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A Method for Evaluating Fire After Earthquake Scenarios for Single Buildings

Elizabeth J. Kelly and Raymond N. Tell, LANL

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Conservative or Beyond?

While conservative assumptions may make an analysis easier to defend, overly conservative assumptions can be counterproductive.

Unintended Consequences

- **Associated Press – 10/28/09**

  "Quake could pose risk to Los Alamos Lab

  "An independent safety oversight board (DNFSB 2009-2) is warning that a major earthquake could cause a catastrophic fire triggering a massive radiation leak at the main plutonium laboratory at Los Alamos National Laboratory. …"

How did we get there?

Too Many Conservative Assumptions

- A fire in any compartment burns at the highest rate that can exist in the compartment based on surface area and ventilation available, regardless of fuel or ignition sources
- Many compartments on fire
- All inventory released instantaneously
- All material assumed to be finely ball milled powder

Moving On

Clearly a new approach was required to estimate the potential exposure to the public

Needed Defensible Reasonably Conservative Fire Scenario

- **Separate fire possibility into random and deterministic ignitions**
  - Random – like general built environment
  - Deterministic – fire more likely

Determination of the Number of Random Fires (Kelly and Tell "Modeling the Number of Ignitions Following an Earthquake: Developing Prediction Limits for Overdispersed Count Data")

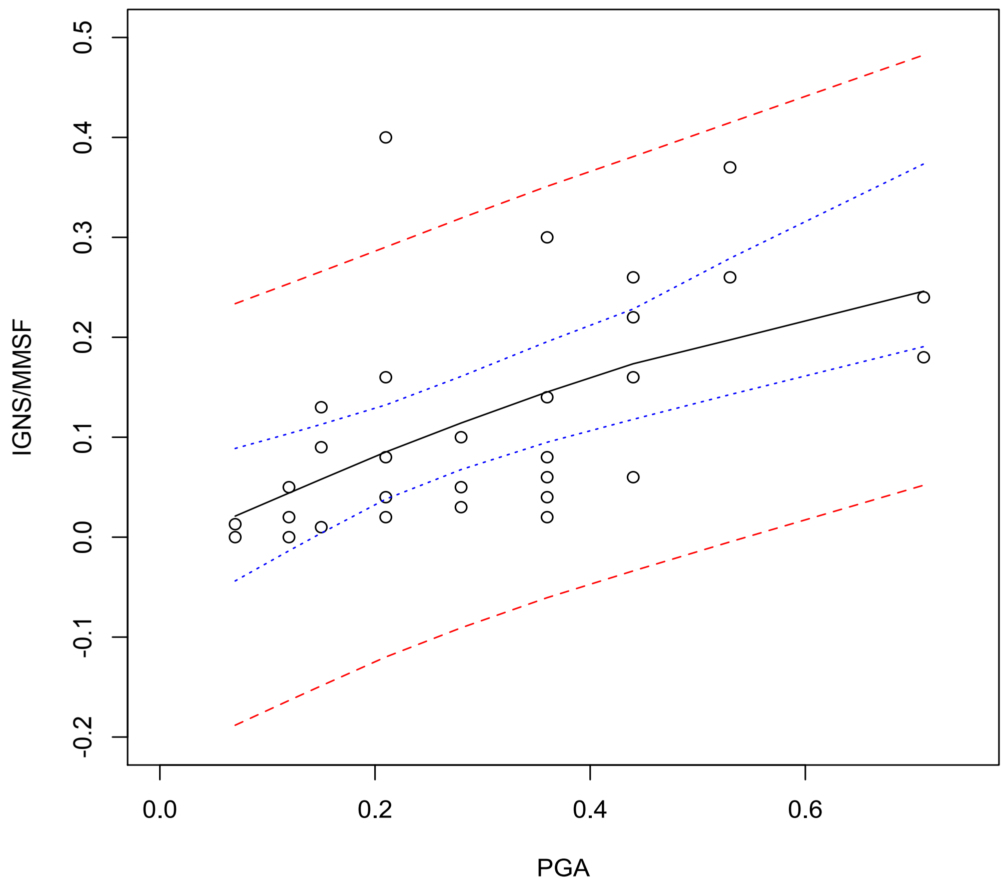
- **Used existing data to develop a statistical model for IGNS as a function of MMSF and PGA**
  - "Fire Following Earthquake," Technical Council on Lifeline Earthquake Engineering Monograph No. 26 (Scawthorn et. al.,2005)
    - Contains data from Alaska and California earthquakes *1906 – 1989*
    - Reports by fire departments
    - The data are for fires in the general built environment, including residential, commercial and industrial structures

- **Data included number of ignitions (IGNS), area affected (MMSF) and peak ground acceleration (PGA)**

APPROACH – Applying data to a single structure

- **Using these data to model a large single structure is inspired by the approach used in the Monograph to guide fire departments**
  - Single Family Equivalent Dwellings (SFED) are 1500 sq. ft areas that can be thought of as detached houses.
  - Thinking of the SFED as the basic unit for a fire is a reasonable approach for communication to fire departments on the number of separate structural fires to expect
  - "A large building of 1.5 *MMSF* can be thought of as 1000 SFED."
  - SFEDs comparable to rooms in building

Finding the Appropriate Statistical Model for Data: Monograph Uses PGA to Predict IGNS/MMSF – *problems with this approach*



- **Ratio estimator (IGNS really discrete variable)**
- **Monograph – Does not address uncertainties**
- **Error Structure Wrong (under estimates for small areas over estimates for large areas)**
- **Negative lower bounds**

Traditional Approach for Modeling Count Data (IGNS)

- **Model IGNS as a Poisson distribution**
- **Problem with this approach – data are overdispersed, i.e., variance larger than the mean**
  - Dispersion coefficient = 5.92 (should be one for Poisson regression)

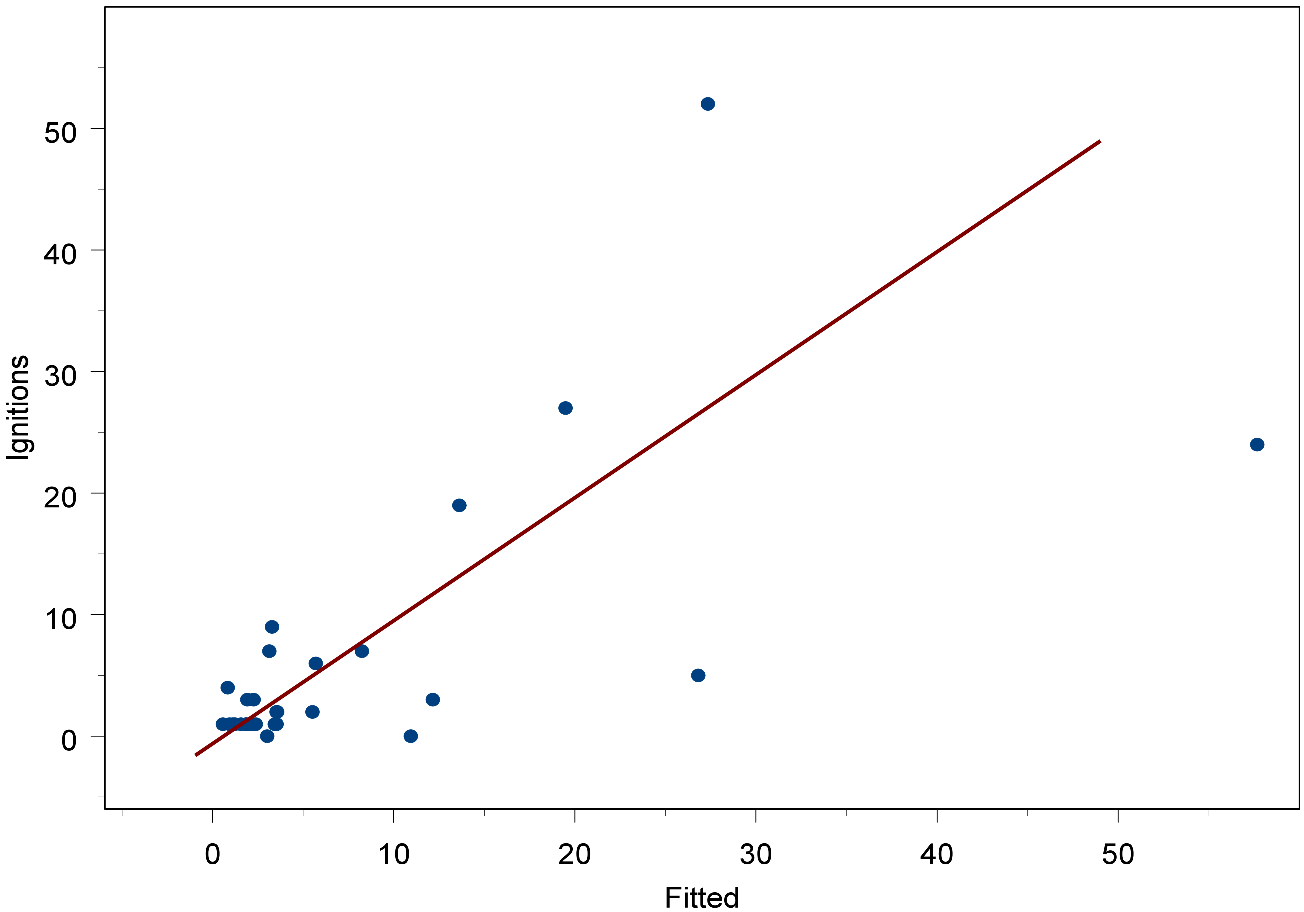
A Better Approach – Negative Binomial Regression (NBR)

- **Common approach used in the case of overdispersion – Negative Binomial Regression**
  - Assume Poisson parameter (μ) is a random variable with gamma distribution

- **IGNS then has a negative binomial distribution with mean μ and variance $\mu + \mu^2/k$**
  - $\mu = b_0 PGA^{b_1} MMSF^{b_2}$ (note: this includes Monograph model!)
  - $\ln(\mu) = \ln(b_0) + b_1 \ln(PGA) + b_2 \ln(MMSF)$

- **Use GLM to estimate parameters and standard errors**

NBR Fit to Data –must evaluate uncertainties



APPROACH – DETERMINING CONFIDENCE LIMITS AND PREDICTION LIMITS (UPL)

- **Uncertainties depend on MMSF and PGA**
- **Confidence limits straightforward from GLM**
- **Prediction limits required some work/research**
  - Developed a spreadsheet approach
  - Compared to numerical integration approach
- **Details in paper "Modeling the Number of Ignitions Following an Earthquake: Developing Prediction Limits for Overdispersed Count Data," Kelly and Tell, LA-UR-11-01857**

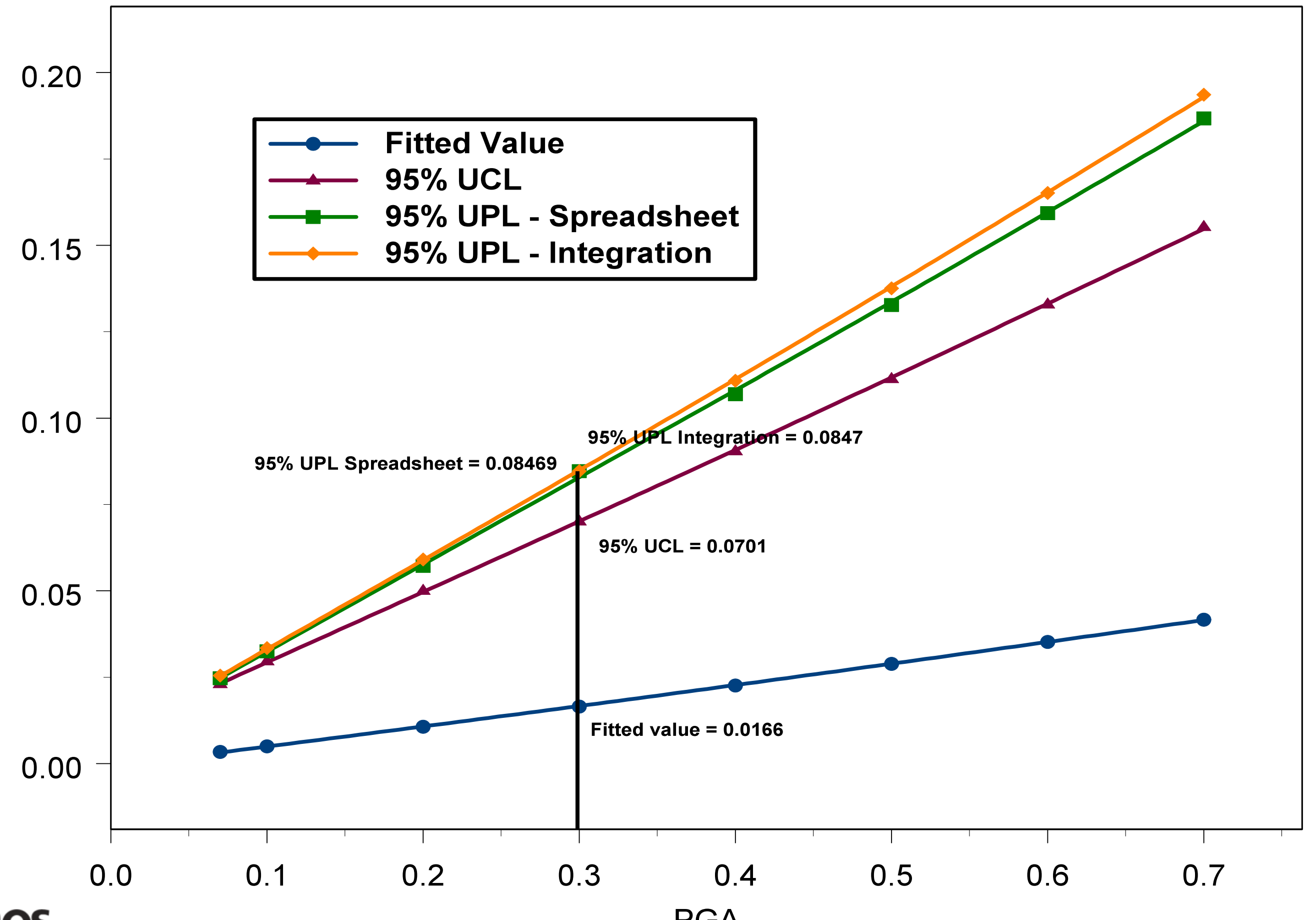
ADJUSTMENT TO THE MODEL

- **Adjusting the model to include potential fire incidents not reported**
  - Monograph data are assumed to represent 73% of the potential fires following an earthquake
    - J.L. Bryan in the report *Smoke as a Determinant of Human Behavior in Fire Situations* (1977)
      - Percentage of the population studied that either “fought fire” or “tried to extinguish” as one of their first three actions is 27%.
  - Use adjusted (UPL)
    - (1.37)* (UPL)   (1.37=1/.73)

CONSERVATIVE APPLICATION TO A SINGLE STRUCTURE

- **Argue that the new earthquake site is the same or less (or at least not more) vulnerable than what would be expected of the population represented by the Monograph data**
- **Determine PGA and MMSF of interest**
  - Example : PGA = 0.3g and MMSF =0.08 MMSF

RESULTS



Fitted Value
95% UCL
95% UPL - Spreadsheet
95% UPL - Integration
95% UPL Spreadsheet = 0.08469
95% UPL Integration = 0.0847
95% UCL = 0.0701
Fitted value = 0.0166
0.20
0.15
0.10
0.05
0.00
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
PGA

Results

Probability table for IGNS following an earthquake for PGA = 0.3g and MMSF =0.08 (adjusted for possible under reporting)

Method	Prob (IGNS≥1)	Prob (IGNS≥2)	Prob (IGNS≥3)
Spreadsheet	0.11	6.20E-03	2.40E-04
Numerical Integration	0.032	1.58E-03	1.34E-04

RESULTS

Annual frequency (AF) table for IGNS following an earthquake for PGA = 0.3g (AF=1/2000 years) and MMSF =0.08 (adjusted for possible under reporting)

Method	Freq(IGNS≥1)	Freq(IGNS≥2)	Freq(IGNS≥3)
Spreadsheet	5.5E-05	3.1E-06	1.2E-07
Numerical Integration	1.6E-05	7.9E-07	6.7E-08

The Method – Determine Compartments with Dose Potential

- **Determine compartments of interest**
  - Hazardous materials

- **Rank compartments of interest by potential dose consequence**

Method – Evaluate Processes

- **Review operations and processes within the rooms of interest for conditions different than in the general built environment**

Method - Determine Number of Deterministic Fires

- **Judge the operations and processes determined to be unusual for their propensity to ignite or cause an ignition during or immediately following an earthquake**
- **Categorize the rooms of interest with a high likelihood of ignition as deterministic fire compartments**

Method – Develop Fire Model

- Assign the random fires to the highest ranked remaining rooms
- Survey the determined and random fire rooms for fuels, ignition sources and locations of fuels and ignition sources
- Determine the worst case credible fuel package for each fire room

Method – Model Fire

- **Bound and characterize the worst case fuel packages using available fire test data**
- **Model the fire rooms using CFAST assuming the available fire test data as input**

Method – Fire Model Output

- Provide CFAST predictions of temperatures and mass flows from the fire rooms for further considerations applicable to the facilities and scenarios of interest