NATURAL DISASTERS AND MAN MADE ACCIDENTS

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"If something does not kill you, it makes you stronger."
Friedrich Nietzsche, German philosopher

"If people never did silly things, nothing intelligent would ever get done."
Ludwig Wittgenstein, Austrian philosopher

"He who knows when he can fight and when he cannot, will be victorious."
Sun Tzu, Chinese strategist

"Bye-bye Miss American Pie
Drove my Chevy to the levee but the levee was dry
Them good ole boys were drinking whiskey in Rye
Singing this'll be the day that I die.
This'll be the day that I die."
Song Lyrics, Don McLean, American Singer

INTRODUCTION

Natural disasters occurrences are an aspect of the dynamic life on Earth and are out of the control of human beings. They occur unexpectedly by environmental changes causing tsunamis or tidal waves, hurricanes, cyclones, typhoons, tornadoes, volcanic eruptions, mud slides, earthquakes and droughts. Etymologically, the word "disaster" has its root in the Latin "aster" for "star." The word "disaster" originally thus meant: "an unfavorable aspect of a star," reflecting the ancient belief in astrology that suggested that the observed motion of the heavenly bodies in the sky affected terrestrial events.

Natural events can be the initiating event for accidents affecting man-made structures. For instance floods can cause dam failures, and hurricanes can also cause flooding followed by dikes failures. Depending on the geographical location, a tropical system in the Atlantic or northeast Pacific is called a hurricane, in the northern Indian Ocean, it is designated as a Cyclone, and in the northwest Pacific west of the international date-line at 180 degrees in longitude, as a Typhoon.

As they affect human-made structures, they can lead to even more serious accidents. For instance, an earthquake can lead to a severing of nuclear reactors coolant piping and result in a serious Loss of Coolant Accident (LOCA). Consequently, their design and operation must account for the possible occurrence of these natural events by the addition of defensive Engineered Safety Features (ESFs) to mitigate their consequences, should they occur.

Table 1 gives estimates of the societal risk of death from accidents in units of fatalities per person per year in the USA.

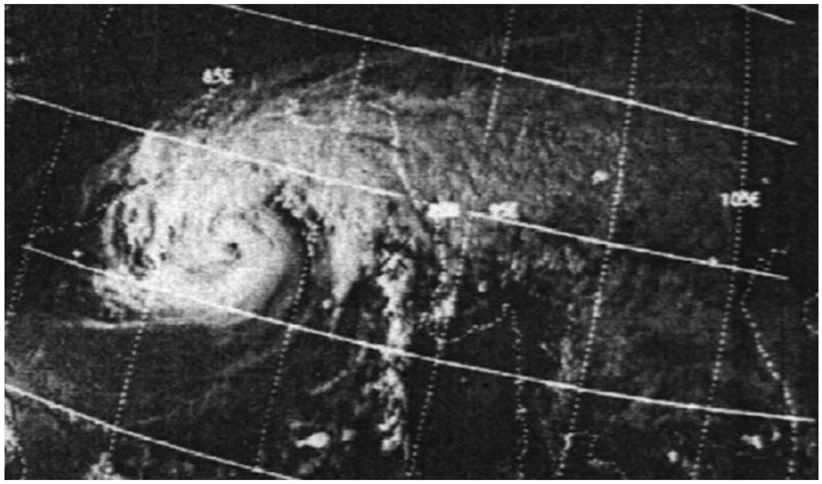


Figure 1. Cyclone Bhola, November 12, 1970. The deadliest cyclone ever recorded storm surge flooded the low lying areas of the Ganges River delta in Bangladesh and India's West Bengal resulting in 500,000 casualties. Source: NOAA.

Table 1. Comparison of individual societal risk of death from accidents in the USA.

Risk source	Fatalities* [fatalities / year]	Risk** [fatalities / (person.year)]
Motor vehicle accidents	55,791	$1.9x10^{-4}$
Accidental falls	17,827	$5.9x10^{-5}$
Fires and hot substances	7,451	$2.5x10^{-5}$
Drownings	6,181	$2.1x10^{-5}$
Poisons	4,516	$1.5x10^{-5}$
Firearms	2,309	$7.7x10^{-6}$
Machinery, 1968	2,054	$6.8x10^{-6}$
Air Travel	1,778	$5.9x10^{-6}$
Water Transport	1,743	$5.8x10^{-6}$
Falling objects	1,271	$4.2x10^{-6}$
Electrocution	1,148	$3.8x10^{-6}$
Railway	884	$2.9x10^{-6}$
Lightning	160	$5.3x10^{-7}$
Hurricanes	93†	$3.1x10^{-7}$
Tornadoes	91††	$3.0x10^{-7}$
All others	8,695	$2.9x10^{-5}$
All accidents	111,992	$3.7x10^{-4}$

* 1969 data from "Nuclear Safety Study," USA Atomic Energy Commission report WASH-1400, 1974.

** Based on 300 million USA population

† 1901-1972 average

†† 1953-1971 average

Table 2. Motor vehicles risk statistics. National Highway Traffic Safety Administration, 2007.

Consequences	Number	Percent of fatalities
Fatalities in traffic crashes	41,059	
Injuries in traffic crashes	2,491,000	
Alcohol related deaths	12,998	32
Speeding related deaths	13,040	32

HISTORY

The most famous natural disaster is the Great Flood recounted in the story of the Noah's Ark. According to religious Judeo-Christian and Islamic accounts, in the 1,600 years after the creation of Adam and Eve, the human race had become wicked and deviated from the right path. Noah was inspired to build an ark and to load it with a female and a male of every living species. Those humans who believed in his teachings followed him. Over forty days and forty nights, rain flooded the Earth, drowning all humans, except those who repented and followed Noah on the ark. Legend has it that the ark settled on top of Mount Ararat in Turkey.

The story may have been a recount of an amalgamation of several actual global floods in the Mesopotamian region about 8,000 years ago. The Earth was coming to the end of a glacial period. The melting of the ice sheets may have caused the oceans level to rise by 5 feet. It could have been caused by a comet or asteroid impact, or an earthquake causing a large devastating tsunami and rain. Most possibly, an astral impact by a short period comet would have given enough of a warning by appearing as a bright object in both the night and day skies. Its impact would have vaporized its ice in the Earth's atmosphere leading to a deluge of rain. The rain would in turn lead to flooding and a possible rise in sea level and to the breakage of natural dams at the Gibraltar or the Dardanelles and Bosphorus straights causing the permanent slow or fast permanent "filling" rather than temporary "flooding" of the Mediterranean and/or the Black Sea beds. Exploration with submersible vehicles has indeed revealed the existence of submerged ancient ruins that were preserved under the cold and clear water of the Black Sea. Drill cores reveal fresh water mollusk shells that may have existed at the bottom of a fresh water lake being superseded by salt water shells.

A dove brought to the ark in its beak a twig from an olive tree, signaling the end of the flood, and became the modern symbol of peace. Whatever actually happened, the moral is that disasters and calamities are eventually followed by new beginnings, redemption, rebuilding, hope and salvation.

Some of the historical natural events and their consequences are compiled in Tables 3 and 4.

Table 3. Consequences of some natural events.

Event	Year of occurrence	Location	Consequence [deaths]

The world's largest volcanic eruption is thought to have occurred at what is today the Yellowstone National Park in the North American continent. The volcano, which is considered as still active today, displays geysers, mud holes, and fumaroles in its caldera that are visited by tourists. It spewed 240 cubic miles of ash through North America about 600,000 years ago, and earlier 600 cubic miles of ash 2.2 million years ago.	2,200,000 BC, 600,000 BC	Wyoming, USA	?
Mediterranean island of Stroggli blew up in a volcanic eruption. At least one tsunami (In Japanese: tsu 'harbor' and 'nami' wave) swept over the island of Crete in the Mediterranean destroying the Minoan Empire's capital. The area is now called Santorini. Possibly what Plato referred to as the lost city of Atlantis.	1,650-1410 BC	Greece, Mediterranean	100,000
Half of the Carthaginian general Hannibal's army and 2,000 of his horses and several elephants were killed by avalanches in the Pyrénées chain of mountains between Spain and France and the Alps Mountains between France and Italy on his way to attack Rome. Carthage is at present day Tunis, the capital of Tunisia.	218 BC	Spain	20,000
After centuries in dormancy, the Mount Vesuvius eruption in Southern Italy buried under 14-17 feet of tephra and pumice the prosperous Roman city of Pompei, and under more than 60 feet of mud and volcanic ash the city of Herculaneum, instantly suffocating and burying thousands. Vesuvius was the first	August 24, 79 AD	Italy	3,000

volcanic eruption described by its survivors.			
Antioch earthquake hit Syria and Antioch near modern-day Antakya, Turkey. The earthquake was followed by a massive fire destroying the rest of the structures unaffected by the earthquake.	May 20-29, 526 AD	Antioch, modern Antakya, Turkey	250,000-300,000
Magnitude 8.5 earthquake caused extensive damage to Aleppo in northern Syria. The region is part of the Dead Sea Fault system resting on the boundary between the Arabian geologic plate and the African plate.	October 11,1138 AD	Aleppo, Syria	230,000
A seismic swarm, which is a localized surge of earthquakes, leveled the cities and killed the residents of Egypt, Syria and adjoining areas. This was the deadliest earthquake event in known history.	1201 AD	Egypt, Syria	1,100,000
Black Death or Bubonic Plague pandemic caused by the Yersinia Pestis bacterium wiping out 30-60 percent of the European population.	1330-1351 AD	Europe, world	75,000,000
A North Sea storm batters the European coastline and resulting in flooding of the low lying areas behind. Such fatal floods reoccurred in 1287, 1338, 1374, 1394 and 1396. Every time the dikes were fixed and the residents moved back in.	November 17, 1421	The Netherlands	10,000
The deadliest 8.0 magnitude earthquake ever recorded occurred in the Shaanxi region devastated eight provinces and was China's worst earthquake ever, reducing the population in the region by 60 percent. China is the world's deadliest earthquake zone. Since then 2.5 million	January 23, 1556 AD	Northern China	830,000

people perished in Chinese earthquakes.			
A two-week storm system wreaks havoc over England. The hurricane-strength winds sank hundreds of Royal Navy Ships.	November 27, 1703 AD	England	10,000-30,000
Japan has been a frequent victim of tsunamis which occur in the Pacific Ocean at the rate of 80 percent of them. They wash out fishermen's small harbor villages. An M8.4 Richter magnitude scale earthquake caused one of Japan's deadliest tsunamis.	1707 AD	Japan	30,000
Typhoon event, once thought to have been an earthquake.	1737 AD	Calcutta, India	300,000
Lisbon, the capital was hit by a M9.0 Richter scale magnitude earthquake. The residents run to their ships for a perceived safety at sea, only to be hit by an ensuing tsunami devastating ports in Spain and Morocco.	1755 AD	Portugal, Morocco	70,000
The Great Hurricane of 1780 hit the British and French fleets and caused damage to 100 merchant ships. It moved through Barbados and St. Vincent.	1780 AD	West Indies	22,000
Yellow fever epidemic. Although a vaccine can prevent it, 20,000 people die worldwide every year from the disease.	October, 1793	Pennsylvania, USA	5,000
Fluvial tsunamis caused by three New Madrid Fault earthquakes with magnitude 7.8. The strongest of the aftershocks, an M8.8 Richter magnitude scale, was felt at 1,000 miles away, and caused church bells to ring at the city of Boston, Massachusetts. In 1811 and 1812 they caused the Mississippi River to temporarily reverse course for several hours.	February 7, 1812	Missouri, USA	Damage was light because of the sparse population in the area.
The Tambora volcanic eruption caused a famine in which 80,000 people died.	1815 AD	Indonesia	80,000

India Cyclone hit the port village of Coringa in Andhra Pradesh, India. It triggered a 40-ft wave destroying ships and the village drowning 20,000 people at sea.	November 25, 1839 AD	Coringa, India	300,000
There are 130 active volcanoes in Indonesia. The Tambora killed 92,000 in 1815. The most powerful event is the Krakatau or Krakatoa small island eruption in 1883, whose pyroclastic flow and falling tephra killed 4,500 people. It was heard 3,000 miles away. Burst eardrums of people 40 miles away. Sound intensity was 170 dB at 100 miles. The sound wave travelled 4 times around the world, The explosion threw 5 cubic miles of earth 50 miles into the atmosphere. Islands 50 miles away were hit by 120-ft tsunamis that killed 30,000 more coastal residents.	August 27, 1883 AD	Indonesia	36,000
Yellow River Flood overtook the dikes in the Henan Province of China devastating 11 large towns and hundreds of villages rendering millions of people homeless. The flood waters covered 50,000 square miles.	September 1887 AD	Henan Province, China	900,000-2,000,000
On July 15, 1888, the Bandai volcano erupts on the island of Honshu, Japan, burying many nearby villages in volcanic ash. Debris was sent thousands of feet in the air leaving an 8,000-foot wide crater. The steam and ash cloud was 4 miles wide.	1888 AD	Japan	100s
The deadliest natural disaster in USA history was a hurricane that hit the port of Galveston, Texas with winds of 101 miles per hour and 25 feet breaking waves. It leveled 1/3 of the city destroying 3,500 homes.	1900	Texas, USA	8,000

The eruption of Mount Pelée destroyed the city of Saint Pierre, known to the European as the Paris of the West Indies. This was the deadliest volcanic eruption of the 20th century.	1902	Martinique	29,000
Turtle Mountain collapsed as a result of a sudden drop in temperature. It sent 30 million cubic meters of limestone in a landslide that buried the town of Frank.	1903	Alberta, Canada	70
The 8.3 magnitude earthquake originating from the San Andreas Fault destroyed more than 500 downtown city blocks. It left half of the 400,000 city residents as homeless, because of the ensuing fires. The gas lines were broken causing the fires. The water mains were also broken preventing its suppression. It left a scar of broken ground that ran half the length of the state of California.	1906	San Francisco, USA	700
An earthquake caused 1.5 cubic miles of rocks and debris to fall into the Murgab River in Tajikistan. As the most massive non-volcanic mud slide, it resulted in a 1,880 ft high dam now holding behind it a 37 miles long lake. Should an earthquake breach it, a massive flooding event is waiting to occur.	1911	Tajikistan	90
A large avalanche kills hundreds of Austrian soldiers in barracks near Italy's Mount Marmolada. Over a period of several weeks, avalanches killed about 10,000 Austrian and Italian soldiers.	December 13, 1916	Mount Marmolada, Italy	10,000
The 8.5 magnitude earthquake Hayuan County area of the Hingsia Province in the Gansu region of western China near the Tibet, destroyed thousands of	December 16, 1920	Haiyuan, China	235,502

dwellings carved into the clay cliffs and silt riverbanks. It is known as ‘Shan Tso-liao’ or ‘when the mountain walked.’			
Thousands of gas ranges ready for meal preparation contributed to the incineration of Tokyo’s business and industrial districts as a result of an 8.3 magnitude earthquake. It hit 25 miles from Tokyo and Yokohama with a then combined population of 2 million people.	1923	Japan	143,000
A deadly tornado moved along 219 miles from Missouri to Illinois and Indiana, destroying 15,000 houses in the process. It had a mile wide funnel that sucked out whole houses and living beings. According to the Saint Louis Post-Dispatch: “A cow was hurled into the village restaurant.”	1925	Central USA	695
Central China Floods. The worst single natural disaster in history occurred when the Yangtze River flooded as a result of a summer monsoon. Millions died from drowning, and starvation and water borne disease infection such as dysentery and cholera as well as the ensuing famine. More than 51 million people or ¼ of China’s population was affected by the flood.	July-August 1931	China	1,000,000-3,700,000
A hurricane known as the “Long Island Express,” created 121 miles per hour sustained winds with peaks of 186 mph. A 12 feet high surge destroyed cottages, marinas and yacht clubs at Narragansett Bay in Connecticut. It washed away the New York and New haven railroad lines.	1938	Northeast, USA	600
On December 21, 1946, an undersea earthquake set off a	1946	Honshu, Japan	-

tsunami that devastated the island of Honshu, Japan. Twenty feet high waves obliterated buildings on the shoreline, capsized 2,000 ships, flooded 60,000 square miles, and completely destroyed 40,000 homes.			
A 7.3 magnitude earthquake killed more than 80 percent of the inhabitants of Ashgabat. It took five years of digging out the victims which were initially estimated at 35,000.	1948	Turkmenistan	110,000
Magnitude 8.6 earthquake	1950	Tibet, China	1,526
A magnitude 8.0 earthquake in the offshore Fairweather fault resulted in a tsunami with the highest ever recorded wave along the coast of Glacier Bay National Park in Alaska. It sent a wall of rocks sliding into Lituya Bay displacing the water and ice forming a wave reaching a height of 1,720 feet.	1958	Alaska	2
Malpasset dam collapses in France after a week of heavy rains leading to flooding. The city of Frejus that was built by Roman emperor Julius Caesar as a harbor on the French Riviera coast was devastated by the flood.	December 2, 1959	France	400
The great Chilean earthquake reached the never ever recorded magnitude of M9.5 on the Richter magnitude scale. A fault break of 1,000 miles in length sent seismic waves around the world for several days and caused tsunamis that reached the island of Hawaii, Japan, the Philippines, and the North American West Coast.	1960	Chile	2,230
A fire at a filled to capacity circus in Brazil kills 300 people and severely burn 500 more. The cause of the fire may have been sparks from a passing train.	December 17, 1961	Brazil	300 dead, 500 injured

The Alaska's 8.4-9.2 magnitude earthquake known as "Good Friday Quake" caused a tsunami with 20-100-ft high waves that hit an expanse from the Gulf of Alaska to California along the West coast of the USA. It affected British Columbia, Canada and Hawaii. Ten of the victims drowned when 250 homes and businesses were swept out in Crescent City, California. This is considered as the strongest earthquake in USA's history.	March 27, 1964	Northwestern USA	118-125 dead, thousands injured
A 7.9 magnitude earthquake near Mt. Huascaran in the Andes mountains resulted in an avalanche causing 2/3 of the 60,000 casualties. A mile long slab of ice traveled a distance of 11 miles at a speed of 100 mph sweeping away dozens of villages in its path.	May 31, 1970	Chimbote, Peru	18,000-70,000
Bhola Cyclone. The deadliest cyclone ever recorded hit Bangladesh with 120 mph winds causing flooding rains and a storm surge. The low lying areas of the Ganges Delta were flooded. In 1991 another hurricane killed 100,000 persons. The North Indian Ocean sees 2-3 hurricanes per year, but they are the most violent on record.	November 12, 1970	Bangladesh (East Pakistan) and West Bengal, India	300,000-500,000
A 7.5 magnitude temblor in the Tangshan industrial city with one million residents in Hebel, northeast China	July 28, 1976	Tangshan, China	255,000-655,000
The "Super Typhoon Tip" spiral was 1,350 miles in diameter with winds reaching 190 mph. Luckily it never left the Northwest Pacific Ocean. It	1979	Pacific Ocean	0

would have covered nearly half of the continental USA.			
A stampede outside a Who concert caused by the general admission ticket holders surging through shattered doors to secure prime seats inside, and causes the asphyxiation of trampled concert goers.	December 3, 1979	Cincinatti, USA	11
On May 18, 1980, a 5.1 magnitude earthquake triggered the volcanic eruption of Mount Saint Helens. It leveled off 230 square miles of forest and covered eastern Washington with a blanket of volcanic ash.	1980	State of Washington, USA	62
Nevado del Ruiz volcanic eruption caused a massive mud flow.	1985	Columbia, South America	25,000
A tornado moved through the tropical delta of the Dhaka region in Northern Bangladesh, leveling the town of Shaturia. This flat low lying region is the most vulnerable area to tornadoes, even more than the American Midwest.	1989	Bangladesh	1,300
Hurricane Andrew resulted in a storm surge of 17 feet and destroyed 99 percent of the mobile homes in Homestead, Florida. Its damage reached the level of $25 billion.	1992	Florida, USA	26
Thanks to a government mandated evacuation of the 12,000 population, the death toll from the eruption of Mount Serrat was minimized. It turned the southern 2/3 of the island uninhabitable. It destroyed its agriculture and tourism industry.	1997	Montserrat	20
Hurricane Mitch within 6 hours, dumped 25 inches of rain on Honduras and Nicaragua resulting in flash floods and mud	1998	Honduras, Nicaragua, Central America	9,000-18,000

slides causing 9,000 deaths and 9,000 missing persons.			
On May 3, 1999, a swarm of 76 tornadoes touched down in Oklahoma and Kansas. One giant tornado of them reached wind speeds of 318 mph, 1 mph below the once unthinkable category "force 6" storms. It resulted to a 38 miles wide path of destruction causing $1 billion in damage during 1 hour of duration.	1999	Oklahoma, Kansas, USA	36
Landslides and flooding resulted from 2 weeks of heavy rain around the capital city of Caracas resulting in damage costing $15 billion. He high casualty rate hit shanty towns that had developed in the vulnerable areas.	1999	Venezuela	20,000-30,000
A massive slide buried the village of Nizhny Karmadon under 2.1 billion cubic feet of debris. It was caused by melting permafrost that led to the breaking off of a 500 ft tall chunk of a glacier from a mountain side in the Caucasus region.	2002	Russia	140
Middle Eastern mud brick and concrete homes construction methods contribute to a high casualty rate. A 6.6 magnitude earthquake devastated the ancient city of Bam leaving 75,000 people homeless. Since 800 AD, about 500,000 people have been killed by earthquakes in this region.	2003	Bam, Iran	43,000
Floods and mud slides following three days of rain in late May wiped out whole villages in Southeast Haiti and the Dominican Republic.	2004	Haiti, Dominican Republic, Hispaniola	2,000
Indian Ocean Earthquake-Tsunami. An earthquake in the Indian and Burma tectonic plates of magnitude 9.3 on December	December 26, 2004	Island of Sumatra, Indonesia, Indian Ocean,	225,000-230,210

26, 2004, 100 miles off the west coast of Sumatra, Indonesia triggered a tsunami that hit 12 countries and left millions of people homeless along the heavily populated Southeast Asia coastline. The tsunami was the deadliest in history. The energy release was equivalent to 25,000 Nagasaki size atomic devices. It is reported to have jolted the Earth from its rotational axis and permanently shortened the length of the day.		South and Southeast Asia	
The storm surge from hurricane Katrina's 175 mph wind on August 29, 2005, caused severe damage along the USA Gulf Coast, devastating the Mississippi cities of Waveland, Bay St. Louis, Pass Christian, Long Beach, Gulfport, Biloxi, Ocean Springs and Pascagoula. In Louisiana, the flood protection system of the city of New Orleans failed at 53 different places. Nearly every levee in metropolitan New Orleans breached as Hurricane Katrina passed east of the city, subsequently flooding 80 percent of the city and many areas of neighboring parishes for weeks. The damage is estimated at $81.2 billion, making it the costliest natural disaster in USA history. 6.5 trillion gallons of rain water.	August 2005	Mississippi, Louisiana, USA	1,836
Magnitude M7.6 earthquake on the Richter magnitude scale. The shallow origin of the earthquake caused much devastation.	October 8, 2005	Northern Pakistan, Kashmir	40,000-75,000
"Super Tuesday" tornado outbreak. In reference to a presidential primary election held that day.	February 5-6, 2008	South USA	Killed 57 people, injured 350 and caused $400 million

A number of 82 tornadoes occurred in 9 states. Second deadliest tornado outbreak in the USA.			in property damage.
Tropical cyclone Nargis category 3 storm in the 5 steps Saffir-Simpson hurricane scale that formed in the Bay of Bengal with sustained winds of 204 kilometers or 127 miles/hour with waves 8.5 meters or 28 feet high. It brought flooding and devastation in low-lying rice fields coastal areas.	May 3, 2008	Myanmar, Burma	68,833-127,990
A magnitude 7.9-8.0 earthquake collapsed buildings, caused cracks in dams and caused mud slides. It was the most powerful to hit China, the world's most populous country with 1.3 billion people, since a magnitude 8.6 quake struck Tibet in 1950, killing 1,526. A 7.5 magnitude temblor in Tangshan in the northeast killed 250,000 in 1976.	May 12, 2008	Sichuan province, China	Death toll reached 69,000 with 245,108 injured and 12 million displaced.
Magnitude M7.0 Richter magnitude scale earthquake. Destroyed 190,000 houses. Followed by a cholera epidemic in June 2011.	January 12, 2010	Port-au-Prince, Haiti	230,000
Earthquake of magnitude 8.5-9.0; the largest in recorded history in Japan, caused a devastating tsunami. It resulted in flooding, refinery fires and a station blackout nuclear accident at four nuclear reactors at Fukushima, Japan.	March 11, 2011	Japan East coast	28,000
Hurricane Sandy, widest in extent Atlantic storm in history caused $50 billion in damage.	October 31, 2012	New York, USA	75
Super Typhoon Haiyan or Typhoon Yolanda, Category 5, 200 mph winds, 20 ft-high storm surge. Largest known typhoon to make land-fall.	November 2-11, 2013	Philippines, Vietnam, Micronesia	5,260 dead, 4 million displaced

Hurricane Harvey, USA. Category 4 with continental record 51.88 inches (132 cms) of rain causing major flooding. $ 140 billion residential property risk; most expensive storm ever in the USA. Curfew in Houston from 12:00 to 5:00 am.	August 21, 2017. 14 trillion gallons of rain water. Gulf of Mexico 1 - 2 ^{0}C warmer than usual. 50,000 flooded homes.	Houston, Texas and Louisiana, USA	>33 deaths
Hurricane Maria. Devastating impact on water, electricity, communications and medical care.	Formed September 16, 2017, dissipated October 2, 2017.	Island of Puerto Rico	2,975 deaths

Table 4. Estimated human toll from natural events, 1900-2004 AD.

Events	Region	Toll [deaths]
Volcanic eruptions	Italy, Indonesia, Central America	96,000
Hurricanes	Caribbean, Bangladesh, Gulf of Mexico	1.1×10^6
Land and mud slides	Central America, Central Asia	45,000
Tsunamis	North American west Coast, Alaska, Japan	300,000
Earthquakes	India, Iran, Turkey	1.8×10^6

ASTRAL IMPACTS

INTRODUCTION

Astral impacts are the most damaging of natural disasters. These events have in fact happened in the past with catastrophic global effects in some cases leading to mass extinctions. The fact that cannot be ignored is that cosmic collisions do occur in the time frame of human life.

Collision between the Earth and other small planetary objects occurs frequently. Air friction leads to the disintegration and burning of the small objects in the Earth's atmosphere. They are noticeable as meteorite trails and showers at night, such as the Leonid meteorite shower when the Earth's orbit intersects their path at certain times of the year. However, there exists a low, even though not negligible, probability of collision with large extraterrestrial objects of 1-2 kilometers in size.

Every day, tons of dust from comets and small shards of asteroids from outer space burn in the Earth's upper atmosphere and some fist size chunks of rock or metal reach the Earth' surface.

Meteorites of more than 50 meters in diameter strike the Earth once every 1,000 years. They will generally explode in the lower atmosphere and can cause massive destruction over thousands of square kilometers and significant loss of life if the happen to occur over a populated area. The 1908 Tunguska event in Siberia is a recent occurrence.

More than 5,400 asteroids and comets have been spotted within 121 million of the sun, close enough to be classified by astronomers as near-Earth objects. About 950 of those measuring more than 460 feet in diameter and pass within 4.6 million miles of the Earth's orbit have been catalogued and are considered as potentially hazardous. These are a part of an estimated 10 million rocky asteroids and ice and dirt comets in space with paths that could intersect our planet.

Humans' responsible stewardship of life on Earth and in the known universe obligates them to observe the ultimate duty of its protection against these infrequent but nevertheless possible events. Good risk management dictates that some countermeasures be immediately available, for the deflection or shattering of any dangerous guests from the far reaches of space.

In addition, a backup system replicating life on Earth, or a modern day Space Noah's Ark needs to be constructed as an ultimate insurance against such calamity as a Lunar or Martian base. High specific impulse nuclear methods are humanity's and life's major hope for global defense against such potential catastrophic encounters.

NEAR EARTH OBJECTS, NEOs, APOPHIS ASTEROID

A 900 feet wide, bigger than a sports arena, asteroid: Apophis or the Destroyer, the god of destruction in ancient Egyptian mythology could be on a collision trajectory with Earth, coming within a 21,000 miles distance by April 13, 2029. It will appear as a bright star in the night sky over Europe.

There is a slight chance that it could pass through a "keyhole" or a corridor in space a few hundred yards wide and be deflected by the Earth's gravity just enough to place it again on a possibly hazardous approach on Easter Sunday, 2036. According to a prediction that NASA scientists made in 2004, there exists a likelihood that it will hit Earth of 1:45,000. The approach in 2029 will tell us whether it is significantly affected by the Earth's gravity giving humanity a precious time of 7 years to plan for its next approach in 2036.

Nasa had deemed Apophis to be one of the most dangerous asteroids to Earth after its discovery in 2004. Close calls in 2029 and 2036 were predicted and later ruled out. A 2068 impact is not in the realm of possibility anymore. Calculations do not show any impact risk for at least 100 years.

Named for the ancient Egyptian god of chaos and darkness, Apophis is estimated to measure 340m (1,100ft) across.

This has galvanized efforts among scientists to predict and prevent potentially apocalyptic impacts. There are about 127 Near Earth Objects (NEOs) that we know about, that have a chance of impacting Earth. NASA classified about 950 asteroids and comets as potentially hazardous.

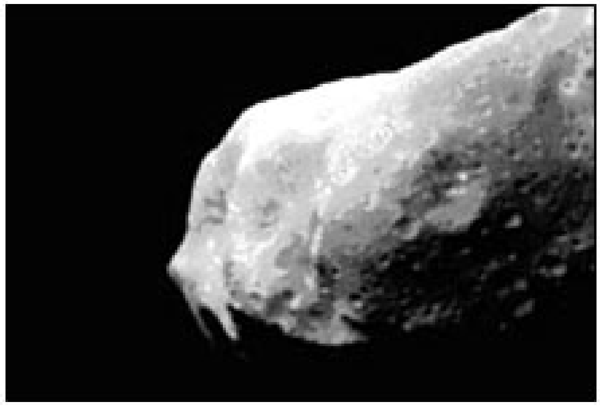


Figure 2. The Apophis, or Destroyer asteroid, named after the ancient Egyptian god of destruction will be visiting the Earth's vicinity in 2029 and again in 2036.

NEAR EARTH OBJECTS IMPACTS

Studies of Near Earth Object (NEO) Interceptions suggest that impacts upon the Earth by civilization-killing sized asteroids or comets are a rare event. However the impact of smaller asteroids of 100 meters in diameters such as the one impacting near Tunguska, Siberia in 1908 is a more frequent event expected to occur with a frequency of 2 impacts each century. This meteorite is estimated to have been 70 meters in diameter. It leveled an area about 25 kilometers in radius.

The tools of satellite imagery and microscopic analysis of rocks and minerals, revealed 174 meteorite distinct impacts on Earth. Many more are believed to have been wiped out by erosion, tectonic movements or have been buried under sediment in the oceans. Some of these are shown in Table 5.

There are over 7000 known near-Earth asteroids of which 500-1000 have diameters greater than 1 kilometer. There are 85 known near-Earth comets.

Asteroids that are larger than 1 km in diameter strike Earth with a frequency of once every 500,000 years while those with 5 kms in diameters occur about every 20 million years. The last known meteorite larger than 10 kms impacted the Gulf of Mexico near the Yucatan Peninsula of Mexico 66 million years ago and is thought to have caused the Cretaceous-Paleogene mass extinction, marking the end of the dinosaurs.

Table 5. Known meteorite impacts on Earth.

Location	Name	Diameter [mile]	Impact Time [years]
North America	Sudbury, Canada	155	1.9×10^9
	Chesapeake Bay, Washington DC, USA	53 2 mile wide asteroid	35×10^6
	Meteor Crater, Arizona	0.73	50×10^3

	Chicxulub, Mexico	106	65×10^6
Africa	Vredefort, South Africa	186	2×10^9
Australia	Gosses Bluff	14	143×10^6

If hitting population centers, these events have enough energy to destroy whole metropolitan areas. They would cause earthquakes and fault disruptions, which would cause further damage such as landslides or even volcanic eruptions at the other side of their impact with earth. If falling in an ocean expanse they would cause a tidal wave or a Tsunami destroying large coastal areas. A doomsday tsunami washing over a city like New York and moving inland to the Appalachian Mountains could result from the impact of an asteroid three to four miles in diameter falling in the middle of the Atlantic Ocean. No asteroid or comet of such size has hit the Earth in recorded history.

However, 35 million years ago a 2 miles wide rock smashed into the ocean and caused a 53 miles wide crater under the southern end of what is known today as Chesapeake Bay in the eastern USA with resulting waves possibly thousands of feet high moving inland hundreds of miles.

Around 65 million years ago, a 6 miles wide meteorite hit the Gulf of Mexico releasing thousands of time more energy than all the existing nuclear weapons. About ¾ of all forms of life became instinct, including the dinosaurs.

Nudging the trajectory of an object of 100 meters in diameter is no trivial task, especially since if the asteroid is stony in composition; it would weigh 20,000 to 30,000 metric tonnes. It is necessary to impart a velocity increment of 10 cm/sec to the object to modify its trajectory and force it to miss the Earth-lunar system.

THE TUNGUSKA EVENT

The largest asteroid or comet meteorite impact that happened in the twenty century happened in central Siberia on June 30, 1908 at 7:17 am. Residents of the Podkamennaya Tunguska River Valley witnessed a fireball through clear skies. A column of flames and clouds of thick black smoke rose after the fireball impacted the ground. A shock wave of hot air followed and knocked people and animals off their feet. Windows were shattered from the force of the blast. The Evenki native Siberian people reported the death of reindeer and dogs. About 80 million trees in a land area of 800 square kilometers were flattened by the blast.

It is believed that the object was 150 feet wide, the size of 15 story building, and tore into the atmosphere at 32,000 miles/hour with the sequence of events shown in Table 6.

Table 6. Sequence of events in the Tunguska meteorite impact.

Time [sec]	Event
0.0	Explosion started 7.5 miles or 12 km above ground

1.5-5.5	As it vaporized, it generated an incandescent trail of ultra hot gases
7.5-9.5	A midair blast of glowing gases billowed the explosion forming mushroom clouds
11-13	The increasing density of the atmosphere slowed the gases and debris in a superhot pileup. The remains dispersed high above ground
15.5	The object never hit the ground, but the shock wave from the explosion generated winds that approached hurricane force over a wide area

In Europe, the explosion was heard over a one million square kilometers area away, and seismographs recorded earthquake waves at 800 kilometers south of the event. The shock wave was recorded at meteorological stations, five hours later in Siberia, and 24 hours later back again after it had circled the globe. Dust particles from the explosion or icy clouds from the water vapor it blasted into the atmosphere reflected light illuminated the night sky over Europe and Asia to the point where people could read newspapers outdoors at night.

The meteorite that is thought to have exploded 10 kilometers above the Tunguska River has not been located, lacking a major crater or fragments. Investigation of the event was delayed as it occurred as Russia was in the initial stages of the upheaval of its communist revolution. Thirteen years later four expeditions by the Soviet Academy of Science failed to find it. Samples collected at the site were later analyzed and revealed small spheres of formerly liquid meteorite dust. It is possible that it totally disintegrated in the atmosphere, scattering the object, likely a comet, into small debris that mostly burned out.

Figure 3. Fallen trees at five miles from the impact point of a 10-100 meters diameter meteorite at Tunguska, Siberia, Russia. Shock wave from the explosion circled the globe twice. Adjoining Patomskiy Crater. Meteorites may have broken into multiple fragments forming local lakes.

Figure 4. Meteor Crater is located 40 miles east of Flagstaff, Arizona, USA, resulted from an 80 feet diameter asteroid that impacted 20,000 to 30,000 years ago.

For tens of years, scientists thought the impact was by a comet that vaporized before striking the Earth. A Russian scientist, Vlasov, suggested it was an antimatter meteorite. There still exists some speculation that comets may contain some antimatter. If this were true, they could be mined for it as a rocket fuel for future space missions to distant planetary systems. The latest belief is that it was a stony meteorite, about 60 meters in diameter that disintegrated at a 5 to10 kilometers height in the atmosphere. The damage was generated by the shock wave, which had the equivalent, in terms of energy release, of a 15 to 20 Megatons (Mt) of Tri Nitro Toluene (TNT0 high explosive equivalent thermonuclear weapon. This is close to the energy release by the Mount Saint Helen's volcanic eruption in 1980 in the state of Washington in the USA, at 10 megatons of TNT equivalent. Figure 3 shows the effects on the trees at five miles from the impact.

If the Tunguska event would have happened 4 hours later in time, it could have impacted the city of St. Petersburg in Russia, totally annihilating it. The village of Vanavara, 70 kilometers from the blast, survived it. At the 100^{th} anniversary of the event in 2008, the city repainted its buildings with vivid "meteoric" colors, and unveiled a monument as a colorful sphere as a symbol of a cosmic body. "Alternativist" mystic locals also built a marker by the blast spot resembling a sacred bird or an Unidentified Flying Object (UFO). Tourists are attracted to a Tunguska meteorite museum with photographs of what is claimed to be fragments of some extra-terrestrial craft.

OTHER IMPACTS AND ASTRAL ASSAILANTS

Weren't it for erosion by water, wind and vegetation, craters from the impacts of celestial bodied would be much observable on Earth like on the Moon and Mars. Nevertheless, some of the more recent impacts are clearly discernible.

Figure 4 shows Meteor Crater that is located about 40 miles east of Flagstaff, Arizona in the USA. It is a tourist attraction with a museum. A nickel and iron meteorite weighting 175 million tons, and releasing energy in the megatons of TNT equivalent upon impact, is thought to have caused it. The crater is 4,150 feet in diameter, 550 feet deep and 2.4 miles in circumference.

A comet or an asteroid smashed into Australia about 140 million years ago, creating a 14 miles wide crater with a 2 miles wide central remnant known as Gosses Bluff.

On August 10, 1972, a 150 ton object 15 feet in diameter was observed streaking over Jackson Lake and the Grand Tetons mountains in Wyoming. The near miss skipped off the atmosphere like a rock on the surface of water.

The Aorounga, 17 km diameter crater in the Sahara desert in Chad is shown in Fig. 5. It appears to be a chain of two craters that could have resulted from fragmentation of a larger body as it entered the Earth's atmosphere. The 70 km diameter Manicouagan crater in Canada is 206-214 million years old (Fig. 6). A synthetic aperture radar picture of 5 million years old Roter Camm crater in Namibia, Africa is shown in Fig. 8.

The 65 million years old buried Chicxulub 110-189 miles diameter crater in the Yucatan Peninsula, Mexico is shown in Fig. 7. The asteroid impact was powerful enough to trigger wildfires, tsunamis and blast so much dust into the atmosphere that it blocked out the sun. The impact was as powerful as 10 billion atomic bombs of the 20 kT of TNT equivalent used in World War II. The impact created an inferno, enough to scorch plants thousands of miles away, followed by cooling due to all the dust being thrown into the air. The rocks from the impact zone shed light on the longer-lasting effects of the asteroid impact that wiped out 75 percent of life on the planet. There was no sulfur in the core of the asteroid impact zone, but the area surrounding the crater is full of sulfur. The lack of sulfur at the core supports a theory that the impact alone of the asteroid instantly vaporized sulfur minerals at the site, releasing them into the atmosphere, blocking sunlight and causing a global cooling.

Figure 5. Aorounga 17 km diameter chain craters in the Sahara desert in Chad.

Figure 6. The 70 km diameter Manicouagan crater in Canada is 206-214 million years old.

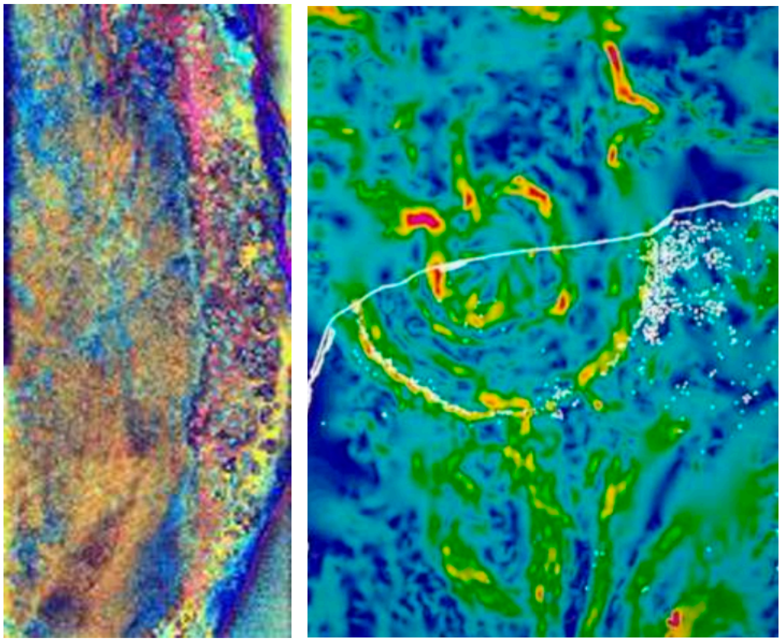


Figure 7. Gravity map of the 65 million years old buried Chicxulub 110-189 miles diameter crater in the Yucatan Peninsula, Mexico. It is thought to have trapped marine sediment eventually forming the giant Cantarell oil deposit. White dots are cenotes, (from Maya dz'onot), are natural wells or reservoirs, common in the Yucatán Peninsula, formed when a limestone surface collapses, exposing water underneath. The major source of water in the modern and ancient Yucatán, they are also associated with the cult of the rain gods, or Chacs. Source: USGS.

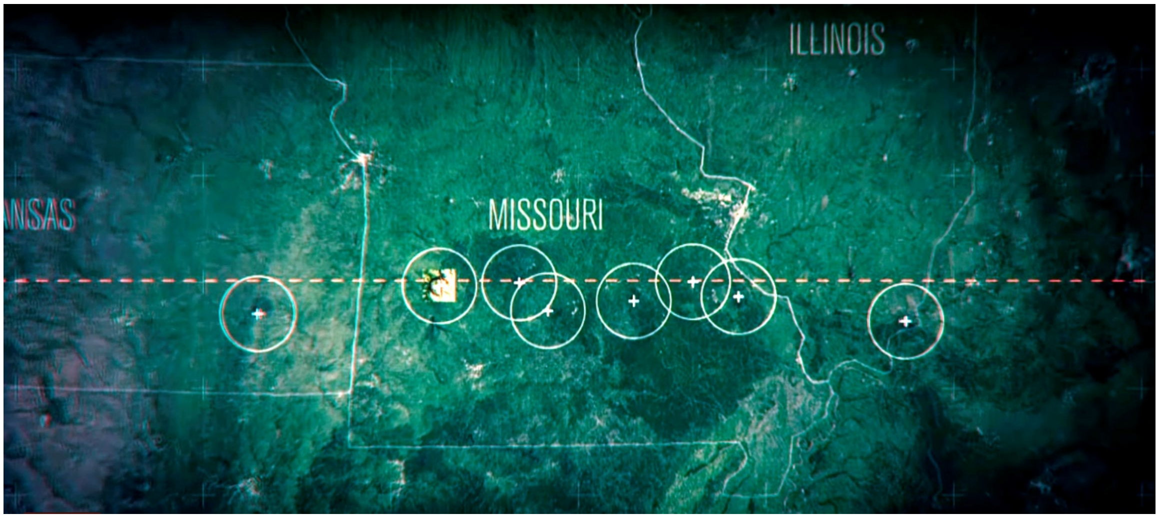


Figure 8. Synthetic aperture radar picture of 5 million years old Roter Camm crater in Namibia, Africa, and 8 craters in Kansas, Missouri and Illinois, USA.

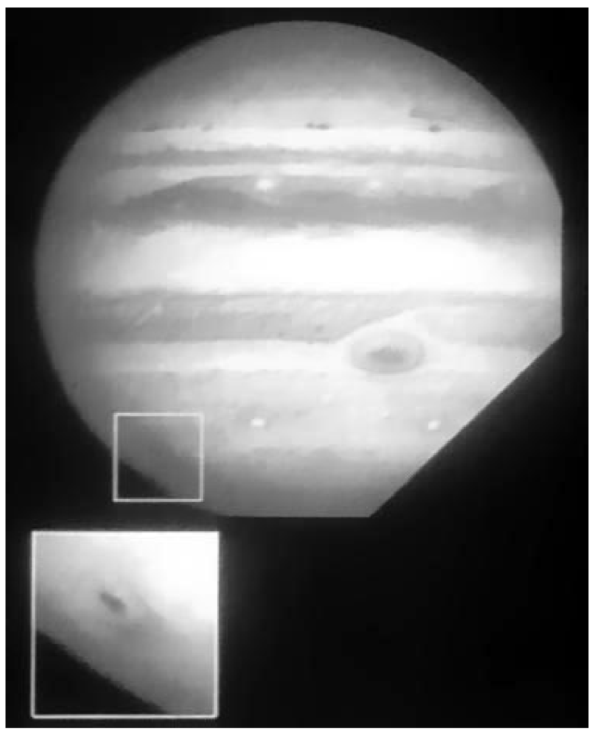


Figure 9. Impact on Jupiter of the Shoemaker-Levy 9 Comet. It collided with Jupiter in 1994, with the giant planet's gravitational pull ripping the comet apart for 21 visible impacts. The largest collision created a fireball that rose about 1,800 miles (3,000 km) above the Jovian cloud tops as well as a giant dark spot more than 7,460 miles (12,000 km) across— about the size of the Earth — and was estimated to have exploded with the force of 6,000 Gigatons of TNT equivalent.

The Comet Shoemaker-Levy 9 was spotted for the first time in March 1993. It turned out to be a string of more than 20 fragments that had separated under the influence of Jupiter's gravitational field and sequentially hit Jupiter. These fragments ended up striking Jupiter on July 1994 as shown in Fig. 9. The fragment A, traveling at a speed of 200,000 kms/hr, struck Jupiter with an energy of 200,000 megatons of TNT, sending a plume 3,000 kms above Jupiter. Fragment G shot a pockmark of debris larger than the diameter of the Earth. The fragmentation before impact explains the linear chains of craters on the moon. But this also suggests that an impact of this kind can deliver a series of blows one after the other.

The fact that cannot be ignored is that cosmic collisions do occur in the time frame of human life.

The Earth skies are crowded with 2,000 near Earth asteroids. Any one of them could become an "astral assailant" and strike the Earth. The Earth resides within an asteroid swarm.

The closest object to Earth was spotted in May 1994 by Tom Gehrls. It is a 6 meters object moving away from Earth at a distance of 150,000 kilometers. A nine meters object at 105,000 kilometers was located in the same year by Jim Scotti. Asteroid 4179 or Toutatis (Fig. 9) is the most hazardous object known. It is a 2 to 3 kilometers wide object with a chaotic orbit that brings it close to Earth once every 4 years. On December 1992, it came to within 3.6 million kilometers of Earth. In September 2004 it came closer to 1.5 million kilometers.

Figure 10. Asteroid 4179 or Toutatis.

Figure 11. Meteor sighting over the Grand Tetons peaks in the Rocky Mountains chain, Wyoming, August 10, 1972.

Only 5 percent of objects of a 1 km size have been identified. The smaller objects that can cause local damage will take decades to identify.

The asteroid 2000 BF19 is about a half mile wide and was spotted by James Scotti using the Spacewatch Telescope on Kitt Peak in Arizona. It is expected to come close to Earth in 2022. It has a probability of 10^{-6} or 1 in 1 million of hitting Earth.

Whereas asteroids would give Earth enough of a lead time to mount some defenses, this is not the case with comets which would not provide enough warning time. The only thing that can be done about long period comets, as suggested by Eugene Shoemaker is "…to maintain eternal vigilance." Figure 11 shows a sighting of a meteor over the Grand Teton Mountains in the American Rockies on August 10, 1972.

Whereas events like what happened at the K-T boundary are presumed rare, events at the level of the Tunguska impact are more frequent and are expected to occur as often as twice each century.

The average risk from astral impacts is suggested to be at the same level as the risk from passenger airlines crashes, and deserves the same attention from society as aircraft safety.

Table 8 shows the Torino scale, similar to the Richter earthquake magnitude scale for the assessment of the severity of an astral impact.

Table 8. The Torino Scale for the severity of Astral Impacts.

Hazard	Level	Description
No hazard	0	The likelihood of collision is zero, or is so low to be effectively zero. Also applies to small objects such as meteors and bolides that burn up in the atmosphere as well as infrequent meteorite falls that rarely cause damage.
Normal	1	A routine discovery in which a pass near the Earth is predicted that poses no unusual level of danger. Current calculations show the chance of collision is extremely unlikely with no cause for public attention or public concern. New telescopic observations very likely will lead to reassignment to level 0.
Meriting attention by astronomers	2	A discovery, which may become routine with expanded searches, of an object making a somewhat close but not highly unusual pass near the Earth. While meriting attention by astronomers, there is no cause for public attention or public concern as an actual collision is very unlikely. New telescopic observations very likely lead to reassignment to level 0.
	3	A *close* encounter, meriting attention by astronomers. Current calculations give a 1 percent or greater chance of collision capable of *localized destruction*. Most likely, new telescopic observations will lead to reassignment to level 0. Attention by the public and by public officials is merited if the encounter is less than a decade away.
	4	A *close* encounter, meriting attention by astronomers. Current calculations give a 1 percent or greater chance of collision capable of *regional devastation*. Most likely, new telescopic observations will lead to reassignment to level 0. Attention by the public and by public officials is merited if the encounter is less than a decade away.
Threatening	5	A *close* encounter posing a serious, but still uncertain threat of regional devastation. Critical attention by astronomers is needed to determine conclusively whether or not a collision will occur. If the encounter is less than a decade away, governmental contingency planning may be warranted.
	6	A *close* encounter by a large object posing a serious, but still uncertain threat of a global catastrophe. Critical attention by astronomers is needed to determine conclusively whether or not a collision will occur. If the encounter is less than 3 decades away, governmental contingency planning may be warranted.
	7	A *very close* encounter by a large object, which if occurring this century, poses an unprecedented but still uncertain threat of a global catastrophe. For such a threat in this century, international contingency planning is warranted, especially to determine urgently and conclusively whether or not a collision will occur,

Certain collisions	8	A collision is *certain*, capable of causing *localized destruction* for an impact over land or possibly a tsunami is close offshore. Such events occur on average between once per 50 years and once per several 1,000 years.
	9	A collision is *certain*, capable of causing *unprecedented regional devastation* for a land impact or the threat of a major tsunami for an ocean impact. Such events occur on average between once per 10,000 years and once every 100,000 years.
	10	A collision is *certain*, capable of causing *a global climatic catastrophe* that may threaten the future of civilization as we know it, whether impacting land or ocean. Such events occur on average once per 100,000 years, or less often.

COMETS AND ASTEROIDS THREATS

The time elapsing between the discovery of a potential impactor and the date of its collision would determine the adopted defense strategy. Comets originate from the Oort Cloud, a reservoir of comets at 20,000 Astronomical Units (AU), at 500 times the distance from the sun to Pluto. It is estimated that up to a trillion comets exist in the Oort cloud. These comets are not affected by the sun's gravity, but other stars, that could propel them into the Milky Way galaxy or deflect them towards the sun, can affect them.

They also originate from the Kuiper belt containing up to 10 trillion comets orbiting closer to the sun beyond Neptune. The Kuiper belt comets can be very large with diameters of 100-300 kilometers. They are formed of icy low-density materials. The large planets like Jupiter and Saturn capture these comets if they veer towards the inner solar system, and in a unique way offer a protection for the Earth against them, allowing life to appear and evolve on Earth. The few that go past the large planets acquire orbits within the inner solar system and could collide with the inner planets.

It could be suggested that the dense asteroids were preferentially captured allowing the lesser dense comets to impact Earth turning it into a water planet.

Figure 12. Haley's comet nucleus.

Two categories of these comets exit.

1. Long Period comets:

Some have highly elliptic orbits or long period comets take millions of years to complete an orbit, and they spend most of their time outside the solar system. These can travel very rapidly within the inner solar system at 50-60 kms/sec. If it hits the atmosphere at high velocity, it would be vaporized before reaching the surface. If it penetrates the atmosphere, it can explode causing a blast and cause large damage. About 10 to 25 percent of the massive objects threatening the Earth are long period comets.

2. Short Period comets:

The second category is short period comets. These have velocities in the range of 30 to 40 kms/sec. They could originate from long period planets affected by one of the large planets, changing its orbit from an elliptic to a more circular orbit. These comets spend most of their time within the inner solar system and can have orbits of less than 200 years. A renowned comet with a period of about 76 years is the Halley's Comet (Fig. 12). The greatest threat to Earth comes from the short period comets since the time between detection and impact could be extremely short in the months range.

3. Asteroids:

In addition to short period comets, the greatest threat to Earth comes from asteroids designated as Near Earth Objects (NEOs). They travel at a typical speed of about 20 kms/sec. They originate from the asteroid belt, which is a broad zone between 1.8-4.3 AU from the sun, between Mars and Jupiter. It is suggested that they are the remains of a missing planet that was 2.8 times the mass of the Earth. It could have been shattered as an effect of Jupiter's gravity. It could have also collided with Mars. These are rocky fragments of main belt asteroids that end up within the inner solar system. A number of 18,000 of these small bodies are thought to exist. They range in length from 10 meters to 40 kilometers. About 200 of them have been identified. Between 5,000-10,000 of a diameter of 500 meters or more remain to be discovered, and there may be 2,000 of them of larger than 1 kilometer in diameters.

Three types of NEOs exist:

1. Atens orbit NEOs: These orbit very close to the sun with a mean distance to the sun of less than 1 AU, and an aphelian distance of larger than 0.983 AU.
2. Apollos orbit NEOs: These orbit just beyond the Earth, with a mean distance to the sun equal or larger than 1 AU. Their perihelion distance is less than 1.017 AU.
3. Amors orbit NEOs: These travel between Earth and Mars with a perihelion distance between 1.017 and 1.3 AU.

These near Earth asteroids have orbits that are highly chaotic and some do cross the Earth's path. The largest Earth path crossing asteroids are 1627 Ivar and 1580 Betulia with diameters of about 8 kms. Luckily NEOs have short lifetimes with 20 percent of them falling into the sun. However, a new supply of NEOs is generated from the main belt asteroids by impacts and by encounters with the planet Jupiter.

Extinct comets that have depleted their supply of volatiles are candidates for capture into near Earth orbits. It is estimated that about 0.3-0.5 of all near earth asteroids are in fact extinct comets.

The orbits of asteroid objects, once detected, can be accurately calculated and can provide years of warning before an impact. This in contrast to long term comets orbits which can give only 250-500 days of warning, in addition to being dark objects that are hard to detect unless they get close to the sun which vaporizes their water and methane ice and displaying their characteristic tails.

QUADRUPLE EXTINCTION THEORY

Offshore of Mexico's Yucatán Peninsula is a 110 mile or 180 km wide crater named Chicxulub. It is believed to be the site of an asteroid impact 65 million years ago that wiped out the dinosaurs. The associated mass extinction, thought to have obliterated 2/3 of the world's species in has been called the K-T extinction since it bridges the Cretaceous and Tertiary geologic periods.

A theory exists that the dinosaurs were killed not by a lone asteroid strike but by the quadruple whammy of global climate change, massive volcanism, and two gigantic collisions. The theory involves tiny glass beads, the rare element iridium, and sediments that might be deposits from gigantic tsunamis caused by the Chicxulub impact.

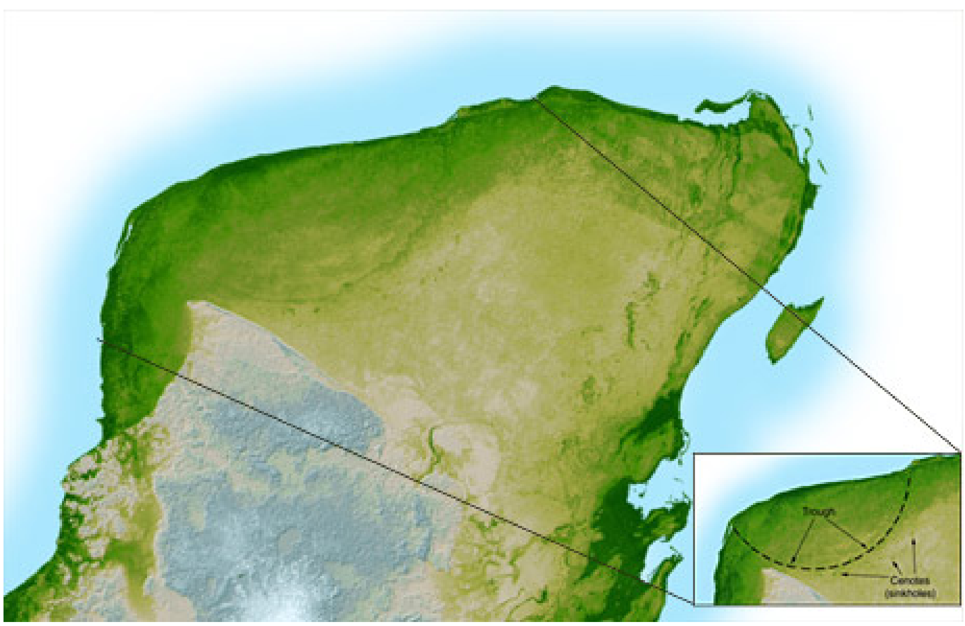


Figure 13. Chicxulub Crater mapping. Source: NASA, JPL, Caltech.

The theory is that Chicxulub impact predated the K-T extinction by about 300,000 years. The Chicxulub event would have filled the atmosphere with vaporized rock that quickly condensed and rained to Earth as tiny spherules, about 1/10 of an inch or1-4 mm in diameter. The spherules and iridium occur in two separate layers of Earth, or strata, separated by as much as 25 ft or 8 m of intervening sediment. It is suggested that the intervening sediment was laid down quickly by a series of tsunami waves created by the Chicxulub impact. An analysis of the sediment layers suggests that the sediment was formed between two separate asteroid strikes, one that laid down the glass and the other the iridium.

According to this theory, Chicxulub, rather than causing widespread devastation, had no long term ecological effect. The geological evidence indicates that Earth was undergoing a large number of changes during the 500,000 years preceding the K-T boundary. These included a global climate change that had slowly cooled Earth during the previous several million years. Massive volcanism on the Indian subcontinent produced a rapid 7-13 degree Fahrenheit or 4-7 degree Celsius warming. The Chicxulub asteroid hit about a hundred thousand years after that, but the warming continued for another hundred thousand years until the Earth suddenly cooled again. The already stressed biota was hit by the second asteroid impact that produced the iridium layer. This was the straw that broke the Earth's back, culling out all but the species that were already adept at adapting to rapid climate fluctuations.

Nevertheless, the scientific consensus accepts a single Chicxulub impact event that has caused tsunamis with the different layers being the result of the complicated tsunami waves surges and associated currents.

ASTEROID 2012 DA14, February 15, 2013

The asteroid 2012 DA14 came close to the Earth by February 15, at 2:24 pm EST, 2013 by 17,200 miles or 27,700 kilometers, ten times closer than the orbit of the moon, flying over the eastern Indian Ocean near Sumatra.

It is 150 feet or 45 meters across, half a football field in width. It passed within the orbits of many communications satellites, making it the closest flyby on record. An asteroid of this size passes this close to the Earth once every few decades."

It was first spotted by observers at the La Sagra Observatory in southern Spain in 2012, soon after it had just finished making a more distant pass of the Earth at 2.6 million miles or 4.3 million kilometers away. It is the closest known approach to Earth for an object its size. There is a 1-in-200,000 chance that it could hit the Earth in the year 2080.

Earth collision with an object of this size is expected to occur every 1,200 years on average. DA14 has been getting closer and closer to Earth for a while, the 2013 event is the asteroid's closest approach in the past hundred years, and it probably would not get this close again for at least another century.

The asteroid 2012 DA14 passed 5,000 miles inside the ring of orbiting geosynchronous weather and communications satellites. An impact from an object this size would have the explosive power of a few megatons of TNT, causing localized destruction similar to what occurred in the Tunguska event in Siberia in 1908. It created an airburst explosion which flattened about 750 square miles or 1,200 square kilometers of a remote forested region of northern Russia.

An impact from an asteroid with a diameter of about half a mile or one kilometer could temporarily change global climate and kill millions of people if it hit a populated area. The small objects like 2012 DA14 could hit Earth once a millennia or so. A survey of nearly 9,500 near-Earth objects half a mile or one kilometer in diameter is ongoing.

ASTEROIDS DETECTION EFFORTS

The USA Congress in 1998 mandated to NASA the task of identifying at least 90 percent of the largest asteroids and comets in the inner solar system. These include objects larger than 0.6 mile in diameter. Telescopes as of 2008 pinpointed more than 700 out of an estimated population of 1,000. In 2005, Congress directed NASA to track down the far more numerous asteroids larger than 460 feet in diameter, which can destroy a city or a state. It amended the Space Act to entrust NASA with the specific responsibility to "Detect, track, catalog and characterize" asteroids and other NEOs.

There exist two large new survey telescope projects to detect would be killer asteroids.

On a peak on the Hawaiian island of Maui, the Panoramic Survey Telescope And Rapid Response System or Pan-STARRS, to begin operation in 2008 uses an array of four 6 ft or 1.8 m wide telescopes and cameras in Hawaii to scan the skies for asteroids. It uses a 1.4 x 109 pixels camera that produces images that, if printed, would cover one half of a basketball court. The data is to be scanned by computers flagging statistical anomalies that astronomers can check with their eyes. Eventually 10,000 potentially hazardous asteroids will be catalogued.

The Large Synoptic Survey Telescope in Chile scheduled for 2014, will use a giant 27.5 ft or 8.4 m wide telescope to search for killer asteroids

The Outer Space Treaty which bans the use of nuclear weapons in space needs to be amended to allow for defense against extraterrestrial objects. The Association of Space Explorers, includes a team of scientists, risk specialists, and policymakers to draft a treaty, which will be submitted to the United Nations (UN) for consideration in 2009. The treaty would detail the standardized international measures that will be carried out in response to any asteroid threat. The uncertainty involved in predicting the path of an incoming asteroid makes a coordinated global response essential.

The occurrence of hurricanes or tornadoes cannot be prevented but humanity has evolved way beyond the dinosaurs with the intellectual and technological capability of preventing an asteroid impact, enhancing the survival of life on Earth.

VOLCANIC ERUPTIONS

INTRODUCTION

The world is covered with about 1500 active volcanoes. Of these, around 50 volcanoes erupt every year. Some of eruptions events in the last 250 years include Laki, Iceland over the 1783-1784 period, 15 eruptions of Mount Vesuvius, Italy, Tambora, Sumatra in 1815, Krakatau, Java-Sumatra in 1883, and Mount Pinatubo, Philippines in 1991. The Tambora eruption spewed volcanic ash and gases into the troposphere and lowered the atmospheric temperatures by about one degree Celsius and resulted in a year without a summer in 1816.

MOUNT VESUVIUS ERUPTIONS

Mount Vesuvius stands as the most famous volcano on Earth. Several times it erupted burying in ash the towns of Pompeii, Herculaneum and Oplontis on its flanks. When Vesuvius started erupting sending clouds of ash, the smart residents heeded the warning and took to their boats into the Mediterranean Sea. Those that stayed behind believing it would blow over, like it did many times, are thought to have suffocated and were buried under the pyroclastic flows of ash and lava. An account witness, Pliny the Younger, reported watching from Castellammare de Stabla, 20 miles from Vesuvius, his uncle's boat get subsumed and succumb to a cloud of ash and smoke.

Figure 14. Mount Vesuvius eruption, August 24, 79 AD.

Vulcanologist Giuseppe Mastrolorenzo from the Naples Observatory in Italy, suggests that the residents killed in Pompeii and the neighboring towns located on the slopes of the volcano died from an extreme heat surge produced by the volcano, not suffocation.

Hundreds of bodies were recovered from the three main cities devastated by the eruption with 3/4 of the remains reflecting people who were killed instantaneously, their bodies suspended in action. Victims of suffocation, in contrast, are generally found in floppy or sleepy positions, crumpled on the floor.

The researchers tested their theory by exposing a set of recent animals and human bones to different levels of heat, ranging from 100-800 °F.

Based on the coloration of the experimental bones, they concluded that the bodies in Pompeii, 6.2 miles from the volcano, were likely exposed to temperatures of between 250 and 300 degrees Fahrenheit.

Bodies recovered from towns closer to the eruption were exposed to much higher temperatures, probably 450 to 500 degrees Fahrenheit.

Using this information, the team modeled temperature gradients of the six major flows of hot ash columns that plowed down the side of the mountain during the eruption.

The results suggest a much wider area around the volcano can be subjected to lethal temperatures than previously thought.

It is believed that the victims of Pompeii were killed during a single heat surge from the fourth pyroclastic surge. A few seconds of exposure to the intense heat was enough to kill the villagers immediately. Being inside a structure provided no shelter.

The blazing heat wave could have traveled up to 12.4 miles from the volcano. Taking this into account, the current plan to evacuate a five-mile radius around in the event of another eruption seems insufficient. The city of Naples sits outside this zone, for example, but it is only 6.2 miles away. Potentially more than 3 million people are at risk if Mount Vesuvius explodes in a similar fashion to the one that wiped out Pompeii.

A pyroclastic flow on the Sorrento- facing side would wipe out the Sorrento side of the Bay of Naples and reach Capri in a few minutes.

MOUNT SAINT HELENS ERUPTION, 1981

The Mount Saint Helens eruption occurred in the USA on May 18, 1981 at 8:32 in the morning. It blew the 1,300 foot lid off her top. The shock wave from the blast was heard or felt around the world. Sixty two people lost their lives, the majority of them well outside the danger zone, some mowed down by the falling trees. He rest, similar to the victims of Mount Vesuvius, those of St. Helens whose bodies were found died through suffocation when their lungs filled with ash.

The United States Geological Survey ((USGS) monitored the mountain from headquarters set in Vancouver through instrumentation including seismographs, tiltmeters and thermal gauges.

A bulge on the side of the mountain expanded at the rate of 5 feet per day to a total projection of 300 feet. The Governor of the state of Washington Dixy Lee Ray ordered an evacuation of an area within a five miles radius of the mountain top to keep the sightseers away. The roads leading to the mountain were blocked. This evacuation was a smart move and should have encompassed a larger area.

On May 18, 1981 at 8:32 am, all at once, the volcano’s north slope where the bulge was observed slid off into Spirit Lake and the Toutle River. In a first eruption, the underground water which had turned to steam and the gases forced their way horizontally through what was left of the north slope. Through this vent another second eruption forced its way straight up sending smoke, steam and ash 12 miles into the atmosphere.

In the first horizontal eruption the debris from the avalanche rushed forward at 250 miles per hour. Travelling 17 miles north and covering 200 square miles, the molten rock and mountain fragments knocked down the trees in their path. Six million mature trees fell in the path of the volcanic matter.

Boiling mud and hot gases swirled everywhere at tremendous speeds in a monumental land slide.

Figure 15 Mount Saint Helens Eruption on May 18, 1980. Photo: John Van Eaton.

Figure 16. Ash fallout from the Mount Saint Helens Eruption on May 18, 1980. Photo: John Van Eaton.


Figure 17. Mount Saint-Helens eruption, May 18, 1980.


Figure 18. Mount Saint-Helens before and after its eruption, May 18, 1980. Source: USGS.

An account of the events is given by the geologist Pat Van Eaton as follows:

> "A strong earthquake, 5.1 on the Richter scale, started the eruption. Hot gas, ash, huge chunks of rock and ice blew from the North face of the volcano. The blast was 500 times greater than the 20 kiloton atomic bomb that fell on Hiroshima. It covered 150 square miles. Millions of 200 year old fir trees were flattened like match sticks. There were winds at nearly 200 miles an hour. It threw some of these old trees over nearby ridges 1,500 feet high. Lightning shot about 63,000 feet into the air. The Toutle River by afternoon was 90 degrees. It flows into the Cowlitz. It raised the Cowlitz temperature into the 80s, enough to kill all its fish. It raised the banks of the Cowlitz in some areas about 15 feet. A mass of steaming mud which had the consistency of wet cement boiled down the Toutle River Valley. Birds roosted because it became dark by approximately 10:00 a.m. People had to use their headlights if trying to drive. The bats came out. Hot gobs of mud rained down soon after the explosion and the windshield wipers could not be used. Hot ash did damage to anyone with a metal roof. Nylon socks were put over the air cleaners in the state patrol cars to help filter the ash and let the cars keep running."

MOUNT RAINIER CONTINUOUS THREAT

Mount Rainier is ranked as third of 169 USA volcanoes in terms of threat of eruption. With the vast quantity of ice on its flanks, massive mud flows or “lahars” pose a unique danger. A large number of people and facilities would be exposed to its unrest, and the time period between reawakening and destructive activity may be short.

A small number of seismic stations has been installed at Mount Rainier to determine the depth of earthquakes occurring in the mountain. There is one real time monitoring instrument on the volcano that can measure ground deformation or the expansion and contraction of the mountain's crust. The need for additional monitoring has been clearly stated by the USA National Research Council. The United States Geological Survey (USGS) proposes to enhance the monitoring capabilities. The upgraded monitoring would improve scientists' ability to detect the onset of volcanic activity, assess the likelihood of an eruption; and detect movements that could lead to collapse of large portions of the volcano.

Figure 19. Mount Rainier covered with lenticular cloud has the potential of eruption.
Photo: Tony Sirgedas.

Figure 20. Mount Vesuvius dormant volcano, Italy.

EYJAFJALLAJÖKULL GLACIER, ICELAND, 2010.

Chaos occurred in April 2010, when the Eyjafjallajökull glacier in Iceland shut down air traffic and closed down air space in Europe. More than 100,000 flights were cancelled across Europe during a week-long airspace shutdown which saw most major European airports completely closed.

The last time Eyjafjallajökull came to life, it erupted periodically from 1821 to 1823.

The disruptions in April 2010 cost the airline industry an estimated €1.7 billion or $2.2 billion. Concerns over huge losses led the Lufthansa airline allowing commercial flights to fly below the clouds on three occasions in April 2010. The flights had passenger jets flying as low as 1970 ft or 600 meters above ground, significantly increasing the danger of collision with hobby pilots.

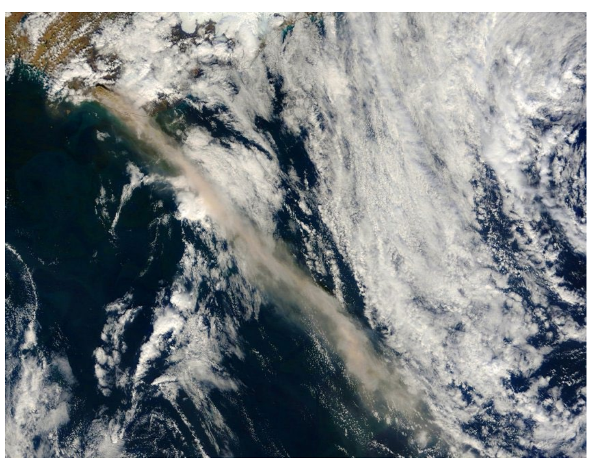


Figure 21. Ash cloud from a volcano under the Eyjafjallajökull glacier in Iceland shut down air traffic and closed down air space in Europe, 2010. Photo: AFP.

Figure 22. Ash deposits from the Eyjafjallajökull glacier. Photo: Reuters.

Figure 23. Eyjafjallajökull glacier eruption in Iceland, 2010. Photo: DPA.

SUPER VOLCANOES

Super-volcanos are located over mantle hotspots and can produce eruptions of an apocalyptic magnitude. They result in massive landscape destruction and catastrophic loss of plant and animal life due to ash flows, ash falls, noxious gases, landslides, and floods. Climatic winters, severe climatic changes and mass extinctions would result.

Super-volcanic eruptions occurred at Taupo, New Zealand, 26,500 and 254,000 years ago, Mount Toba, Sumatra, about 74,000 years ago. The latter may have precipitated the last Ice Age. The largest known super-volcano is the caldera at the Yellowstone Park, Wyoming, USA. It had four large eruptions and another three giant eruptions in the past six million years. The latest Yellowstone caldera eruption was 174,000 years ago and another occurred 640,000 years ago. It is overdue for another eruption.

EARTHQUAKES

INTRODUCTION

Earthquakes are caused by the sudden sliding of the tectonic plates against each other near the surface, or deep into the Earth's crust. The movement results in longitudinal and transverse seismic waves that travel around the globe. The shaking of the ground liquefies it and leads to the collapse of the structures above the ground if they were not initially designed to withstand them.

Some earthquakes are so slight, and some occur in such remote areas in deserts or oceans, that they are barely felt. Earthquakes can result in mud slides burying whole towns and villages with devastating consequences.

Earthquakes larger than 7.0 on the magnitude scale have a frequency of occurrence of 15 times per year according the USA Geological Survey (USGS). They can cause widespread and catastrophic structural damage on land, and may generate deadly tsunamis if the epicenter is located offshore or near a coast. They originate preferentially along the plate boundaries of the Ring of Fire that circumscribes the Pacific Ocean, but they also include South West Asia, the Himalayas of India and China, and the Caribbean. Earthquakes have caused nearly 900,000 deaths since 1990.

EARTHQUAKE MAGNITUDE AND STRENGTH

MAGNITUDE SCALE

Referred-to in Japanese as "san ten ichi ichi" or 3/11, a 2011 earthquake affected two 50 miles thick tectonic slabs and unleashed energy of about 480 Mt of TNT equivalent moving the position of part of the coastline 3.6 m to the east. The Nagasaki nuclear device yield was in the range of 20-22 kT of TNT equivalent. The seabed buckled along a 300 km stretch along the fault line involved. An estimated 67 km^3 of ocean water moved towards 860 km of the Japanese coastline with a wave reaching about 24 m in height.

The reported M9.0 magnitude earthquake was more powerful than the design-basis magnitude M8.6 earthquake. According to Wikipedia:

> "Charles F. Richter then worked out how to adjust for epicentral distance (and some other factors) so that *the logarithm of the amplitude of the seismograph trace could be used as a measure of "magnitude"* that was internally consistent and corresponded roughly with estimates of an earthquake's energy. He established a reference point and the now familiar ten-fold (exponential) scaling of each degree of magnitude, and in 1935 published what he called the "magnitude scale", now called the local magnitude scale, labeled M_L (This scale is also known as the *Richter scale*, but news media sometimes use that term indiscriminately to refer to other similar scales.)"

Seismograph earthquake magnitude trace.

Hence 9M and 8.6M:

9M: ‘log M_2 = 9’
8.6M: ‘log M_1 = 8.6’

designate respectively the actual occurrence and the historical occurrence on which the plant’s earthquake design was based.

The difference between two Richter scale magnitudes is given by:

$$\Delta M = \log_{10} \frac{M_2}{M_1} = \log_{10} M_2 - \log_{10} M_1 \tag{1}$$

The ratio of magnitudes can be calculated by using the relation:

$$\begin{aligned} e^{\ln x} &= 10^{\log_{10} x} = x \\ \frac{M_2}{M_1} &= 10^{\log_{10} \frac{M_2}{M_1}} = 10^{\Delta M} \end{aligned} \tag{2}$$

Since the Richter magnitude scale is a base 10 logarithmic scale, each whole number increase corresponds to a factor of ten increase in the measured amplitude:

$$\Delta M = \log_{10} \frac{10 M_1}{M_1} = \log_{10} 10 = 1$$

The ratio of the experienced magnitude to the design earthquake magnitude is a factor of:

$$\frac{M_2}{M_1} = 10^{(\log M_2 - \log M_1)} = 10^{(9.0-8.6)} = 10^{0.4} = 2.5$$

If we instead take the log of the 9.0 and 8.6 values:

$$\frac{M_{Actual\,occurrence}}{M_{Design\,basis}} = 10^{(\log M_{Actual\,occurrence} - \log M_{Design\,basis})} = 10^{(\log 9.0 - \log 8.6)} = 10^{0.954-0.934} = 10^{0.02} = 1.04\,,$$

we obtain an unrealistic result with only a 4 percent difference.

From the United States Geological Survey, USGS Fact Sheet 017–03, another example is the 1895 New Madrid earthquake, M ~6, which was felt throughout most of the central USA, while the 1994 Northridge quake though almost ten times stronger at M 6.7, was felt only in southern California. In this case we get:

$$\frac{M_{Northridge}}{M_{New\,Madrid}} = 10^{(\log M_{Northridge} - \log M_{New\,Madrid})} = 10^{(6.7-6.0)} = 10^{0.7} = 5.01$$

We here obtain 5.01 instead of the reported 10 by the USGS.

If we use the log of the magnitude's values, we mistakenly get:

$$\frac{M_{Northridge}}{M_{New\,Madrid}} = 10^{(\log M_{Northridge} - \log M_{New\,Madrid})} = 10^{(\log 6.7 - \log 6.0)} = 10^{0.826-0.778} = 10^{0.048} = 1.10$$

which is an unobserved value of only a 10 percent stronger earthquake.

Mistakenly considering the base 10 logarithm as a base e = 2.718 logarithmic scale also yields an underestimated value of:

$$\frac{M_2}{M_1} = e^{(\log M_2 - \log M_1)} = e^{(9.0-8.6)} = e^{0.4} = 2.718^{0.4} = 1.4$$

STRENGTH, ENERGY RELEASE, DESTRUCTIVENESS

The magnitude scale compares the measured amplitudes of waves on a seismograph and does not describe the strength described by the energy release from an earthquake. The energy release is what affects structures and causes the actual damage.

To estimate the energy release E, an empirical formula is usually used that relates it to the magnitude M as:

$$\log_{10} E \;\; \alpha_{\ell} \;\; 1.5M \qquad (3)$$

The energy release or strength can be estimated from:

$$\begin{aligned} 10^{\log_{10} E} &\ \alpha_\ell\ 10^{1.5M} \\ E &\ \alpha_\ell\ 10^{1.5M} \end{aligned} \tag{4}$$

From which:

$$\frac{E_2}{E_1} = \frac{10^{1.5M_2}}{10^{1.5M_1}} = 10^{1.5(M_2 - M_1)} \tag{5}$$

Thus a change of 0.1 in the magnitude M implies:

$$\frac{E_2}{E_1} = 10^{1.5(0.1)} = 10^{0.15} = 1.41$$

or 1.4 times the energy release.

Each whole number increase in the magnitude M corresponds to:

$$\frac{E_2}{E_1} = 10^{1.5(1)} = 10^{1.5} = 31.62 \simeq 32$$

times the energy release by the earthquake.

Each increase of 0.2 in the magnitude corresponds to a doubling of the energy release:

$$\frac{E_2}{E_1} = 10^{1.5(0.2)} = 10^{0.3} = 1.995 \simeq 2$$

The ratio between the strengths or energy releases of a 9M and an 8.6M earthquakes can be estimated as:

$$\frac{E_2}{E_1} = \frac{10^{1.5\times 9.0}}{10^{1.5\times 8.6}} = 10^{1.5\times(9.0-8.6)} = 10^{1.5\times 0.4} = 10^{0.6} = 3.98 \simeq 4$$

times the strength and hence the destructiveness.

Large earthquakes have much larger strength or energy release factors than small ones and are hence are much more devastating.

Thus, for Fukushima on a magnitude basis:

$$\frac{M_{actual}}{M_{design-basis}} = 2.5,$$

but on a strength, energy release, or destructiveness basis:

$$\frac{E_{actual}}{E_{design-basis}} \simeq 4 .$$

Figure 24. An earthquake caused a tsunami and a reactor accident at Fukushima in Japan.

RICHTER MAGNITUDE SCALE

The Richter magnitude scale was developed in 1935 by Charles F. Richter of the California Institute of Technology as a mathematical device to compare the size of earthquakes. The magnitude of an earthquake is determined from the logarithm of the amplitude of waves recorded by seismographs. Adjustments are included for the variation in the distance between the various seismographs and the epicenter of the earthquakes.

On the Richter Scale, magnitude is expressed in whole numbers and decimal fractions. A magnitude 5.3 might be computed for a moderate earthquake, and a strong earthquake might be rated at a magnitude of 6.3. Because of the logarithmic basis of the scale, each whole number increase in magnitude represents a tenfold increase in the measured amplitude. As an estimate of energy, each whole number step in the magnitude scale corresponds to the release of about 31.5 times more energy than the amount associated with the preceding whole number value.

Table 9. Energy releases from different Richter scale magnitude earthquakes.

Richter magnitude	Energy equivalent [tons TNT]
4.0	1.01×10^3
5.0	3.18×10^4

6.0	$1.01x10^6$
7.0	$3.18x10^7$
8.0	$1.01x10^9$
9.0	$3.18x10^{10}$

Seismic waves are the vibrations from earthquakes that travel through the Earth. They are recorded on seismographs at measuring stations throughout the world. Seismographs record an oscillating trace that shows the varying amplitude of ground oscillations beneath the instrument. Sensitive seismographs, which greatly magnify these ground motions, can detect strong earthquakes from sources anywhere in the world. The time, location, and magnitude of an earthquake can be determined from the data recorded by seismograph stations.

Earthquakes with magnitude of about 2.0 or less are usually called micro-earthquakes; they are not commonly felt by people and are generally recorded only on local seismographs.

Events with magnitudes of about 4.5 or greater, of which there are several thousand annually, are strong enough to be recorded by sensitive seismographs all over the world.

Large earthquakes, such as the 1964 "Good Friday Quake" in Alaska, have magnitudes of 8.0 or higher. On the average, one earthquake of such size occurs somewhere in the world each year.

The Richter magnitude scale has no upper limit and is not used to express damage. An earthquake in a densely populated area which results in many deaths and considerable damage may have the same magnitude as a shock in a remote area that does nothing more than frightens the wildlife. Large magnitude earthquakes that occur beneath the oceans may not even be felt by humans.

MOMENT MAGNITUDE SCALE

Another scale called the moment magnitude scale has been devised for more precise study of large earthquakes.

This method of measuring earthquakes estimates the amount of energy content of the event. Factors used to calculate the moment magnitude include the amount of slip on the fault, the type of rock in which the fault developed, and the area covered by the fault break.

MERCALLI INTENSITY SCALE

The intensity of earthquake damage is determined using the Mercalli intensity scale, which is based on the damage to structures at particular locations. Factors influencing earthquake intensity include: distance from epicenter, focal depth, duration of shaking, geologic material on which structures are constructed, the design of buildings, and the magnitude of the earthquake.

Table 10. The Mercalli intensity and Richter magnitude scales.

Richter magnitude scale	Mercalli intensity scale	Description and consequences
1.0-3.0	I	Not felt, except by a few under especially favorable conditions.
3.0-3.9	II	Felt only by a few persons at rest, especially on upper floors of buildings
	III	Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor vehicles may rock slightly. Vibrations similar to the passing of a truck. Duration can be estimated.
4.0-4.9	IV	Felt indoors by many, outdoors by a few. At night, some people are awakened from sleep. Dishes, windows, doors disturbed, walls make cracking sound. Sensation like a heavy truck striking building. Standing motor vehicles rocked noticeably.
	V	Felt by nearly everyone, many awakened from sleep. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop swinging.
5.0-5.9	VI	Felt by all, many frightened. Some heavy furniture moved, a few instances of fallen plaster. Damage is slight.
	VII	Damage negligible in buildings of good design and construction, slight to moderate in well built ordinary structures, considerable damage in poorly built of badly designed structures, some chimneys broken.
6.0-6.9	VIII	Damage slight in specially designed structures, considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.
	IX	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
7.0-higher	X	Some well-built wooden structures destroyed, most masonry and frame structures destroyed with foundations. Railroad rails slightly bent.
	XI	Few, if any masonry structures remain standing. Bridges collapsed. Railroad rails bent significantly.
	XII	Total damage total and destruction. Lines of sight and level surfaces are distorted. Objects thrown into air.

SAN FRANCISCO EARTHQUAKE AND FIRE, 1906

The 5:12 am San Francisco, California earthquake of April 18, 1906 ranks as one of the most significant earthquakes of all times in the USA.

Ancient redwood trees toppled over and large sections of the rocky shoreline collapsed into the ocean. The city of San Francisco was in flames almost immediately with fires caused by broken gas lines and stove fires in demolished buildings.

Its death toll was larger than 3,000 people with 225,000 injured and property damage reaching $400 million in 1906 dollars.

According to the UC Berkeley Seismographic Station:

> "The ground had broken open for more than 270 miles along a great fault - the San Andreas rift. The country on the east side of the rift had moved southward relative to the country on the west side of the rift. The greatest displacement had been 21 feet about 30 miles northwest of San Francisco."

The quake lasted just one minute but caused the worst natural disaster in the USA's history. Modern analysis estimates it registered 8.25 on the Richter scale.

The city of San Francisco is situated on a 50 miles long peninsula into the Pacific Ocean, and is bordered on the east side by a large bay. This brought it great wealth since this is a great harbor location. The city's shoreline was covered with docks, wharves and warehouse where the shipping industries received and shipped cargoes and goods daily.

Its location also makes it a precarious place to live at next to the nearby San Andreas Fault. The two tectonic plates meet in an 800 miles long line that runs nearly parallel to the Californian coast. The North American tectonic plate moves to the southeast and the Pacific Plate pushes northwest at the rate of 2 inches per year, having no effect on the coast line.

At some points along the fault, the edges of the plates have been wedged for years. When the pressure builds up to such a point that the locked edges of the plated suddenly shift, an earthquake does occur.

On the morning of April 18, 1906, the two plates suddenly jerked apart under the Pacific Ocean. Shock waves rushed toward the California coastline at 7,000 miles per hour. The rip hit the land at Point Arena, 90 miles north of San Francisco.

SAN FRANCISCO FIRE

Similar to Chicago in 1871, San Francisco was built primarily out of wood. Wooden houses lined the streets along its Telegraph, Nob and Russian Hills. Wealthy neighborhoods between Powell and Van Ness Avenues and the poor section of Chinatown, became fuel for 50 fires spread throughout the city in both mansions and shanties within minutes of the earthquake.

The city residents rushed out throughout the streets hearing the unusual sounds of nails popping out of wood structures, collapsing buildings, church bells ringing, gas hissing from broken lines and water gushing from water pipes.

At 6:15 am, Brigadier General Frederick Funston, commander of the Presidio, placed the city under military control and declared martial law to prevent looting. He ordered the military troops out to support the fire fighters and policemen.

City dwellers gathered on Russian Hill to watch the fires raging throughout the city. To stop the spread of the fire, Army troops, following a misguided old practice, used high explosives to dynamite buildings to form fire breaks. More often than not, it is reported that they only succeeded in lighting new fires.

ALASKA EARTHQUAKE, GOOD FRIDAY QUAKE, 1964

On March 27, 1964, a powerful earthquake known as the "Good Friday Quake," that measured 8.4-9.4 on the Richter scale hit Anchorage, southern Alaska. This was the strongest earthquake in USA history.

It created a powerful tsunami with a tidal wave that reached a height of 100 feet at points. It devastated towns along the Gulf of Alaska and caused carnage in British Columbia, Canada; Hawaii; and the West Coast of the USA.

A section of Fourth Avenue in Anchorage sank 20 feet below the street level sucking a row of parked cars into it. A newly built J. C. Penney store collapsed to the ground killing two shoppers.

Property damage reached more than $500 million with thousands injured and 118-125 people killed.

Figure 25. Effects of the April 18, 1906 San Francisco earthquake and the ensuing fire.

SAN FRANCISCO EARTHQUAKE, 1989

Another earthquake hit San Francisco on October 17, 1989 that registered 6.7 on the Richter scale.

Power went out all over the city the night of the earthquake and many people spent the night in tents in the parks for fear of the aftershocks.

Fires ensued like in the 1906 earthquake only in the Marina District.

Many highway overpasses collapsed. A thirty-foot section of the Bay Bridge collapsed trapping motorists on the lower level, with rescue workers extracting them from their cars.

NEW MADRID FAULT ZONE

Southeastern Missouri sits along the New Madrid fault zone, and in the early portion of the 19th century this part of the country was shaken by four of the largest earthquakes in USA history. The New Madrid Seismic Zone is the most active earthquake zone east of the Rocky Mountains and spans southeastern Missouri, northeastern Arkansas, western Tennessee, western Kentucky, and southern Illinois.

Between 1811 and 1812, the New Madrid Fault experienced some of the largest quakes in history. They originated in the Mississippi Valley and rang church bells in Boston and shook New York City, Massachusetts, 1,000 miles away. President James Madison and his wife Dolley felt shaking at the White House in Washington, DC.

The USA government conducted a major five day simulation named as "National Level Exercise 11" in which it attempted to simulate what a major earthquake along the New Madrid fault zone would look like. A massive earthquake would kill 100,000 Midwesterners instantly, and force more than 7 million people out of their homes. At the time, National Level Exercise 11 went largely unnoticed; the scenario seemed too far-fetched. Yet, states like Illinois and Missouri are at the center of a tectonic plate, not at the edge of it. A major quake happens there once every several generations.

> "An intraplate earthquake occurs within the interior of a tectonic plate; this stands in contrast to an interplate earthquake, which occurs at the boundary of a tectonic plate.
>
> The 1811–12 New Madrid earthquakes were an intense intraplate earthquake series beginning with an initial earthquake of moment magnitude 7.5–7.9 on December 16, 1811, followed by a moment magnitude 7.4 aftershock on the same day. They remain the most powerful earthquakes to hit the contiguous United States east of the Rocky Mountains in recorded history.
>
> The underlying cause of the earthquakes is not well understood, but modern faulting seems to be related to an ancient geologic feature buried under the Mississippi River alluvial plain, known as the Reelfoot Rift. The New Madrid Seismic Zone (NMSZ) is made up of reactivated faults that formed when what is now North America began to split or rift apart during the breakup of the supercontinent Rodinia in the Neoproterozoic Era (about 750 million years ago). Faults were created along the rift and igneous rocks formed from magma that was being pushed towards the surface. The resulting rift system failed but has remained as an aulacogen (a scar or zone of weakness) deep underground.
>
> The epicenters of over 4,000 earthquakes can be identified from seismic measurements taken since 1974. It can be seen that they originate

from the seismic activity of the Reelfoot Rift. New forecasts estimate a 7 to 10 percent chance, in the next 50 years, of a repeat of a major earthquake like those that occurred in 1811–1812, which likely had magnitudes of between 7.6 and 8.0. There is a 25 to 40 percent chance, in a 50-year time span, of a magnitude 6.0 or greater earthquake."

Fluvial tsunamis were caused by three New Madrid Fault earthquakes with magnitude 7.8. The strongest of the aftershocks, an 8.8 Richter magnitude scale, was felt at 1,000 miles away, and caused church bells to ring at the city of Boston, Massachusetts. In 1811 and 1812 they caused the Mississippi River to temporarily reverse course for several hours.

The Tennessee Earthquake Center has several monitoring stations throughout the region. The major metropolis of Memphis, Tennessee is downstream, as well as Paducah, Kentucky. Cairo, Illinois is upstream with the Ohio River and the Mississippi River connecting there. States as far southeast as Alabama are members of an Earthquake Consortium. This fault is considered as a failed rift as the Gulf of Mexico tried to reach almost to Cairo, but the spread failed and the fault was the result.

Although quiet for a long time from a human perspective, geoscientists call that area “the Hinges of Hell.” Sand blows and a stench of sulfur were reported in past earthquakes in the region. There are several nuclear reactors operating beyond 250 miles from the New Madrid fault zone that could be affected.

Figure 26. New Madrid and Wabash Valley seismic zones in the American Midwest.

The Central and Eastern United States (CEUS) is generally an area of low to moderate earthquake hazard with few active faults in contrast to the western United States. Even so, in 1811-1812, three major earthquakes (Magnitude 7 to 7.7 on the commonly used Richter Scale) shook much of the CEUS. These earthquakes occurred near the town of New Madrid, Missouri. In 1886, a large earthquake (Richter Scale magnitude of about 7) occurred near Charleston, S.C. This earthquake caused extensive damage and was felt in most of the eastern United States. Geologists are aware of these historic occurrences, and knowledge of such earthquakes was taken into account in plant design and analysis.

TSUNAMIS OR TIDAL WAVES

INTRODUCTION

Tsunamis (In Japanese: tsu ‘harbor’ and ‘nami’ wave) or tidal waves affect harbors and coastal areas where most of their damage has been felt. They are caused by submarine tectonic plate slides, earthquakes or volcanic eruptions that generate large sea waves. A comet or asteroid impact into the ocean would also cause a monumental tidal wave.

Figure 27. Aftermath of the December 2004 Indian Ocean tsunami in Indonesia. Fatalities reached the level of 200,000.

Tsunamis can reach propagation speeds of 200-800 km/hour around the oceans, and they possess a large amount of energy in the generated ocean waves. They have resulted in waves that were 135 feet above ground and cause large devastations of the coastal and inland areas that they can reach.

Figure 28. Tsunami waves swirl back out to sea after inundating the land in Oregon on December 26, 2004. Photo: NASA.

INDIAN OCEAN TSUNAMI, 2004

Waves from the Indian Ocean tsunami of 2004 eventually reached the East African and West American Oregon coasts on December 26, 2004. Similar tsunamis have hit the Oregon Coast in the past and will certainly repeat it again. Geologists estimate a roughly one in seven chance that a major earthquake along the Cascadia Subduction Zone off the Oregon Coast could trigger a similar tsunami on the West Coast of the USA in the next 50 years.

As a tsunami hits a shore area, small waves with lower than sea level crests are created with a period of 10-30 minutes between the waves. This could give educated observers a chance for generating an alarm and an escape. Those who were not were well informed, were attracted to the exposed sea level, thinking that it was a lower tide, picking up sea creatures, only to be hit by the following devastating large wave.

TOHOKU-CHIHOU-TAYHEIYO-OKI TSUNAMI, MARCH 11, 2011

A state of emergency was declared on Friday, March 11, 2011 by Japan's Nuclear and Industrial Safety Agency, NISA at the Fukushima Daiichi (number one) site and later at the Fukushima Daiini (number two) site Boiling Water Reactors, BWRs after a combined earthquake of magnitude 8.9-9.0 on the Richter scale near the east coast of Honshu, and a tsunami event generating a 15-24 m high wave. The earthquake event is designated as the Tohoku-Chihou-Taiheiyo-Oki earthquake.

Figure 29. Tsunami damage at Onagawa, March 11, 2011, Japan.

Official records dating back to the year 1600 inspired the deterministic or mechanistic safety analysis design of the plant to withstand the strongest earthquakes at the 8.6 magnitude level for the Fukushima prefecture. The Jogan earthquake in the year 869 produced a tsunami that reached 2.5 miles or 4 km inland with waves 26 ft or 8 m high at Soma, 25 miles north of the plant site. The plant was built on a 14-23 feet or 4.3-6.3 m high cliff offering natural protection against tsunamis. The tsunami wave more than 14 m (46 ft) high that originated 125 miles (200 kms) to the East, impinged on the 6 m protective wall and drowned the Fukushima Daiichi nuclear power plant site. According to Tepco's calculations, the maximum probable tsunami at Fukushima was at 5.7 meters. A 1960 contemporary tsunami in Chile that was caused by a 9.5 magnitude earthquake that produced a 10.5 ft high tsunami wave was used as a reference point for an 18-foot or 5.7 m design point, below the 27-ft or 8.2 m event.

The location is 150 miles or 250 km north of the greater urban area of Tokyo inhabited by 30 million people, and 40 miles from the earthquake epicenter in the Pacific Ocean. It is the most powerful earthquake event in Japan since the start of record-keeping in the 1800s. A folk legend describes the Japanese Islands as lying on the back of a giant fish in the ocean that is constantly twitching and trembling.

MEGA TSUNAMIS

Mega tsunamis can be caused by a massive landslide caused by an earthquake or an astral impact event. Waves 100-300 meters in height can result. Mega-tsunamis could inundate islands and coastlines over significant parts of the Earth causing large scale destruction..

The Hawaiian Islands chain suffered70 major landslides and mega-tsunamis over the past 20 million years giving a periodicity of about 250,000-300,000 years. Landslides associated with tectonic and volcanic activity in the Canary and Cape Verde Islands in the Eastern Atlantic have a high likelihood of generating mega-tsunamis.

HURRICANES, TYPHOONS, TROPICAL CYCLONES

INTRODUCTION

Hurricanes, cyclones, and tropical typhoons are all the same weather phenomenon. The different names refer to their occurrence at different places. In the Atlantic and Northeast Pacific, the term "hurricane" is used. In the Northwest Pacific it is called a "typhoon." "Cyclones" occur in the South Pacific and Indian Ocean.

A statistical analysis by Greg Holland of the National Center for Atmospheric Research, (NCAR), and Peter Webster of Georgia Institute of Technology was published in July 2007 by the Royal Society of London reported that twice as many Atlantic hurricanes formed each year from 1995 to 2005, on average, than formed during parallel years a century ago.

During Hurricane Hugo in 1989, the drawbridge that links Charleston, South Carolina, with Sullivan Island, was rotated around its foundation.

INCREASED FREQUENCY

Research concluded that warmer sea surface temperatures and altered wind patterns associated with global climate change are responsible for the increase in frequency. The increases over the last century correlate closely with sea surface temperatures, which have risen by about 1.3 degrees Fahrenheit in the last 100 years. The changes in sea surface temperatures took place in the years before to the sharp increases in storm frequency; with a sea surface temperature rise of 0.7 degrees Fahrenheit leading up to 1930 and a similar rise leading up to 1995 and continuing ever after.

The analysis identified three periods since 1900, separated by sharp transitions, during which the average number of hurricanes and tropical storms increased and then remained elevated and relatively steady:

1. The first period, between 1900 and 1930, saw an average of six Atlantic tropical cyclones each year, of which four were hurricanes and two were tropical storms.
2. From 1930 to 1940, the annual average increased to 10, consisting of five hurricanes and five tropical storms.
3. In the third period, from 1995 to 2005, the average reached 15, of which eight were hurricanes and seven were tropical storms. This last period has not yet stabilized, which means that the average hurricane season may be even more active in the future.

For comparison, for the 2007 Atlantic hurricane season, the NOAA scientists predicted 13 to 17 named storms, with seven to 10 becoming hurricanes, of which three to five could become major hurricanes of Category 3 strength or higher. An average Atlantic hurricane season brings 11 named storms, with six becoming hurricanes, including two major hurricanes.

INCREASED INTENSITY

According to the 2007 assessment report of the Intergovernmental Panel on Climate Change (IPCC), on a global scale, there has been an increase in hurricanes and tropical storms intensity and it is "more likely than not" that there is a human contribution to the observed trend of hurricane intensification since the 1970s.

Future hurricanes will be even more intense, the IPCC predicted, suggesting: "It is likely that future tropical cyclones (typhoons and hurricanes) will become more intense, with larger peak wind speeds and more heavy precipitation" associated with ongoing increases of tropical sea surface temperatures.

A hurricane that hit Galveston Island, Texas, in 1900 killed more than 6,000 people and is claimed to be the worst natural disaster in USA history.

Hurricane Mitch resulted in 11,000 deaths and 8,000 persons missing in South America on October 26, 1998.

SAFFIR-SIMPSON HURRICANE SCALE

The Saffir-Simpson Hurricane Scale is a 1-5 rating based on the hurricane's present intensity. This is used to give an estimate of the potential property damage and flooding expected along the coast from a hurricane landfall. Wind speed is the determining factor in the scale, as storm surge values are highly dependent on the slope of the continental shelf and the shape of the coastline, in the landfall region.

Table 11. The Saffir-Simpson Hurricane Scale.

Category	Description
1	Winds 74-95 mph, 64-82 kt or 119-153 km/hr.

	Storm surge generally 4-5 ft above normal. No real damage to building structures. Damage primarily to unanchored mobile homes, shrubbery, and trees. Some damage to poorly constructed signs. Also, some coastal road flooding and minor pier damage. Hurricane Lili of 2002 made landfall on the Louisiana coast as a Category One hurricane. Hurricane Gaston of 2004 was a Category One hurricane that made landfall along the central South Carolina coast.
2	Winds 96-110 mph, 83-95 kt or 154-177 km/hr. Storm surge generally 6-8 feet above normal. Some roofing material, door, and window damage of buildings. Considerable damage to shrubbery and trees with some trees blown down. Considerable damage to mobile homes, poorly constructed signs, and piers. Coastal and low-lying escape routes flood 2-4 hours before arrival of the hurricane center. Small craft in unprotected anchorages break moorings. Hurricane Frances of 2004 made landfall over the southern end of Hutchinson Island, Florida as a Category Two hurricane. Hurricane Isabel of 2003 made landfall near Drum Inlet on the Outer Banks of North Carolina as a Category 2 hurricane.
3	Winds 111-130 mph, 96-113 kt or 178-209 km/hr. Storm surge generally 9-12 ft above normal. Some structural damage to small residences and utility buildings with a minor amount of curtainwall failures. Damage to shrubbery and trees with foliage blown off trees and large trees blown down. Mobile homes and poorly constructed signs are destroyed. Low-lying escape routes are cut by rising water 3-5 hours before arrival of the center of the hurricane. Flooding near the coast destroys smaller structures with larger structures damaged by battering from floating debris. Terrain continuously lower than 5 ft above mean sea level may be flooded inland 8 miles (13 km) or more. Evacuation of low-lying residences with several blocks of the shoreline may be required. Hurricanes Jeanne and Ivan of 2004 were Category Three hurricanes when they made landfall in Florida and in Alabama, respectively.
4	Winds 131-155 mph, 114-135 kt or 210-249 km/hr. Storm surge generally 13-18 ft above normal. More extensive curtainwall failures with some complete roof structure failures on small residences. Shrubs, trees, and all signs are blown down. Complete destruction of mobile homes. Extensive damage to doors and windows. Low-lying escape routes may be cut by rising water 3-5 hours before arrival of the center of the hurricane. Major damage to lower floors of structures near the shore. Terrain lower than 10 ft above sea level may be flooded requiring massive evacuation of residential areas as far inland as 6 miles or 10 km .

	Hurricane Charley of 2004 was a Category Four hurricane made landfall in Charlotte County, Florida with winds of 150 mph. Hurricane Dennis of 2005 struck the island of Cuba as a category 4 hurricane.
5	Winds greater than 155 mph, 135 kt or 249 km/hr. Storm surge generally greater than 18 ft above normal. Complete roof failure on many residences and industrial buildings. Some complete building failures with small utility buildings blown over or away. All shrubs, trees, and signs blown down. Complete destruction of mobile homes. Severe and extensive window and door damage. Low-lying escape routes are cut by rising water 3-5 hours before arrival of the center of the hurricane. Major damage to lower floors of all structures located less than 15 ft above sea level and within 500 yards of the shoreline. Massive evacuation of residential areas on low ground within 5-10 miles (8-16 km) of the shoreline may be required.

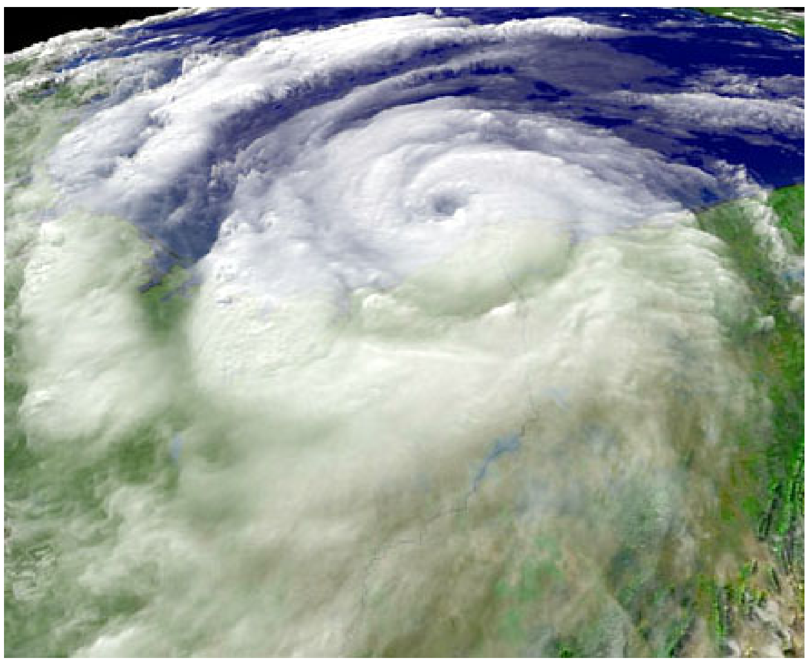


Figure 30. Hurricane Dolly, July 23, 2008. Photo: NASA.

Only three Category 5 hurricanes have made landfall in the USA since records began:

1. The Labor Day Hurricane of 1935. The 1935 Labor Day Hurricane struck the Florida Keys with a minimum pressure of 892 mb, the lowest pressure ever observed in the USA.
2. Hurricane Camille in 1969. Hurricane Camille struck the Mississippi Gulf Coast causing a 25-foot storm surge, which inundated Pass Christian.
3. Hurricane Andrew in August, 1992.

Hurricane Wilma of 2005 was a category 5 hurricane at peak intensity and is the strongest Atlantic tropical cyclone on record with a minimum pressure of 882 mb.

HURRICANE KATRINA

Hurricane Katrina a category 5 storm over the Gulf of Mexico, was still responsible for at least 81 billion dollars of property damage when it struck the USA Gulf Coast as a category 3.

It is by far the costliest hurricane to ever strike the USA.

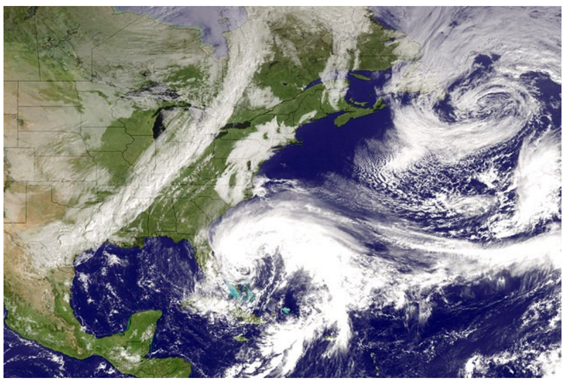
Figure 31. Hurricane Katrina. Photo: NOAA.

Figure 32. Damage to housing at Pensacola Beach, Florida from hurricane Dennis struck the island of Cuba as a category 4 hurricane. July 16, 2005. FEMA photograph.

HURRICANE SANDY

Hurricane Sandy, the biggest Atlantic storm in history, caused 75 USA deaths and blacked out millions of homes and businesses. New York City was hit especially hard, with widespread power outages and significant flooding in parts of the city. Six Northeast refineries with 1.17 million barrels a day of processing capacity shut or operated at reduced rates because of the storm, according to the USA Energy Department. The economic loss from the Texas-size storm reached $50 billion.

Hurricane Sandy resulted in 8 million homes without power, hundreds of thousands of people evacuated, more than 15,000 flights grounded factories, stores, and hospitals shut and lower Manhattan Island, New York, dark, silent, and flooded.



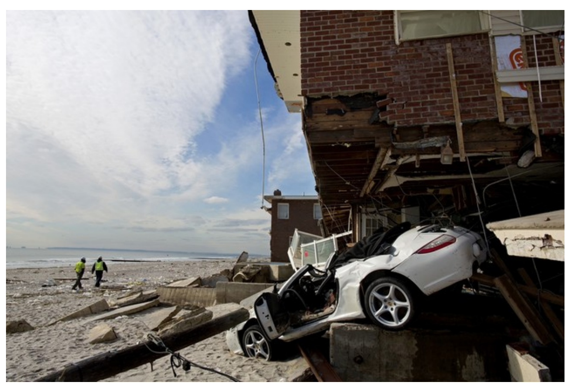


Figure 33. Damage from Hurricane Sandy in the borough of Queens, New York, October 26 - November 1, 2012. Source: NASA.

Climate change is thought to be a factor that contributes to such large storms. The oceans are warmer, providing more energy for storms. The Earth's atmosphere has warmed, so it retains more moisture, which is drawn into storms. As an Atlantic hurricane moving up the East Coast, it crashed into cold air dipping south from Canada. The collision supercharged the storm's energy level and extended its geographical reach. Pushing that cold air south was an atmospheric pattern, known as a blocking high, above the Arctic Ocean. There is evidence that that Arctic ice melting linked to global warming contributes to the very atmospheric pattern that sent the frigid burst down across Canada and the eastern USA.

SUPER TYPHOON HAIYAN, NOVEMBER 2-12, 2013

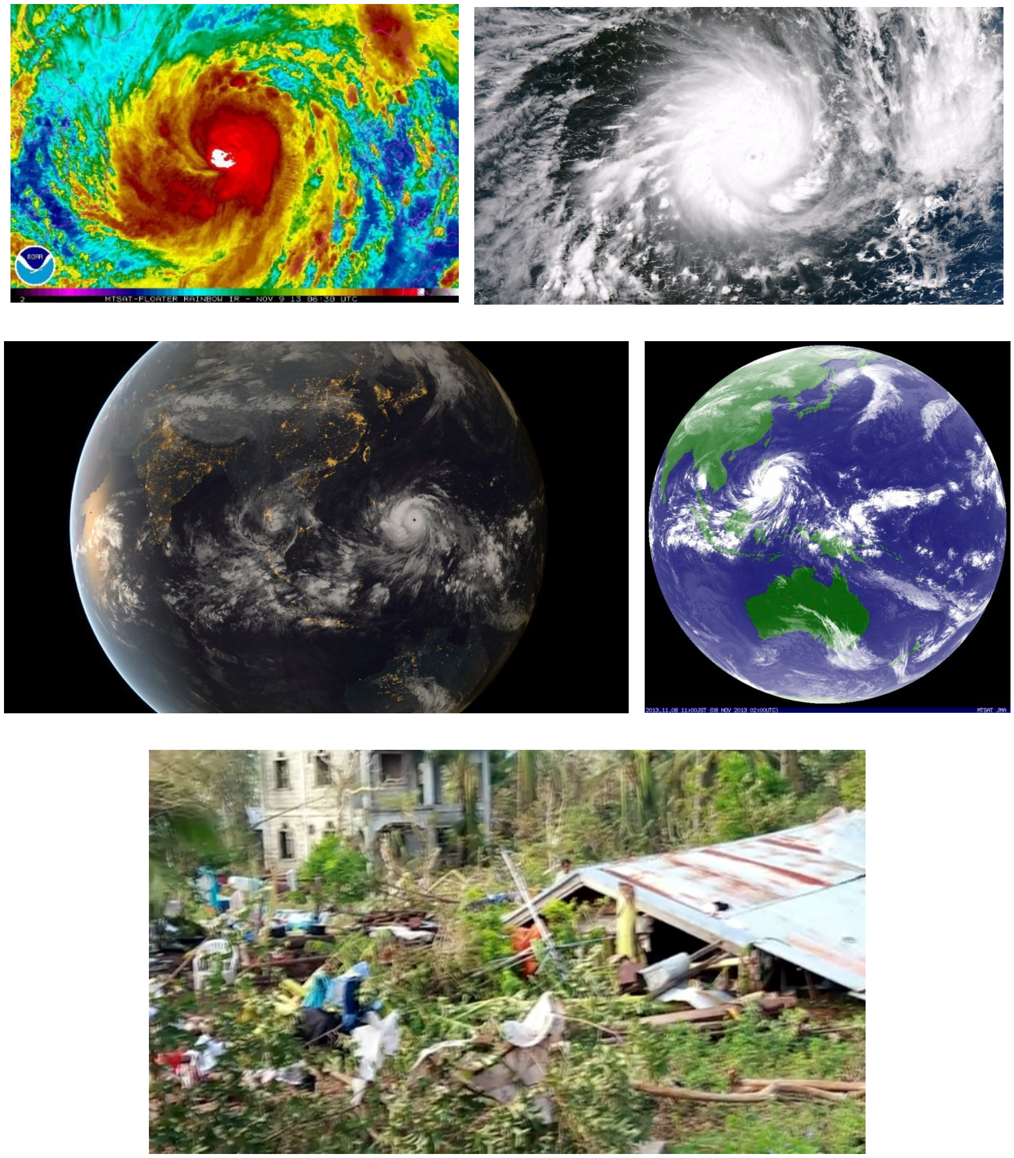


Figure 34. Super typhoon Haiyan, November 2-12, 2013.

Since 1950 the Pacific Ocean waters have been warming at a rate 15 times faster than the rest of the seafloor. This suggested to some that the ocean depths may store more heat from global warming than suspected. The Pacific Ocean, in particular, seems to be absorbing more heat than at any other time in the past 50 years.

The strength of tropical storms is linked to ocean temperature, and in 2013 the western-north Pacific was subject to 30 major storms by early November. Thirteen of them were typhoon-strength, the biggest by some way being typhoon Haiyan, possibly the most powerful tropical cyclone to make landfall in recorded history. Haiyan smashed into the southern Philippines, killing 6,000 people and wreaking massive damage.

"NUKING" HURRICANES

During a speech at the National Press Club in 1961, Francis Riechelderfer, head of the USA Weather Bureau, said he could "imagine the possibility of someday exploding a nuclear bomb on a hurricane far at sea", to dissipate its energy. The idea gets floated during hurricane season.

Nuclear weapons on a hurricane might would not alter the storm and the radioactive fallout would fairly quickly move with the trade winds to affect land areas. The heat release of a hurricane is equivalent to a 10 Mt of TNT equivalent nuclear explosive exploding every 20 minutes.

Attacking weak tropical waves or depressions before they have a chance to grow into hurricanes is not a promising option. About 80 of these disturbances form every year in the Atlantic Ocean basin but only about five become hurricanes in a typical year. There is no way to tell in advance which ones will develop.

As part of the Plowshare Program, in nearly 20 years, the USA exploded 31 nuclear devices in 27 tests in order to test whether America's nuclear arsenal could be used to excavate canals or mines, or create a harbor for ships. Current international treaties bar the exploding nuclear weapons in the atmosphere.

TORNADOES

INTRODUCTION

Tornadoes are violent wind vortices occurring on the back edges of storms. The rotation can generate wind speeds reaching 480 km/minute. The center of the tornado is characterized by a low air pressure region. They are limited by size but they can leave vast areas of destruction and death in their paths.

Fatalities are primarily caused by flying objects and collapsed structures. Due to the skip movement of a tornado, it could leave some areas utterly wrecked while neighboring areas are miraculously spared.

The March 1925 multistate tornado was the deadliest in USA history. It followed a path through the states of Indiana, Missouri, Illinois, Kentucky, and Tennessee leaving massive destruction and 689 dead people.

The town of Frankfurt, Illinois was reduced to rubble and 197 of its residents were killed. At Murphysboro, Illinois, the Longview School was reduced to ruins with 60 children killed. Another 150 people of the town residents were killed.

FUJITA-PEARSON SCALE

Tornadoes strength is measured on the Fujita-Pearson scale. It is a logarithmic scale varying from F-0 to F-6. It should be noticed that small tornadoes could be more destructive than larger ones since their energy is concentrated in a small volume.

Table 12. The Fujita-Pearson scale for tornadoes strength.

Fujita-Pearson Scale	Wind Speed [miles/hour]	Typical Effects
F-0	40-72	Tree branches break.
F-1	73-112	Mobile homes moved off their foundations.
F-2	113-157	Considerable damage, mobile homes demolished, trees uprooted.
F-3	158-205	Roofs and walls blown down, cars thrown around.
F-4	206-260	Well-constructed buildings demolished.
F-5	261-318	Massive destruction, autos thrown away to a distance of 100 meters.

Figure 35. Tornadoes occur at the back edges of storms. Roping tornado and ground debris. Photo: NOAA.

TORNADOES CLASSIFICATION

Tornadoes are categorized by size, appearance and how they form. Tornadoes that touch the ground for long periods of time may transition from one type to another as it changes in size and shape throughout its life cycle.

1. Rope tornadoes

Rope tornadoes are some of the smallest and most common types of tornadoes, getting their name from their rope-like appearance. Most tornadoes begin and end their life cycle as a rope tornado before growing into a larger twister or dissipating into thin air. Some may last for only a few brief minutes, retaining their ropelike appearance the entire time that they are in contact with the ground. Despite their small size, they can be dangerous to those in their path.

Figure 36. Rope tornado, Litchfield, Minnesota, July 11, 2016. Photo: Matthew McKeever. Accuweather.

2. Cone tornadoes

Cone tornadoes, similar to rope tornadoes, get their name from their shape. They are narrower where they touch the ground than where they meet the base of the associated thunderstorm. These are generally more dangerous than rope tornadoes as their paths tend to be wider and they can leave a larger trail of damage. A stovepipe tornado is similar to a cone, the main difference being that they are generally the same width at the base of the thunderstorm as where they meet the ground.

Figure 37. A cone tornado west of Manitou, Oklahoma, November 7, 2011. Photo: Chris Spannagle / NOAA, Accuweather.

3. Wedge tornadoes

Some of the largest and most destructive tornadoes in history fall in the category of a wedge tornado. Wedge tornadoes can appear wider than they are tall, and they can leave behind a large trail of destruction in their wake that is a half-mile wide or greater, and for anything in the path of a wedge tornado, there is going to be some type of damage. Wedges are usually major tornadoes, meaning that they are given the rating of an EF-3 or higher. Some of the worst tornadoes in history were wedge tornadoes, including the El Reno tornado that tracked across Oklahoma on May 31, 2013. This was the widest tornado ever recorded, growing to 2.6 miles wide during the height of the storm.

Figure 38. A wedge tornado, Rochelle, Illinois, April 9, 2015. Photo: Tom Purdy, Accuweather.

4. Multi-vortex and satellite tornadoes

Supercell thunderstorms can produce multiple tornadoes throughout the life of the storm, but others may produce multiple twisters at the same time. Supercell thunderstorms are organized storms that have a strong circulation. This circulation is what helps lead to the formation of a tornado. Multi-vortex implies at least two, if not more, little areas that are swirling around the main parent circulation causing further damage.

Figure 39. Multi-vortex tornado, Dallas, Texas, April 2, 1957. Photo: NOAA, Accuweather.

While multi-vortex tornadoes have small ropes spinning around them, in extreme cases, a storm can produce two tornadoes spinning independently of each other. When this occurs, the second tornado that forms is called a "satellite tornado." These are extremely rare and can lead to multiple trails of damage in the wake of the storm.

Figure 40. Two satellite tornados, Pilger, Nebraska, Monday, June 16, 2014. Photo: AP Photo / StormChasingVideo.com, Accuweather.

5. Waterspouts and land-spouts

Waterspouts and land-spouts look like tornadoes, but they develop when no thunderstorms are in the area. Although waterspouts are always tornadoes by definition; they do not officially count in tornado records unless they hit land. While some waterspouts develop the same way that tornadoes do, many are not associated with supercell thunderstorms. These fair-weather waterspouts are more common than their counterpart and can develop under clouds such as those associated with lake-effect rain and snow showers around the Great Lakes. They are smaller and weaker than the most intense Great Plains tornadoes but still can be quite dangerous. Despite being weaker than most tornadoes, they can still be strong enough to overturn boats and create rough seas.

Figure 41. Waterspout, St. Johns River, Jacksonville, Florida, June 26, 2009. Photo: AP Photo / The Florida Times-Union, Will Dickey, Accuweather.

Landspouts are similar to waterspouts as they can develop when there is not a supercell thunderstorm present with the right conditions for a weak vortex to form, and it is just enough to connect from the ground to the apparent rain shower or thunderstorm above. They tend to be very weak and short-lived lasting for only a few minutes. However, they can be strong enough to cause some damage equivalent to an EF-0 tornado.

DROUGHTS, DUST STORMS AND DESERTIFICATION

INTRODUCTION

Droughts are catastrophic shortages of water, primarily caused by a lack of precipitation. They are classified in different ways:

1. A meteorological drought is a measure of rain due to climatic conditions. A meteorological drought in a given region may not be a drought in another.
2. Agricultural droughts occur when the moisture in the soil does not meet the growing needs of a particular crop.
3. A hydrological drought happens when the water supplies in wells from aquifers, lakes or streams are low.
4. Socioeconomic droughts start when populations, communities and economies are affected.

Droughts are exacerbated by human competition for the remaining water resources, resulting in national and civil wars, mass migrations and social dislocations.

In 1875 in the USA Great Plains, drought was accompanied by a locust plague of epic proportion. A locust plague extending 110 miles wide and 1,800 miles long covered the region from Canada to Texas.

On July 26, 1931, a swarm of grasshoppers descended on the crops in the American heartland , devastating millions of acres in Iowa, Nebraska, and South Dakota. The swarm was so thick that it blocked out the sun and people could scoop the insects with a shovel. Corn stalks were eaten to the ground and fields were left completely denuded of vegetation.

Droughts could result in forest and grass fires in the accumulated dry brush, and can be started by lightning strikes from storms, from negligence in the management of fires, from sparks from trucks, trains, and cars exhaust along highways, and even from malicious acts of vandalism and arson.

AMERICAN DUST BOWL, 1931-1939

Long lasting droughts associated with overgrazing and excessive plowing and removal of the plant cover in fragile soil would destroy the top soil and can turn a once fertile land into a barren sand or salt desert. Drought conditions lasted for eight years from 1931 to 1939 bankrupting 250,000 farmers across the Great Plains. In areas prone to wind erosion, large tracts of land were reconverted into grasses for grazing or abandoned altogether, from growing field crops. Oklahoma now has less than 10 million acres of cultivated farmland, less than half the farmland that initially existed.

Severe droughts combined with poor soil conservation practices can lead to extreme topsoil erosion, with devastating effects on the arable land. This occurred in the Great Plains region of the USA during the 1930s Dust Bowl years. Soil conservation measures such as the practice of no-till planting have mitigated their effects.

The rapid uprooting of millions of acres of prairie grass for the cultivation of wheat contributed to a series of huge storms that eventually drives out 25 percent of the population of the affected area in the southern Great Plains. Farming practices changed, a decade-long drought ended in the late 1930s, and life returned to normal, as the promises of the land boom that led to the crisis were long forgotten.

On May 11, 1934, a dust storm carried out 350 million tons of eroded topsoil from the parched Great Plains all the way to Washington D. C., New York City, Boston and Atlanta in the USA. The dust reached 300 miles offshore and collected on ships decks. This was a distance of 2,400 km or 1,500 miles away. In 1935, the USA established the Soil Conservation Service to promote good soil management practices.

Figure 42. Dust Storm cloud engulfing a Kansas town during the Dust Bowl, 1935. Photo: NOAA.

Figure 43. Oklahoma dust bowl, 1936. Library of Congress.

Figure 44. Ulysses, Kansas dust storm, 1935.

Figure 45. Phoenix, Arizona Haboob dust storms, July 2011 and October 17, 2015.

Dust storms could last 3-4 days and the winds carrying the black clouds raged as fast as 100 miles per hour. Dust filtered through the doors and window frames of houses, keyholes and chimneys, covering everything inside homes with a layer of dirt.

Thousands of people throughout the 1930s contracted various respiratory diseases, including strep throat and dust pneumonia. People wore damp towels around their faces to walk around. Windswept sand dunes piled overnight against barns to allow cows to walk above their roofs. Dust had to be shoveled like snow in a blizzard as it piled in front of house's doors as people tried to get out.

The Arkansas River which often flooded in previous years had completely dried by August of 1934. A Little Rock, Arkansas, resident placed a "for sale" sign on the dry bed.

Farmers throughout the Midwest and the Great Plains from Colorado, Kansas, Oklahoma and Texas, abandoned their home sites as conditions became too harsh to bear. During the storms, people sought shelter inside overturned cars or wagons or nearby cellars. In the 1930s, a large migration of "exodusters" occurred to the state of California for seasonal employment and migrant agricultural work. These exodusters picked out lettuce, peaches, prunes, oranges, asparagus, cotton and flax for large agribusinesses, as long as there were crops in the fields for below poverty level wages.

The Red Cross provided thousands of dust masks. The CCC conservation corps was formed and dispatched to plant trees and to dam up rivers and streams. It planted 200 million trees along a thousand miles belt to slow the killer winds and storms. The dams helped the areas in which they were located by slowing the path of water into rivers and streams.

Human accelerated soil erosion continues to occur because much of the Great Plains expanse of land is suited to moderate grazing rather than for extensive farming. In 1975, the Council of Agricultural Science and Technology warned that severe drought in the Great Plains could eventually trigger another Dust Bowl.

In 2012, more than 60 percent of the contiguous USA suffered drought conditions affecting 80 percent of the country's agricultural land.

DESERTIFICATION

In semiarid grasslands, such as the Sahel region of Africa, dust storms are often generated where the ground has been stripped of vegetative cover by cultivation or grazing. The path of dust from a single desert storm can be traced as far as 4,000 km or 2,500 miles.

Desertification occurs when land surfaces are transformed by human activities, including overgrazing, deforestation, surface land mining, and poor irrigation techniques, during a natural time of drought. Desertification in the Sahel Region of Africa can largely be attributed to greatly increased numbers of humans and their grazing cattle in addition to the effects of global warming.

Most overgrazing is caused by excessive numbers of livestock feeding too long in a particular area. Extreme overgrazing results in the compaction of the soil and diminishes its capacity to hold water, and exposes the soil to erosion.

The relationship between drought, climate change and human influences is rather complex, and desertification can be successfully mitigated if financial resources for water capture and management are available. However, exploding population growth in developing African nations means that pressures on the land there will continue to intensify.

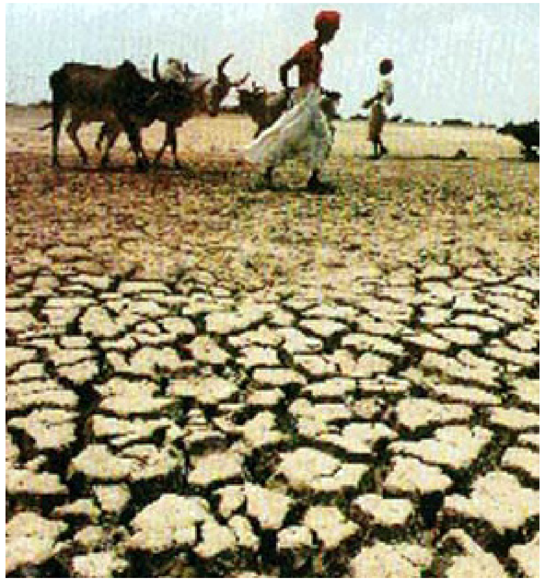


Figure 46. Parched agricultural land in India.

Figure 47. Drought in Ethiopia, 2010. Carmi, Illinois, USA 2012 drought. Photo: AP.

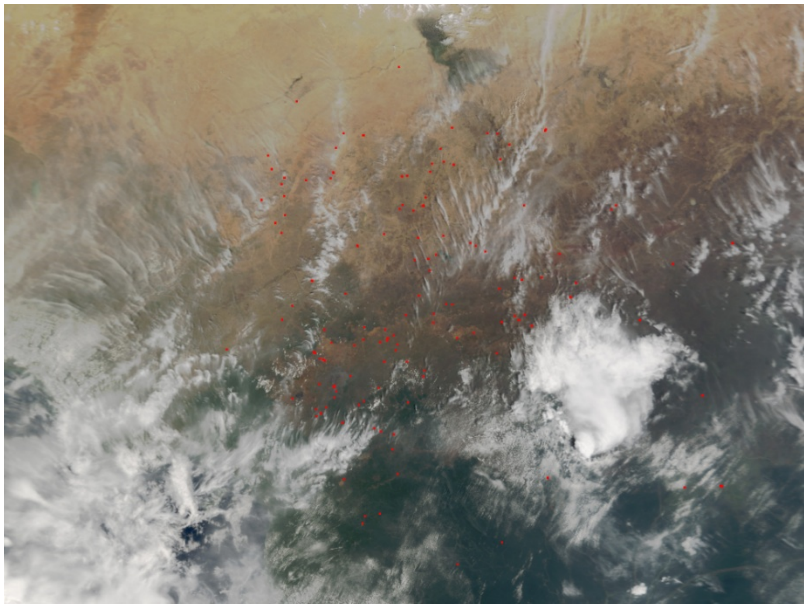


Figure 48. Fires smoldering throughout the Sahel region in Africa result in dust storms, March 2, 2001. The arid grasslands of the Sahel are to the north at the top of the image. The fan shaped green area is Lake Chad that is shrinking in size. To the center and south of the region, in northern Nigeria, northern Cameroon and southern Chad, increased annual rainfall results in a gradually increasing tree cover and a darker appearance of the Sudanese woodlands. Photo: NASA.

SAHEL REGION FIRES

The Sahel, or Sahelian Zone, lies south of the Sahara Desert in North Africa. The dry savanna environment is particularly prone to devastating drought years. Several years of abnormally low rainfall alternate with several successive years of average or higher than average rainfall. Since the late 1960s, the Sahel has endured an extensive and severe drought.

In March and April of each year, thousands of fires smolder in the grasslands, scrub, and dry forests of the West African Sahel and the Sudanese woodlands.

The Sahel of West Africa is of great importance to regional economies and human welfare. While water is always scarce in the Sahel, even during the brief rainy season between June and September, the grasslands provide high quality grazing for domestic livestock such as cattle, sheep and goats.

The human populations to the south rely on the Sahel's grasslands as summer grazing for their herds in a land usage system known as "transhumance." In such a system, large numbers of animals travel north into the Sahel every year. The grasslands and woodlands of the Sudanese zone are less nutritious for domestic animals, but the higher rainfall allows more agriculture.

Fire is used to clear new agricultural land and to improve grazing potential of the natural vegetation by removing dead grass and promoting new growth. Many fires in the Sudanese zone are also ignited by lightning strikes. During the long Sahel dry season water supplies limit cattle numbers and many herds travel south again to winter on crop residues in the south. In this way, they provide much needed organic manure fertilizer to the fields.

Fire has been used for centuries as a management tool in West African agricultural and pastoral systems. However, increasing human populations and food production requirements can reduce the length of the fallow periods and increase the frequency of fire usage. In this situation, the benefits of fire as a management tool can be outweighed by the negative impacts of fire on soil fertility, leading to a long term decline in productivity.

FLOODS AND MUD SLIDES

INTRODUCTION

Flooding can occur naturally after a sudden deluge of rain, sending streams out of their banks. They may also occur when weather systems persist a long period of time over a defined region, saturating the ground with runoff causing river banks to overflow. This happened on the Mississippi River in 1993 and then again in 2008.

Flooding can occur from the breach of man-made structures such as dams, levees an dikes resulting from poor engineering and lack of maintenance.

Cholera cases among the March 14, 2019 cyclone survivors in Mozambique have reached 271 by April 2nd, 2019 adding to a death toll of 571 from the cyclone. Doctors Without Borders reported some 200 likely cholera cases per day in the city of Beira of half a million residents, where relief workers were hurrying to restore the damaged water system. Cholera is spread by contaminated food and water and can kill within hours if not treated. Cholera is endemic to the region, and it breaks out fast and it travels extremely fast.

Epidemiologists speculate that a flooding event in the Central Asian steppes triggered the 1347 Eurasian bubonic plague outbreak through the widespread multiplication of rodents such as mice and rats carrying fleas as a disease spread vector. Rumors of a mass human die-off in India reached Europe in the mid 1340's. The Mongols besieging the coastal city of Trebizond on the shore of the Black Sea catapulted bubonic plague infested corpses over the city walls and Italian merchant ships fleeing Trebizond carried the infestation to Genoa which foolishly permitted the dying crews to land. Rodents hosting plague spreading fleas typically inhabit arid grassland regions such as the Great Plains of America and the semi deserts of California and New Mexico and flooding in these regions such as in 2019 in the states of Nebraska and Iowa can initiate hazardous epidemic events.

Figure 49. Rushing flood waters washing away house in Wisconsin, USA, Spring 2008.

Figure 50. Levee breached on Missouri River near Montescue, Missouri, March 31, 2019. At least 62 levees had been breached or overtopped in the American Midwest in March 2019, and hundreds of miles of levees had sustained damage.

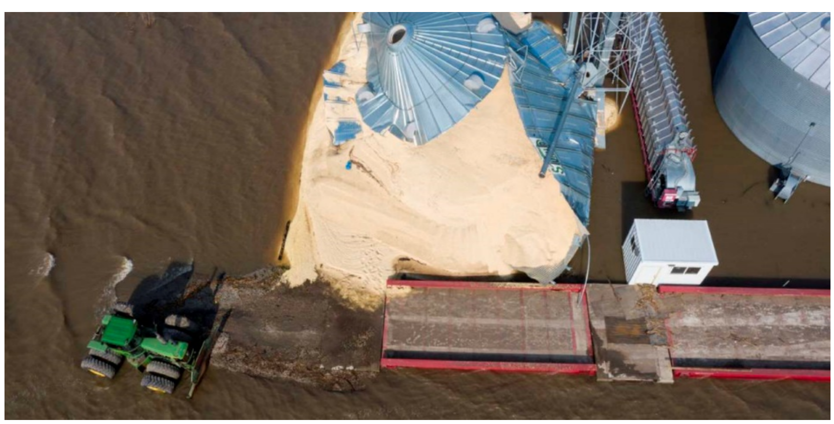


Figure 51. Grain bin collapse due to flooding at Hamburg, Iowa, March 2019. In the Great Flood of 1927, 27,000 square miles were inundated in the USA and one million people were displaced.

BREACH OF TETON DAM, 1976

The Teton Dam on the Snake River near Idaho Falls, Idaho, was considered as a poor civil engineering project fed by pork barrel politics. As the project was reaching completion and the reservoir was being filled, a large leak formed, and, on June 5, 1976, the developing project came to an abrupt and tragic end. Two bulldozers were used in trying to stem the developing leak. They were both were carried out by the flood.

The water rushed at fifteen miles per hour and covered several small towns downstream in the Snake River Valley. Fourteen people lost their lives. It caused $500 million in economic damage.

Figure 52. Breach of Teton Dam on June 5, 1976. Photo: Eunice Johnson.

BUFFALO HOLLOW DAM, 1972

On February 26, 1972, a slag pile dam collapse occurred at Buffalo Hollow in Logan County, West Virginia, giving way to 20 million cubic feet of water. First, the small village of Saunders had its houses and churches swept in front of the flood. The next village of Pardee had no defense against a 40 feet high wall of black water. Lorado, the next town down the valley, the water destroyed the homes of 500 residents and tore the railroad rails from their ties. The towns of Lundale, Stowe and Crites followed. Halfway through the hollow, the water was still 20 feet high and spread out to 500 yards across. When the water reached the village of man at the mouth of the hollow, the water carried tons of mud into homes and businesses.

The death toll was 114 known dead, 4 unknown dead, and twenty people missing.

The Appalachian Mountains are rich in coal deposits and are home to many mining camps using strip mines or underground shaft mines.

The Lorado Mining Company during World War II strip mined coal from the sides of the mountains at Buffalo Hollow. The slag which is the slate and rock covering the coal or taken from mining shafts, was dumped into a narrow valley near5 the head of the hollow.

Over the years, the slag dammed up the hollow's tributary system creating a long lake behind the dump. After the war the Buffalo Mining Company, owned itself by the Pittston Company, bought the mines and continued strip mining. More strip mining caused the rainfall to flow directly into the lake. The seepage water pumped from the mine shafts was pumped at the rate of 360,000 gallons per year and discharged into three lakes which filled up with acid black water.

On February 26, 1972, the water in one of the lakes was one foot from the top of the slag pile. The sheriff and the mine employees spread the word about the dangerously high water level, but few residents took heed.

The buffalo Mining Company disclaimed responsibility as the state of West Virginia had not allowed the company to release water from the lakes to relieve pressure on the slag pile. The Pittston Company settled out of court a damage suit by the residents for $13.5 million, for an average of $20,640 per plaintiff.

Figure 53. Cars and road buried in a mud slide.

PAKISTAN MONSOON FLOOD, 2010

In July 2010, the monsoon rains have caused the rivers in large parts of Pakistan to spill over their banks, transforming entire provinces into giant lakes. The United Nations estimated at least 20 million people have been affected by the floods, people whose homes and fields were destroyed, who lost their entire possessions and, because of a lack of clean drinking water, were forced to drink from the polluted flood waters flowing by and suffering from diarrhea.

More than 1,600 people have died in the flooding. At least 6 million people needed urgent supplies and care. And disease such as dysentery and cholera and a lack of drinking water and food rapidly increased the number of fatalities.

The Pakistani government failed miserably in its response to the disaster. Around 60,000 soldiers were attempting to provide relief across the country while many more remained stationed on the border shared with India, while another 140,000 soldiers were still occupied with a war on terror.

The USA withdrew helicopters and soldiers from neighboring Afghanistan and redeployed them to evacuate flood victims.

Pakistani President Asif Ali Zardari at the beginning of August, traveled to France and appeared at a castle owned by his family, despite the fact that television stations were already broadcasting footage of entire regions that had been submerged in muddy flood waters.

The masses of water have destroyed rice, sugar, wheat and cotton possibly valued at billions of dollars, with much of the damage being caused along the Indus River and its tributaries. The flooding has destroyed the fields where almost one out of two people find their employment.

As soon as the water has retreated, disputes erupted all over the place over land ownership. The earth walls that demarcate the fields are gone. Judges and prosecutors are often corrupt and there is a tendency for court cases to drag on.

Figure 54. Stranded flood victims in Pakistan's Swat River Valley, August 2010. Source DPA.

Figure 55. Punjab province, Pakistan Flood, August 15, 2010. Source: UN/AP.

Figure 56. Vistula River Flooding of the Village of Swiniary, Poland, May 2010.

Figure 57. Houston (top), and Beaumont (bottom), Texas flooding as a result of Hurricane Harvey, August 27, 2017.

FIRES

LONDON FIRE, SEPTEMBER 2nd, 1666

The Great Fire of London breaks out in the house of King Charles II's baker. When it was finally extinguished, four days later, it had destroyed more then 4/5 of London.

THE GREAT CHICAGO FIRE, OCTOBER 8-10, 1871

The Chicago Evening Journal of October 9, 1871, claimed that the Chicago fire was caused by "a cow kicking over a lamp in a stable in which a woman was milking."

The newspaper contained no illustrations, but a contemporary drawing printed by the Kellogg and Bulkeley Company was entitled: "The Cause of the Great Chicago Fire Oct. 9th 1871," and included the ominous subtitle: "A Warning to all who use kerosene Lamps: Never forget that more lives have been lost, and more comfortable homes burned up by a careless use of this light than any other ever introduced into common use."

The Urban Legend has it that Mrs. O'Leary's cow kicked over the oil lantern in the Patrick and Catherine O'Leary family's barn that started the great Chicago Fire of 1871.

The three-days blaze kills between 200-300 people, destroys 17,450 buildings and leaves 100,000 people homeless.

In 1997, the Chicago City Council exonerated Mrs. O'Leary and her cow.

FIRE PROGRESSION

Critical mistakes were made during the first hours of the fire. The first alarm about the fire that was generated at around 9:00 pm on a Sunday night did not reach the courthouse where the city of Chicago maintained its telegraph fire alarm system. The fire was seen a few minutes later by the watchman on duty at the courthouse, but he dispelled it as being of no significance. At about 9:30 pm he realized that the fire was of significance, and was spreading. He again misjudged the location of the fire and sounded the wrong alarm.

At around 9:45 pm, fully ¾ of an hour after the start of the fire, the first fire-fighting equipment sped up DeKoven Street where the O'Leary's farm was. A mild wind sent sparks flying and thwarted the firemen's efforts.

At 10:00 pm sparks landed on the steeple of the St. Paul's Church, five blocks north of DeKoven Street. A furnishings finishing factory was next to the church, and the fire spread into the building contents of flammable paints, varnishes, and other combustible materials. From then on, the fire was out of control.

By 12:00 pm, strong southwest winds spread the fire across the Chicago River to the South Side. It consumes the Parmelee Omnibus and Stage Company and moved into Conley's Patch; a slum filled with wooden shacks and saloons.

At 1:30 am, the entire business section was on fire, including the post office, the couthouse, the customs house, Crosby's Opera House, and the Field and Lieter dry goods store.

On Monday morning, the fire jumped the Chicago River into Chicago North Side. The residents leaped from their beds, gathered a few belongings they could carry and rushed away from their houses and their lifetime possessions.

The fire destroyed 2,000 acres and 18,000 building of the city of Chicago, which was built primarily of wood and masonry at the time.

AFTERMATH

The rubble from the Chicago fire was dumped on the east side of the town into Lake Michigan and provided a large park and recreation extension of the city along Lake Michigan.

The aftermath of the fire revolutionized the world in that Pittsburgh steel magnate Andrew Carnegie advocated the use of steel in rebuilding the city instead of wood, concrete and masonry.

Since the beginning of civilization buildings had been erected with stone foundations. This limited the practical size of structures to about 50 feet except for the Pyramids of Egypt that are some 400 feet in height.

Andrew Carnegie, looking for new markets for his steel, suggested Chicago be rebuilt using steel foundations. The high strength of steel and its unlimited availability due to Carnegie's adoption and streamlining of the Britisher Bessemer's steel melting and manufacturing process_allowed buildings to be practically constructed to hundreds and eventually one thousand feet in height.

The modern skyscraper and twentieth century urban life was born. This also made Andrew Carnegie the richest man in the world at the time.

Figure 58. Urban legend has it that the cow being milked by Mrs. O'Leary kicked a kerosene lamp that started the Great Chicago Fire, October 9, 1871. Source: Kellogg and Bulkeley Company.

Figure 59. An engraving view from the west side of the Great Chicago Fire depicting the rush of people, October 9, 1871.

Figure 60. Animals seeking refuge in a water-stream during a forest fire.

Figure 61. Helicopters fighting wild fire in California, 2008. Photo: Noah McMurray.

Figure 62. Village of Golo Vanovo fires in the summer of 2010 destroyed one third of the wheat crop in Russia. Amazon region fires following land grab invasion by farmers and tree logging in the Rondonia state region of Brazil, August 2019. Source DPA, BBC.

TEXAS CITY OIL REFINERY FIRE, MARCH 23, 2005

Figure 63. Texas City oil refinery fire, March 23, 2005.

The British Petroleum (BP) oil company operated the Texas City, Texas, refinery. The 1200-acre facility processed up to 460,000 barrels of raw crude oil per day. On March 23, 2005, the steel isomerization unit, which boosts the octane level of gasoline was being restarted after two weeks that it spent offline. The most risky time for an oil refinery or a power plant is when it is in transient state. During a refinery turnaround, some 30,000 separate procedures are performed. Dozens are required to move volatile contents safely out of and into position when the isomerization unit is coming back on line.

As workers restarted a component of the unit, abnormal pressure built up in the production tower, and so three relief valves opened to allow highly volatile gasoline components to escape to the 10 x 20-ft. "blowdown" drum. However so much fuel flooded into the drum that its capacity was rapidly exceeded. Liquid and vapor shot straight up the 113-ft. vent stack, into the open air and ignited.

Refineries separate raw crude oil into its various components, called fractions, by taking advantage of the different boiling point of each. The process of fractional distillation starts with crude petroleum being heated to about 720 ^oF. Hot liquid and vapors enter a distillation column where the vapors cool as they rise, condensing on collection trays at different heights. These liquids, such as naphtha and kerosene, may then be diverted to other units for further processing. Each fuel is made of a distinct chain of hydrocarbons, and manipulating these molecules produces different petroleum products. Cracking units and cokers break large chains into smaller ones to create medium-weight and heavy fuels. Alkylation units combine short chains, forming mainly aviation fuel. Isomerization units rearrange the structure of molecules to turn naphtha into high-octane gasoline.

When a cloud of highly flammable material is ignited, two events occur almost instantaneously, producing two blasts. An initial flash consumes all available oxygen, creating a vacuum. The low pressure suction brings in fresh oxygen. The combustibles explode into a well-fueled deflagration that generates a diverging shock wave that is actually visible as it expands outward at more than 1000 ft. per second. Eleven workers were killed instantly by the blunt force of the shock wave which was followed by a fireball. There may have been as many as five separate explosions in rapid succession.

Within one hour the fire had been contained, and within two, it was nearly out. The toll was15 dead and over 170 injured.

According to the Chemical Safety Board:

> "Computerized records from the control system equipment indicate pressure inside the production tower (1) rose rapidly from 20 psi to 60 psi. This triggered three pressure-relief valves (2) to open for 6 minutes, discharging enough fuel into the blowdown drum (3) to overwhelm the system. Petroleum could not be recycled back through the refinery (4) quickly enough, forcing liquid and vapors up the 120-ft. stack (5). As fuel settled to the ground, it ignited in a blast strong enough to rip the roof off a benzene storage tank 300 yards away. Investigators discovered that a 6-in. drain leading to the plant sewer (6) had been chained open. Fumes traveling under the refinery may have fueled one of what is believed to have been five explosions."

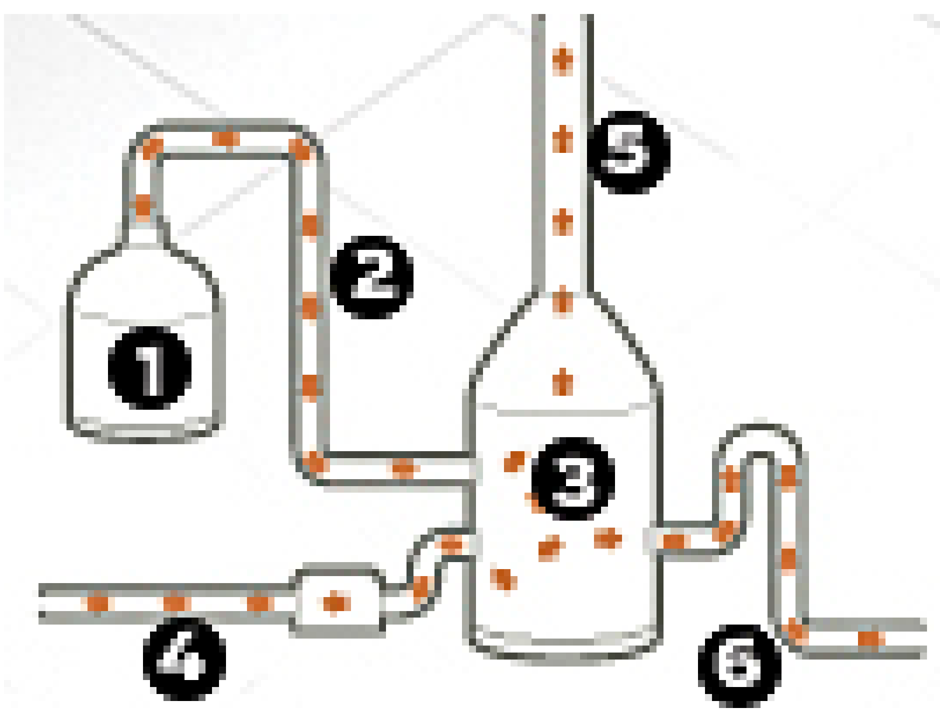


Figure 64. Isomerization unit refinery fire.

Texas City is referred to as "Toxic City," as it is home to 4 chemical plants and 3 refineries. The sprawling BP complex, built in 1934, is the third largest of 149 petroleum refineries in the USA. Since records were kept in 1971, there have been nine other accidents at the refinery that injured or killed workers.

Blowdown drums are a common feature at refineries, as are towers used to release evaporating gases. Most tower vents, however, include a flare system--a sort of pilot light that ignites potentially hazardous vapors as they funnel out. In 1992, the Occupational Safety and Health Administration (OSHA) mandated that the Texas refinery switch to a flare system. Amoco, which merged with BP in 1998, appealed the provision and OSHA withdrew the request. The refinery continued to use stacks that allowed gases to escape.

An accident analysis report confirmed the critical factors which led to the explosion and greatly increased its consequences:

> "Over the years, the working environment had eroded to one characterized by resistance to change, and lacking of trust, motivation, and a sense of purpose. Coupled with unclear expectations around supervisory and management behaviors this meant that rules were not consistently followed, rigor was lacking and individuals felt disempowered from suggesting or initiating improvements.
>
> Process safety, operations performance and systematic risk reduction priorities had not been set and consistently reinforced by management.
>
> Many changes in a complex organization had led to the lack of clear accountabilities and poor communication, which together resulted in confusion in the workforce over roles and responsibilities.
>
> A poor level of hazard awareness and understanding of process safety on the site resulted in people accepting levels of risk that are considerably higher than comparable installations. One consequence was that temporary office trailers were placed within 150 feet of a blowdown stack which vented heavier than air hydrocarbons to the atmosphere without questioning the established industry practice.
>
> Given the poor vertical communication and performance management process, there was neither adequate early warning system of problems, nor any independent means of understanding the deteriorating standards in the plant."

OIL SPILLS

INTRODUCTION

Oil seeps occur naturally and appear as tar balls floating on ocean and lake water surfaces. Weathering and the photochemical breakdown of oil by the sun's radiation on the surface of the oceans plays a major role in natural and accidental oil seepages.

In addition, marine microbes contribute to the breakdown of organic matter. They are ultimately the principal agents responsible for the removal of spilled hydrocarbons from the oceans.

In the usual environment, the oil eating bacteria exist in equilibrium with their surroundings. If there is not much oil in the water, the bacteria are few but if the oil is added, the bacteria bloom. As the bloom progresses, more bacteria eat more of the oil until they deplete their food supply. When the oil food is gone, the bacterial bloom dies off. The result is much less oil, and much more microscopic biomass in the water, which is another source of fish food benefiting the fishing industry.

Volatilization and churning by wave action also removes the low molecular weight hydrocarbons. The remaining dense tar is less toxic to marine fauna and flora than newly spilled petroleum. It is degraded slowly over time by both solar radiation and bacterial action.

EXXON VALDEZ, 1989

The oil tanker Exxon Valdez is owned by the Exxon-Mobil Corporation. It ran aground with its captain apparently under the influence of alcohol. The ship spilled its oil near the coast of Alaska, destroying the local environment and the native wildlife. The ensuing oil spill was the largest ever in the history of the USA.

On March 24, 1989, the ship hit the Bligh Reef near Alaska, opening a large hole on its hull. The ship was full of oil at the time, carrying a total of 1.2 million barrels or 190 million liters of petroleum.

Figure 65. The Exxon Valdez oil tanker oil spill in Prince William Sound, Alaska, March 24, 1989.

The company paid $4.84 billion in cleanup costs, fines, punitive damages and interest for the incident that affected wildlife and the fishing industry.

On July 10, 1992, the Alaska court of appeals overturned the conviction of Captain Joseph Hazelwood. He had been found guilty of negligence in 1989. The Exxon Valdez was renamed as the "Sea River Mediterranean" and continued to transport petroleum, but was legally prohibited from entering Prince William Sound, Alaska.

Large amounts of oil spilled into the ocean. In total, 265,000 barrels of oil or 42 million liters were dumped, which amounted to 22 percent of that present of the ship.

Once out of the ship, the oil spread quickly. It ended up creating a 1,776 square miles or 4,600 square kilometers spill and gave 3,167 miles or 5,100 kilometers of coastline an oily covering.

Between 100,000 and 600,000 birds, 5,500 sea otters, 30 seals, and 22 whales were killed. Many other animals likely died as well and were never found. Other animals, such as bald eagles, that ate the oil contaminated fish from the spill area were also killed.

Figure 66. Oil spill cleanup crew on the coast of California.

Though public outrage eventually mounted, the reaction to the oil spill came slowly. The Alaska Oil Spill Team was slow to respond, and by the time that work on cleaning up the area began, massive amounts of oil had already spread to a large area surrounding the ship.

The Exxon-Mobil Corporation was forced to clean up the spill and fined heavily for the damage it had caused. The company spent $2.2 billion for cleanup work, and the total cost amounted to over $4 billion.

A large amount of oil is spilt every year. In fact, the amount spilt by the Exxon Valdez amounts to just 5 percent of all that was spilt in 1989.

FIRST GULF WAR OIL SPILL, 1991

In a retreat from Kuwait in 1n 1991, the Iraqi army opened the valves of oil well and pipelines and set them on fire in a bid to slow down the advancing USA troops. This led to a spillage of 240-336 million gallons of crude oil into the Gulf; an area about the size of the Island of Hawaii.

Wells sealing and recovery efforts waited until the end of the war. Twenty five miles of booms contained the floating oil above water and 21 skimmers separated the oil from water to protect the inlets to desalination, industrial, and power plants.

With the help of vacuum trucks, about 59 million gallons of oil were recovered from the Gulf.

Considered as the largest ever oil spill, it nevertheless led to little permanent damage to coral ecosystems and fisheries; according to a report by the Unesco's Intergovernmental Oceanographic Commission. Half the oil evaporated, 1/8 was recovered and a quarter washed ashore in Saudi Arabia.

Figure 67. Gulf War oil spill, 1991.

IXTOC 1 OIL WELL, BAY OF CAMPECHE, MEXICO, 1979

An oil well collapsed after a pressure buildup caused an explosion. Over ten months, 140 million gallons of leaked into the Gulf of Mexico.

Mud and steel and lead balls were dropped down the well's shaft to slow down the oil flow. Half the oil burned as it reached the surface and 1/3 evaporated according to the Mexican Petroleum (Pemex) Company. A dispersant was sprayed over 1,100 square miles of the resultant oil slick. Skimmers and boomers were used on the Texas side of the Gulf of Mexico to protect the bays and lagoons at the Barrier Islands.

The dispersant, Corexit 9500, which contains emulsifier soaps and solvents, is feared to be as risky to the environment as the actual oil spill.

ATLANTIC EMPRESS, TRINIDAD AND TOBAGO, WEST INDIES, 1979

In July 1979, two super tankers collided in a night storm off the coast of Tobago in the Carribean Sea, leading to the release of about 88.3 gallons of crude in the largest ship release. Both vessels leaked their oil and caught fire causing the sinking of the Atlantic Empress. It was towed 300 nautical miles offshore where it exploded.

Twenty six crew members lost their lives and 90 million gallons of crude were spilled. The Aegean Captain's fire was controlled and the vessel towed to Curacao to recover its oil shipment.

Dispersants were used sending the oil to the bottom of the ocean and only minor shore pollution was reported on nearby islands.

FERGANA VALLEY, UZBEKISTAN, 1992

About 87.7 million gallons of crude spilled in the Fergana Valley energy and oil refining area and became the largest inland oil spill.

The spill was absorbed by the ground with minor need for cleanup.

NOWRUZ OIL FIELD, 1983

An oil tanker crashed into the Nowruz Field Platform during the Iran-Iraq war in 1983, damaging the oil well under it and spilling 80 million gallons of crude oil.

The rate of leakage was about 1,500 barrels of oil per day, and being within a war zone, it took 7 months before it was fixed.

The spread of the oil was controlled with booms and skimmers by Norpol, a firm from Norway.

Figure 68. Nowruz Oil Field spill, 1983.

ABT SUMMER TANKER, ANGOLA, 1991.

An explosion occurred and caused a fire on board of the tanker ABT Summer on its way to Rotterdam, 900 miles off the coast of Angola.

The 80 million gallons oil slick spanned 80 square miles as the tanker burned for three days then sank.

The high seas broke out the oil that did not burn at a little environmental cost because of the offshore location.

CASTILLO DE BELIVER, SALDANHA BAY, SOUTH AFRICA, 1983

The tanker Castillo de Beliver caught fire at 70 miles northwest of Capetown, South Africa on August 6, 1983, spilling 78.5 million gallons of crude oil.

The burning tanker drifted offshore, broke in half, the stern capsized and sank leading with 110,000 tons of oil in its tanks. The bow section was towed away and a controlled explosion was used to sink it.

AMOCO CADIZ, BRITTANY, FRANCE, 1978

The tanker Amoco Cadiz ran aground off the coast of Brittany after its steering system failed in a severe storm. Its 246,000 tons cargo of light crude spilled into the English Channel seriously affecting marine life.

Strong winds and heavy sea prevented the use of dispersant chemicals of which 3,300 tons were used. About 200 miles of the French shoreline was affected by oil within a month time. Vacuum trucks and agricultural vacuum units were used to pump some the spilled oil, with a large fraction removed by hand.

Figure 69. Amoco Cadiz tanker, Brittany, France, 1978.

ODYSSEY SPILL, NOVA SCOTIA, CANADA, 1988

The Liberian flag tanker Odyssey broke into two parts and caught fire as it sunk at 700 nautical miles in the North Atlantic off Nova Scotia, Canada in November 1988, leading to a 43 million gallons spill.

Being far from coastlines the oil dissipated naturally requiring g no cleanup effort.

M/T HAVEN TANKER, GENOA, ITALY, 1991

The M/T Haven 820 ft or 250 meters long tanker exploded, caught fire and sunk off the Italian coast killing 6 persons and spilling 42 million gallons of oil.

The spill was controlled with an inflatable barrier deployed under water around the tanker and the surface oil was pumped using vacuum machines. As the largest shipwreck in the world it became a popular destination for divers.

Figure 70. M/T Tanker fire, Genoa, Italy, 1991.

MACONDO OIL WELL BLOWOUT, DEEPWATER HORIZON OIL RIG FIRE, GULF OF MEXICO, USA, APRIL 22, 2010

A gas explosion in the Macondo oil well caused a fire then the sinking of the Transocean-owned Deepwater Horizon oil rig and causing a daily spillage of 20,000-60,000 gallons per day and the loss of 11 lives among its 126 member crew.

The cause of the accident is attributed to human error involving gross negligence in applying safety rules. The oil rig operator Transocean for British Petroleum (BP) contracted Schlumberger Company to run the Cement Bond Log (CBL) test that is the final test on the well plug. Schlumberger is a highly regarded service company placing a high standard on safety and trains their employees to shut down unsafe operations. Its employees on the Deepwater Horizon run the CBL test and found the well pressure unstable and the well still "kicking heavily," which it should not be that late in the operation. The Schlumberger engineers order the "company man" on the scene that runs the operation to dump kill fluid down the well and shut-in the well. The company man refused, being concerned about the cost of downtime for a well finishing that was behind schedule. The Schlumberger personnel then requested a helicopter to take them back to shore. The company man said there were no more helicopters scheduled for the rest of the week; meaning that they are there to do a job, and that they must finish it. The Schlumberger personnel called their corporate headquarters, and had a helicopter flown out there at Schlumberger's expense to take them back to shore. The platform explosion occurred six hours later.

Figure 71. New Horizon, Transocean and British Petroleum fire and spill.

Four design flaws were highlighted by three engineering studies in 2004, 2006 and 2009 commissioned by the USA Mineral Management Service (MMS) in the operation blowout preventers operating in deep water:

1. DEEP WATER PRESSURE EFFECT ON CLOSURE DEVICE GASKETS AND SEALS

In the fall of 2006, West Engineering Services of Brookshire, Texas, turned over to MMS officials a study on the effects of pressure on BOPs. Among its key findings: High deep-water pressure could severely damage the critical gaskets and seals on BOPs' hydraulic ram valves, causing them to leak and fail in an emergency.

One type of hydraulic ram valve, called a shear ram, is designed to prevent a situation like the one that occurred in the Gulf of Mexico. In the event of a catastrophic failure, the shear rams are supposed to stop the flow of oil by cutting and crumpling the pipe between them. The Deepwater Horizon's shear rams failed, though it is not yet clear why.

Many BOP gaskets are designed to handle up to 15,000 pounds per square inch (psi) of internal pressure – the pressure of the oil and natural gas pressing outward on the BOP. But they are not mandated to handle external water pressure, which can equal more than 2,000 psi in deep water.

Moreover, stress on seals and gaskets could be exacerbated if the pressure inside the well drops dramatically, meaning pressure is higher outside than inside.

The study noted that neither the MMS nor the American Petroleum Institute (API) had any specific standards dictating how much external pressure the seals and gaskets must be able to withstand.

The maximum allowable external pressure is never published and indeed may not even be known by the manufacturer. If differential pressure is applied to a component not designed to withstand it, there could be serious consequences for well control; the deeper the water the greater the risk.

The study recommended that the industry have an external-pressure test for closure mechanisms that would demonstrate a factor of safety in this critical area.

Some manufacturers have upgraded seals and gaskets voluntarily. But the lack of specific federal standards resulted in a lack of uniformity both in seal quality as well as their maintenance.

2. TEST RAM VULNERABILITY

Test rams are a relatively new innovation in the offshore oil and gas industry and are currently on only a few deep water drill rigs' BOPs. They are designed to streamline costly and time-consuming hydraulic test procedures required under federal regulations. The Deepwater Horizon was one of the few rigs whose BOP had a test ram. One big problem: The devices do not help in an emergency – and they may obscure emerging dangers.

That is precisely what happened in one of the "safety critical" failures reported in the 2009 report. One of the BOPs studied experienced a critical failure when a leak developed at the wellhead connector, compromising its ability to maintain the correct pressure. On rigs with test rams, the leak, regardless of size, would not have been identified.

The report strongly criticized test rams because they obscured leaks and took up space on a BOP that otherwise could have been used for a real ram. The test ram retrofitted onto the Deepwater Horizon may have impaired the BOP's redundancy and, therefore, reliability of the BOP.

3. NO SAFETY ALERT

The 2009 study recommended a "safety alert" concerning the threat of failure of a BOP valve called an annular. Annular valves are like a large doughnut made of rubber and steel that can be mashed into the pipe to seal a well. The study recommended an alert that would derate – or lower – the estimate of how much pressure the annulars could handle when special large-bore drill pipe was being used.

Failures have occurred while using this drill pipe size with standard annular elements.

4. FAILURE TO CUT PIPE

The 2004 study for MMS suggested that changes in industry practices made shear rams increasingly prone to failure in deep water. Among the problematic changes: higher well-bore pressures and greater drill pipe thickness.

Only 3 of 14 newer deep-water drilling rigs were found able to shear pipe at their maximum rated water depths. Only half of those rigs' operators required a shear-ram test during commissioning or acceptance. This grim snapshot illustrates the lack of preparedness in the industry to shear and seal a well with the last line of defense against a blowout.

The industry was increasingly compounding the problem by using thicker, harder-to-cut pipes in deeper water. The shear rams could also fail if a thicker "tool joint" in the drilling pipe was between the rams when a disaster struck.

LACK OF OVERSIGHT

During the past decade, MMS's approach has been to set a performance goal but not to dictate any specific requirements or regulatory standards. MMS did not ensure that BP had proof that shear rams on Deepwater Horizon would work. The agency had "highly encouraged" companies to have backup systems to trigger blowout preventers in an emergency. There was no enforcement.

REMEDIES

A remedy is a relief well or bottom-kill that would intersect the blowout and pump mud into it from the bottom to reestablish the mud column and kill the well. Pumping of the heavy weight mud at a high rate will make the flow heavier and slower until the column of mud becomes heavy enough to stop the flow. The well cementing can be repeated from the bottom, including any formation sealing and blocking additives needed to keep it from leaking out.

The relief well needs to intercept the damaged wellbore at the level of the producing horizon. It is important to establish communication with the producing geologic horizon. It is possible to tell by pore pressure reading while drilling the position of the blow out. If it is not possible to get into the old well, an attempt at squeezing the formation with cement outside the old well bore can be achieved.

In June 1979, engineers with the Mexican oil company Pemex lost control of the Ixtoc I, an exploratory well in the Gulf of Mexico. The engineers drilled two relief wells. The first relief well was finished by the end of November, but it took until March 1980, more than nine months after the accident, to cap the well. By then, 480,000 tons of crude had flowed into the Gulf, the second-biggest oil spill the world has experienced.

On August 21, 2009, the operators lost control of the well beneath the West Atlas oil rig in the Timor Sea off Australia's northern coast. It took 10 weeks to stop the flow of oil. About 4,300 tons of oil flowed into the sea. By drilling a relief well the Thai company overseeing the operation managed to pump enough mud into the well to cap the flow of oil. They had drilled to a depth of up to 3,500 meters or 11,500 feet below the sea floor when gas and oil suddenly began shooting upward. There was no explosion, and the 69 workers at the site were evacuated without harm.

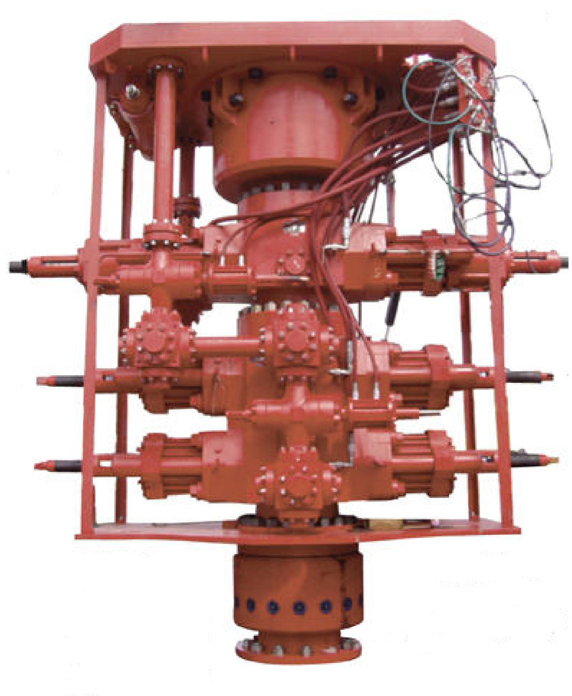


Figure 72. Blowout preventer, BOP is bolted to the top of the well on the sea floor. The hydraulic rams are horizontal piston-like protrusions. They are designed to cut and seal the pipe in an emergency, shutting off the flow of oil. Height: 50 ft or 15.2 m, weight: 500,000 lb or 226,000 kg.

Figure 73. Leaking and capped underwater oil well.

Figure 74. Underwater robot submarine attempted to activate the hydraulic shear rams on the Deepwater Horizon's blowout preventer on April 22, 2010 to close off the flow of oil from the Macondo well.

A contingency remedy was considered as the use of the shock wave from a nuclear civil engineering explosive of 5-20 kT of TNT equivalent to collapse the well column and seal it. This approach was used successfully five times in the 1970s by Russia to seal the flow from leaking natural gas fields.

CHEMICAL PLANTS

BHOPAL UNION CARBIDE FACTORY, 1984

On December 2, 1984, the Union Carbide pesticide plant in Bhopal, Madhya Pradesh, India, leaked 40 metric tons of toxic Methyl Isocyanate (MCI) gas, with about 2,259 casualties, 100,000 injuries and damage to livestock and crops. Union Carbide is now owned by the Dow Chemical Corporation.

The accident is one of the biggest chemical accidents in history. The facility was intended to bring work and prosperity to the capital of Madhya Pradesh, a largely rural state in the heart of India, a little bigger than Italy. Instead, the plant brought death to the residents of Bhopal. Several dozen tons of methyl isocyanate, a highly toxic chemical, leaked from a tank, releasing a deadly cloud of gas over the city. The leak is believed to have caused up to 30,000 deaths, although the exact number, especially in the slums adjacent to the plant, was never determined.

Figure 75. Union Carbide chemical plant before and after its abandonment.

MCI is an organic chemical that is used in the production of pesticides. It is highly toxic to humans. Short term exposure may cause death or adverse health effects including pulmonary edema or respiratory inflammation, bronchitis, bronchial pneumonia, and reproductive effects. The Occupational Safety and Health Administration's (OSHA) permissible exposure limit to MIC over a normal 8 hour work day or a 40 hour work week is 0.05 mg/m^3.

The International Medical Commission on Bhopal estimated that as of 1994 upwards of 50,000 people remained partially or totally disabled.

Amid charges of corruption, graft and suppression of medical and environmental research about the tragedy, there were charges that the victims were not adequately compensated and cared for.

The pesticide plant was located 3-4 miles outside the city center of Bhopal. At the time of the incident, the plant employed 630 people. Bhopal had a population of 900,000 people with a community of squatters situated immediately outside of the plant boundary.

The plant started to produce the pesticide carbaryl with trade name: Sevin in 1969. MIC is an intermediate chemical in Sevin production. Methylamine $MeNH_2$ is reacted with phosgene to form methyl isocyanate CH_3NCO, which is then reacted with 1-naphthol to form carbaryl.

For the first decade of operation the plant imported MIC from a Union Carbide sister plant located in Institute, West Virginia. In the late 1970s, the plant added an MIC production unit. The MIC produced at the plant was stored in two of three 15,000 gallon tanks. One tank was kept empty at all times for reserve storage capacity in the event of an emergency. The tanks were partially buried and equipped with safety relief valves. The vented MIC passed through a sodium hydroxide scrubber and flare towers. Union Carbide's degree of involvement, and therefore degree of responsibility for the incident, in the Bhopal plant design, operation, system maintenance, and operator training were contentions during a subsequent trial.

Between 1979 and 1982, the Bhopal plant underwent three Union Carbide audits. According to Union Carbide, the last audit was a 1982 "Operational Safety Survey," conducted at the request of Union Carbide India Limited (UCIL) management. The Survey found "major concerns" in the MIC production unit that could lead to serious personnel exposures. Whether Union Carbide or UCIL held responsibility for implementing the Operational Safety Survey's recommendations was a contention during the trial.

At 11:30 pm on December 2, 1984 workers at the Bhopal plant detected an MIC release. The workers informed their supervisor. At approximately 12:45 am on December 3, workers observed a rapid pressure increase in one of the MIC storage tanks, which opened the safety relief valve. The venting MIC passed out of the facility and into the atmosphere.

As a large amount of water entered tank 610, containing 42 tons of MIC, the resulting exothermic reaction increased the temperature inside the tank to over 200 °C or 392 °F, raising the pressure to a level the tank was not designed to withstand. This forced the emergency venting of pressure from the MIC holding tank, releasing a large volume of toxic gases into the atmosphere.

The gases flooded the city of Bhopal, causing great panic as people woke up with a burning sensation in their lungs. Thousands died immediately from the effects of the gas and many were trampled in the ensuing panic. Three days after the release, a lawsuit was initiated in USA courts.

Both Union Carbide and the Government of India sponsored investigations into the incident. Union Carbide and the Government of India were parties to the associated lawsuit. As a result, there are very few issues about the incident that were not in dispute. For example, both parties agreed that the MIC release was due to a violent reaction from the inappropriate introduction of water into the storage tank. How the water reached the tank and the capacity of the plant to safely handle this problem were issues addressed in the trial.

In 1985, the Government of India passed the Bhopal Gas Leak Disaster Act. This Act made the Government of India the representative for all individuals seeking compensation from the incident. When the cases were combined in the USA court system, there were approximately 145 actions involving 200,000 plaintiffs. In 1986, the USA District Court of Southern New York ruled in favor of Union Carbide, and directed that the trial be moved to India.

The Government of India contended that Union Carbide was actively involved in the detailed plant design and that while finalizing the plant design Union Carbide intentionally reduced or eliminated safety items. During plant operation Union Carbide purportedly neglected oversight and responsibility, including ensuring that appropriate maintenance was conducted, or that the recommendations of audit teams were implemented. For example, the MIC should have vented through a scrubber and flare tower before exiting the facility, but a leaking vent line released the MIC directly to the atmosphere. Moreover, the MIC that did reach the scrubber was not removed because neither the scrubber nor the flare tower was operational at the time of the incident. If all the MIC reached the scrubber, and the scrubber and flare tower were operational, there may still have been a release since it is believed that the venting MIC would have exceeded the scrubber design capacity.

Union Carbide disputed these claims, stating that although it had provided the basic MIC unit design to UCIL, the Government of India had prohibited Union Carbide's active participation in the final plant design. Union Carbide asserted that it had provided appropriate training, including bringing some workers to Institute, West Virginia for training, and that the safety procedures were appropriate. However, Union Carbide contended that the UCIL management was generally responsible for safety and maintenance at the plant and that the government of India was the responsible regulator.

Ultimately, after reviewing the plant records, interviewing plant employees, and studying the incident, Union Carbide concluded that the MIC storage tank was sabotaged by a disgruntled worker.

The trial ended in 1989 when the Supreme Court of India ordered Union Carbide and UCIL to pay $470 million in damages to the Government of India. The settlement was challenged in 1991. The Courts upheld the civil settlement, but allowed the criminal case to be reopened. The criminal case remained open until 2010, and Union Carbide has sold its stake in UCIL.

In June 2112, almost 28 years after the accident, a group of cabinet ministers in New Delhi decided to sign over the disposal of the toxic waste from Bhopal to the GIZ subsidiary International Services that will transport roughly 350 tons of toxic waste to Germany for disposal in an incinerator.

The problems associated with contaminated ground water, which still affect Bhopal residents, are another issue altogether. In the long term, India will need its own facilities to dispose of chemical and other toxic waste on-site and in environmentally correct ways.

EMERGENCY PLANNING AND COMMUNITY RIGHT TO KNOW ACT, 1986

In August, 1985, the Union Carbide sister plant in Institute, WV released a cloud of methylene chloride and aldicarb oxide that affected four neighboring communities and led to the hospitalization of over 100 people. In the wake of this and the Bhopal incident, the USA Congress passed the 1986 Emergency Planning and Community Right to Know Act. This act, implemented by the Environmental Protection Agency (EPA), facilitates state and local accident contingency planning, public participation, and access by individuals and communities to information regarding hazardous materials in their locales.

In 1990, while developing the Clean Air Act Amendments, the USA Senate considered an EPA analysis that compared USA chemical incidents in the early to mid-1980s to the Bhopal incident. Of the 29 incidents considered, 17 USA incidents released sufficient volumes of chemicals with such toxicity that the potential consequences, depending on weather conditions and plant location, could have been more severe than in Bhopal. Based on the incident review and existing State and Federal USA programs, the Senate concluded that accident prevention had not been given sufficient attention in the existing Federal programs.

As a result of this analysis, the Amendments tasked the EPA and the Occupational Safety and Health Administration (OSHA) to develop programs to prevent chemical incidents. Congress authorized EPA to promulgate the Risk Management Program Rule (40 CFR 68) for protection of the public, and OSHA to promulgate the Process Safety Management Standard (29 CFR 1910.119) to protect workers. The two programs share a requirement for covered facilities to develop accident prevention plans; other provisions are complementary.

The Amendments also established the independent USA Chemical Safety and Hazard Investigation Board (42 U.S.C. 7412). Using the National Transportation Safety Board as a model, the Amendments tasked the Board with investigating and reporting on the causes and probable causes of domestic chemical incidents. Moreover, the Senate recommended that the Board provide investigative assistance to other countries both as a means of helping and as a means of learning. Through its international outreach efforts to government and industry, the Board can ensure its safety research program, professional services and technical information accurately and adequately address the world's chemical safety

FOOD SAFETY

A free school lunch killed 23 Indian children on July 16, 2013. It was contaminated with a concentrated pesticide that is not widely available. The children fell ill within minutes of eating a meal of rice and potato curry in their one-room school in the Bihar State, vomiting and convulsing with stomach cramps. The free lunch program in India covers 120 million children and aims to tackle malnutrition and encourage school attendance.

The meal had been prepared with cooking oil that contained Monocrotophos, an Organo-phosphorus compound that is used as an agricultural pesticide. The pesticide found in the oil was of a concentration more than five times that used in a commercial version. Typically it has to be diluted five times with one liter of Monocrotophos mixed with five liters of water. The concentrated form is not widely available and the pesticide was normally sold commercially in the diluted state.

The cooking oil used in the meal had been kept in a container previously used to store the pesticide. The World Health Organization (WHO) describes Monocrotophos as highly hazardous and says that the handling and application of it should be entrusted only to competently supervised and well-trained applicators. The Food and Agriculture Organization of the United Nations (UN) suggests all waste and contaminated material associated with the chemical should be considered hazardous waste and destroyed in a special high-temperature chemical incinerator plant.

SINKING ACCIDENTS

THE SINKING OF THE TITANIC, 1912

INTRODUCTION

The intensely competitive transatlantic steamship business had seen recent major advances in ship design, size and speed. White Star Line, one of the leaders, determined to focus on size and elegance rather than pure speed.

In 1907, White Star Line's managing director J. Bruce Ismay and Lord James Pirrie, a partner in Harland and Wolff, which was White Star Line's shipbuilder since its founding in 1869, conceived of three magnificent steam ships which would set a new standard for comfort, elegance, and safety.

The first two were to be named the Olympic and the Titanic, the latter name chosen by Ismay to convey a sense of overwhelming size and strength. It took a year to design the two ships. Construction of Olympic started in December, 1908, followed by Titanic in March 1909.

The Belfast, Ireland shipyards of Harland and Wolff had to be redesigned to accommodate the immense projects while White Star's pier in New York had to be lengthened to enable the ships to dock. During the two years it took to complete the Titanic's hull, the press was primed with publicity about the ship's magnificence, making the Titanic virtually a legend before her launch. The "launch" of the completed steel in May, 1911, was a heavily publicized spectacle. Tickets were sold to benefit a local children's hospital.

SPECIFICATIONS

The specifications of the Titanic were:

Overall length	882.5 feet
Gross tonnage	46,329 tons
Beam	92.5 feet
Net tonnage	24,900 tons
Cost	$7,5 million

ACCIDENT

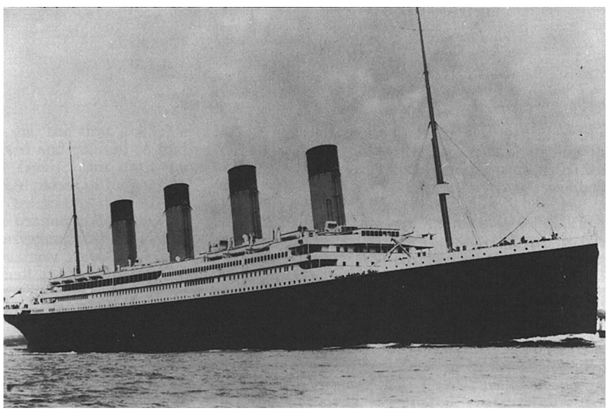
On April 10, 1912, the Titanic commenced her maiden voyage from Southampton, England, to New York, with 2,227 passengers and crew aboard. At 11:40 pm on the night of April 14, 1912, traveling at a speed of 20.5 knots, she struck an iceberg on her starboard bow.

Its compartments sequentially filled with water from their tops and it sunk within 4 hours after hitting the iceberg. It is argued that the mild steel used is in its hull’s construction turned brittle in the ice cold waters of the Northern Atlantic.

At 2:20 a.m. she sank, approximately 13.5 miles east-southeast of the position from which her distress call was transmitted.

Lost at sea were 1,517 people, including passengers and crew, because of an inadequate supply of lifeboats. Those available were made available to the first class passengers. The coah class passengers were denied access with some lifeboats leaving nearly empty. Captain E. J. Smith, commander of the Titanic refused to leave and gallantly sunk with his ship. The 705 survivors, afloat in the ship's twenty lifeboats, were rescued within hours by the Cunard Liner, Carpathia.

The wreck of the Titanic was located by a French and American team on September 1, 1985 in 12,500 feet or 3,810 meters of water about 350 miles or 531 kilometers southeast of Newfoundland, Canada. A 1986 expedition documented the shipwreck more thoroughly.



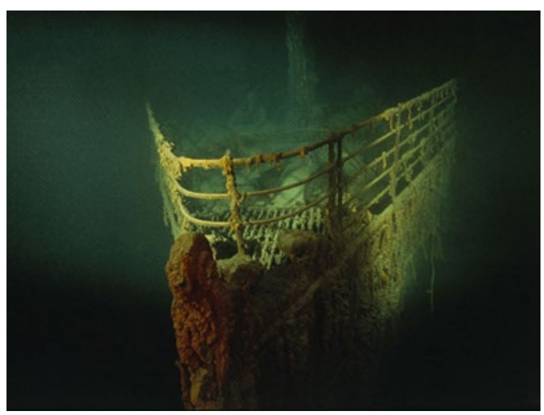


Figure 76. The Titanic sinking ended the era of large passenger liners.

COSTIA CONCORDIA SINKING, 2012

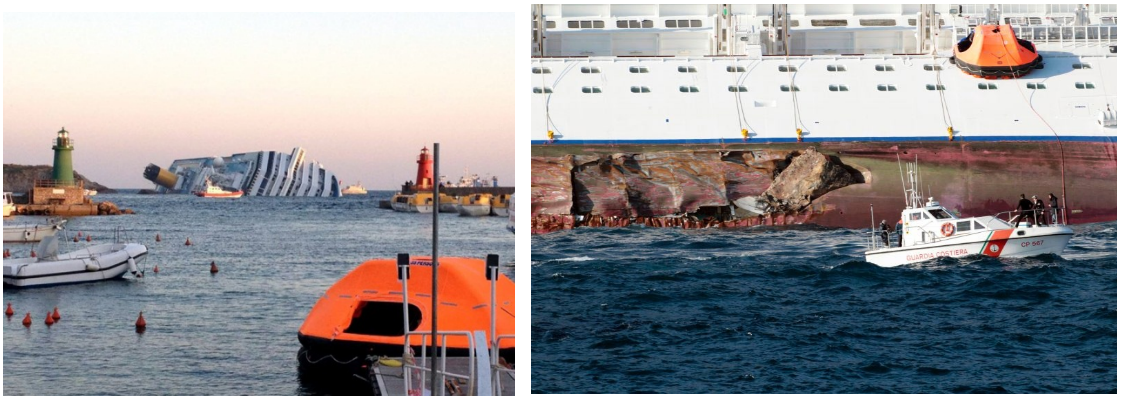


Figure 77. Sinking of the Costa Concordia 13-decks luxury liner with 3,200 passengers and 1,068 crew members and unregistered passengers off the Tuscan island of Giglio, at 9:30 pm on Friday, January 13, 2012.

Three hours after the ship left the port of Civitavecchia near Rome into the Tyrrhenian Sea, the 290-meter-long (951 feet long) vessel ran aground at 10 pm on Friday, January 13, 2012, off the coast of Tuscany in Italy. As it approached the island of Giglio, the ship collides with a rocky reef known as Le Scole, a few hundred meters off the coast. The hull rips open with a 230 ft or 70 meter-long gash in the 114,500 tonne ship, leading to a power blackout. The ship starts taking water and listing by 7 degrees. The captain continues for a few hundred yards and then turns back toward the port as he realizes his ship is damaged. The captain gave the order to abandon ship at 10:30 pm as the ship came close to the harbor, but it scrapes up against the rocky coast and keels over to the right in shallow water.

The captain tried to turn around and head into the island's port in an attempt to make it easier to evacuate. The early recognition of the situation at hand by the captain, to his credit, saved most of the lives of the passengers and crew. The casualties included 16 dead and 16 missing out of the 4,268 miraculously evacuated passengers and crew.

Following the massive jolt, the Costa Concordia began to list steeply. There were scenes of panic. Many passengers jumped into the cold water in order to swim to the island of Giglio. Some passengers on board described the accident as being "like a scene from the Titanic." Some survivors who could not board lifeboats waited for hours aboard the capsizing craft for rescue by helicopters, while others jumped into the water and swam to safety. The last survivor, found aboard 36 hours after the crash, was an Italian crewman who broke his leg in the confusion and could not leave the ship.

The cruise ship Costa Concordia came carelessly too close to the coast of the Italian island of Giglio before it became ship-wrecked. The dangerous maneuver was not an isolated incident. Residents report that such maritime greetings are commonplace. The mayor of Giglio even praised an earlier occurrence as an "unequalled spectacle." It is common for cruise ships to approach the island at close quarters to greet the inhabitants with their foghorns. "It's a nice tradition, normalissima;" absolutely normal.

The Costa Concordia is one of the largest cruise ships ever to founder. The wreck resulted from human error. The ship's navigation systems were fully operational and the route had been correctly programmed. The captain of the ship took an initiative of his own that is contrary to the written rules of conduct. Operator Costa Crociere, a subsidiary of

USA-based Carnival Cruise Lines, said that the captain, Francesco Schettino had deviated without permission from the vessel's route in an apparent maneuver to sail close to the island and impress passengers. Israeli-American businessman Micky Arison is the CEO and chairman of the Costa Cruises Company that operates the cruise. He also owns the National Basketball Association's Miami Heat, is the head of the Carnival Corporation, of which Costa Cruises is a subsidiary. Arison, 62, is the son of the late Carnival Corp. founder Ted Arison. He is number 169 on the Forbes list of the world's billionaires, with a net worth of $5.9 billion.

In addition to having sailed too close to the rocky coastline, the captain has been accused of leaving the ship prior to completion of the evacuation of its 4,200 passengers and crew onboard. Eyewitnesses have reported seeing the captain onshore, even as the ship's crew on the ship was completing the evacuation. The captain, despite audiotapes of his defying Coast Guard orders to scramble back aboard, has denied he abandoned ship while hundreds of passengers were trying to get off the capsizing vessel. He said that he coordinated the rescue from aboard a lifeboat and then from the shore.

There were fears that the Concordia's double-bottom fuel tanks could rupture in case of sudden shifting, spilling almost 500,000 million gallons or 2,200 metric tons of heavy fuel into pristine sea around Giglio, which is part of a seven-island archipelago in some of the Mediterranean's most pristine waters and a prized fishing area.

THE HINDENBURG ACCIDENT, 1937

INTRODUCTION

Hydrogen was used as the filling gas in the German Zeppelin dirigibles. Unlike helium that is inert and used in other designs, hydrogen is flammable as well as highly reactive with air. The USA had denied Germany access to helium as a strategic material since balloons were earlier used in the First World War for troop movement observation and for directing artillery fire.

In 1936, the Hindenburg made 10 transatlantic flights. In May 1937, it crossed the ocean at 84 miles per hour for a 76 hours trip to Lakehurst, New Jersey. The ship carried a crew of 61 and 36 passengers who paid a $400 ticket each for the trip.

In 1931 the construction of the LZ 129 Hindenburg started as the largest German commercial passenger-carrying rigid airship built by Luftschiffbau Zeppelin GmbH. The Hindenburg was 803.8 feet long with an envelope of 7,062,000 cubic feet in volume filled with Hydrogen gas which is highly flammable to provide the buoyancy. Forward and reverse power was provided by four Daimler-Benz 16-cylinder diesel engines. In 1936 the Hindenburg, named after Field Marshal Paul von Hindenburg former President of Germany, made its maiden test flight. It makes 17 round trips across the Atlantic Ocean; 10 trips to the USA and seven to Brazil. On May 3rd, 1937, the Hindenburg leaves Frankfurt, Germany bound for Lakehurst, NJ, USA. At 7:21 pm on May 6th, 1937 while attempting to dock with its mooring mast at the Lakehurst Naval Air Station the Hindenburg bursts into flames killing 35 passengers, crew and 1 ground crew, when watching the disaster. It is amazing any passengers and crew survived. The incident together with other high profile problems in the Airship Industry shattered public confidence in passenger-carrying rigid airships and marked the end of the era for Airships.

ACCIDENT SEQUENCE

As it was approaching the landing station at Lakehurst, it suddenly burst into flames. Charges of intentional sabotage were made. Department of Commerce inspectors examined the debris and concluded that a small spark from a thunder squall had ignited hydrogen leaking from the rear of the airship.

To prevent water damage, hydrogen cell expansion, and sun radiation damage, the covers of airships were "doped," that is, painted with a sealing compound.

The Hindenburg had been coated with a supposedly "new and improved" formula: powdered aluminum and iron oxide which, according to what we know today, is used as solid rocket fuel.

ALTERNATE EXPLANATION

Aircraft gather static electricity as they fly. The airships were grounded so that the electricity would flow through the landing lines as soon as they touched the ground. The methods used to ground airships were not infallible, though, due to the materials that were used. Thus several cells in the Hindenburg likely did not expel their static electricity when the landing lines dropped. A cell near the very back of the Hindenburg retained its electricity and caused a spark to the girder which caused the cell to heat up. The heat ignited the dope and ignited the cover.

At this point the hydrogen became fuel for the fire, but the rocket fuel coating is what consumed the ship.

Shortly after the Hindenburg accident, that World War II broke out.

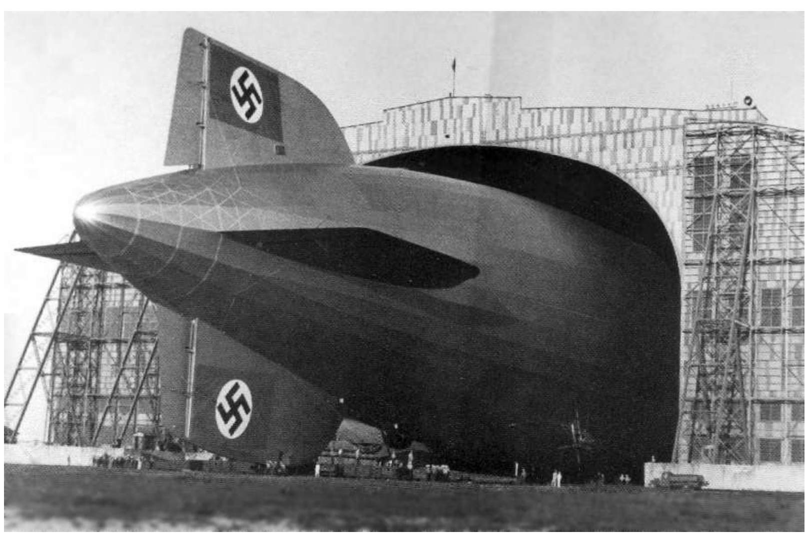


Figure 78. Hindenburg Zeppelin airship at its hangar at Lakehurst Air Station, New Jersey, USA. The flying ship Hindenburg exploded while attempting to hook itself to a mooring post and signaled the end of the flying ship industry in 1937 as a major form of transport. The immortal words of reporter Herb Morrison who was filming the Hindenburg still reverberates: "Oh the Humanity! The Humanity" around the world.

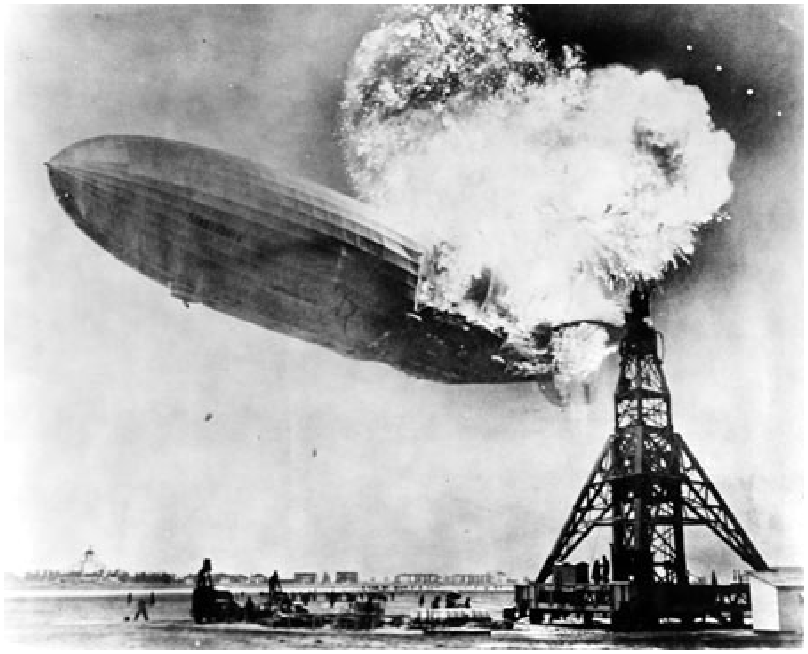


Figure 79. A hydrogen explosion destroyed the Hindenburg at its mooring at Lakehurst, New Jersey; the largest airship ever built, and ended the technological alternative. Some sailors were holding onto the blimp with long ropes. A gust of wind caused the blimp to rise suddenly and quickly. Some sailors let go after hanging on for a few seconds. Some dropped from a height of 6 feet, others from 10 feet. Three hung on for dear life. One was hauled onto the blimp – two fell to the ground from a great height and died.

TRAIN DERAILMENTS

About 80 people lost their lives on July 24, 2013 when a train derailed not far from Santiago de Compostela in Spain. A security camera shows the train going way too fast travelling between 144 and 192 kilometers per hour for the corner. The car just behind the locomotive was the first to jump off the tracks. The rest of the eight-car train piled up behind the locomotive, which tipped on its side and slammed into the concrete wall. camera.

Figure 80. About 80 people lost their lives on July 24, 2013 when a train derailed not far from Santiago de Compostela in Spain. The train was travelling between 144 and 192 kilometers. Source: AP.

Figure 81. Crude oil train derailment, Canada.

On July 6, 2013, 72 rail cars loaded with crude petroleum derailed, ruptured and exploded in the small town of Lac-Megantic in Québec, Canada. Much of the town was incinerated, and 47 people were killed. It took days to extinguish the flames with some 30 buildings in the town destroyed.

Authorities believe that the rail operator parking the train did not set the brakes firmly before leaving for the night. The train slowly rolled away, but quickly picked up speed.

The tanker car was owned by Montreal, Maine and Atlantic Railway, a subsidiary of privately held USA-based Rail World. It was transporting petroleum from North Dakota to Irving Oil's massive refinery in Saint John, New Brunswick. The Saint John refinery is one of the 10 largest in North America. It is situated near the Canaport Crude Receiving Terminal, which receives Ultra Large Crude Carrier (ULCC) tankers transporting oil primarily from Saudi Arabia and the North Sea.

As of 2000, crude oil shipments by train were 9,000 carloads. By 2012, that amount had surged some 25 times, to over 233,811. This quick ramp-up is resulting in a surge of accidents. According to the USA National Transportation Safety Board (NTSB), rail accidents are on the rise. Over the past few years, people have been killed from oil tanker explosions in Illinois, Wisconsin and Pennsylvania.

The problem isn't just the amount of oil traveling by railroad, it is the cars that oil is riding in. About 70 percent of North American tanker cars are DOT-111 cars. While they are certified by the USA Department of Transportation, they are also more prone to rupturing during accidents. The National Safety Transportation Board has noted that an accident involving a DOT-111 is 87 percent more likely to result in death than with some newer tanker cars being developed. It costs approximately $15 per barrel to send oil by rail, compared with $1 a barrel by pipeline and $2 a barrel by ship.

THE CHALLENGER AND COLUMBIA ORBITERS ACCIDENTS

INTRODUCTION

The Challenger and Columbia orbiters or space shuttles accidents happened because the environmental conditions were not taken into account before proceeding with a launch.

In both cases, the conditions were not optimally met and scheduling management took precedence over good engineering judgment.

CHALLENGER SPACE SHUTTLE ACCIDENT

The Challenger accident occurred in 1986 when both primary and backup O-rings failed during a fiery liftoff on its right Solid Rocket Booster (SRB).

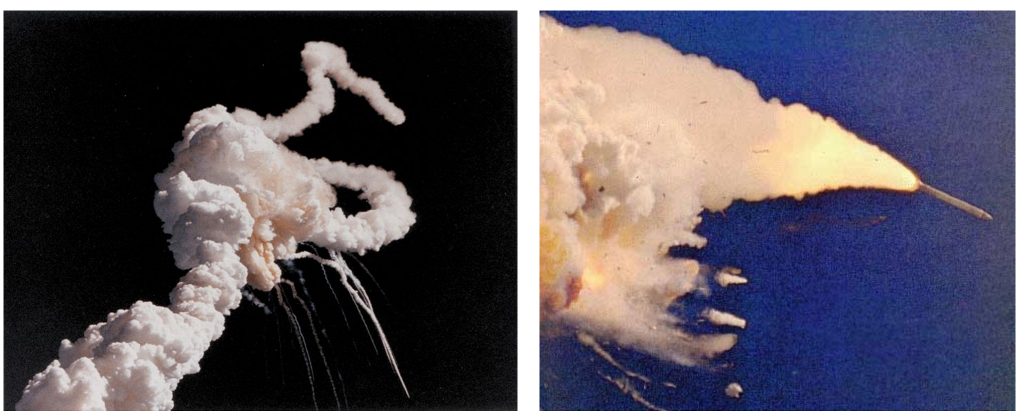


Figure 82. The Challenger space shuttle explosion upon launch showing the separation of the Solid Rocket Boosters (SRBs), January 28, 1986.

The skies were clear and the sun shone on the cold freezing morning of January 28, 1986. The Kennedy Space Center in Florida was busy preparing the launch of the 25th space shuttle into space: Mission 51-L, the 10th flight of Orbiter Challenger.

It was one of the most publicized launches because it was the first time that a civilian, a school teacher, was going into space. The launch of Challenger had been delayed five times due to bad weather. That day, January 28, 1986, was the coldest day on which NASA has ever launched a shuttle.

At 11:38 am, Eastern Standard Time, the Challenger left Pad 39B at Kennedy Space Center.

Seventy three seconds into flight, the Orbiter Challenger exploded, killing all seven of its crew including Christa McAuliffe, a high school teacher from Concord, New Hampshire, as the first civilian participating in the space shuttle program.

ACCIDENT SEQUENCE

The temperature at ground level at Pad 39B was 36 °F. This was 15°F cooler than any other previous launch by NASA. The Solid Rocket Boosters (SRB) was ignited, and a thundering noise started.

At 0.68 seconds after ignition, videotape showed black smoke coming off from the aft or bottom field joint of the right SRB. The aft field joint is the lower portion of the SRB. The black smoke suggested that grease, joint insulation and rubber O-rings were being burned. The smoke continued to come from the aft field joint facing the exterior tank, on cycles of 3 puffs of smoke per second. The last puff of smoke was seen at 2.7 seconds. The black smoke was an indication that the aft field joint was not sealing correctly.

Later in flight, flashes were seen on the Challenger. Three bright flashes shot across the challenger's wings, 45 seconds after liftoff. Each of the three flashes lasted only 1/13th of a second. As these flashes had been seen on other shuttle missions and were not considered problems. Theses bright flashes were completely unrelated to the flame that was seen later in flight.

At 58.8 seconds into flight on enhanced film a flame was seen coming from the right SRB. The flame was coming from the aft center and aft joint, at 305° around the circumference of the SRB. The flame was burning gas that was escaping from the SRB.

A fraction of a second later, at 59.3 seconds, the flame was well defined, and could be seen without enhanced film. As the flame increased in size, the flame had begun to push against the external tank by the rushing air around the orbiter.

The SRB is attached to the external tank by a series of struts along its side. One of these struts is located at 310° of the circumference of the SRB. The flame as it grew pushed against this strut, with an intense heat of 5,600°F, making it hot and weak.

The first sight that the flame was hitting the external tank was at 64.7 seconds, when the color of the flame changed. Color change indicated that the flame color was being produced by the mixing with another substance. This other substance was liquid H_2 which is stored in the external tank. The external tank stores H_2 and O_2 in two tanks. The top tank contains the O_2 and the bottom one contains H_2. Pressures changes from the H_2 tank confirmed there was leak.

Forty five milliseconds after the color change, a small glowing light developed between the external tank and Challenger's black silicon carbide SiC heat insulation tiles.

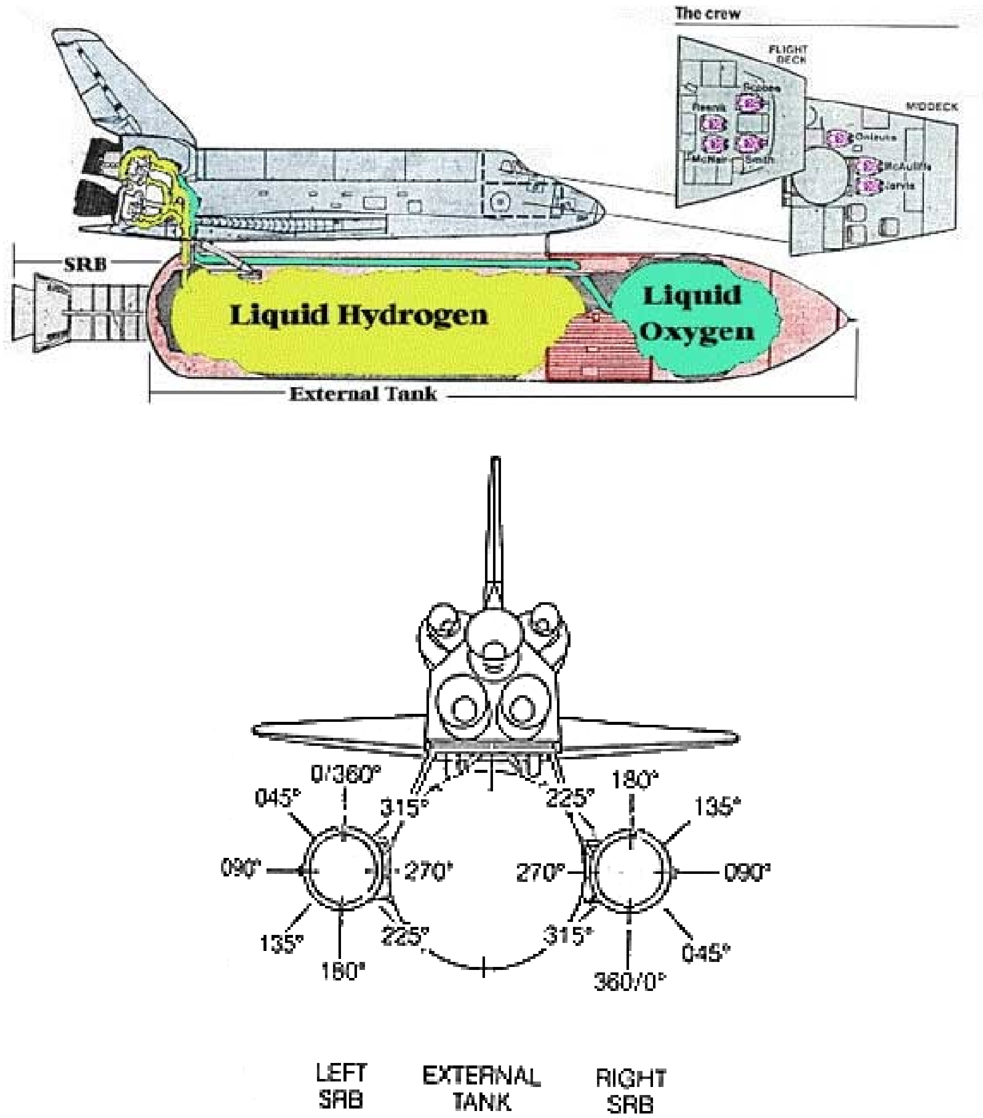


Figure 83. Schematic of space shuttle showing the Solid Ruel Boosters (SRBs) and main fuel tank.

From 72 seconds there was a very sudden chain of events that destroyed the Challenger orbiter and the seven crew members on board. All of these events happened in less than two seconds.

By now the lower strut, connecting the right SRB to the external tank was extremely hot and very weak. With the amount of force given by the SRB, the lower strut broke away from both the right SRB and the external tank, allowing the right SRB to rotate freely around the top struts. The SRB was out of control, the bottom of the SRB swung around hitting, burning and denting the Challenger's wing.

At 73.12 seconds into flight a white vapor was seen from the bottom corner of the right SRB. The external tank was weak due to the intense heat given by the flame. The dome structure under the external tank failed and fell. The tank of H_2 inside the external tank ruptured and released the liquid H_2 contents. With the sudden absence of H_2, there was an extreme force that shot the H_2 tank forward into the O_2 tank and that one too burst.

As the two internal tanks collided, the top of the right SRB on the outside hit the top of the external tank, and also broke the O_2 tank. The white vapor seen was the mixture of H_2 and O_2.

At 73.14 seconds, all the structures failed. Only milliseconds after the white vapor was seen from the right SRB, the glow had turned to a fireball in a huge explosion.

The main explosion was the H_2 and O_2 that come from the external tank.

The Challenger was traveling at a speed of Mach 1.92, at a height of 46,000 feet, when it blew up.

The last recorded transmission from Challenger was at 73.62 seconds after launch, when it truly fell apart.

Just before Challenger had blown up, it was engulfed in a cloud of smoke, that grew larger after the explosion. From under the gray smoke of the explosion, a red smoke was spreading. This red smoke was the reaction control system burning from the wreckage of the Challenger. Debris from Challenger were seen falling and racing towards the ocean. Both of the SRBs flew in opposite directions out of the fireball and cloud.

The explosives on the SRB were detonated by the USA Air Force Safety Commander, 110.25 seconds after launch or 36.6 seconds after the explosion. The SRBs have parachutes in the top cone so they can slowly come back to the ground in a normal launch. The parachutes from the blown SRB had come loose and were floating down to the ground. The watching public thought that the crew had escaped from the shuttle using their escape system. What the watchers did not know was that there was no escape system on any of the shuttles.

The SRB could be seen speeding away from the gulf of smoke caused by the exploding challenger.

FAILURE ANALYSIS

The right aft field joint sealing was the prime suspect to the cause of the accident, because the smoke after ignition and flame during flight came from the region of the aft field joint.

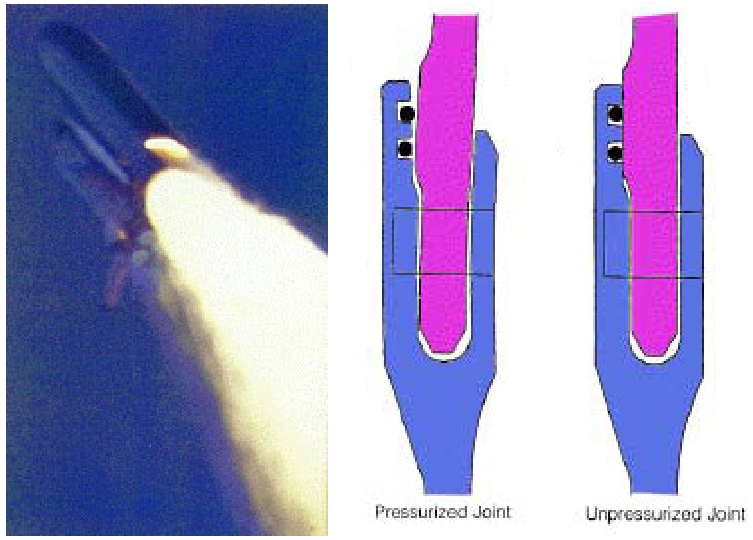


Figure 84. Tang and Clevis configuration showing pressurized joint deflection with the associated O-rings on the Solid Rocket Boosters (SRBs). Flame can be seen coming out of the right SRB.

The Solid Rocket Booster's are made up of four main segments. They are joined together by a Tang and Clevis joint. Each segment has a tang on the bottom and a clevis at the top. The clevis has a shape like a "U", while the tang has a shape of a straight line. The tang would fit by sliding down the sides of the "U" of the clevis.

The aft mid segment connects to the aft segment with the nozzle. The joint that connects these two segments together is called the aft field joint. This is the joint that failed on the right SRB.

The joint is sealed by two rubber O-rings, with a diameter of 0.280 inches (+ 0.005, -0.003). The sealing is used to prevent the gases from inside the SRB from escaping. The seal had failed, because the flame seen during the flight was gas being burnt.

There were several causes that were found that could have lead to joint seal failure. These causes are:

1. Assembly damage and contamination:

The joint seal could have been damaged or contaminated during assembly of the SRB.

The assembly of the SRB could have damaged the sealing joint. The segments of the SRB are transported to the assembly plant horizontally. Each segment is heavy and therefore with its weight, changes the shape of the segment so it is not perfectly round.

The irregular shape of the segments can be distorted and stressed from previous missions, and or the effects of handling.

At assembly the aft segment is lowed vertically, with the tang sliding into the clevis of the previous joint. Because of the distortions, the dimensions of the segments may have changed.

Mission 51-L, was one of the missions where the dimensions had changed. Even during the assembly process of the SRB, the dimensions of the segments continue to change, with the amount of weight that is applied to each of the segments.

At the assembly plant, to make the segments fit more easily the tang shape is changed with a special tool. The important thing during assembly is whether the diameters of both segments are the same. If the difference of diameters is too big, then the sides of both the tang and clevis are flat against each other. When this happens, the inside of the joint cannot be seen to access if the joint is good. When the differences in diameters are small, then the tang is slanted against the clevis but, the slant still allows the assembly of the SRB to continue.

Another consideration during assembly is if the centers of the segments line up. A difference of +0.25 inch is allowed for misaligned segments. If the difference is more than +0.25 inch then there is a chance of contamination. When the tang and clevis fit together and the centers are off, then there is metal to metal contact. Metal splinters can flake off and can land on the O-ring. The metal segments can also scrape against the O- rings and ruin them. There has been tests that show that contaminates with a size of 0.001 and 0.003 inch in the joint have actually passed a leak test. Thus, there is always a possibility that contamination did actually occur on the SRB of mission 51-L.

2. Gap opening:

The gap between the joints opens as the pressures are applied.

On the inside of the tang and clevis there is a gap that needs to be sealed. It is the O-rings that seal this gap. The size of the gap changes as the pressure of gases inside the SRB change. The gap gets bigger when the amount of pressure rises. Gap opening change is called Delta Gap Opening. There are two O-rings, the primary and secondary O-rings. The gap at each O-ring in the aft field joint is different, the gap at the primary O- ring is approximately 0.029 inches, and the secondary is approximately 0.017 inches. During launch the O-ring should move to seal the delta gap opening, and return to its proper state.

3. O-ring compression:

This depends on the width of the gap. The gas pressure formed by combustion inside the SRB also helps to seal the O- ring. This process of sealing is called: Pressure Actuation Of O-Ring Seal. As the gas goes toward the O-ring, gas meets one side of the O-ring and pushes the O-ring from all the sides possible into the gap, thus helping to seal the joint. The pressure is needed in the very early stages of SRB ignition. For pressure actuation of the O-ring to work perfectly, the gas pressure should be behind the O-ring while it is in its groove. The pressure can go around one complete side. When the gap is too big for the O-ring, then the gas will go past, blow by the O-ring and this would not seal the joint. Gas can blow by the O-ring when the groove that the O-ring sits in is too narrow. In this case the O-ring is squashed into the groove with all the O-ring sides flatly against the groove sides. The gas would not be able to help seal the joint. When blow by occurs the gas leaks, and the O-rings get damaged or even destroyed.

4. Joint temperature:

The temperature has effects on the sealing ability of the O-ring.

Temperature was also involved in failure of the joint seal. On the cold morning of the launch, the coldest joints were the aft field joints of the right SRB. The approximate temperature of the aft field joint on the right SRB was 28°± 5°F. The temperature of the opposite side, left SRB was approximately 50°F. There are two effects of O-rings at a low temperature. One effect of low temperature on O-rings is that they do not seal properly. When the O-rings are cold, they are very stiff and they do not move as quickly as they should. Tests were done to see how fast O-rings seal at different temperatures. At 75°F the O- rings seal within 530 milliseconds. On the opposite side of the scale an O-ring at 20°F takes 1.9 seconds to seal. It is this difference in time that could have put an end to Mission 51-L. From ten previous missions of shuttles, eight of these had O-ring damage in the SRB. The two missions that had no damage to the O-rings, were from warm launches. The joints of the SRBs had a temperature of 81°F and 79°F. This finding could be shown that temperature is a big contributor to the effects of O-ring damage.

The second effect from cold temperature is ice formation. Ice can form in the joints, and damage the O-rings, which will lead to joint seal failure. Ice in the grooves for the O-rings would unseat them and would not let them seal the joint. Around Pad 39B there was plenty of evidence of ice formation. The entire tower was covered with icicles. The Challenger orbiter, the SRBs and external tank had been on the launching pad for a total of 38 days. Within that period of time, there has been 7 inches of rain. There was a large chance that water had gone into the joints of the SRBs and damaged some of the O-rings.

5. Putty performance:

Putty in the form of zinc chromate is applied before assembly inside the joint to stop the gases from going to the O-rings.

Putty performance is another possible cause of the joint seal failure. Putty as zinc chromate is placed on the inside of the joints before assembly. It is there to stop the heat of combustion gas from going to the O-rings. Putty is also forced between the gap of the tang and clevis, to make sure that the seal is tight. The zinc chromate can affect the joint in many ways.

First, the putty can affect the amount of pressure that is sent to the O-ring for actuation of the O-ring. The hot gases can make holes in the putty, thus letting gas go through to the O-rings which could cause damage. Having gas go to the O-ring could decrease the time it takes for O-ring actuation.

Second, the putty moves by gas pressure and could go all the way to the O-rings. The putty could be blown into the grooves of the O-rings and block the O-rings from properly sealing the joint.

CAUSES OF FAILURE

For most of the causes of the joint seal failure, it was assumed that the segments stay perfectly round during launch. When a shuttle is launched, the SRBs are actually subjected to a great deal of force. For the final launch of the Challenger, the SRBs were bolted to the pad for 6.6 seconds after ignition. The large forces bend and strain the SRBs forward. The circular segments are changed to an elliptical shape. The side that is most flat of the elliptical is on the shortest distance between 045°-315° of the right SRB. The bending and straining occurs in cycles of three per second.

At launch when the SRBs were ignited, there were puffs of smoke coming from the same location, also at three puffs per second. There are other changes with the forces being applied to the SRBs. The tang and clevis joints change shape and therefore the gap opening becomes bigger, thus the O-rings have a bigger gap to seal. If the O-ring does not follow the gap opening then the seal fails.

From the above failure analysis, the cause for the explosion was the failure of the right SRB aft joint sealing, most likely due to the extremely cold temperature on the morning of January 28, 1986.

Out of the two SRBs that were used, the one that was in the extreme cold was the one that failed. O-rings when they are cold do not move as quickly as ones that are warm. Therefore if the O-rings were nearly frozen in place during ignition, the gases burnt the O-rings and produced the black smoke.

The Challenger orbiter left the launch pad and headed for space. During flight the O-rings continued to not seal the joint, and the gases leaked through the aft field joint. The flame grew larger and later blew Challenger up.

January 28, 1986 was the day when seven USA astronauts died when their shuttle exploded 73 seconds after launch. It was the coldest day in history that a shuttle has been launched. The cause of the accident was due to bad weather and the failure of the aft joint seal in the right Solid Rocket Booster. This tragic accident will always be remembered in the space program.

COLUMBIA SPACE SHUTTLE ACCIDENT

INTRODUCTION

On February 1, 2003, seven astronauts were lost in the Space Shuttle Columbia accident.

The orbiter's two Protuberance Air Load (PAL) ramps act as aerodynamic covers to the various cables and air lines running up the side of the external tank.

The PAL ramps are sprayed with insulating foam, like the rest of the tank, to prevent the formation of ice when it is filled with freezing liquid H_2 and O_2 fuel.

During an earler Discovery's launch on July 26, 2002, a 0.5 meter long chunk of foam weighing about 1 pound or 450 grams broke away from one of the PAL ramps.

It caused no damage by itself, but a similar incident of foam loss is believed to have caused the Columbia’s accident in 2003.

ACCIDENT ANALYSIS

The foam punched a hole in Columbia's left wing, allowing super heated gases to enter the vehicle as it attempted reentry into Earth's atmosphere 16 days later. The shuttle broke up, killing seven astronauts.

Figure 85. The Columbia space shuttle explosion upon reentry on February 1st, 2003.

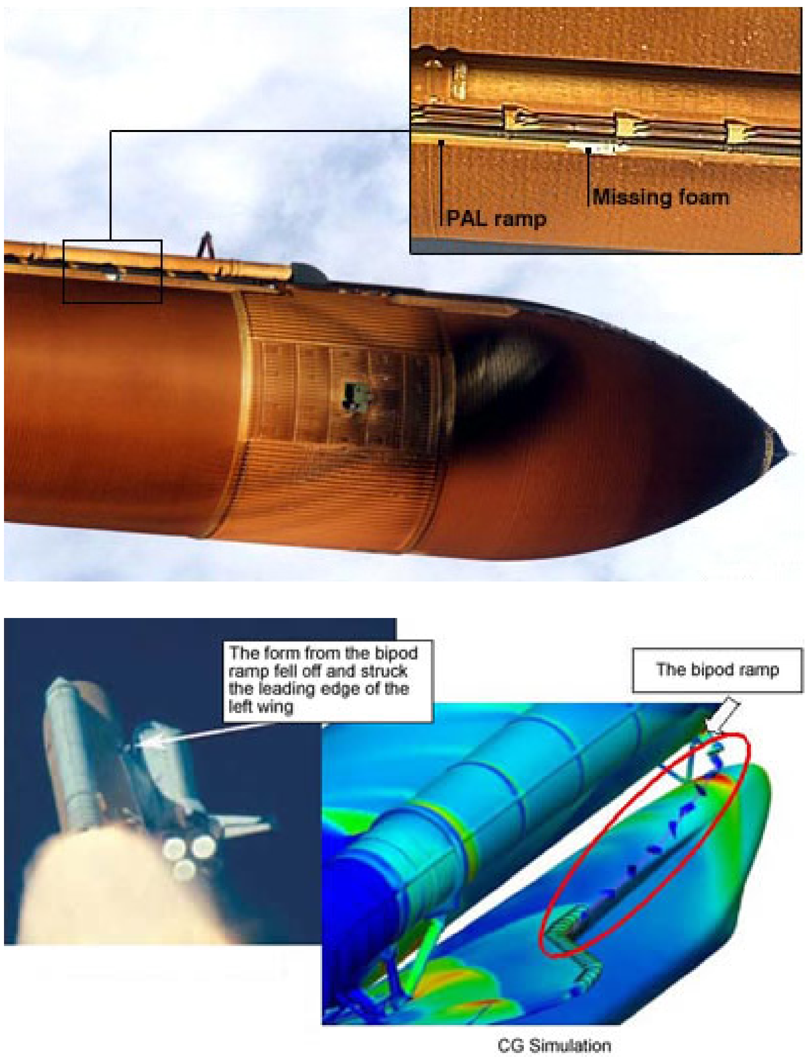


Figure 86. Falling foam from the Protuberance Air Load (PAL) bipod ramp struck the leading edge of the left wing on the Columbia space shuttle. Source: NASA.

CAUSE OF ACCIDENT

After the accident, the Columbia Accident Investigation Board (CAIB) was formed to determine the cause of the accident. It was chaired by Admiral Harold Gehman and consisted of thirteen members. Over 120 people and about 400 NASA engineers were involved in the research. More than 25,000 people got together to search and collect the Columbia debris.

The final CAIB report was issued nearly seven months after the accident on August 26, 2003.

According to the CAIB report, the cause of the accident was a breach made by a piece of foam that hit the vehicle on its left wing.

At 81.7 seconds after the launch, the "bipod ramp," an attachment between the orbiter and the external tank, fell off and struck the leading edge of the left wing and made a breach in its Reinforced Carbon-Carbon (RCC) panel.

In order to protect the Shuttle from extremely high temperatures of up to 1,500 degrees Celsius during reentry, it is covered by 20,000 ceramic silicon carbide SiC tiles.

The edges on both sides are covered with 22 RCC panels. When Columbia made its reentry, the hot air streamed into the vehicle through the breach and burned the aluminum off on the left wing.

The Shuttle then lost control, which resulted in a midair breakup.

There was a need to establish an on-orbit method of repairing the Thermal Protection System and RCC panels before returning to flight and the development of techniques and tools suitable for each damage level.

CHERNOBYL ACCIDENT

The accident on April 26, 1986 at unit 4 of the RBMK-1000 reactors plant at Chernobyl in the Ukraine is considered as the worst accident in the history of nuclear power production. RBMK is an acronym standing for: “Reaktory Bolshoi Moshchnosti Kanalynye,” or “High Power Pressure Tube Reactors.” In some English language publications, the RBMK reactors are designated as: LWGR for Light Water Graphite moderated, pressure tube Reactors with boiling, light water coolant.

Ironically the accident resulted from the human error violations of safety restrictions during a safety test. The test was carried out to determine if one of the turbo generators could supply power to the feed water pumps until the standby diesel generators came on line in the case of a local power failure.

Figure 87. Damaged unit 4 of the Chernobyl plant, before being enclosed in a concrete structure designated as the “sarcophagus.” Accident occurred on April 26, 1986.

THREE MILE ISLAND ACCIDENT, 1979

The Three Mile Island (TMI) Accident at Harrisburg, Pennsylvania in the USA was a severe and expensive incident that has seriously affected, and will continue to affect the peaceful development of Nuclear Energy worldwide.

It was the most severe industrial accident in recent history, with a partial core meltdown and a radioactive fluids and gas leakage from the containment structure to the auxiliary building.

It occurred in the early hours of the morning at 4:00 a.m. on March 28, 1979, in Metropolitan Edison's unit 2, while it was operating at 97 percent of full power.

The plant consisted of two Pressurized Water Reactors (PWRs) each of an electric capacity of 961 MWe. Neither the electrical utilities nor the nuclear power industry nor regulatory agencies, can be proud about its occurrence.

Figure 88. Metropolitan Edison's units 1 and 2 Pressurized Water Reactors (PWR) of 961 MWe electrical capacity each with two cooling towers. An accident occurred at unit number 2 on March 28, 1979, putting it out of service.

FUKUSHIMA EARTHQUAKE, TSUNAMI AND STATION BLACKOUT ACCIDENT

The March 11, 2011 earthquake and tsunami Station Blackout accident at the Fukushima Daiichi site caused an unprecedented cascading multiple failures event including fuel damage in both reactor cores and spent fuel storage pools, and ensuing hydrogen explosions and fires associated with fission products releases.

This induced a global review of nuclear safety practices worldwide and ongoing projects. This is compounded by low natural gas prices. In addition, regulatory delays resulting from political activism, plunged the nascent nuclear renaissance back into the dark ages.

Figure 89. Fukushima tsunami destruction, March 2011, towns of Oganawa, Natori and Sendai.

NUCLEAR INCIDENTS

Nuclear accidents in the military and civilian sectors occurred worldwide with different degrees of seriousness and radioactive releases.

Table 13. List of nuclear incidents.

Incident	Date	Description
Chalk River Incident	December 12, 1952	Level 5 event. Damage to reactor core released radioactivity, Canada.
Kyshtym, Russia	September 29, 1957	Level 6 event. Explosion at reprocessing site contaminated 500 square miles, Russia
Windscale Fire, UK	October 10, 1957	Level 5 event. Graphite moderator fire released radioactivity.
Sodium Reactor Experiment (SRE) core damage, Santa Susana Field Laboratory, California, USA	July 13, 1959	Partial fuel meltdown.
SL-1 USA Army Boiling Water Reactor, Idaho, USA	January 3, 1961	Level 4 event. Steam Explosion. Three operators' fatalities.
Three-Mile Island PWR partial core meltdown, Pennsylvania, USA	March 28, 1979	Level 5 event. Unit 2 partial core meltdown. Minor release of radioactivity.
Yucca Flats incident, Nevada nuclear test site, USA	December 18, 1980	Seal breakage during underground nuclear testing. Exposure of 86 workers to radioactivity.
Buenos Aires incident	September 23, 1983	Level 4 event leading to the death of an operator and the exposure of 17 others. Buenos Aires, Argentina
Chernobyl Accident, USSR	April 26, 1986	Level 7 accident. Core criticality and fire. Thirty operators and firefighters fatalities.
Goiania incident, Mexico	September 13, 1987	Four deaths and exposure of 249 individuals. A radiotherapy device with a

		radioactive source was stolen from a junkyard and opened for disposal.
Tokaimura incident, Japan	September 13, 1999	Second Level 4 event at a fuel reprocessing facility. Two fatalities and 119 workers exposed to radiation.
Fukushima Daiichi Station Blackout, Japan	March 11, 2011	Resulting from a 9M earthquake and tsunami off the coast of Japan. Level 7 event affected 4 units with hydrogen explosions, fires, core meltdown and possible steam explosion.

CHEMICAL EXPLOSIONS

WEST FERTILIZER FACILITY, TEXAS

An explosion occurred on April 17, 2013 at the West Fertilizer facility at West, Texas. Emergency personnel were then responding to a fire, when an explosion occurred in 200 tons of stored Ammonium Nitrate (AN), which is relatively stable, but becomes unstable when mixed with propane or fuel oil.

Fourteen people perished and 160 were injured, with 150 buildings damaged or destroyed in the town of West [6].

Figure 90. Fertilizer plant explosion, West Texas, April 17, 2013 [6].

TIANJIN EXPLOSION, CHINA

Figure 91. Tianjin Harbor chemical explosions, August 12, 2015, China.

Figure 92. Fire in Tianjin chemical explosions, China.

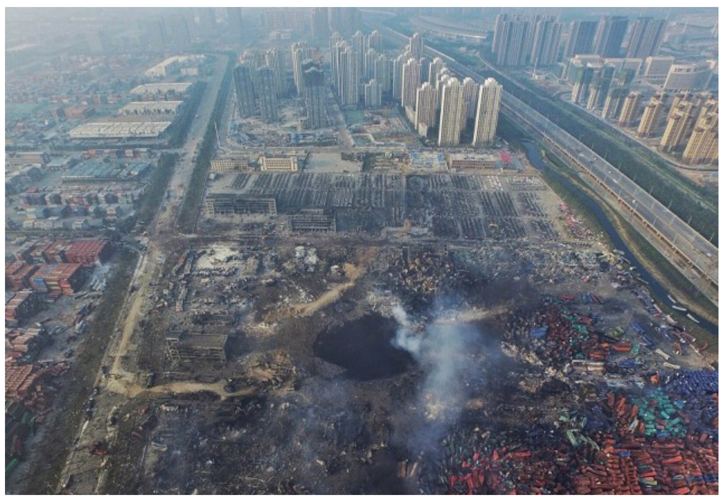


Figure 93. Crater resulting from Tianjin chemical explosions, China.

The source of the Tianjin on August 12, 2015 three consecutive blasts was identified to have originated from the Hazardous Materials Warehouses of the company Rui Hai International Logistics Company. The warehouse contained calcium carbide, potassium nitrate and ammonium nitrate. Calcium carbide is used in the production of PVC plastic, while the other two chemicals are used in producing fertilizer and dynamite. There were reports that the warehouse contained 700 tonnes of sodium cyanide, stored in wooden boxes or steel barrels. The chemical is used in the mining industry, among other uses. Potassium nitrate can cause breathing problems and damage to kidneys, while ammonium nitrate can be toxic when burned. Calcium carbide can be harmful if touched or breathed.

Calcium carbide, when mixed with water, produces acetylene gas, which is flammable. An acetylene explosion could have detonated the ammonium nitrate. The magnitude of the three blasts suggests that the explosions may have been caused by chemicals such as potassium nitrate igniting. The industrial safety manuals state that a calcium carbide fire should be put out using dry powder fire extinguishers; not by water, and cleaned up by mixing sand into the chemical. In the case of a release of sodium cyanide the United Nations recommends neutralizing it with sodium hydroxide.

The center of the blast crater is located at least 200 yards away in an area of the yard that had no buildings prior to the blast. The blast killed 160 people and injured 700, being located close to residential neighborhoods.

One week later, two chemical explosions in Shandong affected one of China's main trading cities. A fourth explosion shook a chemical plant in the Chinese province of Zhejiang. The blast caused a fire and thick smoke to bellow from the plant in Lishui city. The main chemical involved at Tianjin was sodium cyanide and at Shandong adiponitrile.

The chemical sodium cyanide is a white crystalline or granular powder which can be rapidly fatal if inhaled or ingested, as it interferes with the body's ability to use oxygen. It is mostly used in chemical manufacturing, for fumigation and in the mining industry to extract gold and silver. It is soluble in water, and absorbs water from the air, and its dust is easy to inhale. When dissolved or burned, it releases the highly toxic gas hydrogen cyanide.

The Zhejiang Limin Chemical Industry Co. Ltd. manufactures industrial explosives such as: emulsion explosives, rock powder emulsion explosive, porous granular ammonium nitrate fuel oil explosive, heavy ammonium nitrate fuel oil explosive and pharmaceutical intermediates such as: 1-Chlorocarbonyl-2-Imidazolidone, 3-Acetyl-1-Chlorocarbonyl-2-Imidazolidone, 3-Methanesulfonyl-1-Chlorocarbonyl-2-Imidazolidone, N-Acetyl-2-Imidazolidinone, 1,3-Dimethyl-2-imidazolidinone, 1-Methanesulfonyl -2-Imidazolidone and 2-imidazolidinone. The latest products are supposed to be sealed, stored indoors, under dry conditions and sun-light must be avoided.

Incidentally, two days after the first Shandong explosion, a USA munitions depot in Tokyo, Japan suffered an explosion. These events may be associated with inappropriate storage of hazardous chemicals insufficiently cooled under the summer heat. Due to backed-up inventory caused by a slowing down economy, the chemical storage facilities in China may have been overfilled beyond their safety limits.

SOLAR STORMS

Large solar magnetic storms occur about every 500 years with severe events once a century. They can result in power outages and disrupt or destroy worldwide communications systems including satellites, electrical devices, and radio, television, wireless, and telephone networks.

In 1859 a solar storm caused telegraph communications to fail worldwide and gave their operators electrical shocks. The resulting Aurora Borealis was visible as far away as the subtropical regions. The economic cost of such a storm can $2.6 trillion. A small storm in 1989 caused a loss of electrical power over most of Quebec, Canada.

GEOMAGNETIC FIELD REVERSALS

Geomagnetic field reversals involve a change in the Earth’s magnetic field wherein the positions of magnetic north and magnetic south poles are interchanged. In the process, the magnetic field would reach zero, leaving the Earth’s vulnerable to cosmic radiation and the solar wind. The 1000-10,000-year reversal process could also result in significant mass extinctions. There is no periodicity of the process. Most occurrences range from 100,000 to 1 million years, and the average is once every 450,000 years. There have been six reversals in the Quaternary period with the last major reversal 780,000 years ago. A short reversal happened 41,000 years ago.

ICE AGES INITIATION

Ice ages are rare events in the Earth's geological history. The Quaternary was a 2.6 million year period characterized by multiple, continental-scale glacial periods with an advance in the Earth's ice cover and inter-glacials with a retreat in the ice cover. These cycles generally last from 40,000 to 100,000 years.

The ice ages are thought to have been by massive volcanic eruptions in Central America that created the land bridge at the Isthmus of Panama which separated the Atlantic and Pacific Oceans, drastically altering the circumglobal ocean current, and resulted in a rapid cooling of the Earth.

The last ice age started to retreat 10,000 years ago and coincided with the emergence of modern man and spread of human civilizations. The continental ice sheets still cover about 10 percent of the Earth's surface in Greenland and Antarctica. The next ice advance is predicted to start in about 15,000 years and could last from 25,000 to 85,000 years.

DISCUSSION

General experience reveals that human accidents can be attributed to several general "initiating events":

1. Natural disasters,
2. Design flaws,
3. Equipment failures,
4. Human errors.

In the history of technology, severe accidents in some cases meant a total disavowment of the technology.

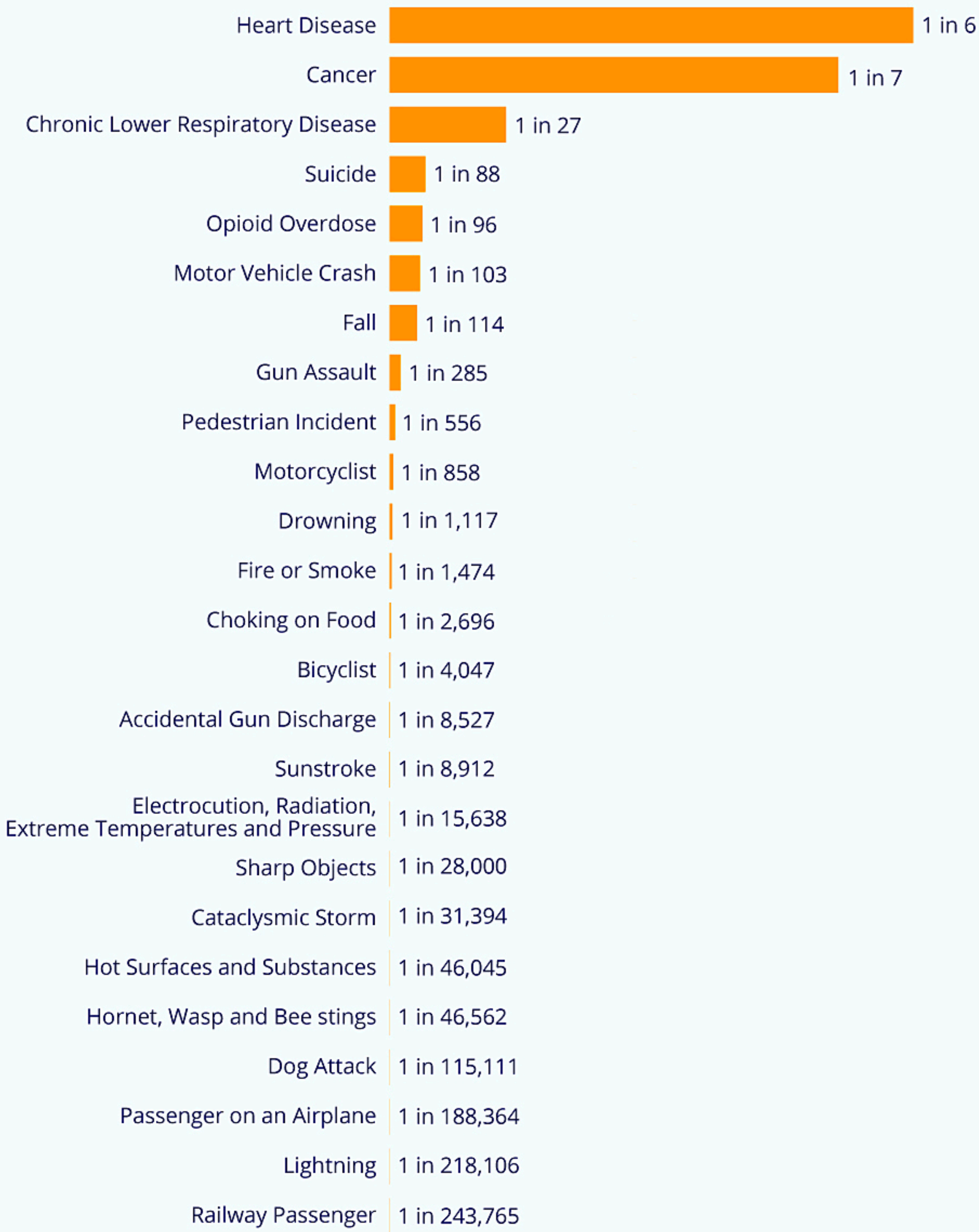
For instance, the sinking of the Titanic, meant the end of the era of large ocean liners. The Hindenburg Zeppelin accident meant the end of air transportation using lighter than air Dirigibles.

Unlike these, nuclear electrical generation has continued to be used in the USA after the TMI accident, with marked improvements in the safety of existing nuclear power plants. However, in spite of the fact that many nuclear plants have been constructed in other parts of the world, none has been built since then in the USA. It is clear that any construction of new nuclear power plants in the USA will depend on more innovative designs than the existing ones, incorporating passive and inherently safe safety features.

APPENDIX I

Opioids More Likely To Kill Americans Than Car Crashes

Lifetime odds of dying from selected causes in the U.S. in 2017*



* 1 year odds approximated by dividing 2017 U.S. population by number of deaths.
Lifetime odds approximated by dividing 1 year odds by life expectancy of a person born in 2017 (78.6 years).

 Source: National Safetly Council

APPENDIX II
VOLCANIC ERUPTIONS

Mount Etna, Sicily, Italy.

Mount Etna, Sicily, Italy, eruption, February 16. 2021.

Mount Etna, Sicily, Italy, February 23, 2021.

Mount Etna, Sicily, Italy, February 24, 2021.

Volcán de Fuego, Guatemala.

Mount Bromo, Indonesia.

Mount St Helens, Washington, USA.

Mount Yasur, Vanuato.

Mount Pelée Martinique.

Volcán de Colima or Volcán de Fuego, Mexico.

Arenal volcano, Costa Rica.

Mount Teide, Tenerife, Canary Islands, Spain.

Yellowstone caldera, Wyoming, USA.

Villarrica volcano, Chile.

Telica volcano, Nicaragua.

Kīlauea volcano, Hawaii, USA.

Cotopaxi volcano, Ecuador.

Taal volcano, the Philippines.

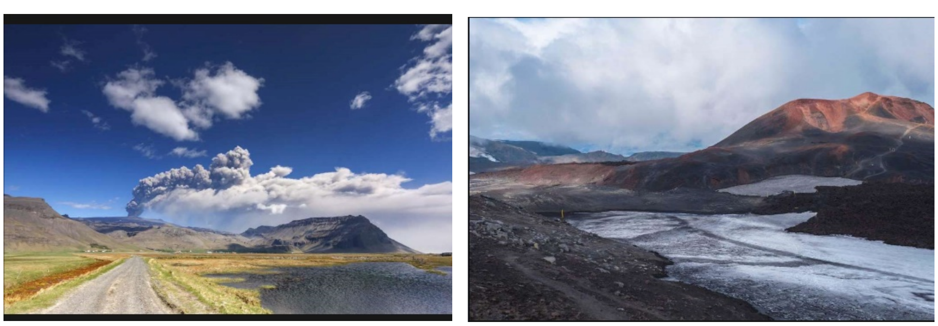
Taal volcano, the Philippines,

Mount Nyiragongo, Democratic Republic of the Congo.

White Island or Whakaari in Maori, New Zealand.

Mount Fuji-san, Japan.

Mount Vesuvius, Naples Italy devastated the city of Pompei in 79 AD.



Eyjafjallajökull volcano, Iceland.

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EXERCISES

1. Describe the difference between hurricanes, typhoons ad cyclones.
2. Identify the 10 most devastating known natural disasters in terms of human casualties.
3. The difference between two Richter scale magnitudes is given by:

$$\Delta M = \log_{10} \frac{M_2}{M_1}$$

Estimate the ratio of the actual magnitude (9.0M) to the design-basis magnitude (8.6M) for the Fukushima 2011 earthquake.

4. The relationship between the intensity (E) and magnitude (M) scales can be expressed as:

$$\frac{E_2}{E_1} = 10^{1.5(M_2 - M_1)}$$

Estimate the ratio of the actual intensity to the design-basis intensity for the Fukushima 2011 earthquake.