow and temperature which would increase the spread of Division 6.1 toxic gaseous and volatile materials to passenger and crew areas of the aircraft in flight.
12. Acquire data on actual shipment frequencies of different hazardous material by cargo compartment type
13. Specifically address devices such as oxygen generators and other devices which include own ignition source as separate subclasses of materials
14. Refine threat factors to the event tree model, where appropriate
15. Produce risk estimates for individual classes of hazardous material in the aggregate as well as by cargo compartment type
16. Analyze the sensitivity of results to key assumptions
17. Identify and analyze critical causal event chains
18. Extend and refine current list of potential new countermeasures
19. Estimate the costs and benefits of countermeasures and develop effective allocations of resources to maximize risk reduction benefits
20. Extend and refine the definition of experiments to enhance study results

In addition to the countermeasures proposed by the panel of experts, the NTSB, in response to a September 5, 1996 fire onboard a DC-10 cargo plane, offered the following recommendation to DOT/RSPA:

- Require, within 2 years, that a person offering any shipment for air transportation provide written responses, on shipping papers, to inquiries about hazardous characteristics of the shipment, and develop other procedures and technologies to improve the detection of undeclared hazardous materials offer for transportation.
- Require, within two years, that air carriers transporting hazardous materials have the means 24 hours per day, to quickly retrieve and provide consolidated specific information about the identity (including proper shipping name), hazard class, quantity, number of packages, and location of all hazardous materials on an airplane in a timely manner to emergency responders.

WHY SHOULD DOT PROPOSE UNITED NATIONS AND/OR INTERNATIONAL CIVIL AVIATION ORGANIZATION (ICAO) REVISIONS TO THE DANGEROUS GOODS CLASSIFICATION SYSTEM?

For Division 2.2 Oxidizing Gases?

There are approximately ten United Nations table entries that are currently assigned proper shipping names both as a Division 2.2 and Division 5.1 non-flammable oxidizing gas. The safety risks presented by the oxidizing properties of these gases far outweigh their risks as a non-flammable compressed or liquified gas, not only in air cargo compartments, but in all modes of transport.

The United Nations has previously recognized the wisdom of simplifying the communication of multi-risk dangerous goods hazards when they created a separate division of Class 2 for toxic gases, that is Division 2.3. The definition of Division 2.3 toxic gases is technically precise and legally enforceable. Oxidizing gases, when released accidentally, present a threat of fire initiation or severe worsening of a fire in the cargo areas during transport and can be considered no less catastrophic than an accidental toxic gas release. They deserve consideration for a separate Division with a technically precise and legally enforceable definition as well.

The current United Nations definition for oxidizing compressed gases states: "gases which may, generally by providing oxygen, cause or contribute to the combustion of other material more than air does." There is no scientific standard or test by which one can clearly determine what would fall within this definition, since the "other material" that is caused to combust is undefined. The creation of a new Division of Class 2 for oxidizing gases could address this deficiency as well as develop a precedence ranking equivalent to Division 2.3 toxic gases that truly reflects the danger of these reactive materials. Under the present ranking, an oxidizing gas is of lower precedence than either a toxic or flammable gas, yet only oxidizing gases have the potential of actually starting a cargo fire without a concurrent initiation event, which is the most severe threat to an aircraft in flight, next to a spontaneous explosion.

For Class 8 Corrosive Oxidizing Liquids?

Concentrated nitric acid (other than red, fuming) is believed to have caused the loss of a Pan American cargo aircraft in 1973. The United Nations Dangerous Goods Test and Criteria Manual (Second Revised edition) shows in its results for its Test Method 0.2 that 65 percent nitric acid meets the definition for a Division 5.1, Packing Group III hazardous material.

The United Nations system of precedence has 65 percent nitric acid primarily classed as a Class 8, Packing Group II liquid which does not reflect its greatest potential threat in air transport. There is supposition that nitric acid at or above 65 percent can present a greater danger to aircraft passengers and crew than non-oxidizing Class 8 corrosive materials of the same Packing Group.

Other powerful oxidizing acids such as perchloric acid, even when in concentrations below 50 percent, could present more risk to an aircraft as a Packing Group III oxidizer than as a Packing Group II corrosive because of their ability to worsen an independent cargo compartment fire.

WHO WERE THE PANEL OF EXPERTS PARTICIPANTS?

Organization / Contact	Group
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