Cloud Rise Model (& some related issues) for RDD & Nuclear Terrorism Scenarios

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Outline

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- Qualitative Description
- Status Before GF-Series
- GF- Set of Experiments
- GF- Results & Analysis
- GF vs. Church (Hot Spot)
- Summary
- Particles

Problem definition

- For realistic & reliable estimation of contamination (total dose, ground deposition etc.) followed by HE dispersion of RA materials into the atmosphere it is necessary to know the cloud properties:
- Dimensions (volume, effective height).
- Particles size distribution within the cloud.

All as function of the explosive amount, space & time and atmospheric stability!

GF project (conducted is Israel) aimed to answer all these issues.

Qualitative description of cloud evolution

- One of the most remarkable phenomena followed an explosion is the formation of a cloud composed of hot air, smoke and dust.

- Although the cloud’s evolution is a continuous process, it is sometimes convenient to divide it to several stages due to the different mechanisms in each stage.

Qualitative Description (cont.)

- **Stage 1**: Fast spread of the hot explosion products, that heats the air in close vicinity of the detonation point. This stage lasts fractions of second. Hence the fastest part in the entire process and the least meteorology dependent.

Qualitative Description (cont.)

- **Stage 2**: Expansion and elevation of the cloud formed from detonation products, hot air and entrained dirt. The average temperature inside is significantly higher than the ambient atmosphere. Cloud dimensions & its velocity determined by the average density inside, atmospheric density, aerial viscosity and the speed and temperature distributions inside.

  The active processes cooled down by radiation, convection inside the cloud and heat transport to the atmosphere. This step lasts seconds to tens of seconds.

Qualitative Description (cont.)

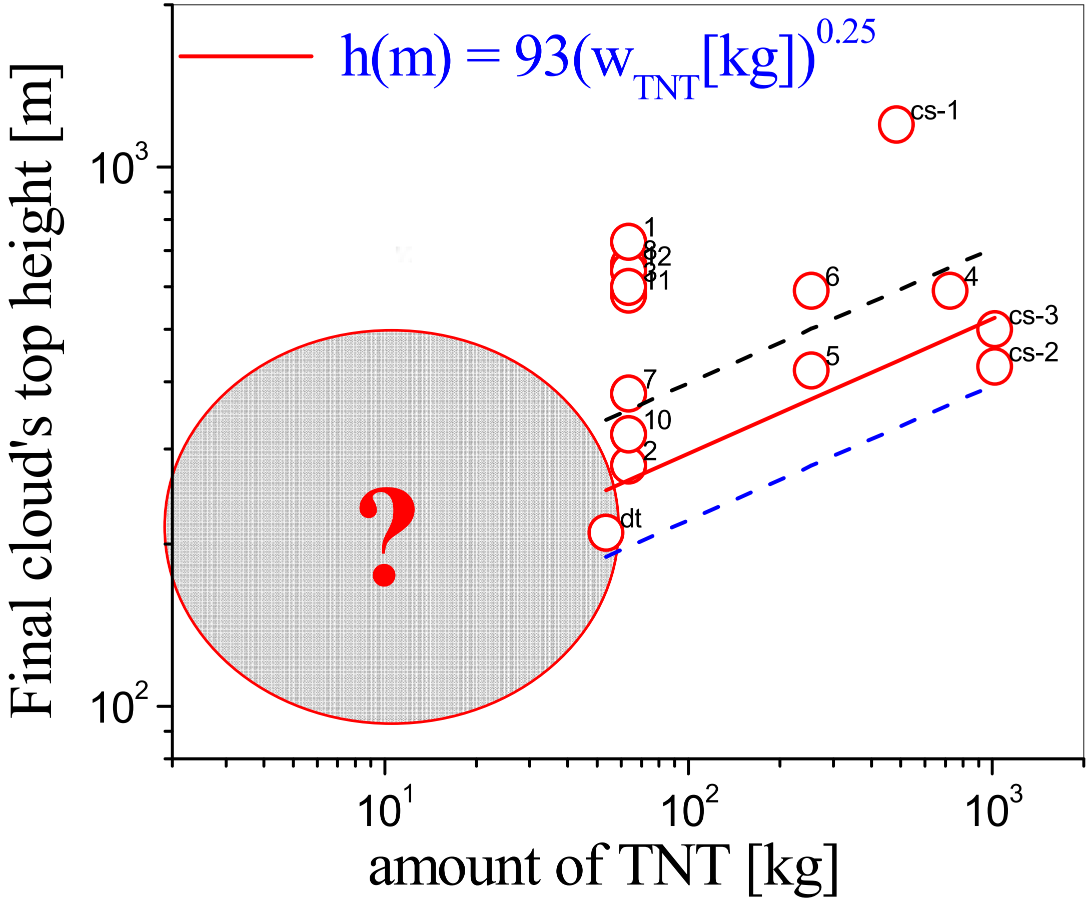
- **Stage 3**: Still expansion and elevation, while the average temperature of the cloud is close to the ambient. The processes that levitate the cloud are buoyancy and inertia of gases inside the cloud. The growth of the cloud caused mainly due to diffusion and turbulence. This step lasts 10’s of sec. (up to hundreds of seconds for large amounts of explosives).

Status Before GF Project

- The main database used for the calibration of explosion cloud-rise models is the one obtained in the "Roller-Coaster" Experiment (Double Track & Clean Slate) conducted more than 40 years ago.
- These experiments were conducted using 60-1200 kg of TNT, very high for most typical RDD scenarios.
- RDD Scenarios are more realistic, to explosive amounts of less than 50 kg.

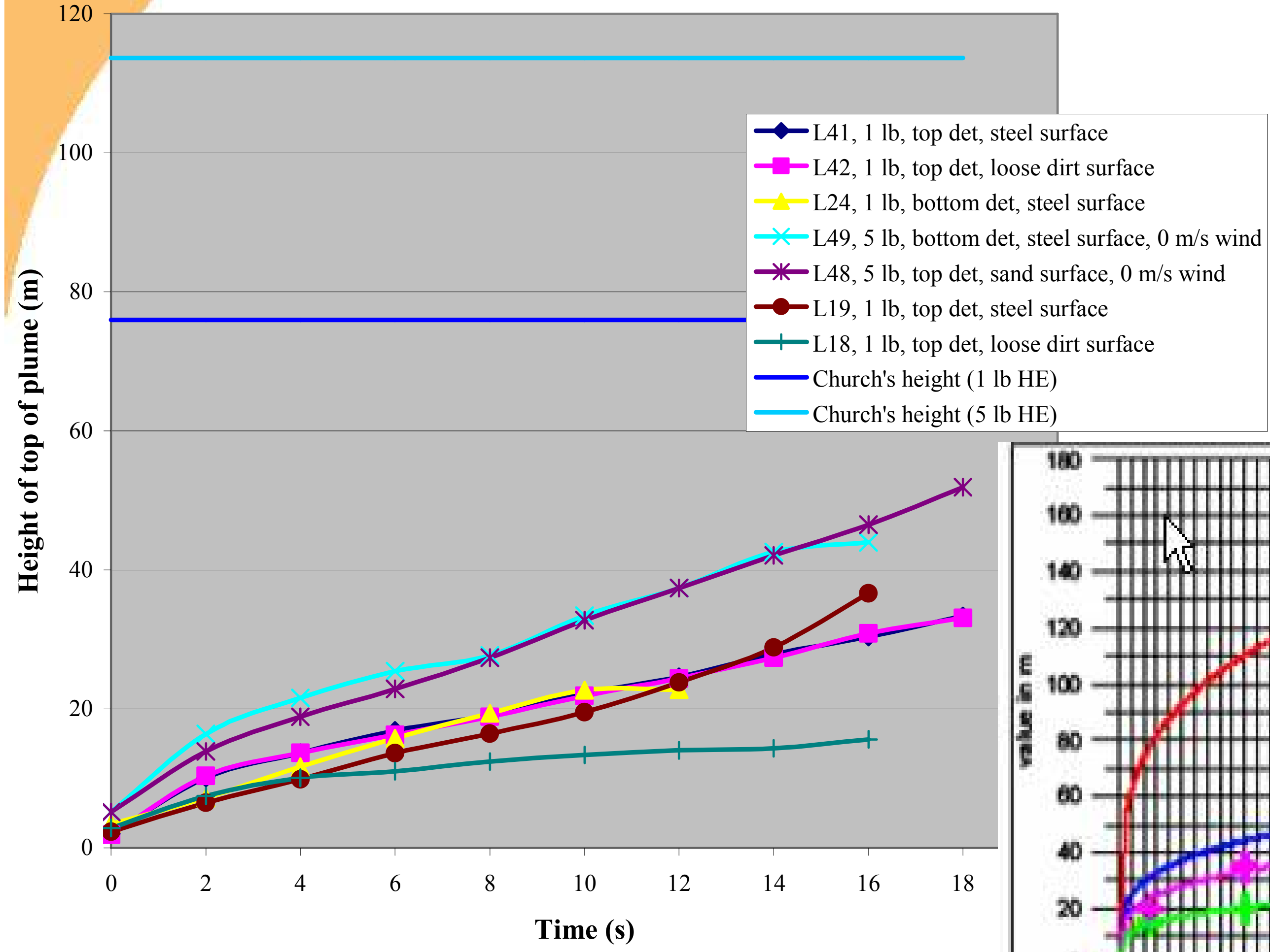
Status Before GF Series (cont.)

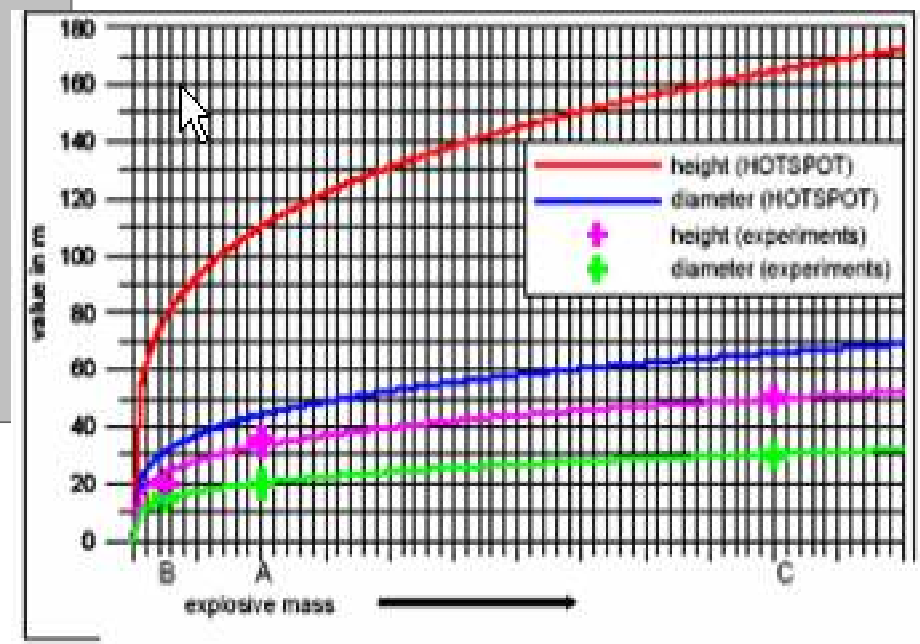
The "Roller-Coaster" experiments results[1,2]



[1] E.J. Kansa, UCRL-1D-128733 (1997).
[2] H.W. Church (1969).

Church's model vs. exp.





GF Targets

- Cloud rise model for RDD terror scenarios.(GF1-7)
- 3D Dispersion analysis.(GF2,5)
- Particles analysis (size, mass, morphology).(GF4-7)
- Indoor/Outdoor cloud rise comparison.(GF6,7)
- Material fraction stay/escape the room after an explosion.(GF6,7)

GF Set of Exp.

- Over 100 explosion tests
- Different amount of explosive (0.25-100 kg's of TNT.
- Different geometries (rectangular, spherical, cylindrical).
- Different atmospheric stability classes.
- Different RA material simulants.

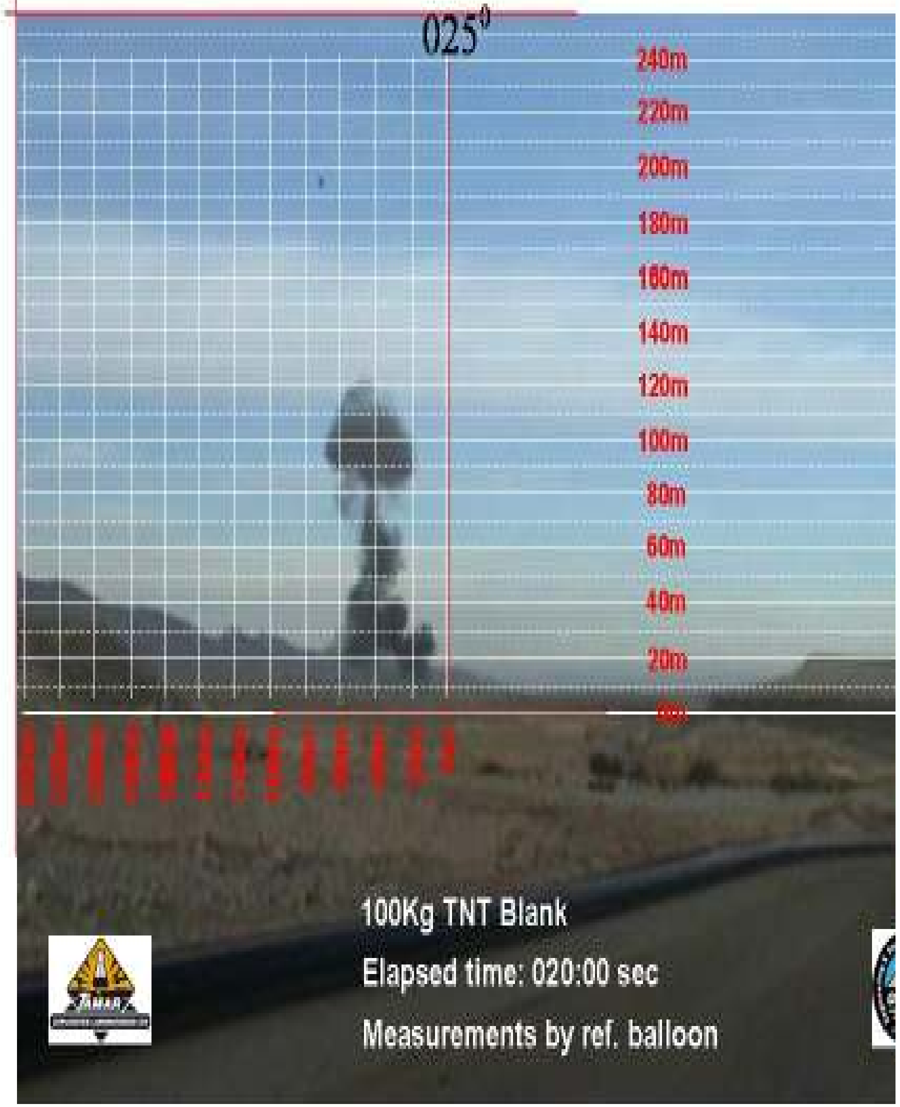
GF's Documentation

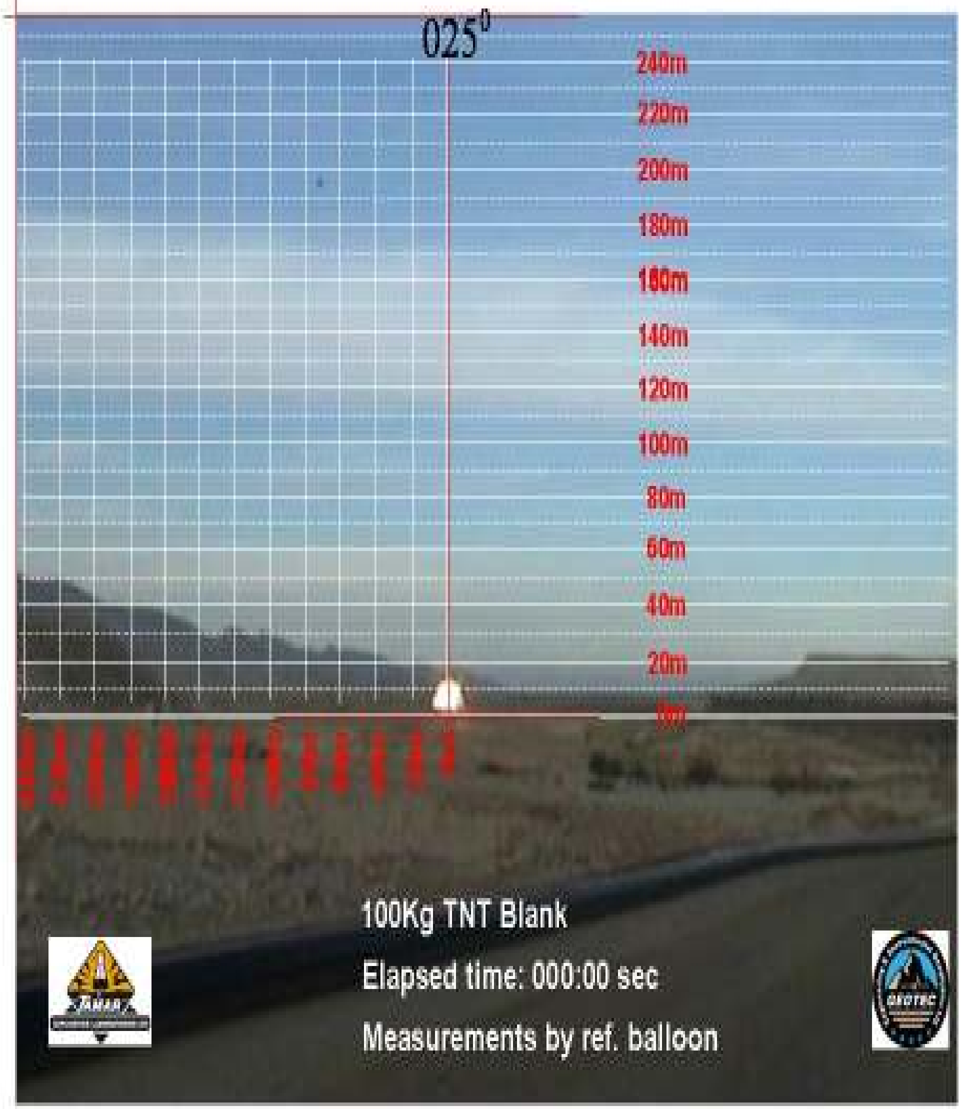
- **GF 1-3** Cloud rise detection- 3 video cameras, IR(GF1), fast camera. (GPS-Sounding +Met mast).
- **GF 4-5** Cloud rise, WC aerosolization- 3 video cameras, IR(GF4,5), fast camera, lidar (GF4). (GPS-Sounding +Met mast).
- **GF 6-7** Cloud rise, salt & ceramic aerosolization, indoor vs. outdoor cloud evolution. 3 video cameras, fast camera, IR(GF6). (GPS-Sounding +Met mast).

Explosive's Geometry

Explosion clouds

GF-2 site's

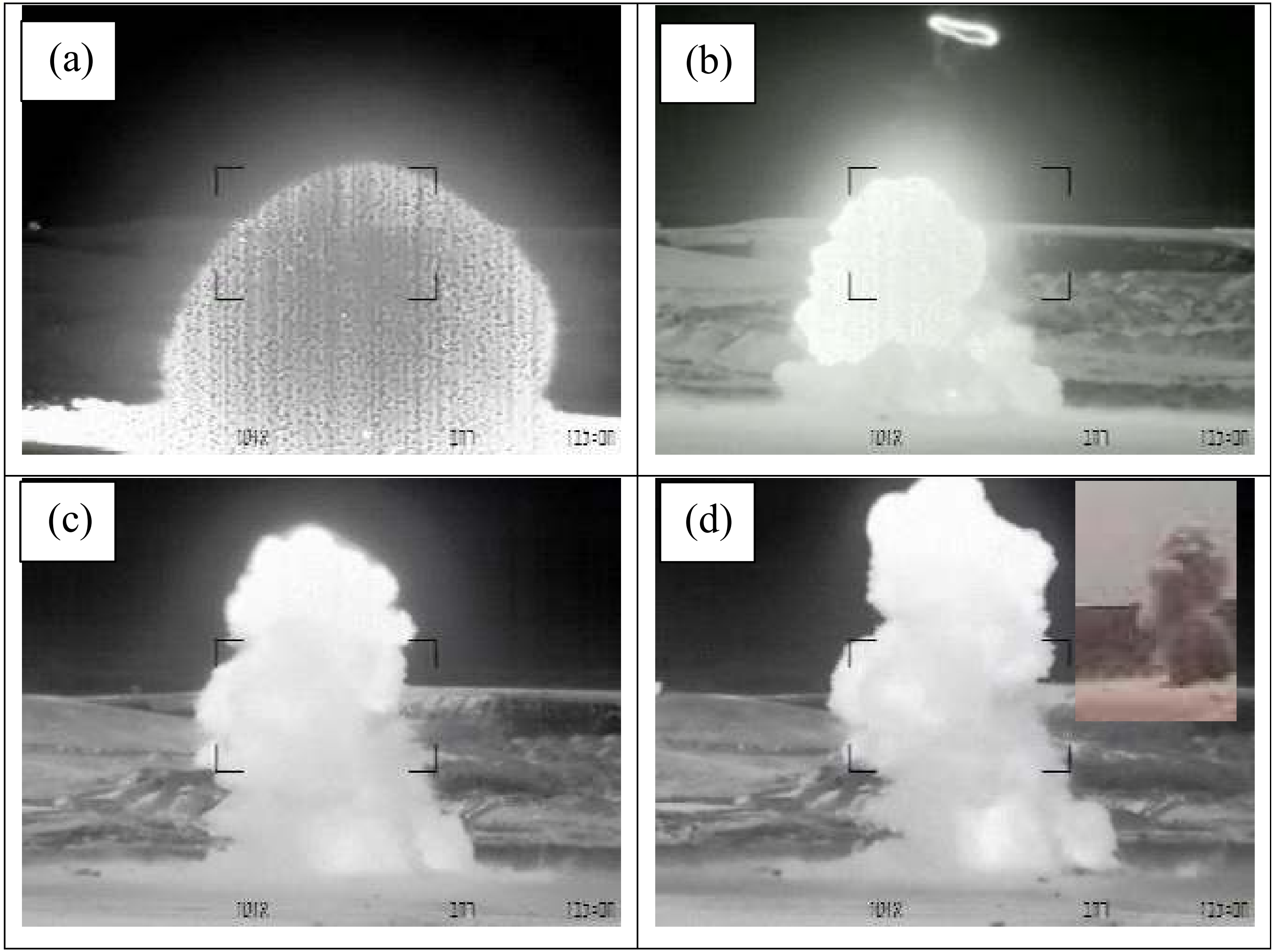

025⁰
240m
220m
200m
180m
160m
140m
120m
100m
80m
60m
40m
20m
100Kg TNT Blank
Elapsed time: 020:00 sec
Measurements by ref. balloon


025⁰
240m
220m
200m
180m
160m
140m
120m
100m
80m
60m
40m
20m
0m
100Kg TNT Blank
Elapsed time: 000:00 sec
Measurements by ref. balloon

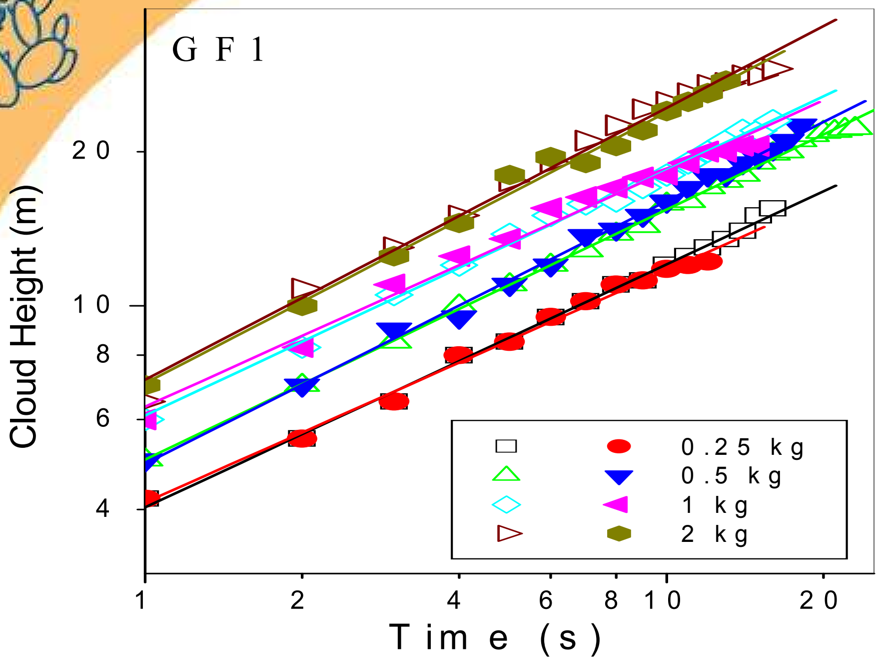
GF-4 Exp.

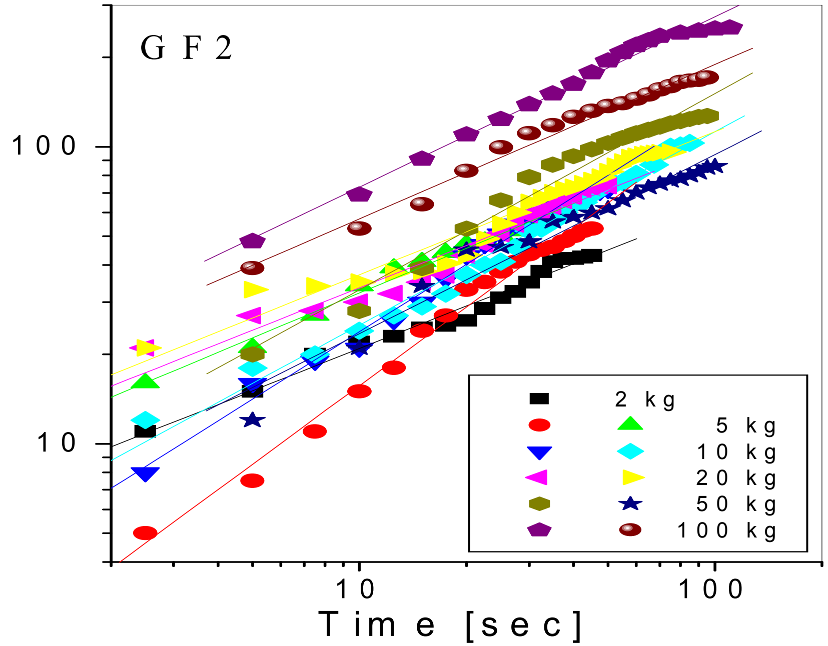


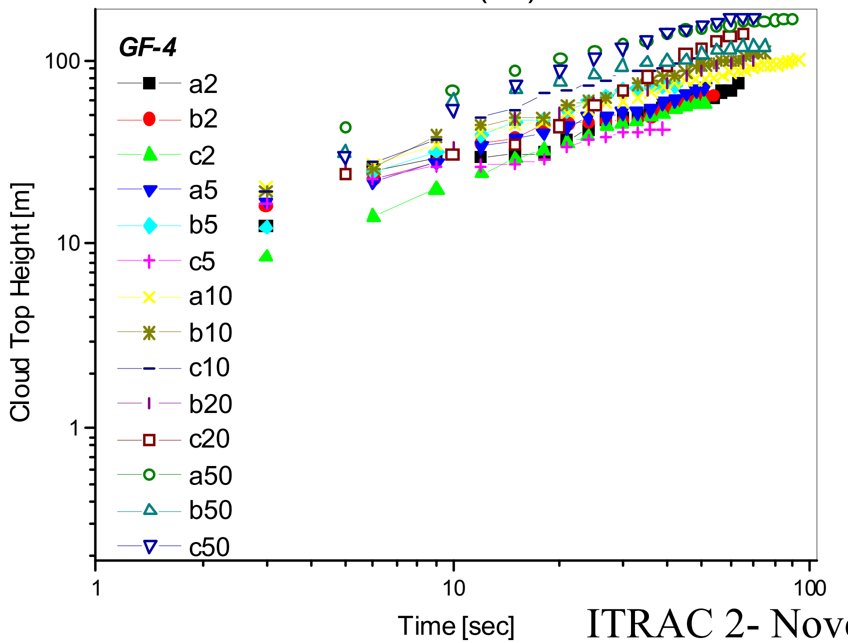

IR Cameras

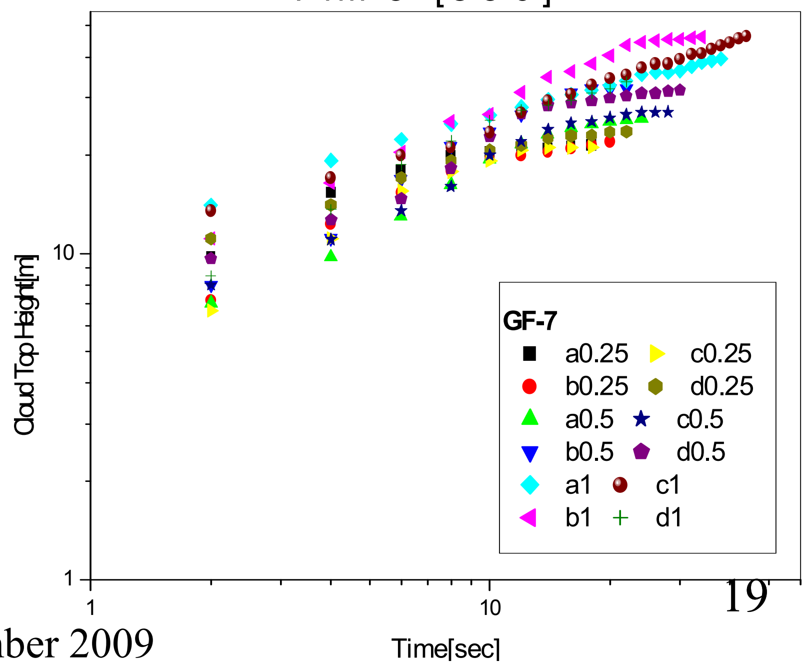


GF Results *(log-log scale)*









Results Analysis

- The experimental results were fitted assuming a simple power law dependency (due to close fit (R^2> 0.94) to linear in the logarithmic scale):

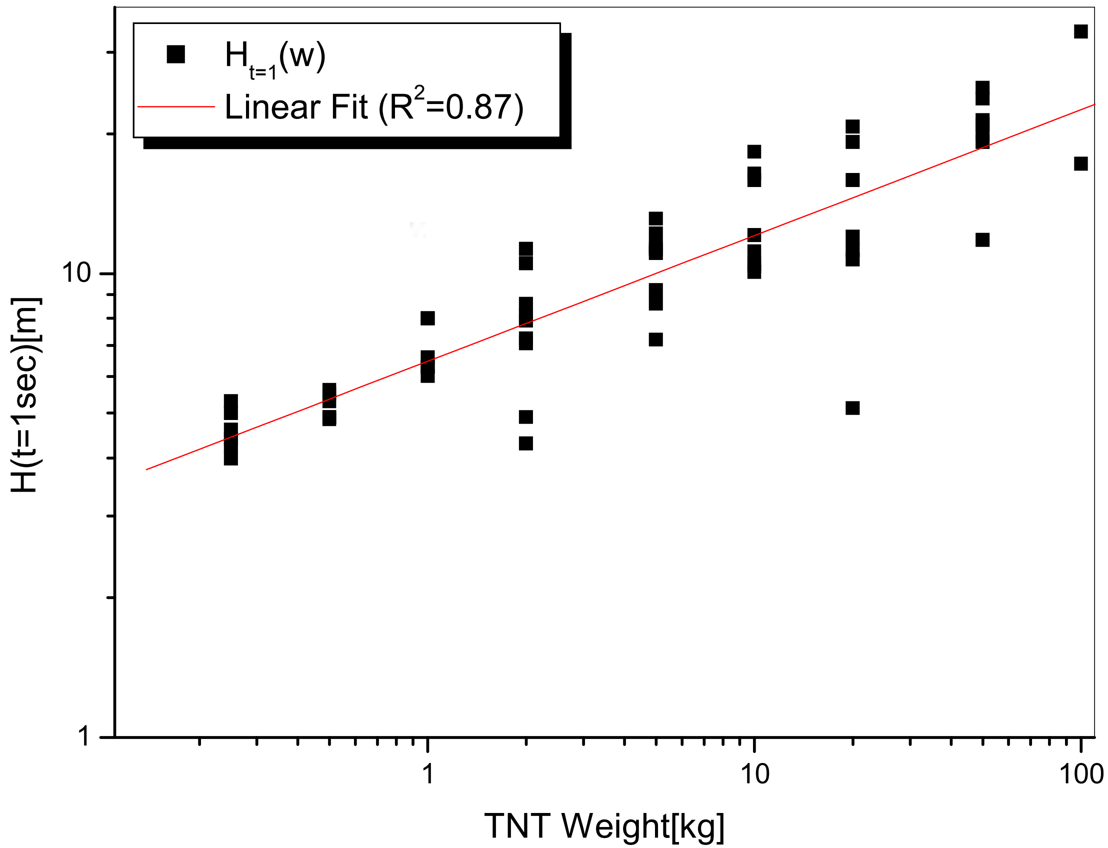
$$H(w,t) = H(t=1) * t^a$$

Where,

- H(t) - The cloud top in meters as a function of time.
- $H_{t=1}$ - The cloud top in meters after one second.
- t - The time in seconds.

Results Analysis (cont.)

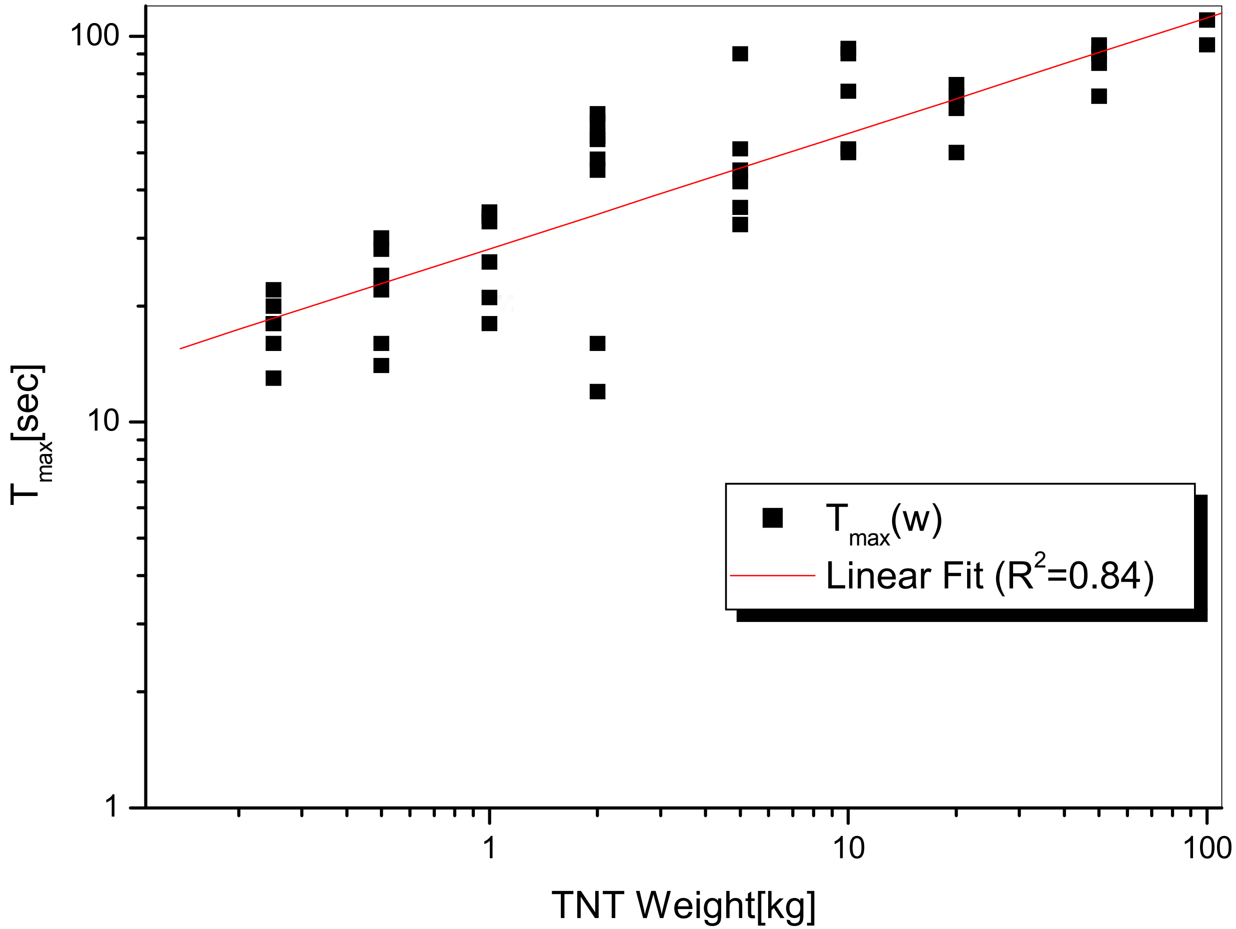
Dependency of the cloud top height at t=1sec on the amount of explosive:



$$H_{t=1}(w) = 6.3(1) * w^{0.29(0.03)}$$

Results Analysis (cont.)

Time validation of the model



$$t_m(w) = (28.0 \pm 1.1) * w^{(0.33 \pm 0.04)}$$

Results Analysis (cont.)

- Combine the two relations (for $H_{(t=1)}$, a), the cloud top height vs. t, w is:

$$h(w,t) = (6.3 \pm 1) \cdot w^{(0.29 \pm 0.03)} \cdot \begin{cases} t^{(0.55 \pm 0.1)} & \textit{Unstable} \\ t^{(0.50 \pm 0.05)} & \textit{Stable} \end{cases}$$

…and the time to the end of stage 3 (the effective height):

$$t_m(w) = 28.0(1.0) * w^{0.33(0.04)}$$

Results Analysis (cont.)

- Combine the last two equations:

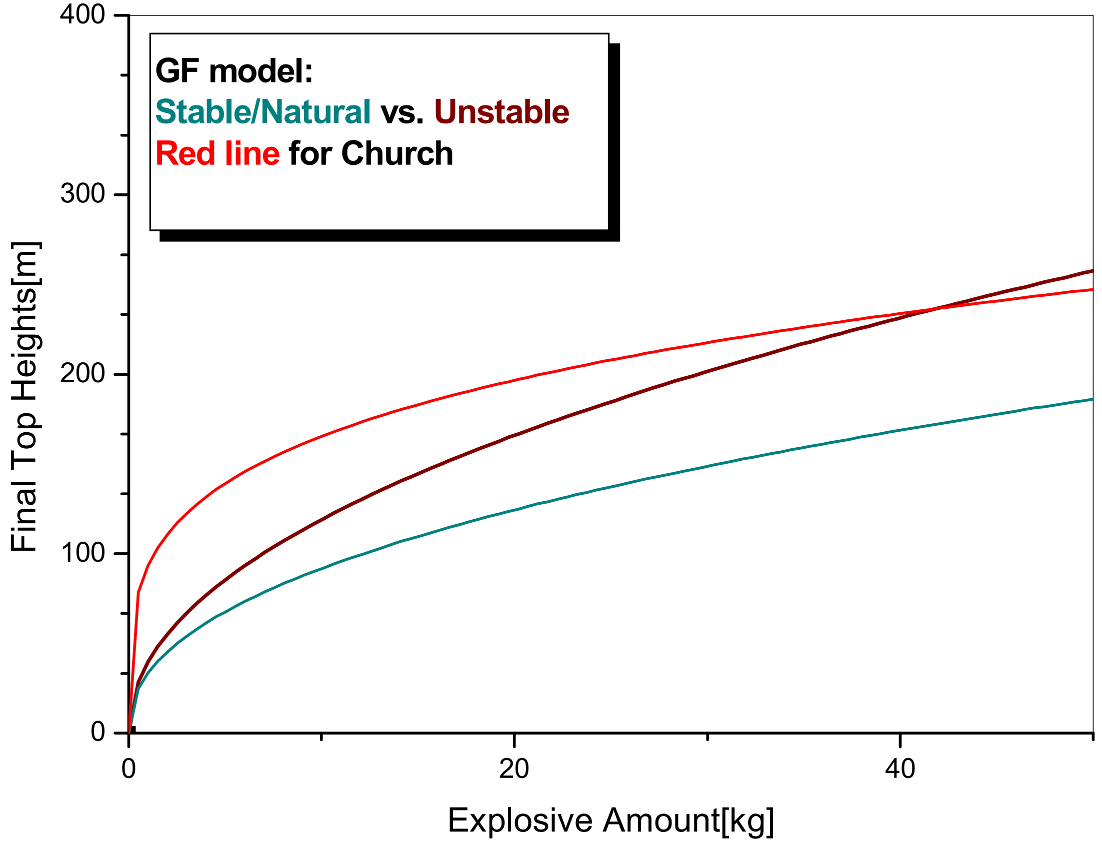
$$H(w) = 40 * w^{0.48} - UnStabe$$
$$H(w) = 33 * w^{0.44} - Stable / Neutral$$

Comparison with Church

$$H(w) = 93 * w^{0.25}$$

$$H(w) = 40 * w^{0.48} - UnStabe$$

$$H(w) = 33 * w^{0.44} - Stable/Neutra$$



Radiological Consequences

- We run a RDD scenario (using HotSpot) for two different cloud rise models:

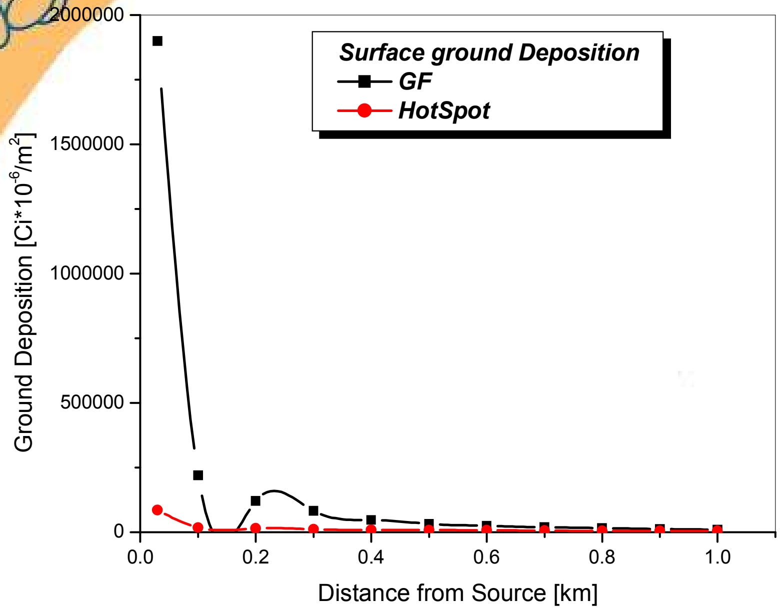
GF vs. Church:

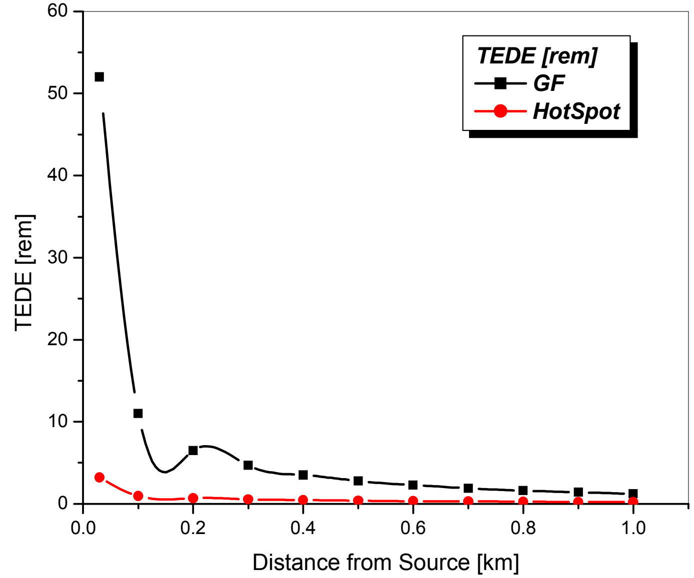
- Case 1: w=0.454kg, ^{137}Cs=3000Ci, F(2).

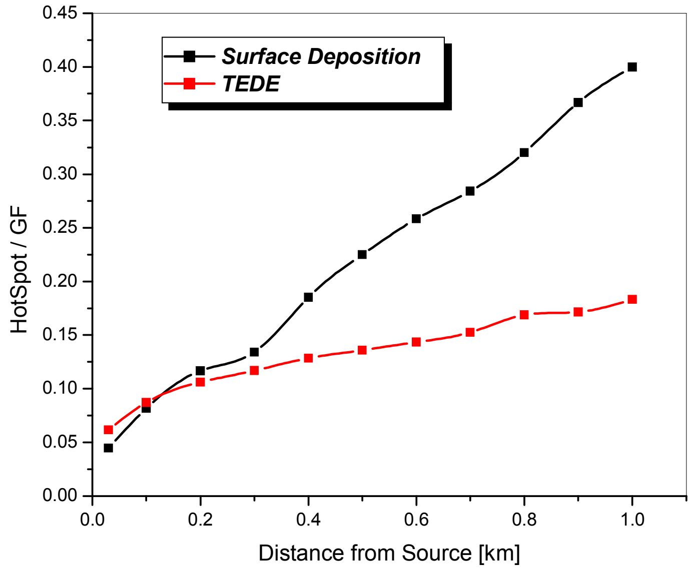
H_{Church}=76m, H_{GF}=23.5m.

Is it sensitive to the cloud final height?

Case 1:







Summary- part 1

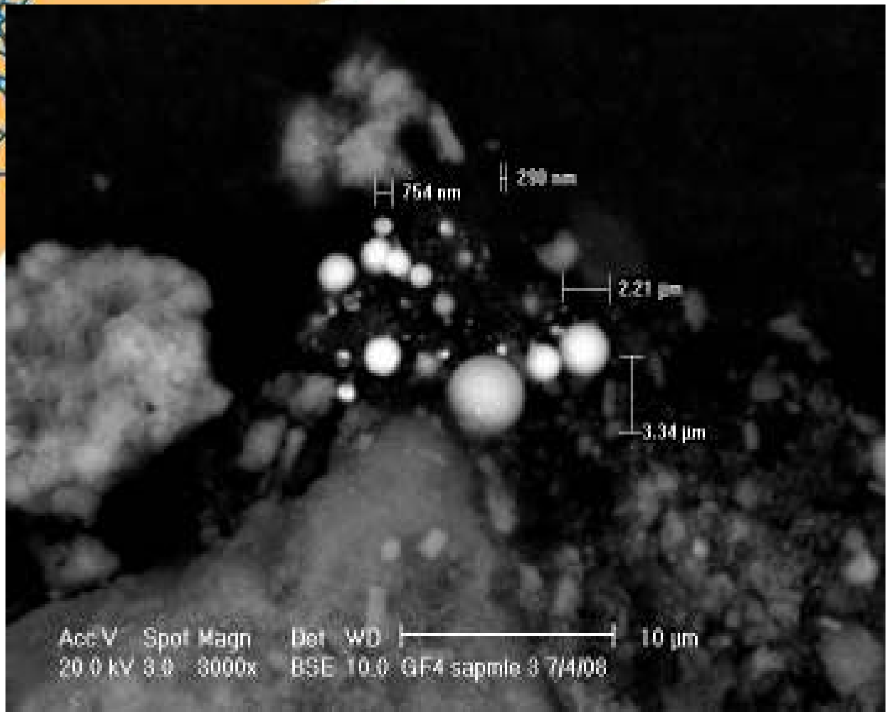
- We introduced a simple cloud rise model for RDD / Nuclear terrorism scenarios.
- The model predicts the experimental data to a good accuracy.
- It includes time & local atmospheric stability dependency.
- It predicts lower top heights than Church model.
- Means much higher doses close to the detonation point.
- Means grate risks for first responders (or others there).

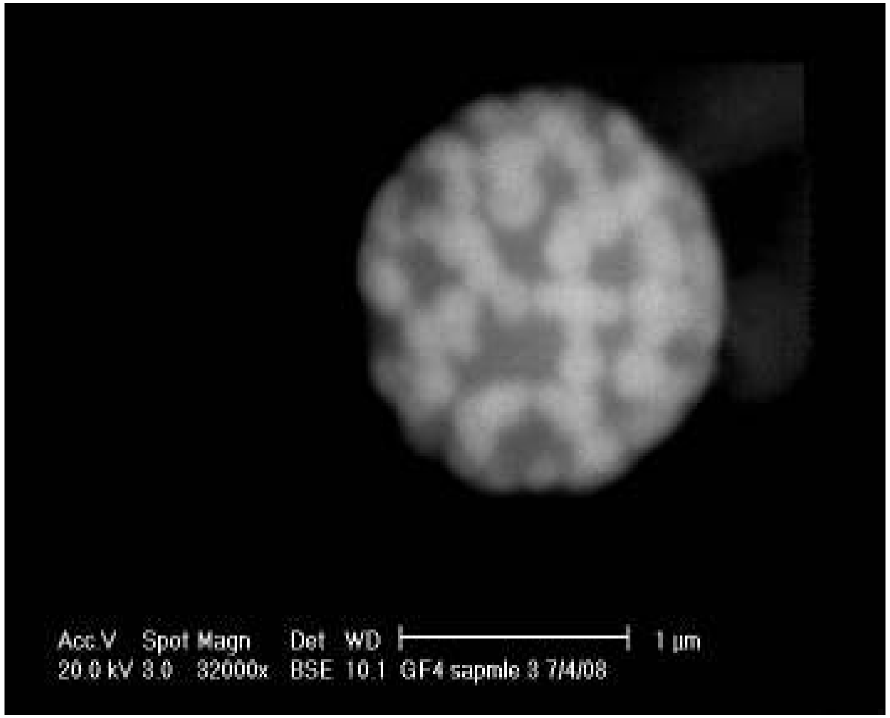
We Recommend to Use GF Model for the Relevant Explosive Amounts!

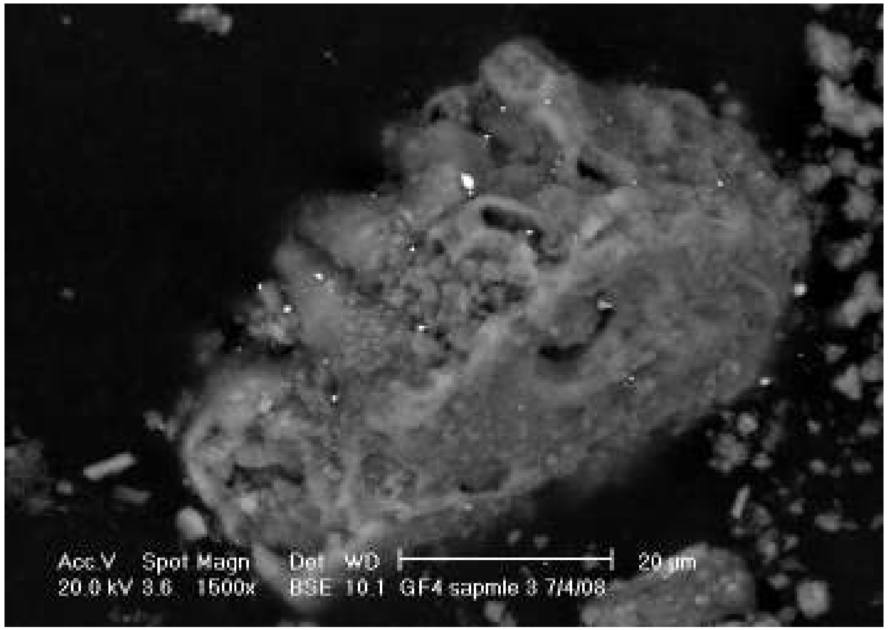
Particles' Analysis

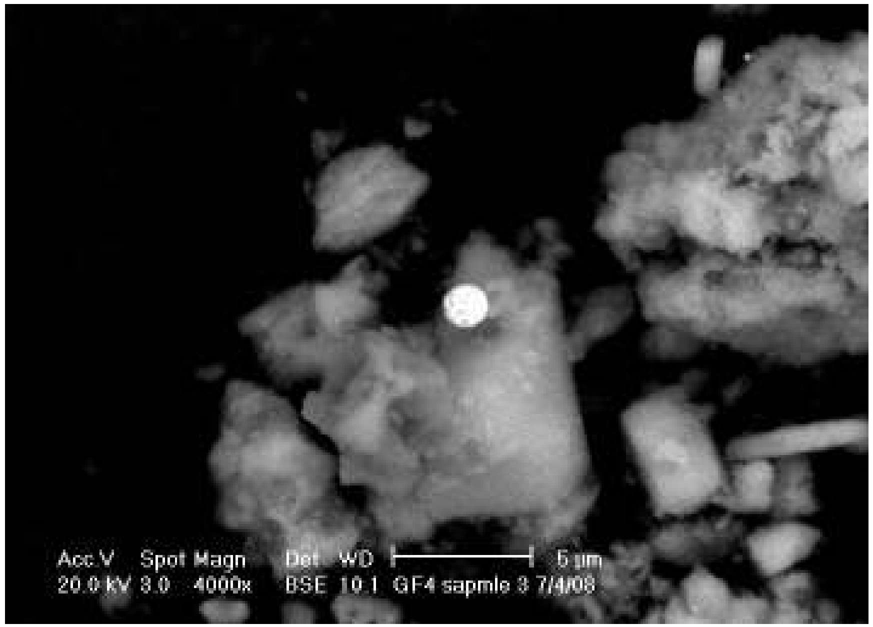
- In GF-4,5 we have used WC micron size powder.
- In GF-6,7 we have used CsCl (salt) & SrTiO3(ceramic), resp.
- The powder was dispersed by the HE.
- Either from the top of the charge or from the side of it.
- Aims: (a) to measure size distribution. (b) to measure mass distribution. (c) particle's morphology.

To understand the aerosolization and agglomeration processes

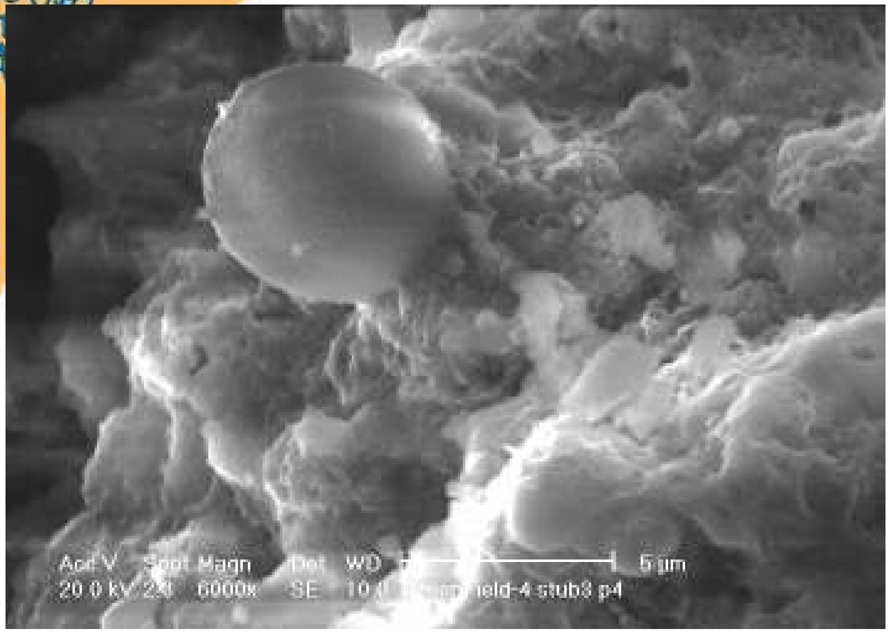

754 nm
290 nm
2.21 µm
3.34 µm
Acc.V Spot Magn Det WD 10 µm
20.0 kV 3.0 3000x BSE 10.0 GF4 sapmle 3 7/4/08

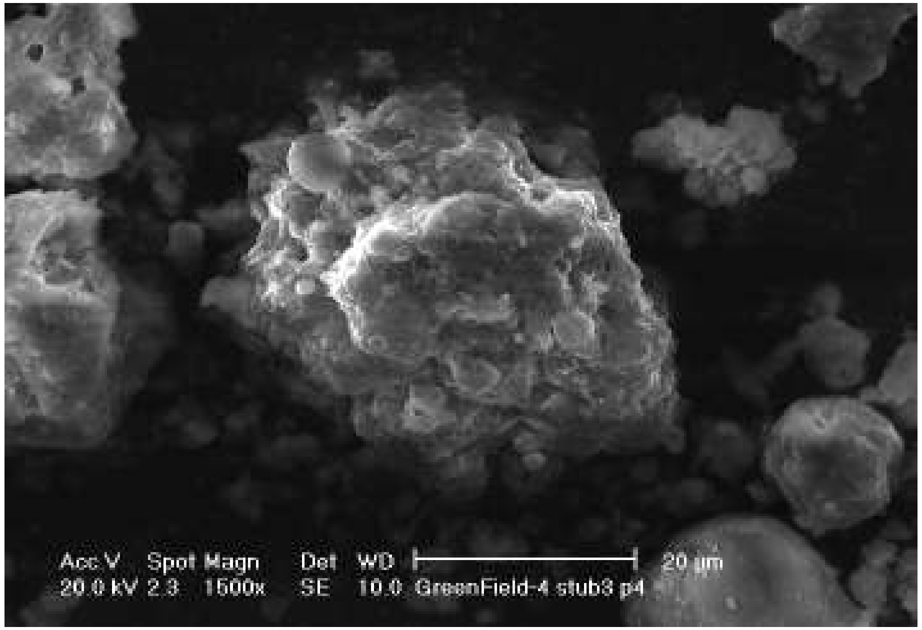

Acc.V Spot Magn Det WD 1 µm
20.0 kV 3.0 32000x BSE 10.1 GF4 sapmle 3 7/4/08

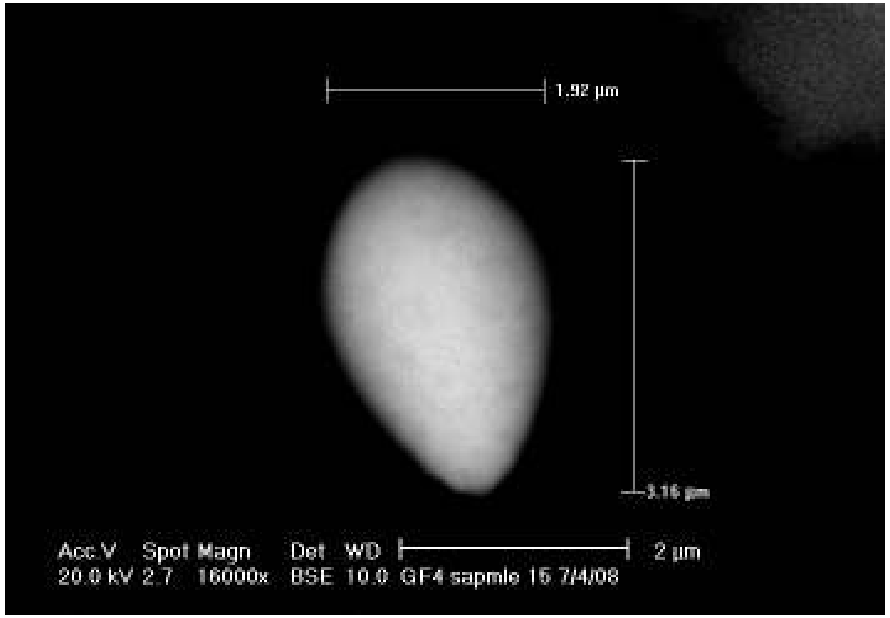

Acc.V Spot Magn Det WD 20 µm
20.0 kV 3.6 1500x BSE 10.1 GF4 sapmle 3 7/4/08

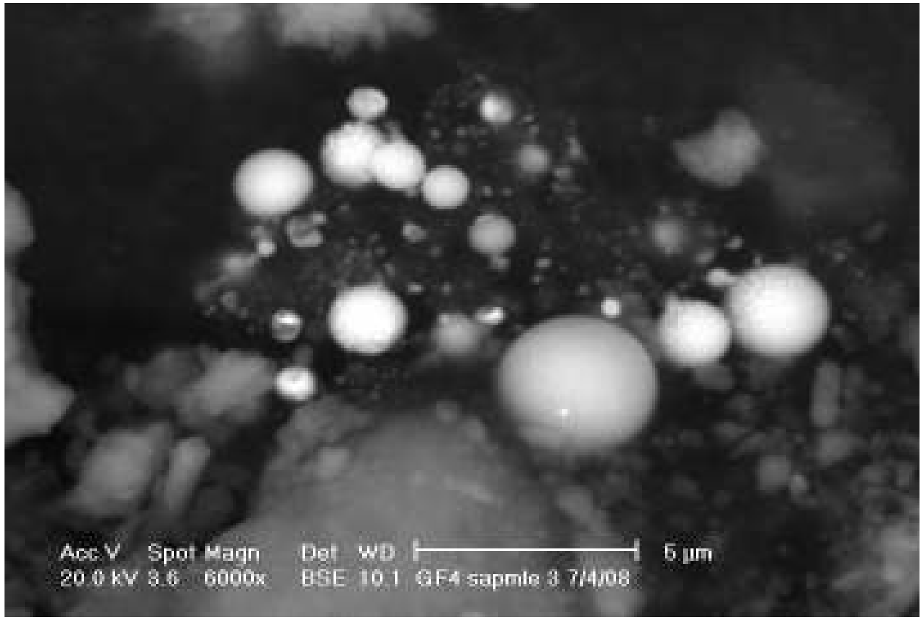

Acc.V Spot Magn Det WD 5 µm
20.0 kV 3.0 4000x BSE 10.1 GF4 sapmle 3 7/4/08

SEM Analysis…(GF4)









Thank you for your attention!