



Identification and Analysis of Factors Affecting Emergency Evacuations

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Background & Purpose

- **NRC-sponsored study to investigate large-scale evacuations occurring on U.S. mainland since 1990**
- **Purpose is to provide insight into factors affecting the efficacy of emergency evacuations**
- **First project of its kind since 1989**



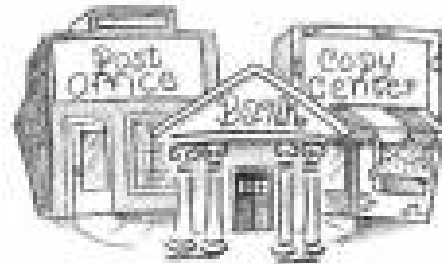
Approach

- **Perform extensive background search on evacuations in general, as well as on specific evacuation experiences**
- **Identify “universe” of evacuation incidents meeting specified criteria**
- **Conduct 50 representative case studies**
- **Develop and apply method of evaluating evacuation success**



Specific Evacuation Criteria

- **U.S. mainland public evacuation**
- **Occurred after January 1, 1990**
- **Evacuation >1,000 people**
- **Evacuation from more than a single building or industrial facility**



Research


- **Books, journals, conference proceedings**
- **News archives (AP, UPI, etc.)**
- **Government websites (NTSB, NRC, FEMA, DOT, DOD, NOAA, ARC, EPA)**
- **Professional organizations (API, NFPA)**
- **University websites (Dartmouth, U. of Delaware, U. of Colorado, FSU, etc.)**





Review of Numerous Databases

- **EPA Accidental Release Information Program (ARIP)**
- **DOD Hazardous Materials Information Resource System (HMIRS)**
- **Chemical Incidents Reports Center (CIRC) Database**
- **ATSDR Hazardous Substances Emergency Events Surveillance (HSEES)**
- **FRA Railroad Accident/Incident Reporting System (RAIRS)**



Extensive Research Yielded the Following Results

- **230 evacuation incidents identified that meet criteria in 12.5-year period (1/1/90 – 6/30/03)**
- **Considering post-1997 events, an evacuation meeting the criteria occurs every 2 weeks**
- **Data and information prior to 1997 was not as readily available**

EVACUATIONS IN THE U.S.

A map of the United States illustrating evacuation routes and locations. The map features a network of red lines representing evacuation routes, which are densely packed in the eastern half of the country and more sparse in the western half. Numerous red dots are scattered across the map, indicating specific evacuation locations. Major cities are labeled in blue text, including Seattle, Portland, San Francisco, Sacramento, San Jose, Los Angeles, Anaheim, San Diego, Phoenix, Tucson, Albuquerque, Denver, Colorado Springs, Kansas City, St. Louis, Indianapolis, Chicago, Milwaukee, Detroit, Cleveland, Pittsburgh, New York, New York, Newark, Philadelphia, Baltimore, Washington, Richmond, Charlotte, Atlanta, Memphis, Dallas, Austin, Houston, San Antonio, New Orleans, and Miami. State abbreviations are also visible, such as WA, OR, ID, MT, ND, SD, MN, WI, MI, NY, ME, VT, NH, MA, CT, NJ, DE, PA, OH, WV, VA, NC, SC, GA, AL, MS, AR, OK, NM, UT, NV, CA, AZ, and TX.

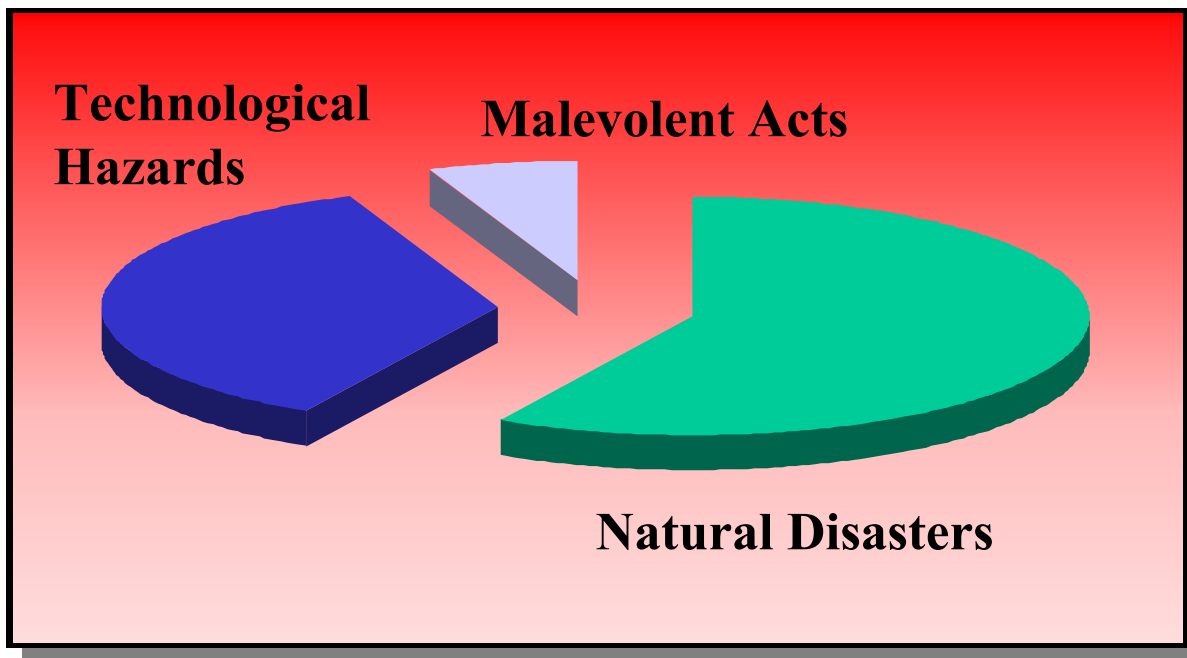


Each Incident Profiled By...

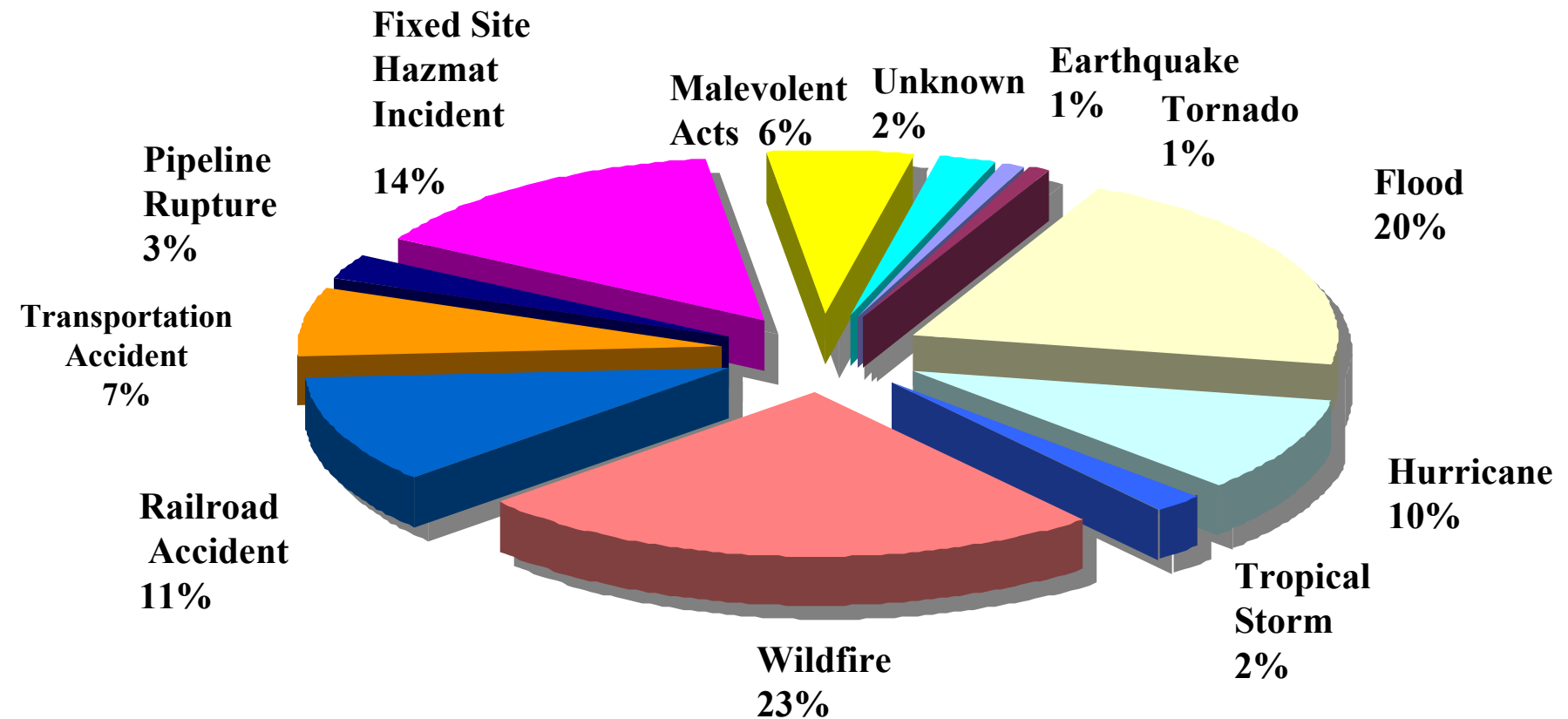
- **Size of evacuation**
- **Type of incident**
(natural, technological,
or malevolent acts)
- **Category of hazard**
(hurricane, railroad
accident, etc.)
- **Year of occurrence**
- **Special issues**
- **Community size**
- **Region in U.S.**

Evacuation Universe Cross-Section

- 133 (58%) due to natural disasters
- 84 (36%) due to technological hazards
- 13 (6%) due to malevolent acts

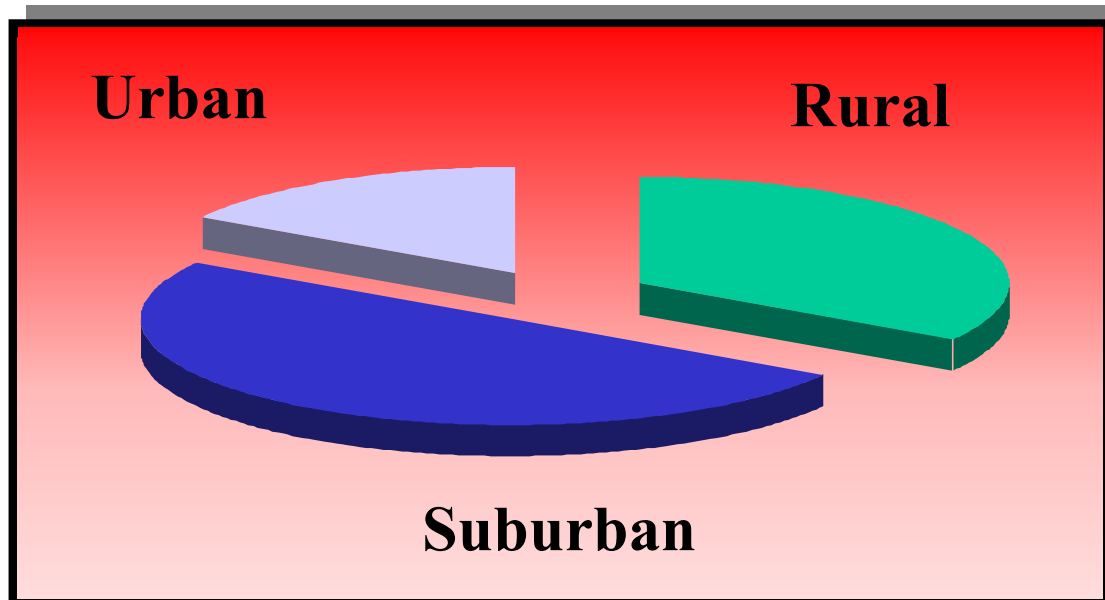


Principal Causes of Large-Scale Evacuations in the U.S.

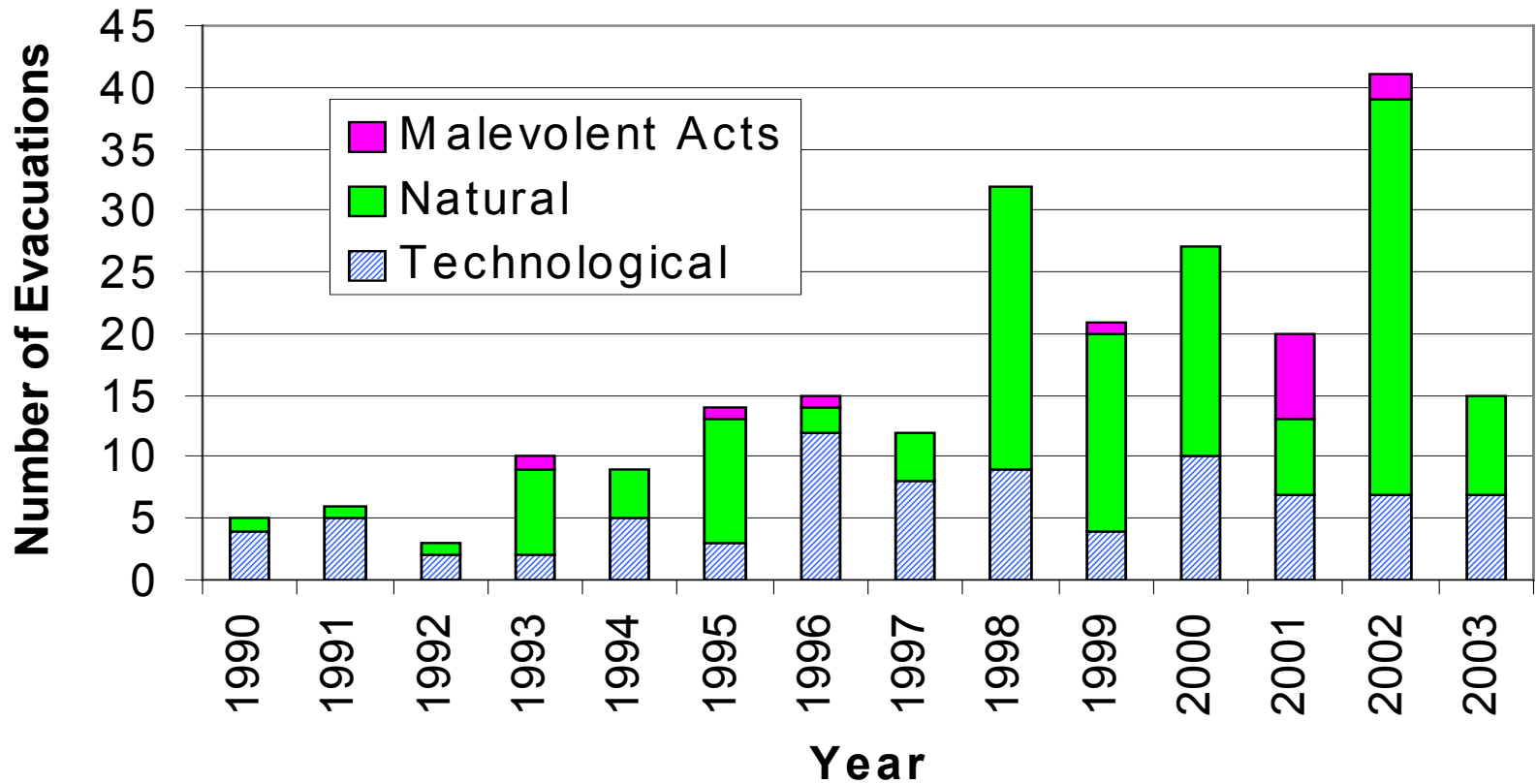


Evacuation Universe: Community Context

- 77 (34%) Rural
- 116 (50%) Suburban
- 37 (16%) Urban

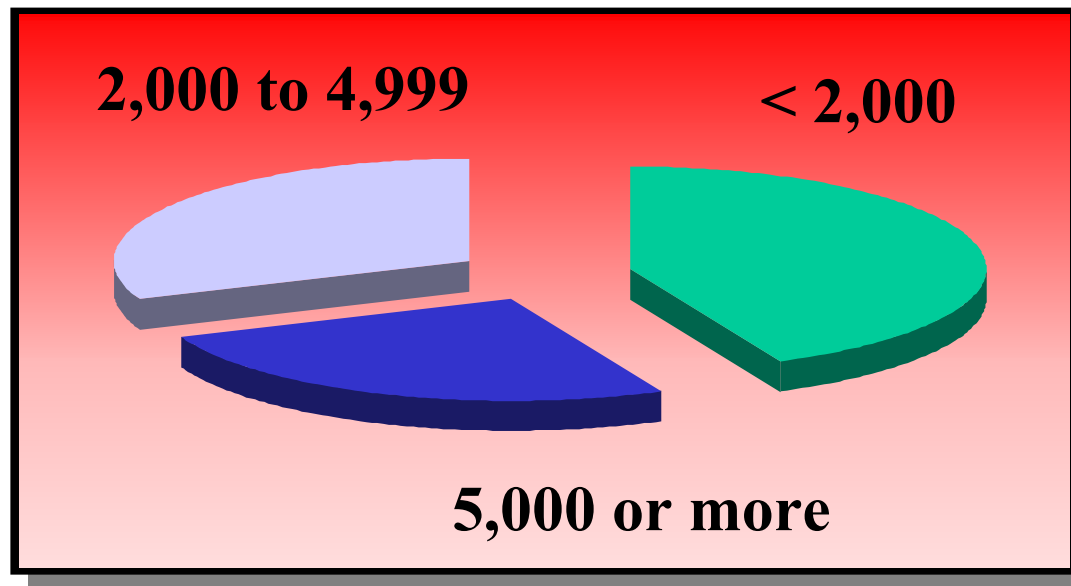


Evacuations by Year of Occurrence



Evacuation Universe: Evacuation Size

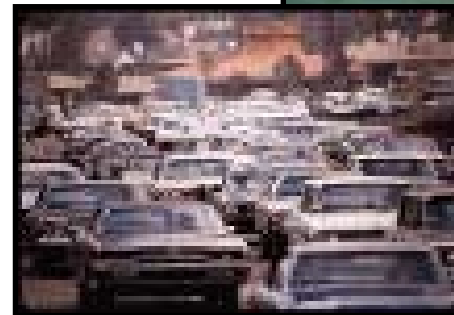
- 100 (43%) involved <2,000 people
- 60 (26%) involved 2,000 to 4,999 people
- 70 (31%) involved 5,000 or more people



Evacuation Universe: Special Issues

24% involved a special issue including:

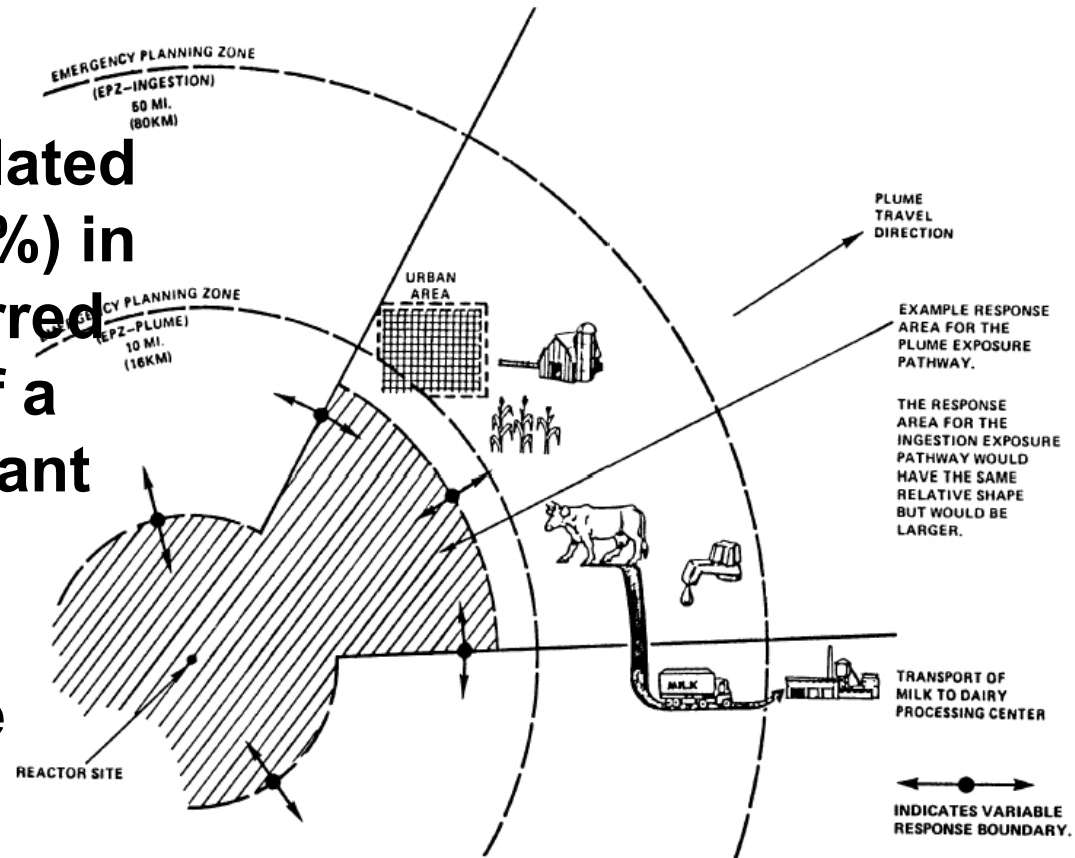
- **Evacuation of special facilities**
 - nursing homes, hospitals, prisons, or schools
- **Other evacuation methods**
 - air or boat
- **Unusual circumstances**
 - shadow evacuations, traffic issues, or law enforcement issues



Evacuation Universe: Emergency Planning Zone

6 non-nuclear-related
evacuations (2.6%) in
“universe” occurred
within the EPZ of a
nuclear power plant

4 of the 6 were
analyzed as case
studies





Case Study: Emergency Planning Zone (EPZ)

Four cases analyzed were in an EPZ:

- Warehouse chemical spill in Charlotte, NC**
- Hurricane Andrew in Miami-Dade Co., FL**
- 2 Hurricane Floyd evacuations in SE FL**



Total Ranking & Case Study Selection

- **“Total Ranking” was sum of products of weights & ratings for each factor**
- **Total rankings were then normalized to a 100-point scale (“Normalized Ranking”)**
- **50 representative cases selected from top 100 ranked incidents; selection based on ranking & professional judgment**



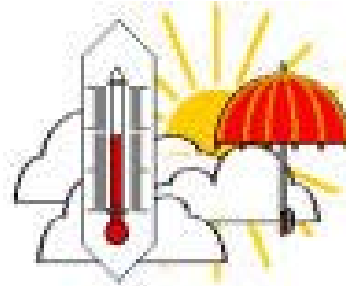
Ranking the “Universe”

FACTOR	WEIGHT	RATING
Number of Evacuees	5	3 = >5000; 2 = 2,000-5,000; 1 = <2000 evacuees
Preparedness Level	5	3 = Within an EPZ; 2 = Within a hurricane prone region ; 1 = None of above
Hazard Type	3	3 = Technological Hazard or Malevolent Act; 1 = Natural Disaster
Year	3	3 =2000-2003; 2 = 1997-1999; 1 = 1990-1996
Special Issues	3	3 = Special issues encountered; 1 = Few or no special issues
Community	1	3 = Urban; 2 = Suburban; 1 = Rural
Region of U.S.	1	3 = North, South, or Midwest; 1 = West, Southwest, or Northwest

Case Study Questionnaire

Questionnaire contained >80 questions in four major areas:

- **Community Context (general community info, history of emergencies, emergency preparedness)**
- 2. Threat Conditions (type of hazard, time of day, road conditions, unusual circumstances)**



Case Study Questionnaire (Concluded)

- **Consequences**
(number evacuated, injured, killed, cost information)
- 4. Emergency Response**
(decision-making, communications, notification and warning, traffic movement and control, sheltering, law enforcement, re-entry)



Evacuation Case Studies



Eunice, LA Train Derailment (2000)
Technological Hazard – Chemical Spill
>2,000 Evacuated

Hanford, WA Wildfire (2000)



Natural Disaster
>2,500 Evacuated

Hurricane Floyd (1999)



Natural Disaster
>1.7M evacuated

Evacuation Case Studies (Continued)

World Trade Center “9-11” (2001)



300,000 Evacuated
Some evacuated by boat

60,000 Evacuated



**Centennial Olympic Park
Bombing, Atlanta (1996)**

Evacuation Case Studies (Concluded)

Baltimore, MD Tunnel Fire (2001)



**Baseball stadium evacuated
Downtown closed for days**

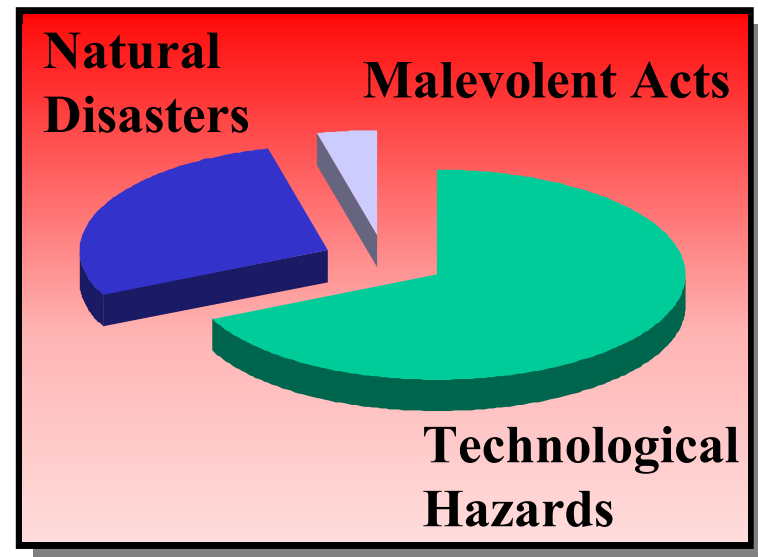
Cerro Grande Fire Evacuation, Los Alamos, NM (2000)



**Fire started from controlled burn
Entire town evacuated**

Case Study Cross-Section

- 50 case studies
- 33 (66%) due to technological hazards
- 14 (28%) due to natural disasters
- 3 (6%) due to malevolent acts





Case Study: Community Context

- **72% involved suburban communities**
- **42% had manufacturing and industry as their main economic base**
- **82% involved residential areas**



Case Study: Issues Considered

- **Emergency communications**
- **Traffic movement & control**
- **Shadow evacuations**
- **Citizen action**
- **Evacuation decision-making**
- **Re-entry**
- **Law enforcement**
- **Notification of response/officials**



Method of Evaluating Case Studies

- **Factors Considered:**
 - Direction and control (evacuation decision-making process)
 - Emergency communications
 - Notification of response personnel and local officials
 - Citizen warning
 - Traffic movement and control
 - Law enforcement
 - Re-entry



Regression Analysis Description

- **Statistical technique to find relationships between a dependent variable (success score) & one or more independent variables (from questionnaire)**
- **Each variable in questionnaire was compared to evacuation score using an ordinal logit model which is a generalized linear model**



Regression Analysis Description (Concluded)

- **Chi-squared (probability or “p”) value indicates variable’s association to success score:**
 - **If $p < 0.01$, highly statistically associated to success score**
 - **If $p 0.01 - 0.05$, statistically associated to success score**
 - **If $p 0.05 - 0.10$, marginally statistically associated to success score**



Correlation Analysis

- **Correlation coefficient (r) is a statistical measure of the interdependence of two or more random variables**
- **Variables with $|r| > 0.30$ are considered statistically significantly correlated; higher $|r|$ value, more significant the correlation**



Hazard Type

- **Hazard type statistically associated to evacuation success score**
- **Increased probability of evacuation issues for natural disasters**
- **Natural disasters generally involve larger land areas & more time between start of hazard & decision to evacuate than technological hazards or terrorism events**
- **After adjusting for hazard type, these two variables (i.e., elapsed time and land area) no longer associate to evacuation success score**



Multiple Ordinal Logistic Regression Analysis

- **Since hazard type is often associated with other variables, results were adjusted for hazard type by performing a multiple ordinal logistic regression analysis**
 - **In logistic regression, dependent variable is qualitative (rather than continuously variable) & likelihood functions are used to find best relationship**
 - **In multiple regression, dependent variable depends on more than a single independent variable**



Case Studies

Sept-99	Miami-Dade, FL	Hurricane Floyd	270,403 evacuated
Sept-99	S-Broward, FL	Hurricane Floyd	374,144 evacuated
July-01	Riverview, MI	ATOFINA Fixed Site Hazmat	6,000 evacuated
Aug-92	Miami-Dade, FL	Hurricane Andrew	650,000 evacuated
Sept-99	Central Florida, FL	Hurricane Floyd	665,969 evacuated
July-98	Mims, FL	Mims Wildfire	16,000 evacuated
Sept-02	Charlotte, NC	Charlotte Fixed Site Hazmat	1,000 evacuated
July-01	Baltimore, MD	CSX Train Fixed Site Hazmat	10,000 evacuated
Sept-01	Lower Manhattan, NY	World Trade Center Terrorism	300,000 evacuated
July-96	Atlanta, GA	Centennial Olympic Park Bombing	60,000 evacuated
Oct-95	Bogalusa, LA	Gaylord Tank Car Railroad Accident	3,000 evacuated
May-00	Eunice, LA	Union Pacific Railroad Accident	2,000-3,000 evacuated
May-03	Brandon, FL	Pipeline Rupture	2,000 evacuated
Feb-03	Slocomb, AL	Mathis Farm Supply Fixed Site Hazmat	3,500 evacuated
Mar-01	Forest, MS	Choctaw Maid Plant Fixed Site Hazmat	2,000 evacuated



Case Studies (Continued)

Aug-00	Hugo, OK	Truck Accident	2,000-2,500 evacuated
July-99	Iowa City, IA	Procter & Gamble Fixed Site Hazmat	5,000 evacuated
Jan-98	Maysville, KY	Cargill Chemical Plant Fixed Site Hazmat	2,500 evacuated
May-00	Los Alamos, NM	Cerro Grande Wildfire	12,000 evacuated
June-02	Deadwood, SD	Deadwood Wildfire	15,000 evacuated
May-00	White Rock, NM	Cerro Grande Wildfire	7,000 evacuated
June-02	Douglas County, CO	Hayman Wildfire	5,500 evacuated
July-97	Flora, MS	Railroad Accident	6,000 evacuated
July-98	Flagler County, FL	Wildfire	45,000 evacuated
Oct-01	Alexandria, LA	LSU Anthrax Hoax	2,000 evacuated
Mar-00	Sterling Heights, MI	Fixed Site Hazmat	2,400 evacuated
May-02	Pottersville, MI	Grand Trunk Railroad Accident	2,200 evacuated
Dec-00	Oshkosh, WI	Railroad Accident	2,300 evacuated
Sept-02	Farragut, TN	Norfolk Southern Railroad Accident	3,000 evacuated
Dec-95	North Attleboro, MA	Pipeline Rupture	40,000 evacuated



Case Studies (Continued)

May-02	Arlington, WA	Twin City's Plant Fixed Site Hazmat	1,500 evacuated
Mar-94	Prichard, AL	Railroad Accident	2,000 evacuated
June-92	Superior, WI	Burlington Northern Railroad Accident	40,000 evacuated
June-00	Benton City, WA	Hanford Wildfire	2,200 evacuated
Nov-00	Scottsbluff, NE	Burlington Northern Railroad Accident	5,000 evacuated
Oct-01	Morro Bay, CA	Ammonia Leak Fixed Site Hazmat	3,500 evacuated
Nov-98	Louisville, KY	Louisville Cargo Fixed Site Hazmat	2,400 evacuated
April-94	Balch Springs, TX	Pesticide Tanker Explosion	5,000 evacuated
Oct-91	Oakland, CA	East Bay Hills Wildfire	20,000-30,000 evacuated
Nov-97	Appleton, WI	Railroad Accident	5,000 evacuated
Dec-97	Bath, PA	Keystone Cement Fixed Site Hazmat	>1,600 evacuated
Oct-98	Pascagoula, MS	Pascagoula Propane Fixed Site Hazmat	>1,500 evacuated
Sept-98	Bossier City, LA	Transportation	~2,000 evacuated
Aug-97	Chicago, IL	Paint Plant Fixed Site Hazmat	2,500 evacuated
May-98	Mason City, IA	Mason City Chemical Fixed Site Hazmat	3,600 evacuated



Case Studies (Concluded)

Aug-92	Odessa, TX	Champion Inc. Fixed Site Hazmat	27,000 evacuated
May-91	Henderson, NV	Chlorine Leak Fixed Site Hazmat	~7,000 evacuated
Nov-91	Shepherdsville, KY	Railroad Accident	1,000 evacuated
June-02	Show Low, AZ	Rodeo-Chedeski Wildfire	20,000 evacuated
July-02	Cave Junction, OR	Biscuit Wildfire	1,000 evacuated



Project Status

- **Quantitative, qualitative & statistical analyses are being conducted**
- **Related NUREG, with results, summaries & recommendations is being drafted & will be delivered to the NRC at the end of this calendar year**