SAND2007-7025C

Radiological Dispersal Devices: Physically Based Dispersal Characteristics and Limitations

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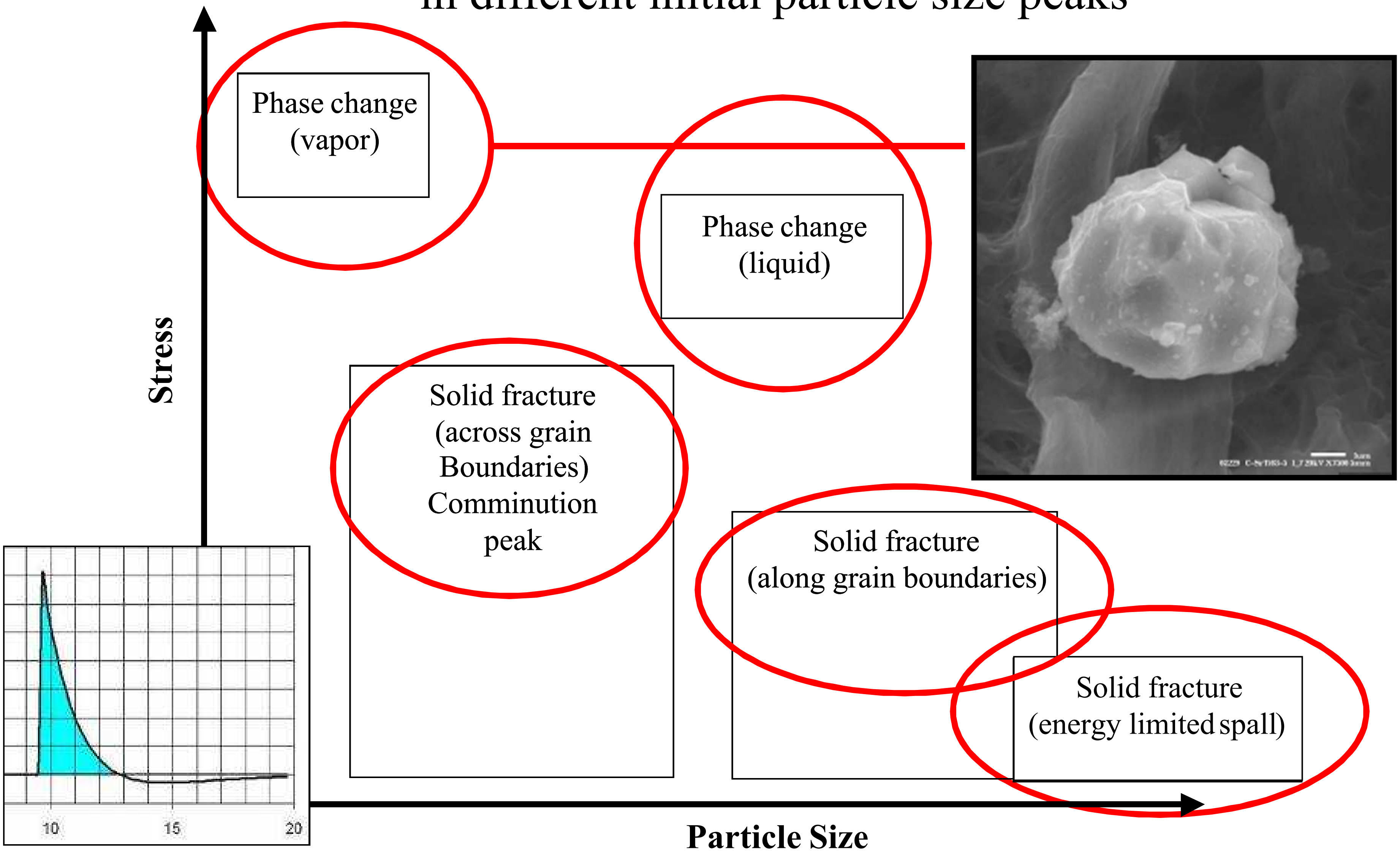
Different stress induced mechanisms result in different initial particle size peaks



Final size distribution can be a combination of several of these Peaks and can be modified by combustion and agglomeration

Priority Nuclides

Nuclide (Half life)	Large source size (Ci)	Typical source size (Ci)	Dominant physical form
Cs-137 (30 years)	250000	5000 - 10000	CsCl
Co-60 (5 years)	300000	1000 - 5000	Co metal (slugs and pellets)
Sr-90 (30 years)	300000	40000 - 100000	$SrTiO_3$ (ceramic)
Ir-192 (74 days)	100s	10 - 1000	Ir metal
Am-241 (432 years)	10s	10 - 20	AmO_2 in pressed powder form

Point to make – varied particle/fragment sizes

- Will divide problem up into:
  - Respirable particles (< 10 µm aerodynamic) – I know it is an oversimplification
  - Intermediate size particles (> 10 µm 100 µm)
  - Large particles (> 100 µm, < 500 µm)
  - Fragments (> 500 µm)
- All forms produce all sizes – relative fractions depend on material properties and device geometry

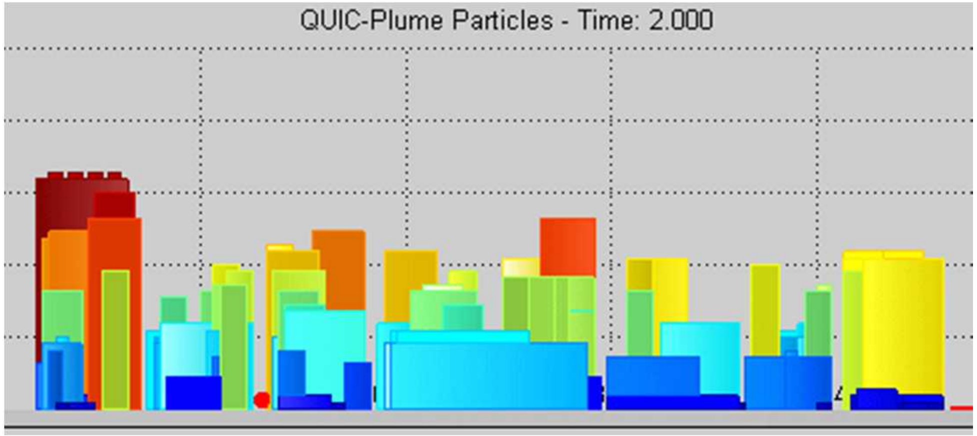
Some basic concepts

- Small particles (< 10 μm) -- primarily an inhalation problem, but can also be a shine problem
- Large particles (> 100 μm – primarily a shine problem)
- To be an inhalation problem, particles must be in the vicinity of people
- Will divide problem into small particles (< 10 μm), intermediate particles (> 10 μm, < 100 μm), and larger particles (> 100 μm, < 500 μm), and fragments (> 500 μm)

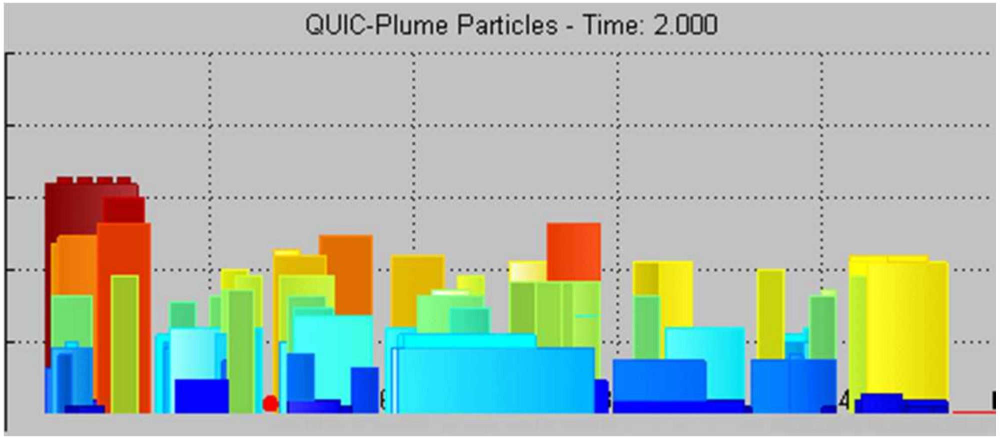
Particle Size Effect
From Mike Brown (LANL)

Transport & Dispersion

5 micron particles



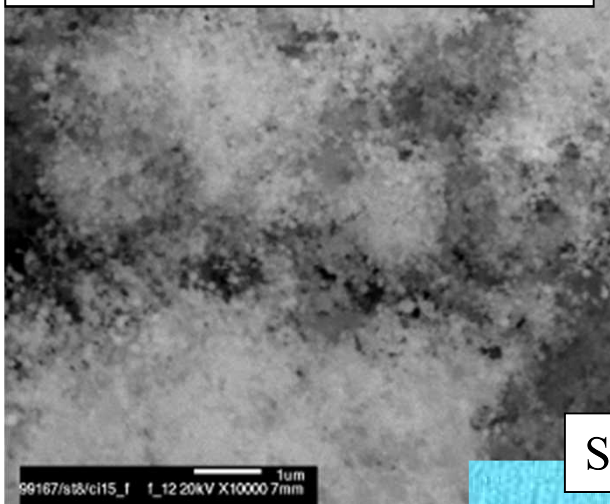
250 micron particles



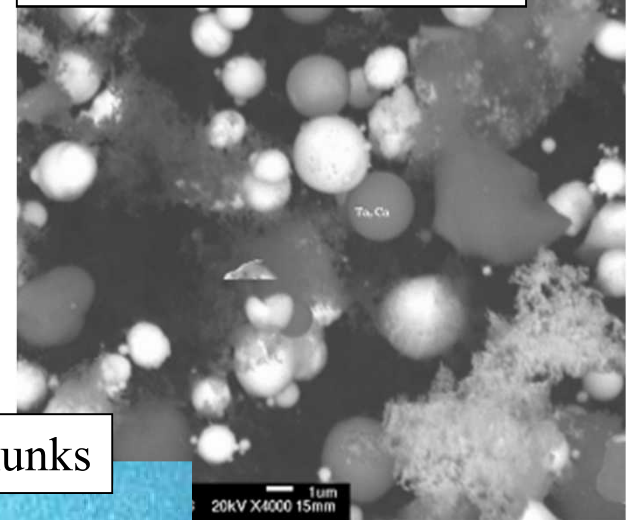
Applications

5 micron particles lofted high into the air, 250 micron particles settle towards ground

Phenomena: Explosive aerosolization of metals

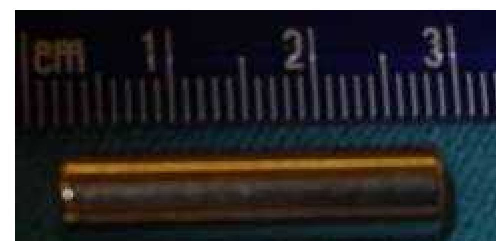


Shock sublimation of metals → particles < 1 μm



Shock melting of metals → particles < 10 μm

Solid fracture → chunks

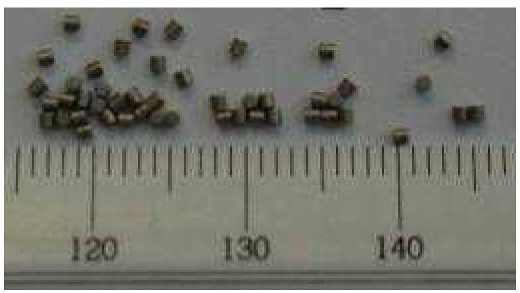


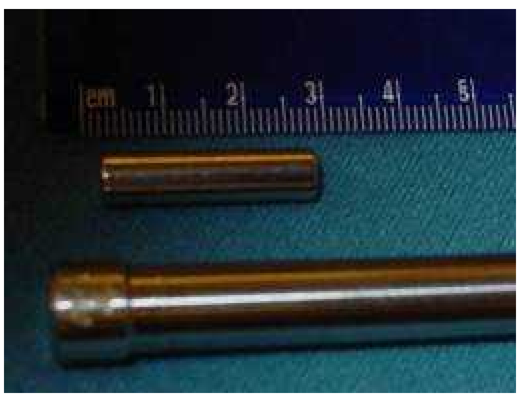
1000 Ci (20 g) Co pellet

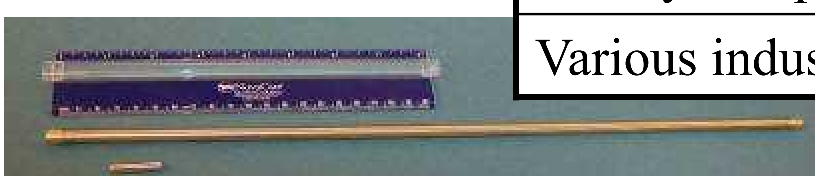
- Fractions depend on material properties and device geometries
- Respirable aerosol ranged from .2 % to 80 %
- Very little aerosol generated between 30 μm and 200 μm

Materials of concern: Cobalt-60

- Half life: 5.27 years
- Gamma emitter
- Typical Form: Co metal (pellets or slugs)



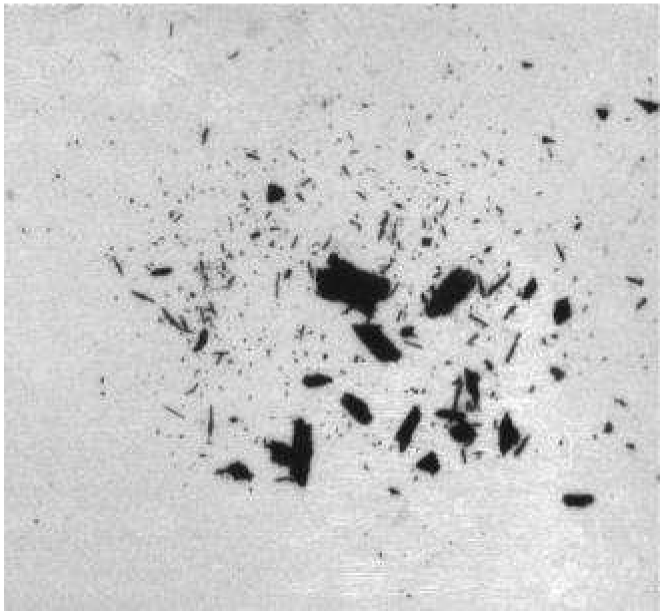


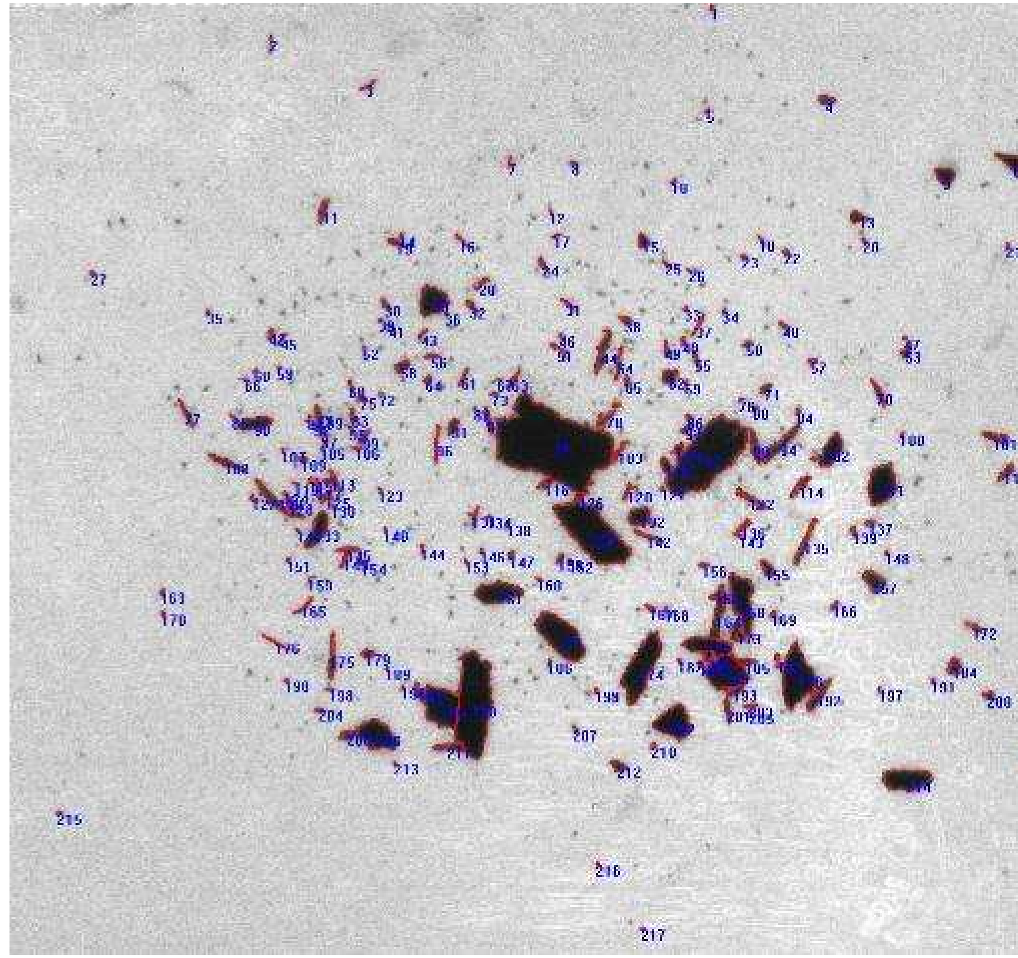


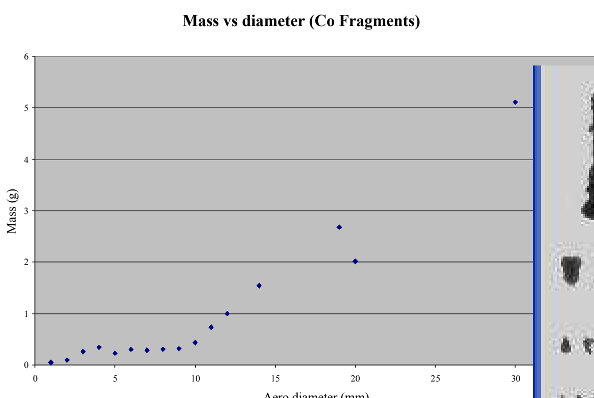
Typical Uses	Activity (Ci)		
	Min	Max	Typical
Irradiators: Sterilization	5k	15M	4M
Irradiators: Self shielded	1.5k	50k	25k
Irradiators: Blood/Tissue	1.5k	3k	2.4k
Gamma knife	4k	10k	7k
Teletherapy	1k	15k	4k
Industrial radiography	11	200	60
Brachytherapy	5	20	10
Various industrial gauges	0.1	10	2

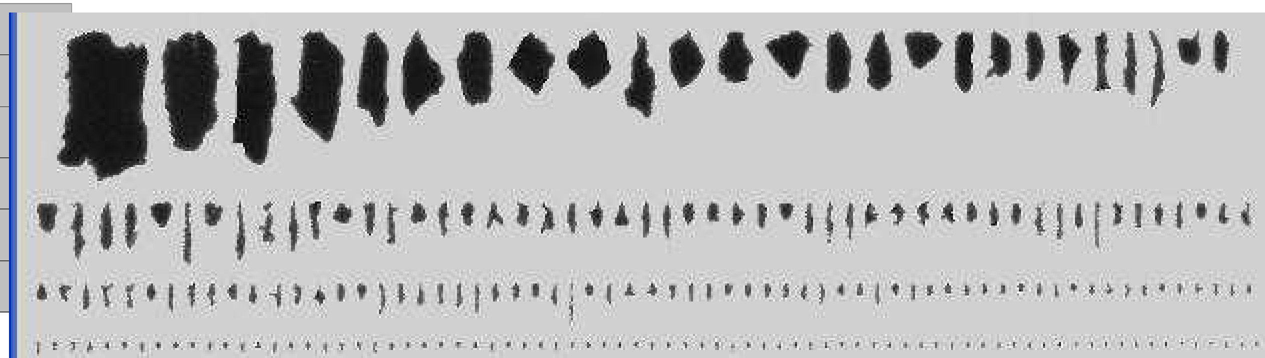
Ballistic/fragmentation studies on irradiator slugs

Photometric analysis of cobalt fragmentation – 90 % of mass in 20 frags out of about 200 – smallest frag about 1 mm (aero diameter)

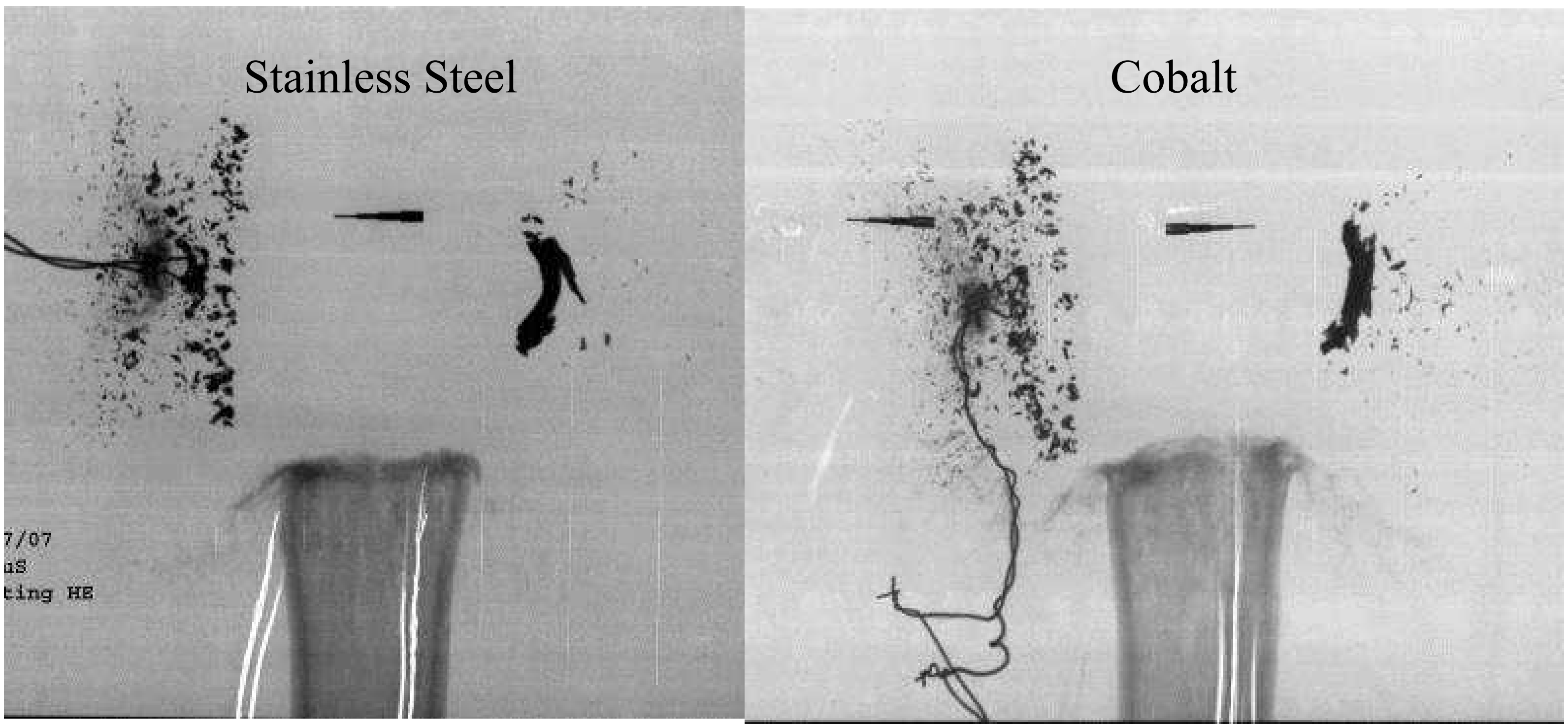




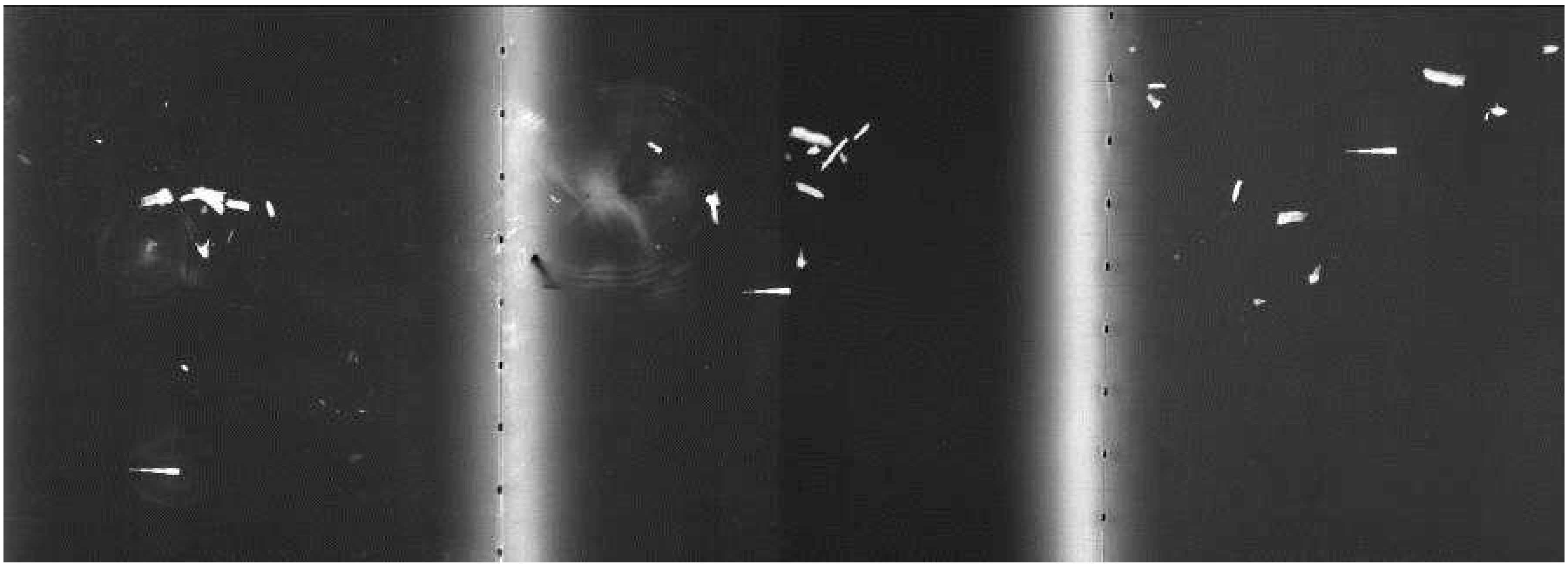




Comparison between stainless steel slug fragmentation and Nordion cobalt slug fragmentation



Observed range of velocities from 3 exposure shot (419 – 580 m/s)

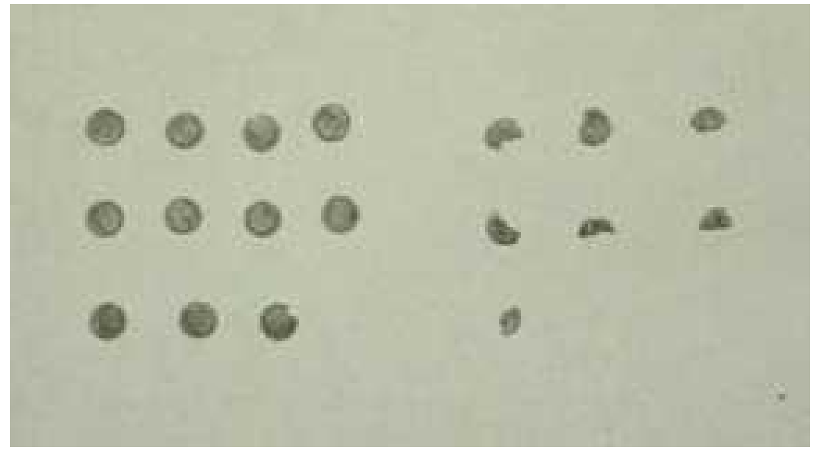


Materials of concern: Iridium-192

- Half life: 73.8 days
- Gamma emitter
- Typical Form: Ir metal pellets or wire

Typical Uses	Activity (Ci)		
	Min	Max	Typical
Industrial radiography	5	200	100
Brachytherapy	5	20	10

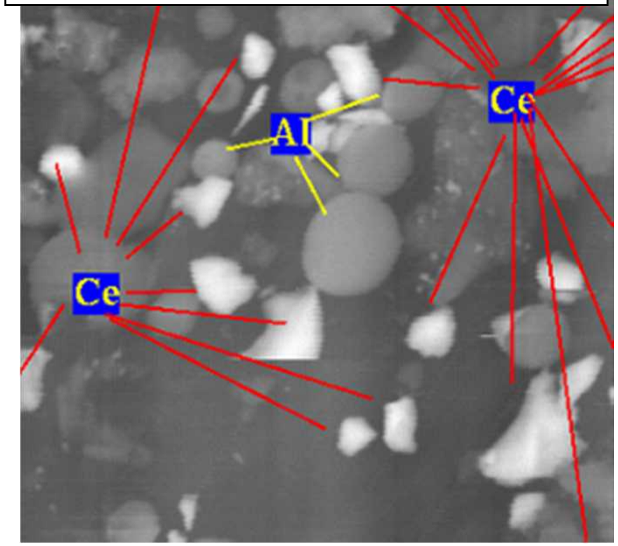
Iridium fragmentation/aerosolization experiments

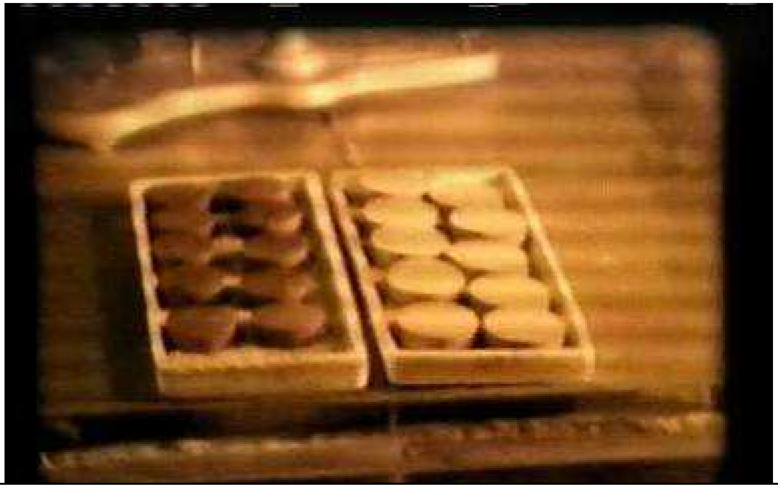


Phenomena: Explosive aerosolization of ceramics

- Fractions depend on material properties and device geometries
- Respirable aerosol ranged from 2 % to 40 %
- No phase change
- A lot of aerosol generated between 30 µm and 200 µm

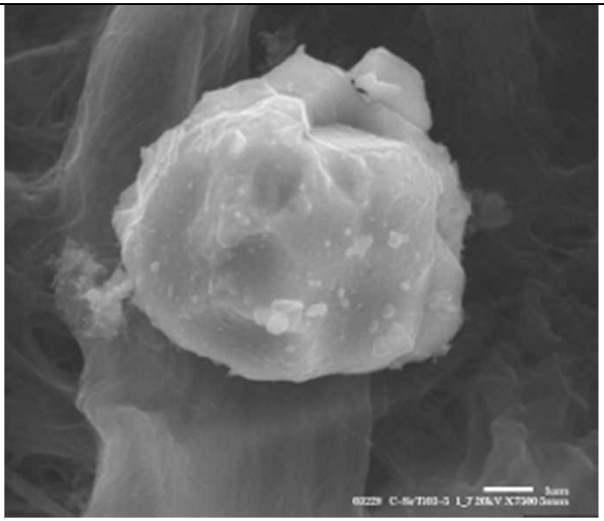
Aerosol produced from shear



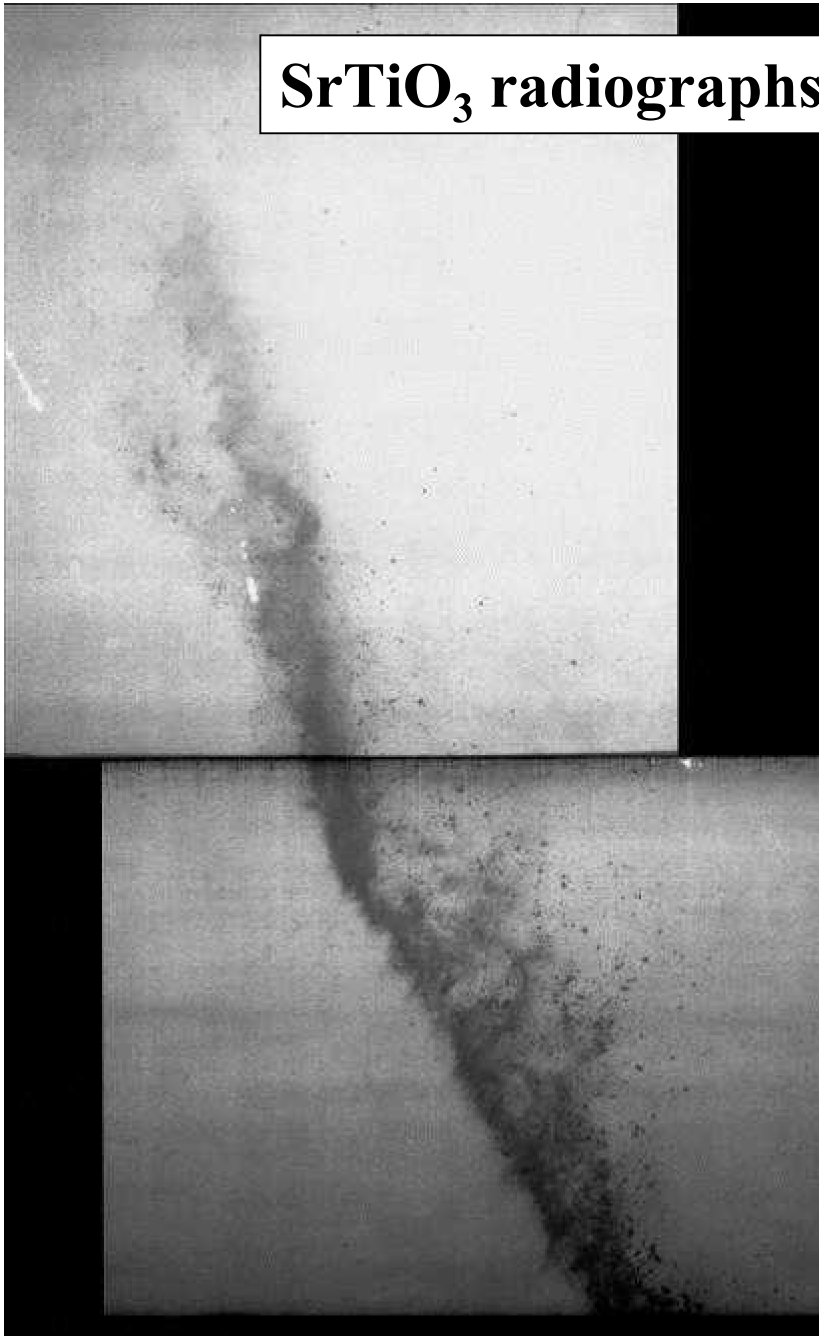


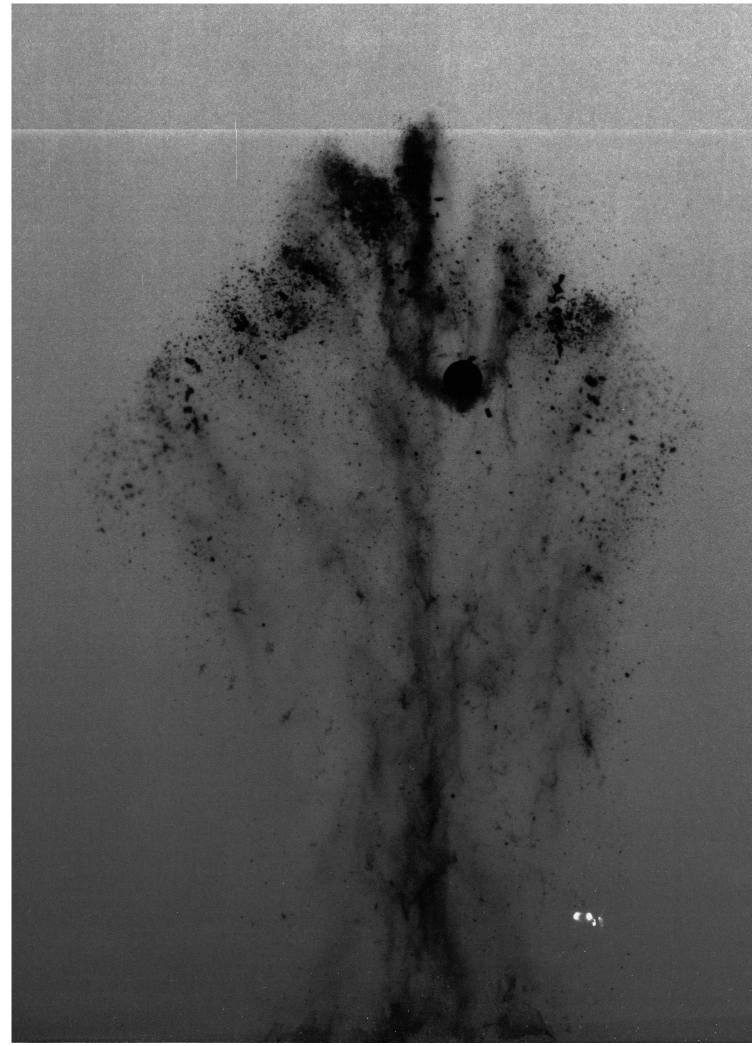
Courtesy of B. Wham, B. Patton, B. Jubin (ORNL)

Aerosol produced from compressive stress

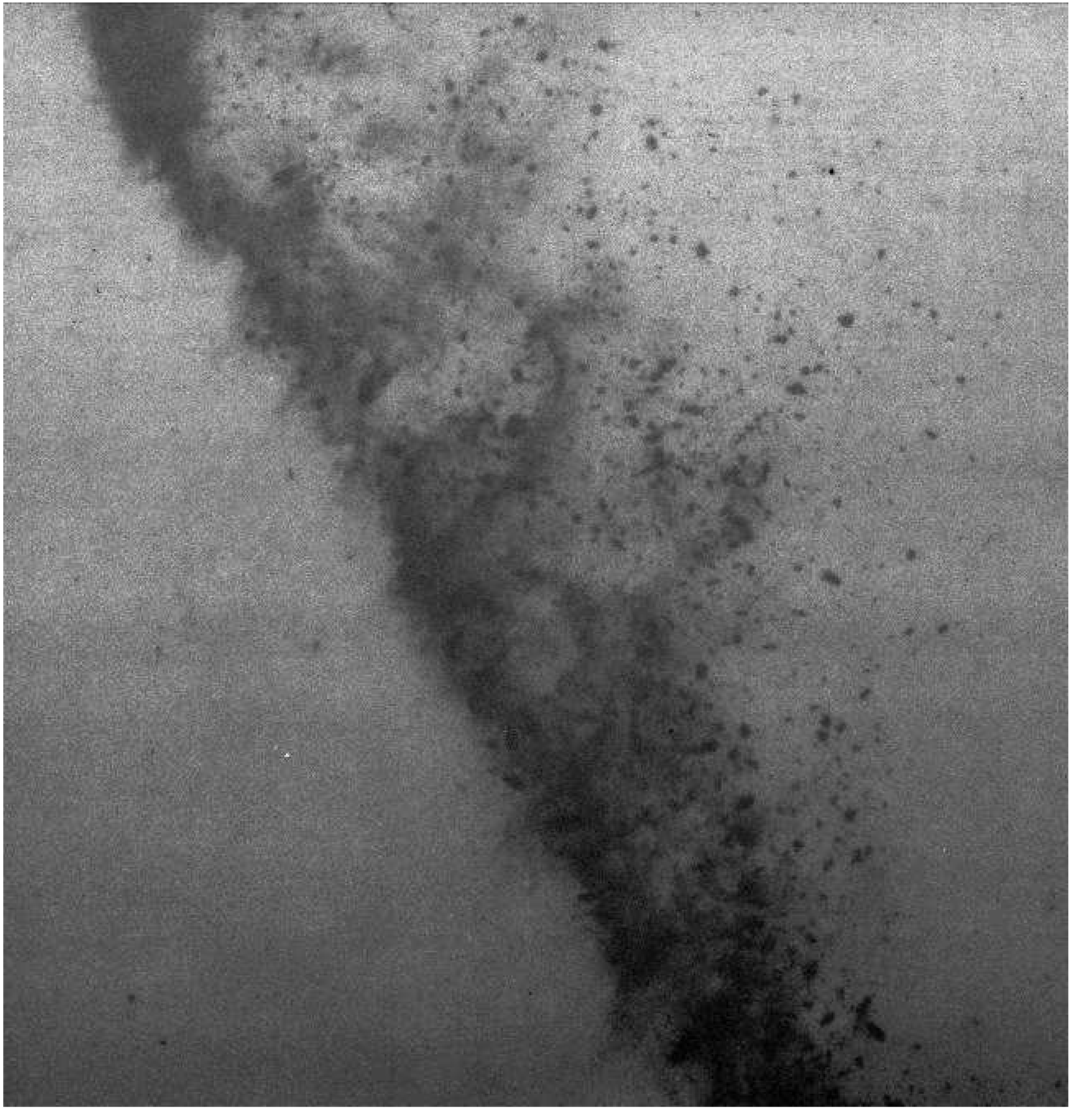


$SrTiO_3$ radiographs of particles (2 geometries)

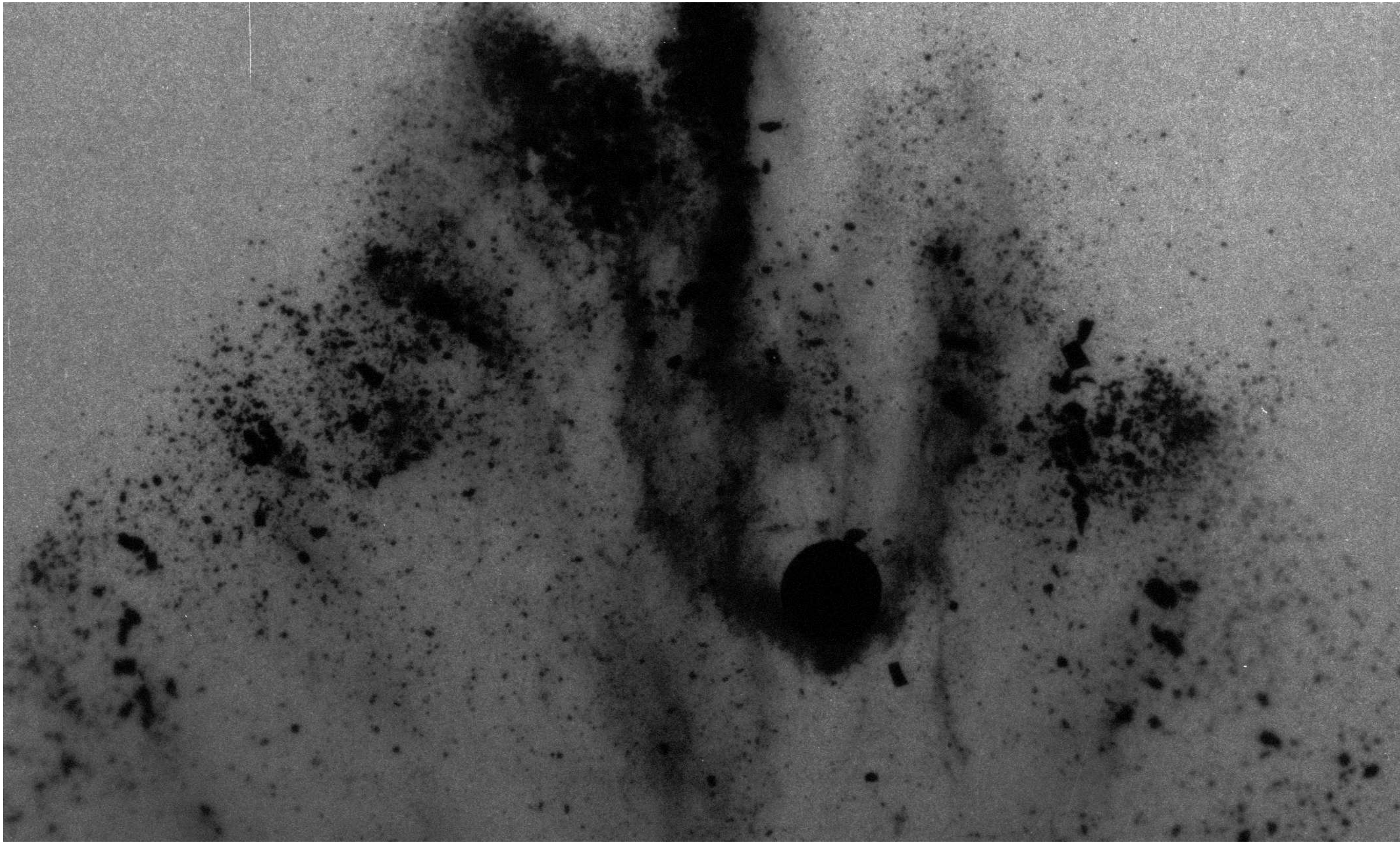




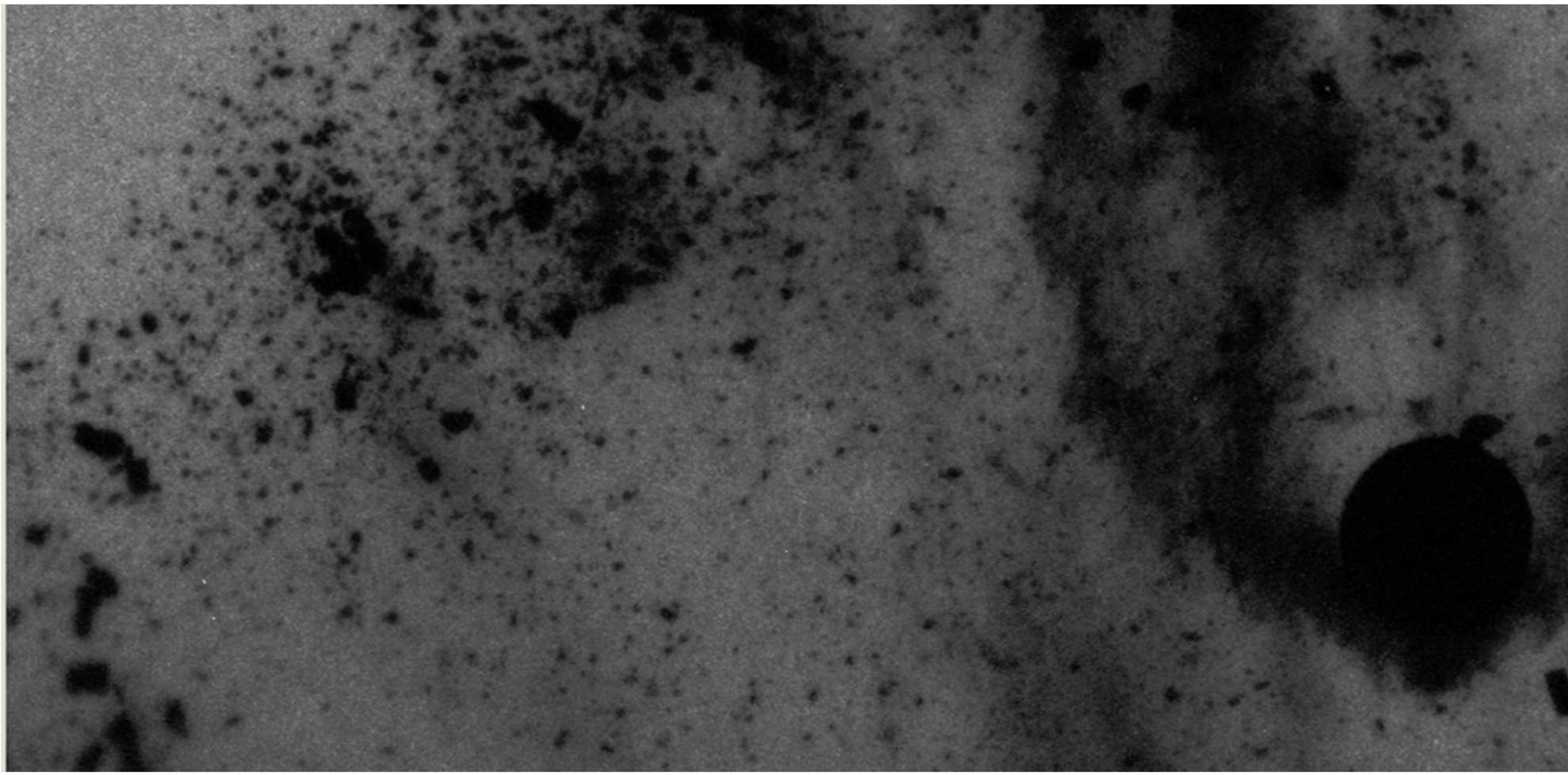
Expanded view
$SrTiO_3$
(Largest particles
About 1 mm)



Expanded view $SrTiO_3$



Reference (.5 in) – large particles 3 – 4 mm, most small distinguishable in this Image are between .5 and 1 mm



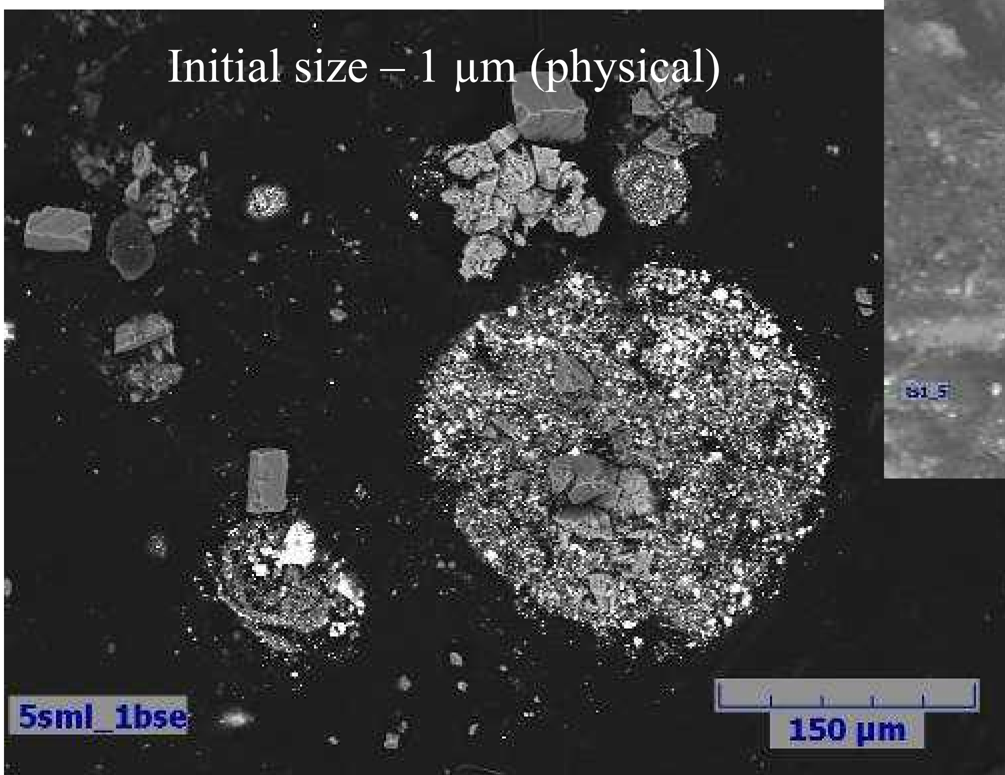
Materials of concern: Americium-241

- Half life: 432.7 years
- Alpha emitter, AmBe is a neutron emitter
- Typical Form: AmO_2 or encased AmO_2 with Be metal

Damaged AmBe Well logging Source

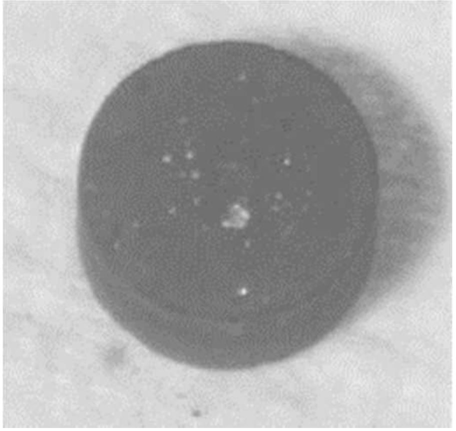
Typical Uses	Form	Activity (Ci)		
		Min	Max	Typical
Calibration Facilities	Am	5	20	10
Research reactor startup	AmBe	2	5	2
Well logging	AmBe	0.5	23	20
Thickness gauges	Am	0.3	0.6	0.6
Fill level gauges	Am	0.012	0.12	0.06
Moisture detectors	AmBe	0.05	0.1	0.05
Moisture/density gauges	AmBe	0.01	0.1	0.05
Bone densitometry	Am	0.027	0.27	0.14
Static eliminators	Am	0.03	0.11	0.03

Shock sintering of ceramics results in larger particles



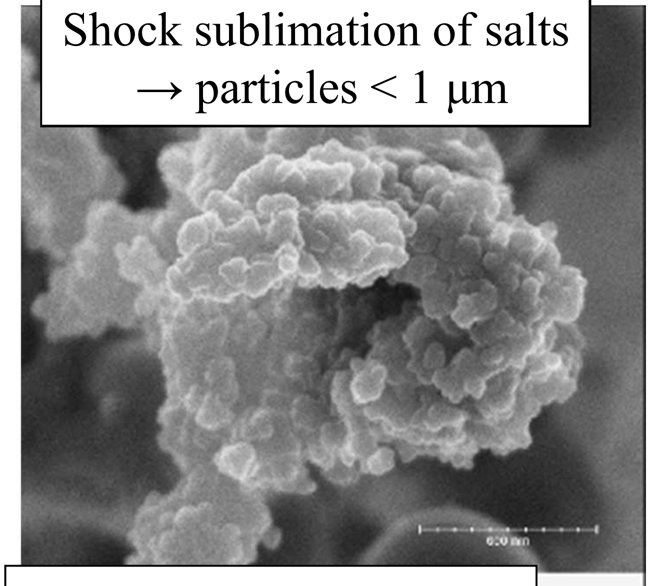
Materials of concern: Cesium-137

- Half life: 30.2 years
- Gamma emitter
- Typical Form: Encapsulated CsCl salt

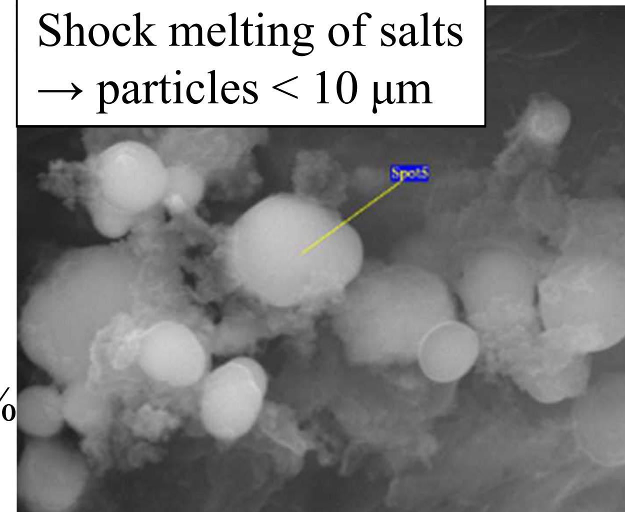


Typical Uses	Activity (Ci)		
	Min	Max	Typical
Irradiators: Sterilization	5k	5M	3M
Irradiators: Self shielded	2.5k	42k	15k
Irradiators: Blood/Tissue	1k	12k	7k
Teletherapy	500	1.5k	500
Calibration facilities	1.5	3k	60
Brachytherapy	3	8	3
Various industrial gauges	0.01	5	2
Well logging	1	2	2

Phenomena: Explosive aerosolization of powders

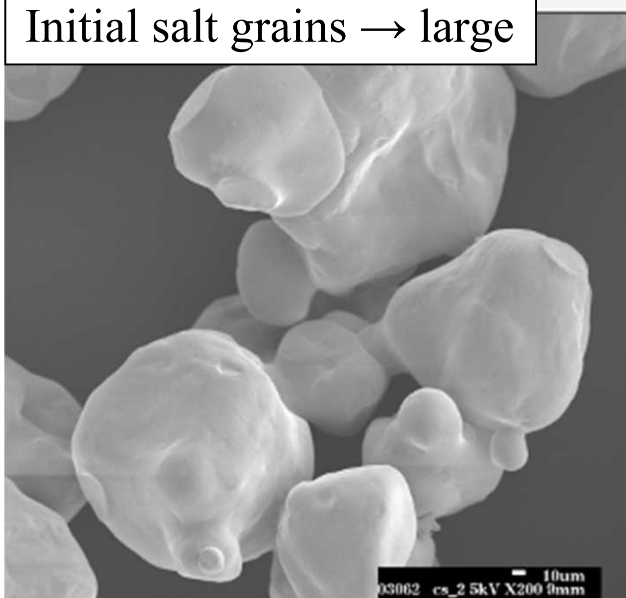


Shock sublimation of salts → particles < 1 µm

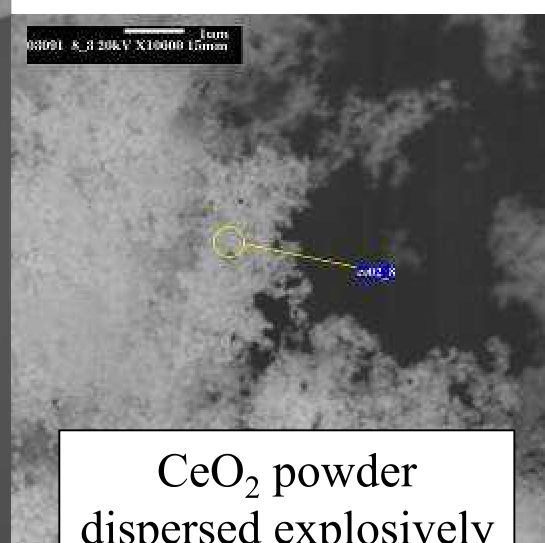


Shock melting of salts → particles < 10 µm

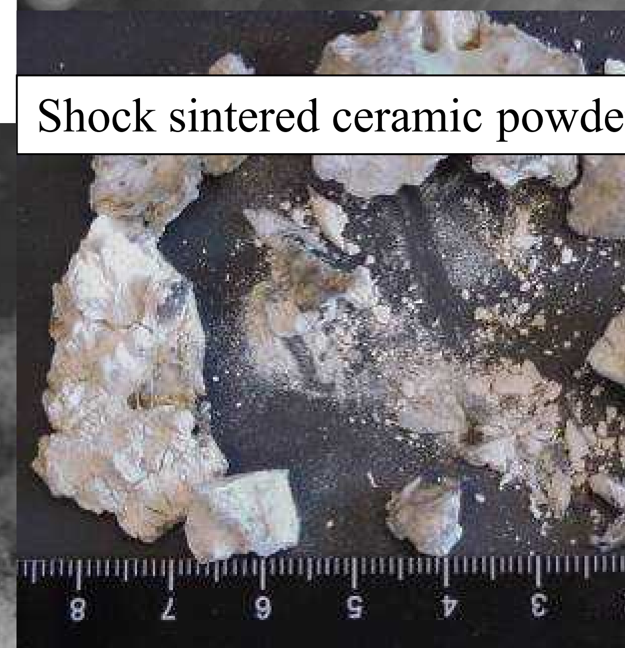
- Fractions depend on material properties and device geometries
- Respirable aerosol ranged from 20 % to 80 %
- Very little aerosol generated between 30 µm and 200 µm



Initial salt grains → large

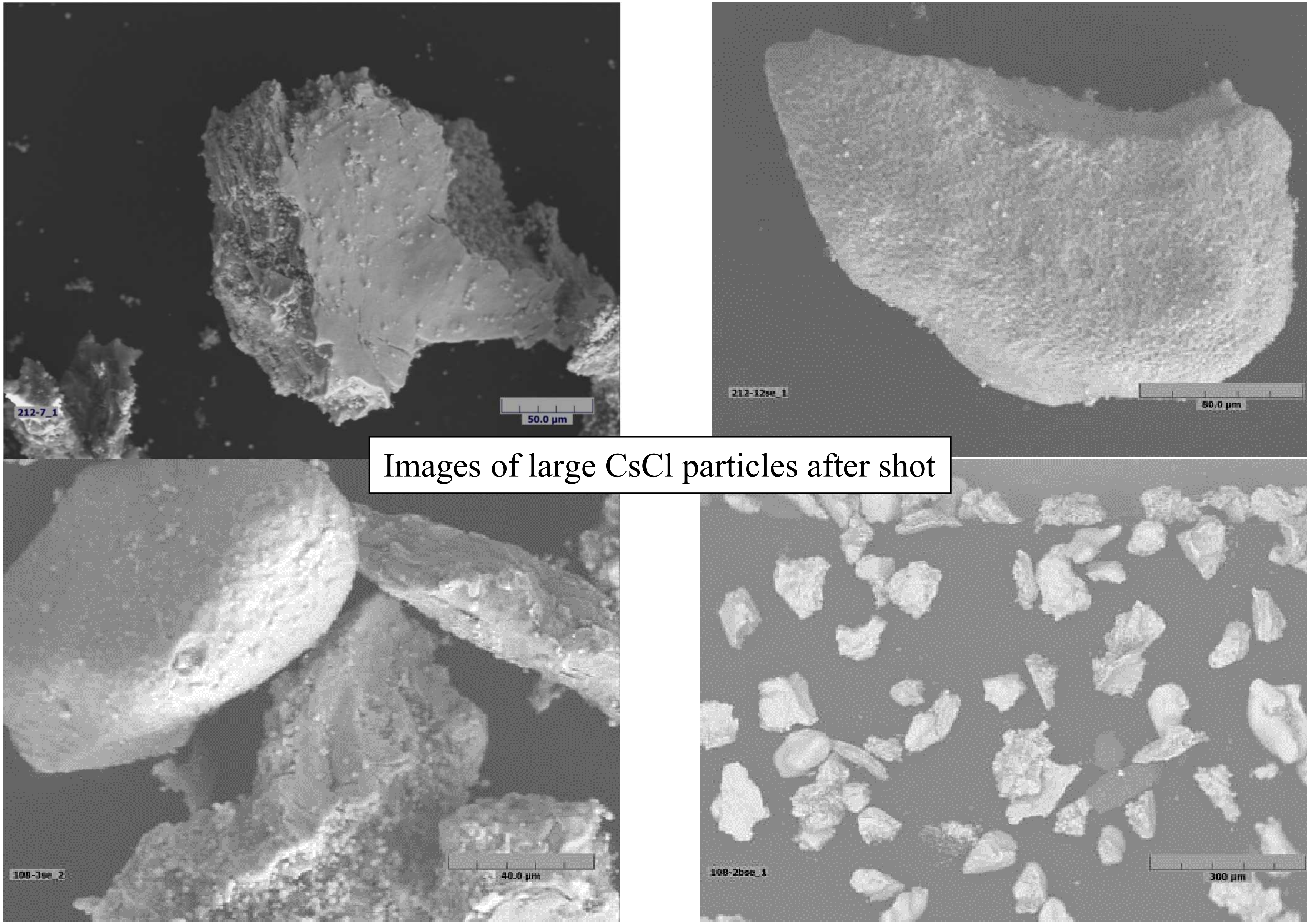


CeO_2 powder dispersed explosively



Shock sintered ceramic powder

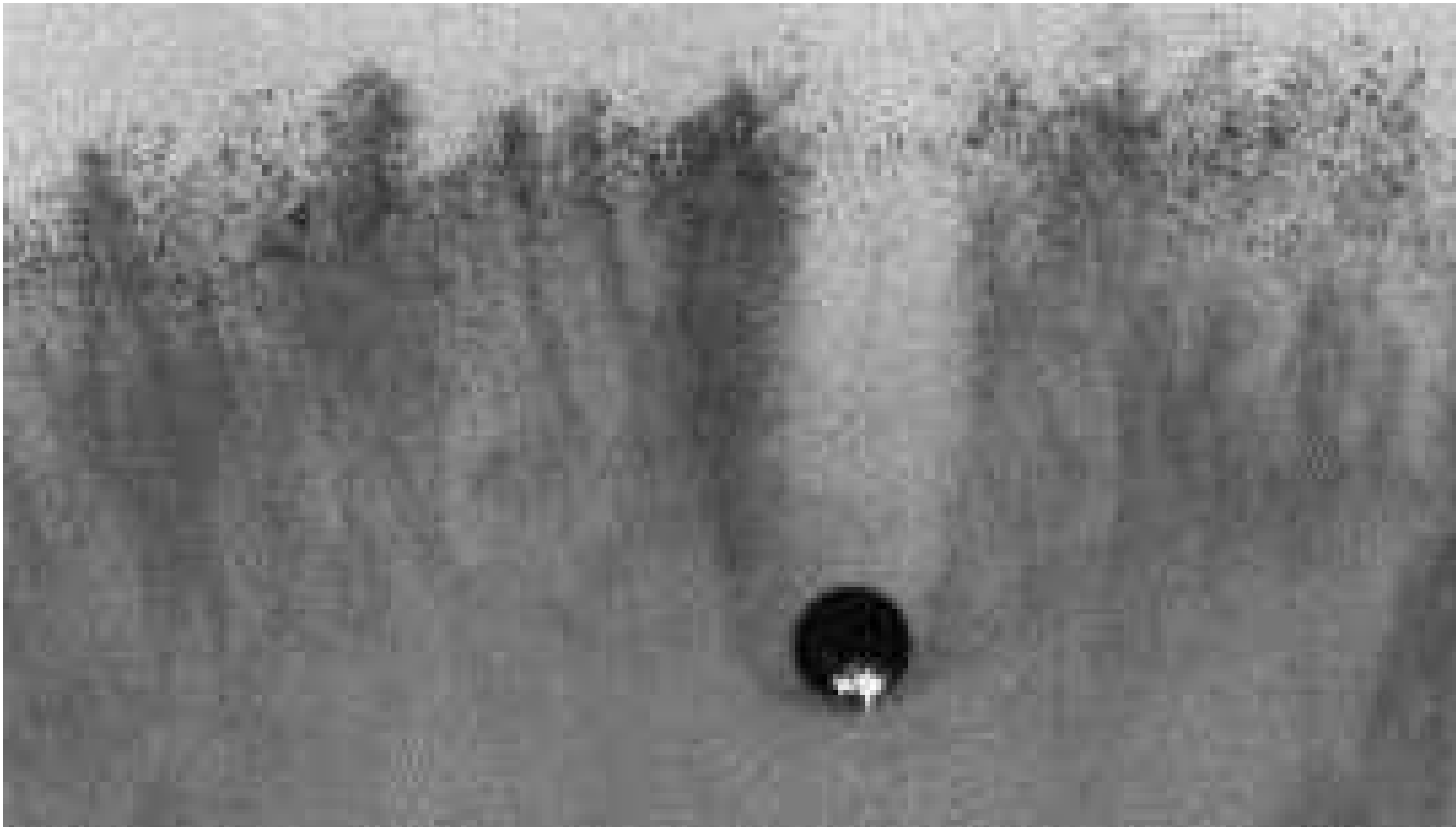
Images of large CsCl particles after shot



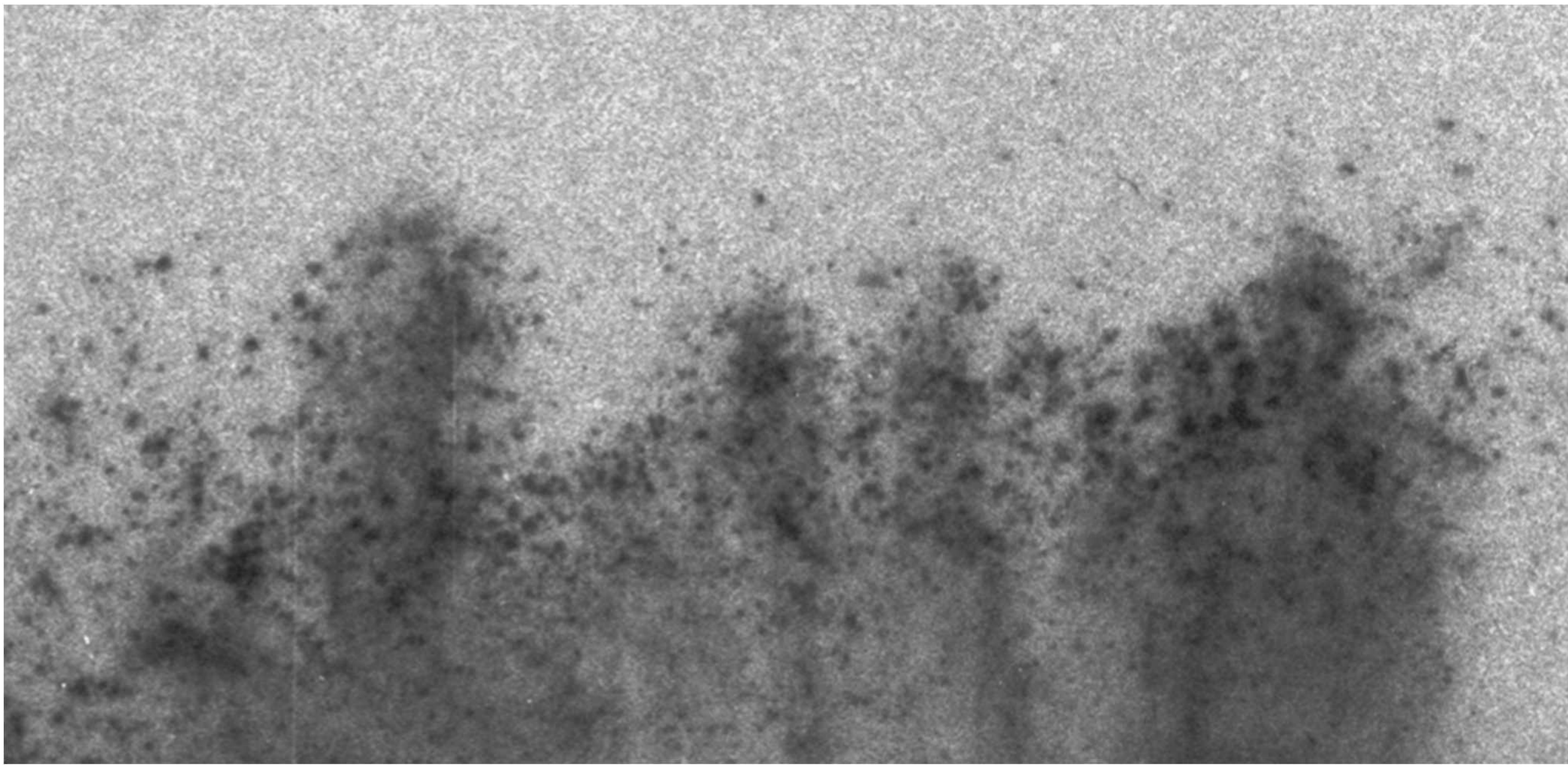
Note evidence of plastic deformation and evidence of bimodal size distribution

CsCl Powder – geometry 1

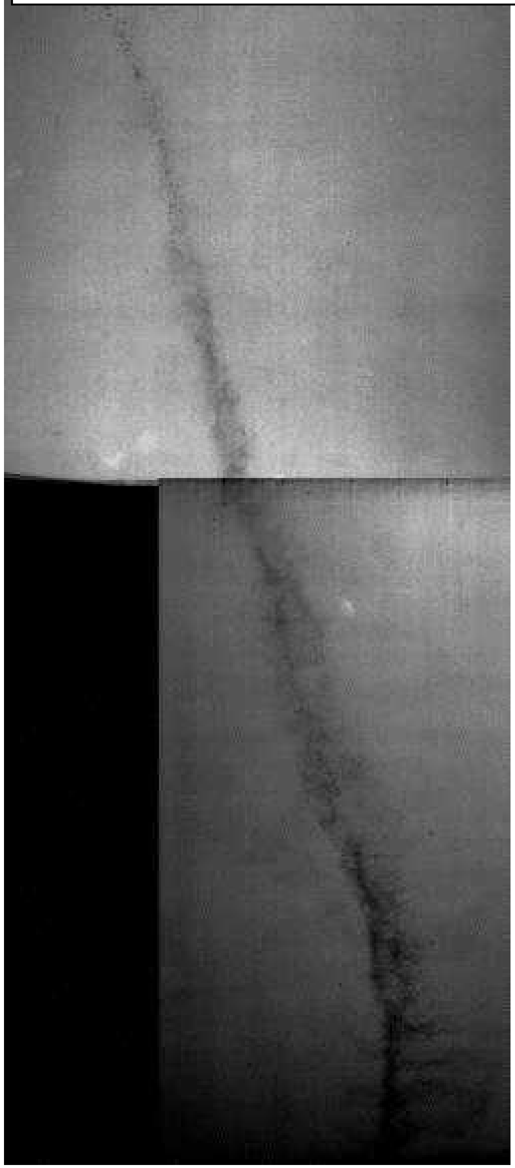
CsCl geometry 1 (expanded)

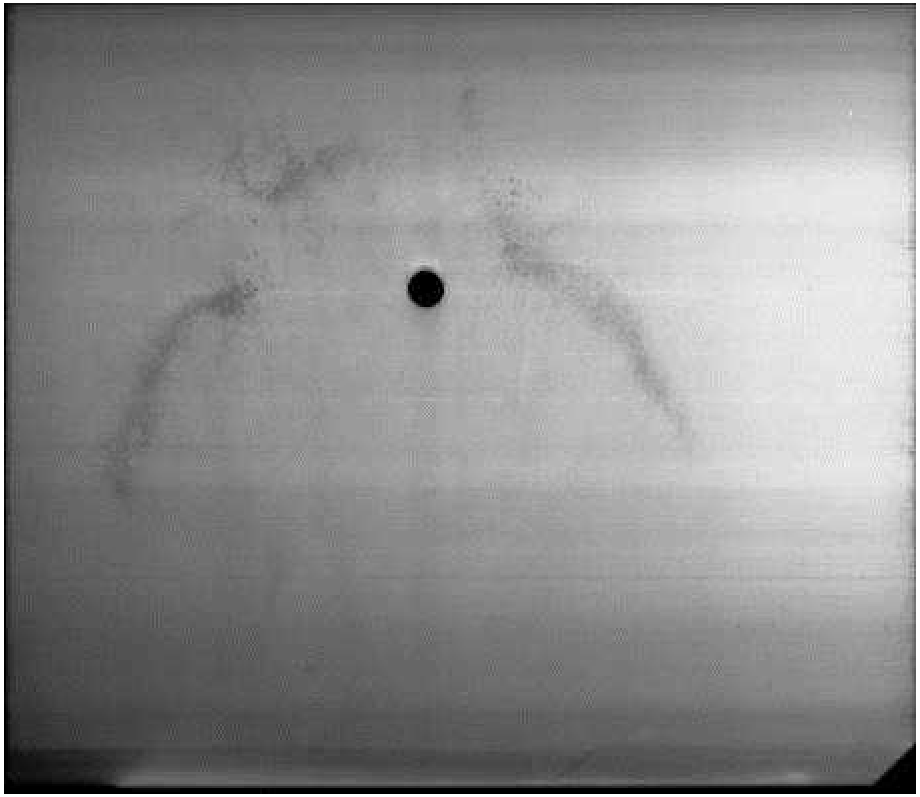


Most distinguishable particles between .3 and 1 mm

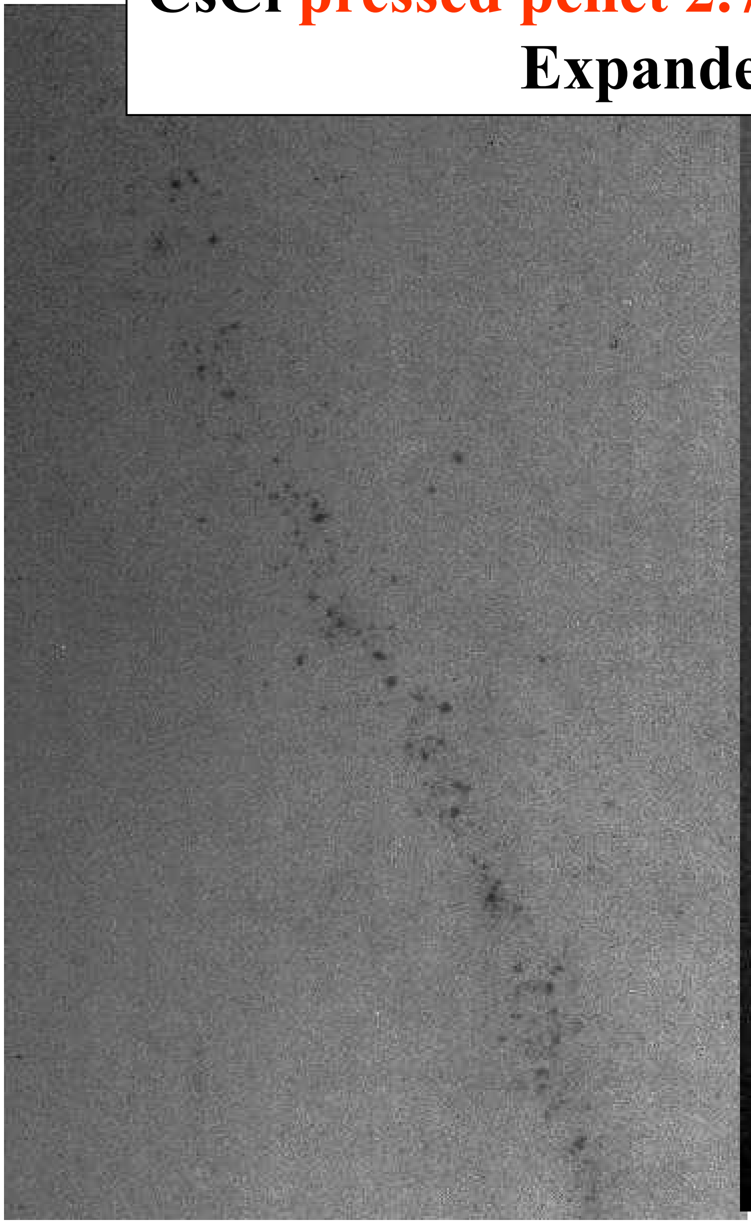


CsCl radiograph of particles (Geometry 2 and 3) (pressed pellet 2.7 g/cm3)

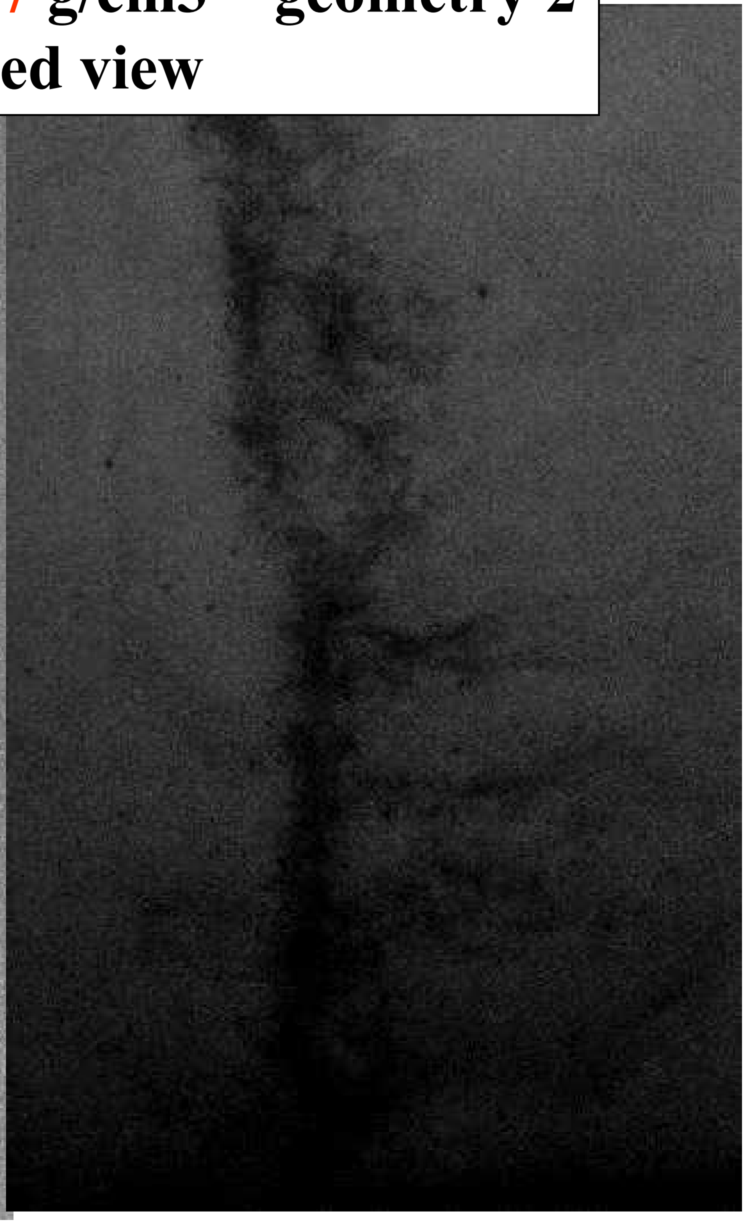




CsCl pressed pellet 2.7 g/cm3 – geometry 2
Expanded view

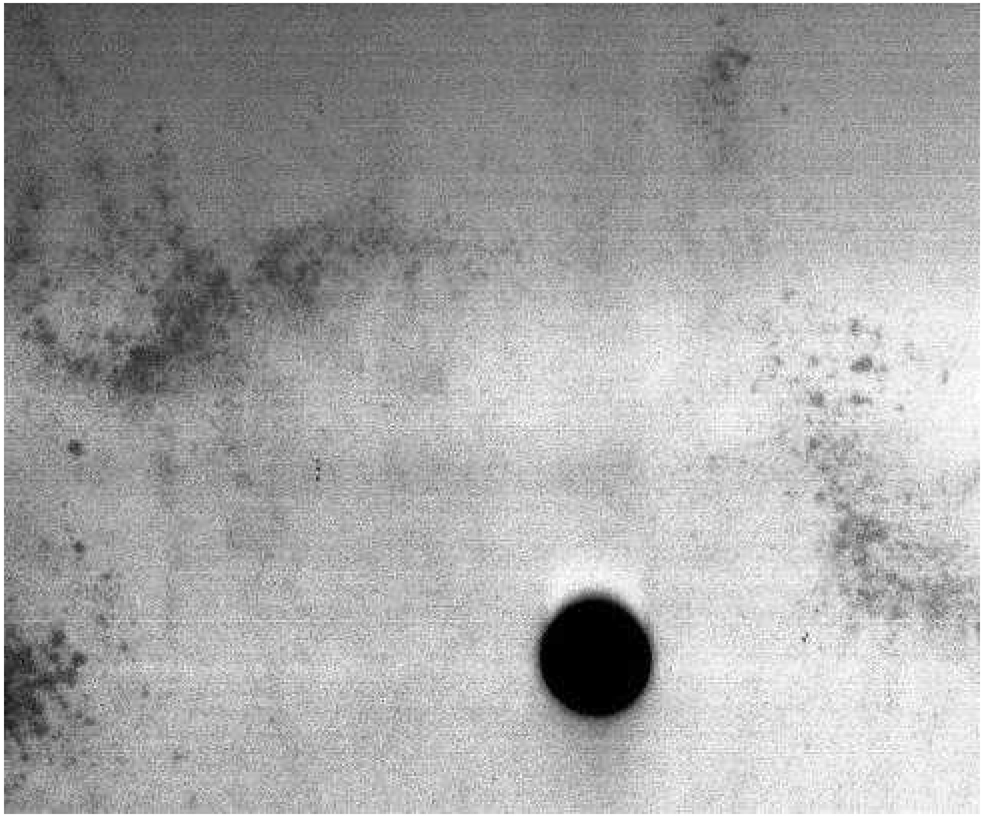


Jet top



Jet bottom

Expanded view CsCl geometry 2 (pressed pellet 2.7 g/cm^3)



Preliminary CsCl pressed pellet conclusion

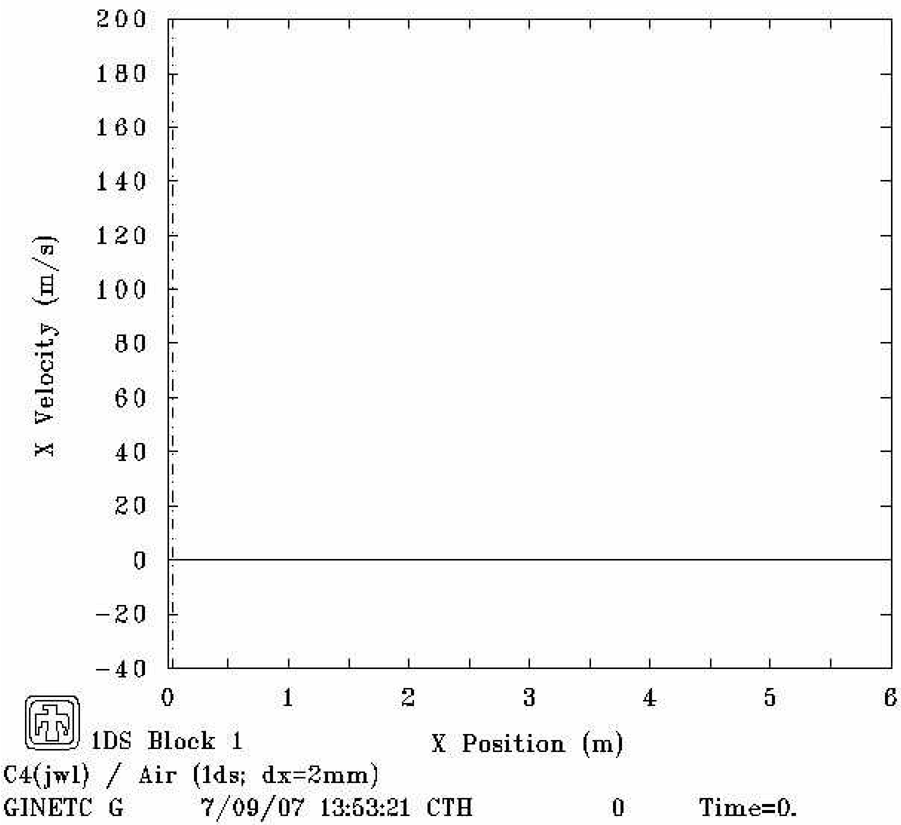
Many large particles (> 100 μm)

In order to get a pressed density of 2.7, it was necessary to grind CsCl granules (originally of a size 300 – 400 μm) to a size of about 5 μm prior to cold pressing)

Varied particle sizes – so what

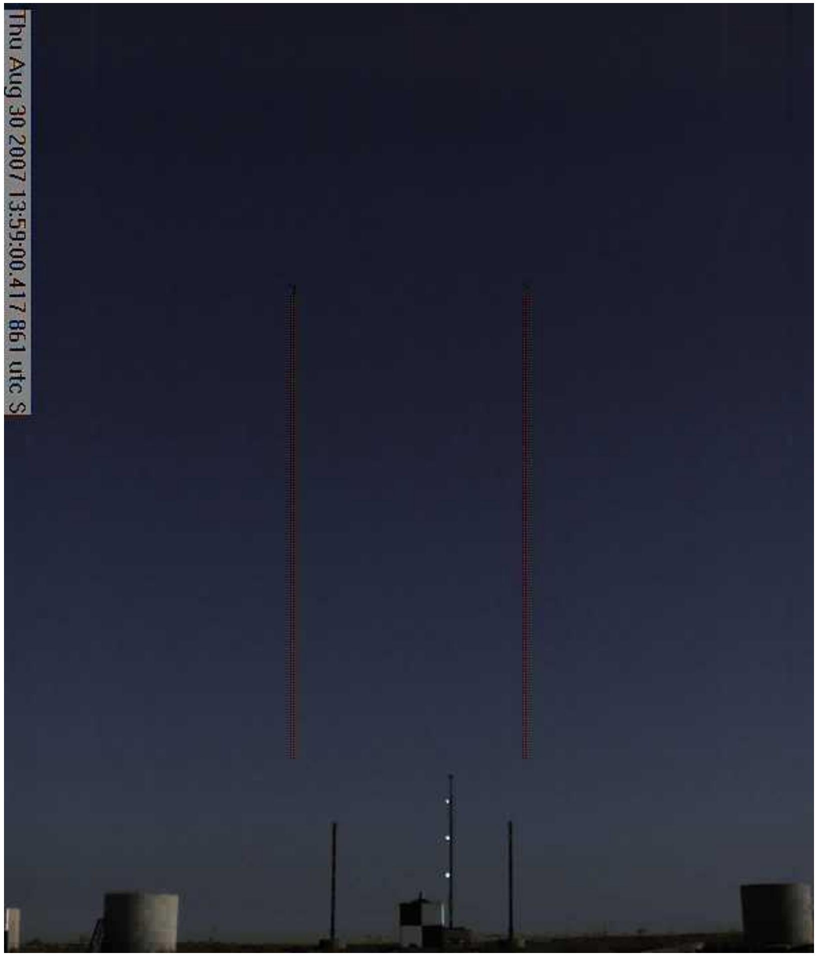
- Localized concentrated shine problem – bad for first responders
- or
- Dilute cleanup problem (low level inhalation problem) – bad for EPA
- Will treat respirable and intermediate transport with traditional aerosol transport codes and large particles and fragments with ballistic models (based on experimental observations)

Velocity of air behind shock (1 lb C4)

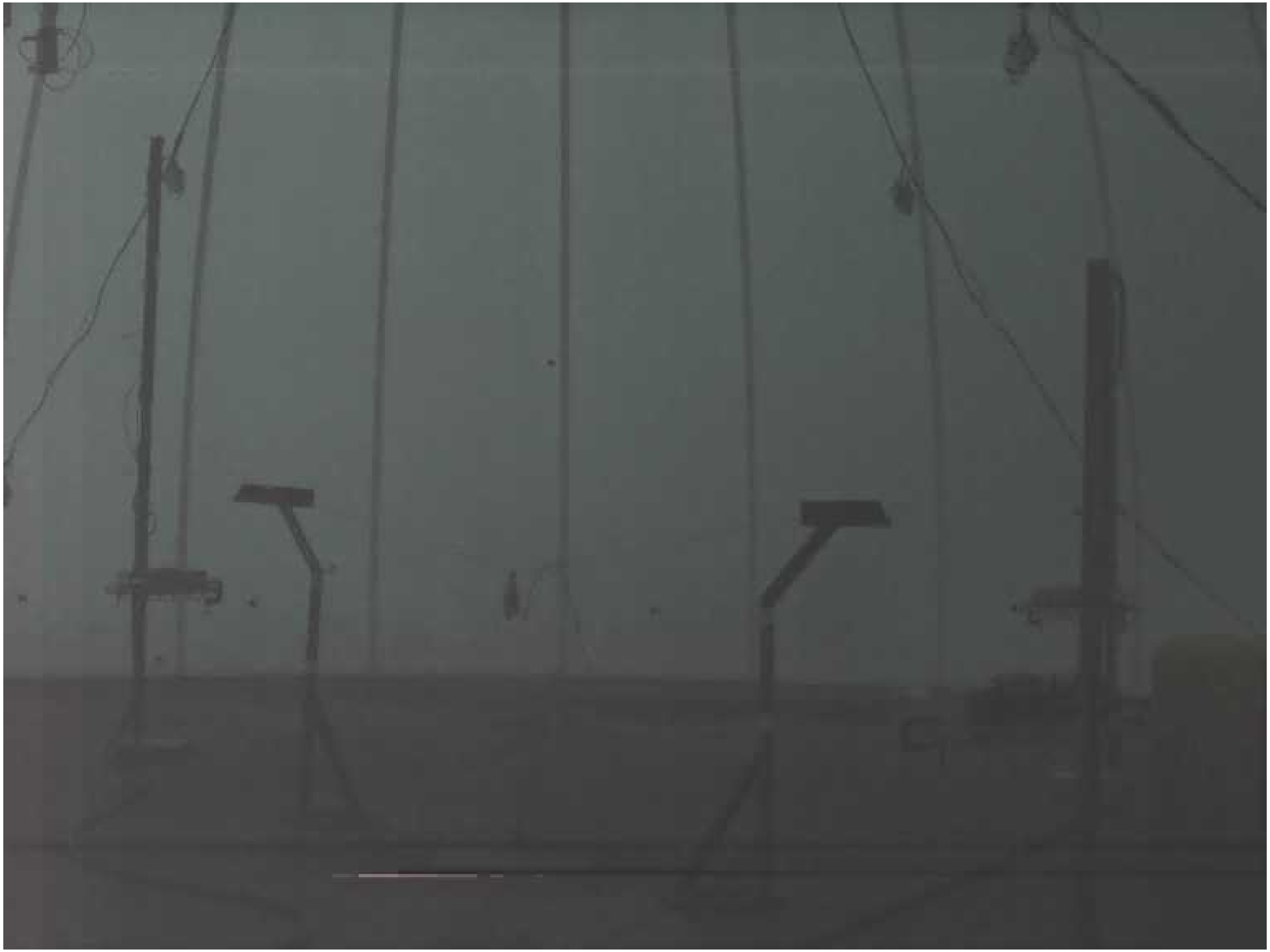


100 µm (aero) WC – Geometry 1

Large particle/frag velocity at 4 m – 725 m/s, at 10 m 400 m/s, at 23 m 145

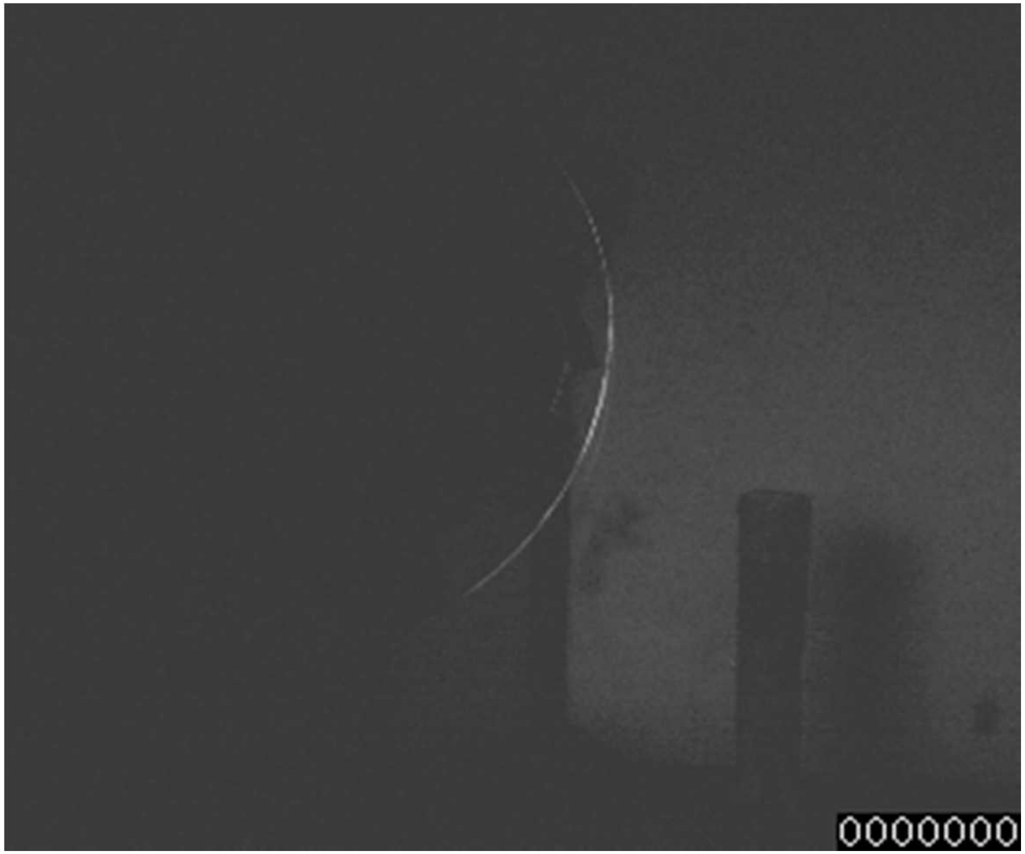


100 µm (aero) WC – geometry 2



Larger particles can penetrate the air shock in diverging devices

Large particle/frag velocity at 2 m – 900 m/s, at 10 m 700 m/s, no dropoff in v when air shock penetrated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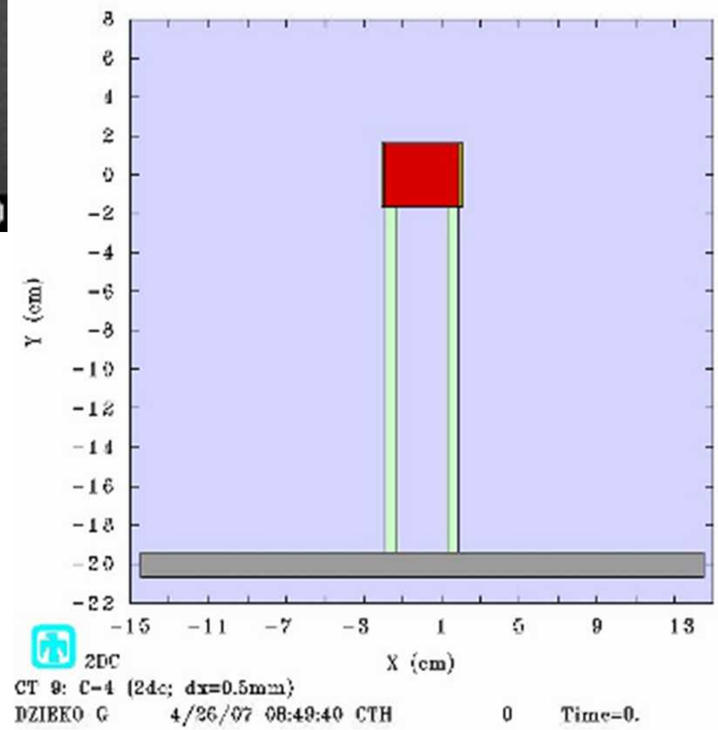
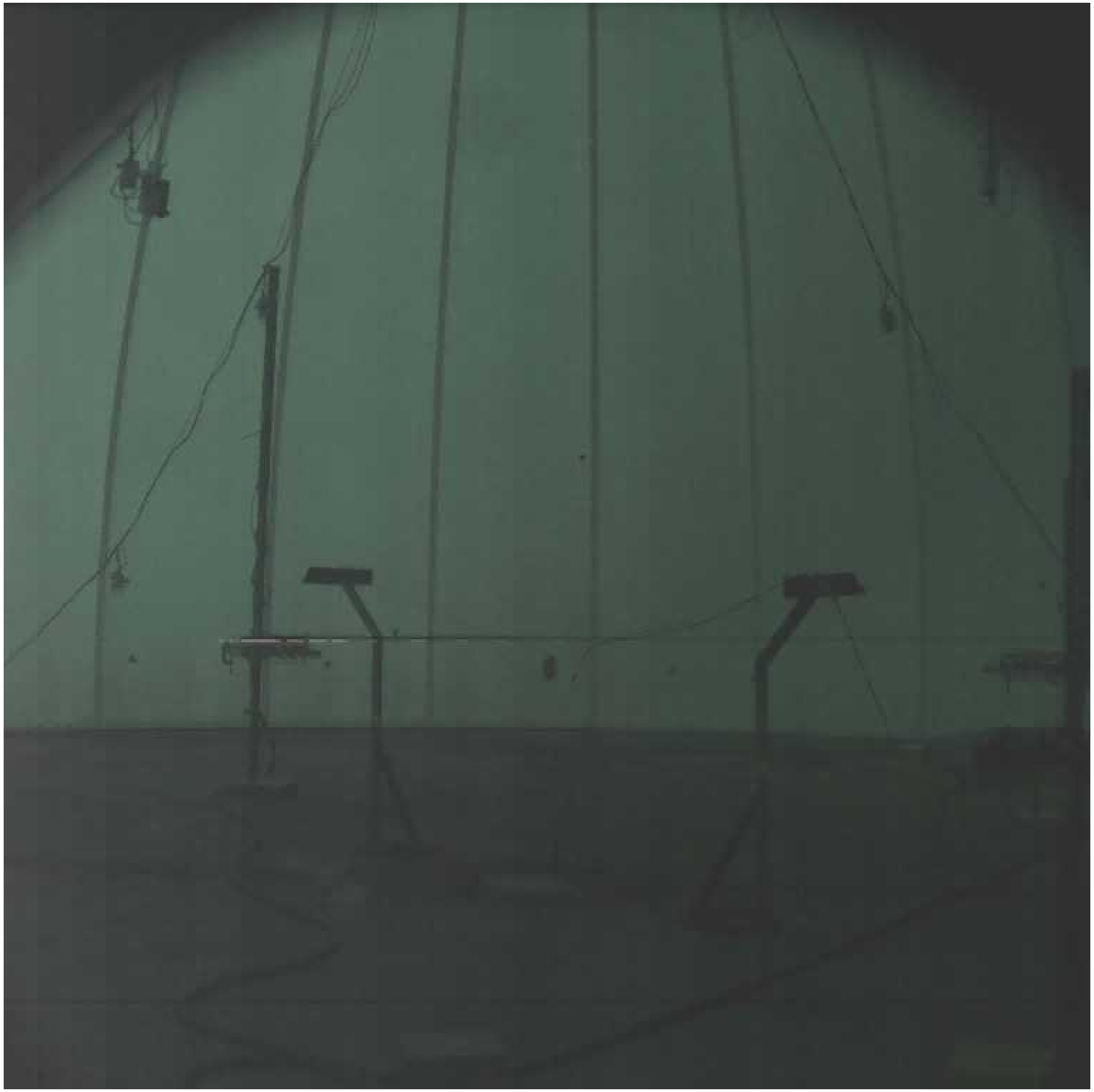

Y (cm)
X (cm)
2DC
CT 9: C-4 (2dc; dx=0.5mm)
DZIEKO G 4/26/07 08:49:40 CTH 0 Time=0.

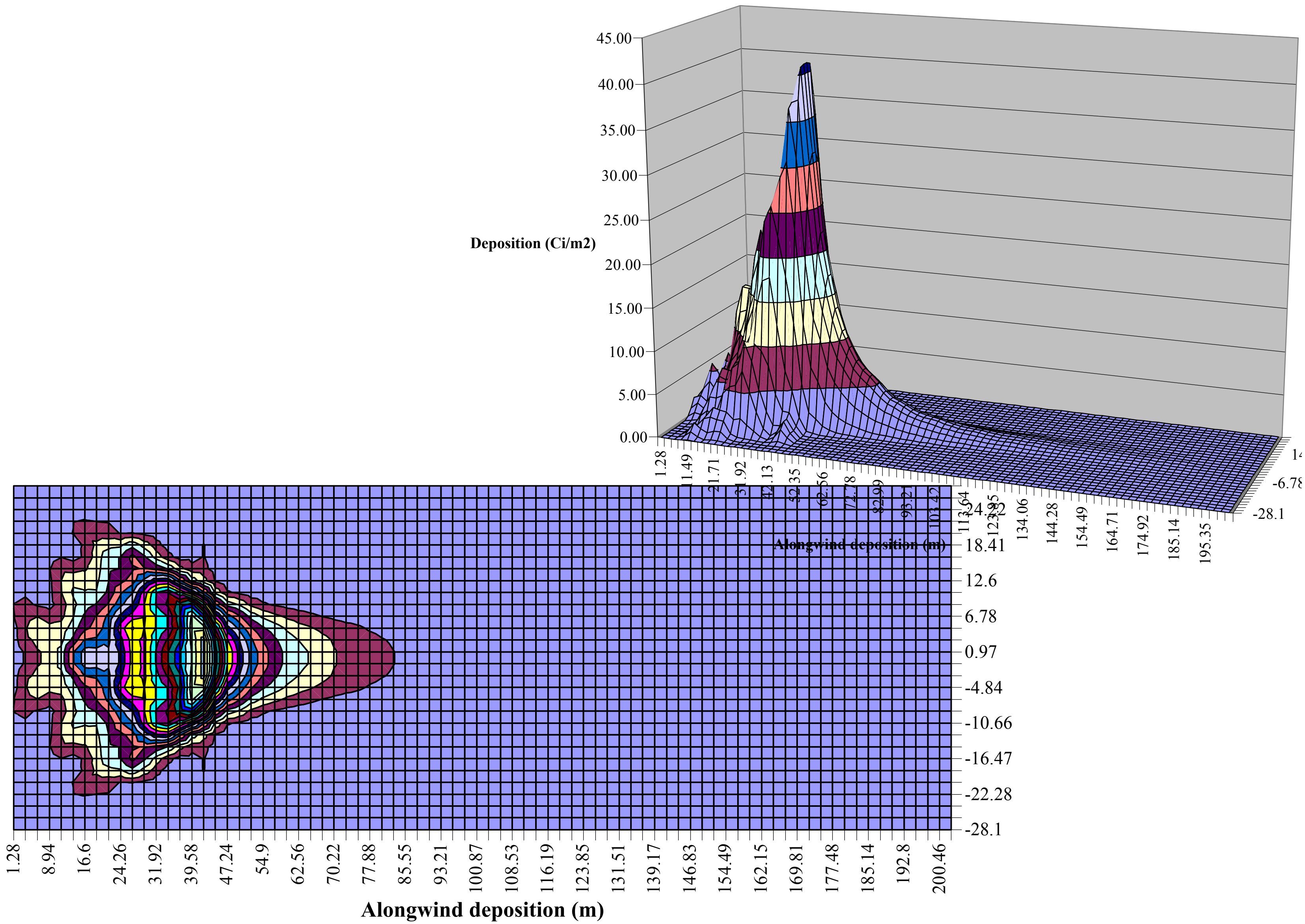
100 µm (aero) WC – hemispherical wave geometry

CsCl – 2 & 400 µm (aero)



CsCl – mostly 2 µm (aero)

Example of ground deposition from explosive dispersal of ceramic large particles (> 100 µm, < 500 µm) – 2D and 3D representations – Scatterme



Realistic RDD Hazard Boundaries for Varying Device Designs (Areas of highest concern for early response)

		Int. Size Source, Basic Eng'g	Very Large Source, Basic Eng'g
Groundshine dose of 100 rad, 24-hour exposure assumed	Acute groundshine threshold	0	~ 300 m
Inhalation dose of 100 rad to the bone marrow (30-day committed dose)	Acute haematopoietic syndrome threshold	0	0
Inhalation dose of 270 rad to the lung (30-day committed dose)	Acute pneumonitis threshold	0	0
Lifetime inhalation dose of 100 rem (50-year committed dose)	Chronic radiation sickness threshold	0	0
5 rem groundshine dose (5-hour exposure assumed)	Workers can work unrestricted for 5 hours	~ 100 m	~ 600 m
10 * ALI for inhalation	Use of Prussian Blue DTPA highly recommended	0	0

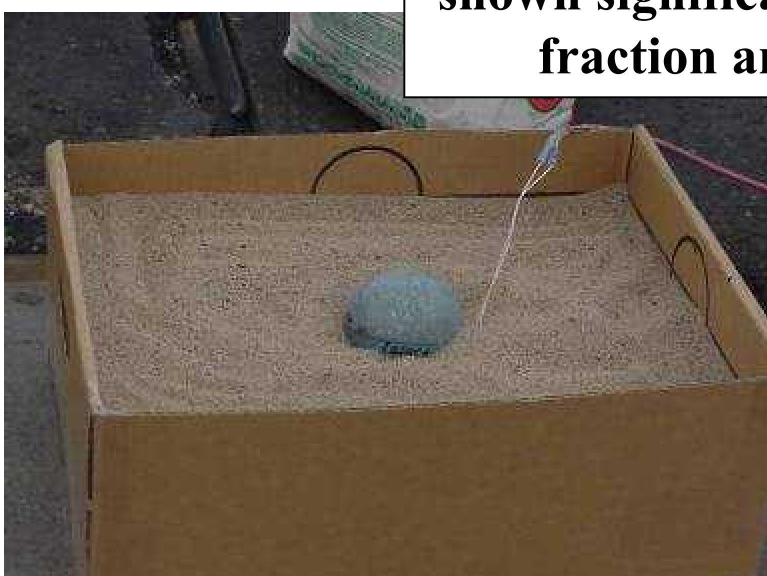
Applications

Supplemental Viewgraphs

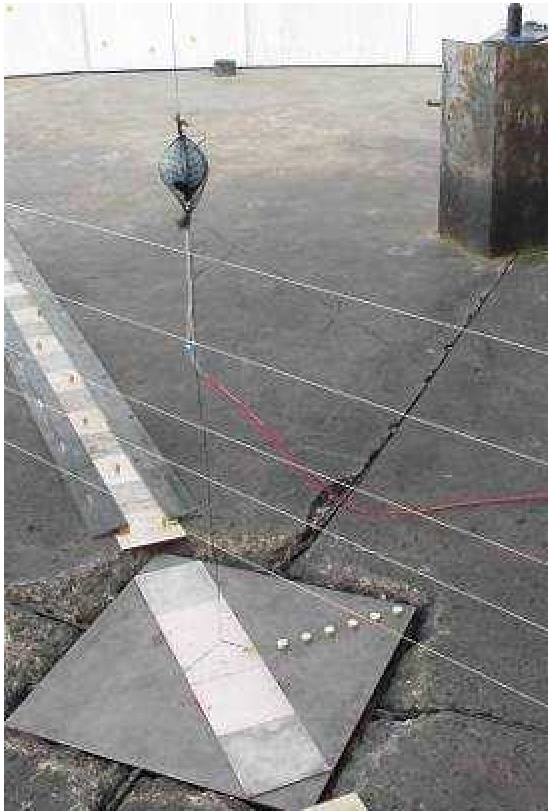
Inert material entrained into the fireball can coagulate with respirable particles causing an effective increase in size

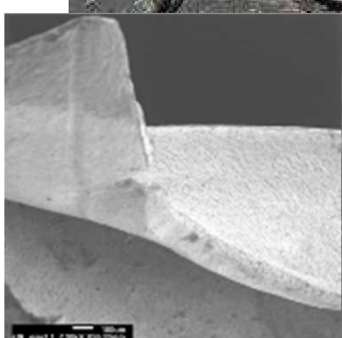
- Material entrained within 100 ms of the blast is most effective
- Efficiency of entrainment depends on the surface type , the elevation, and device geometry
- Nature of the dispersion can be altered drastically

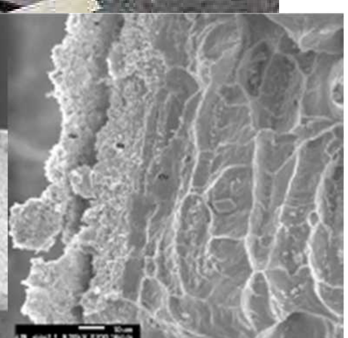
Agglomeration/condensation studies have shown significant reduction in airborne aerosol fraction and a shift in size distribution

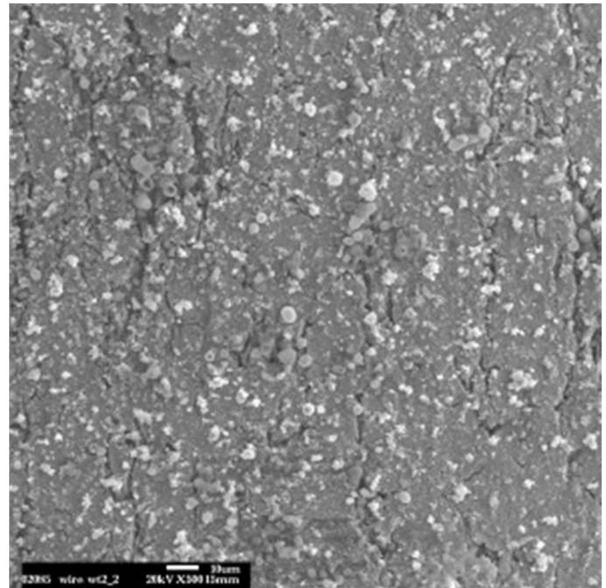


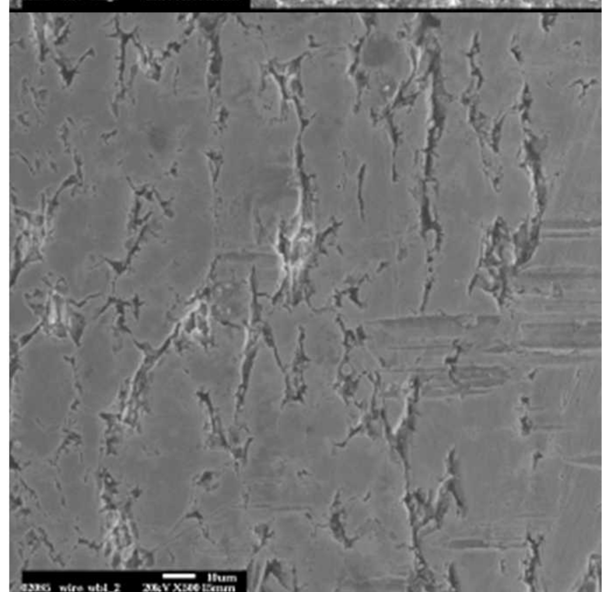
Region of heavy deposition and active agglomeration is smaller than visible fireball

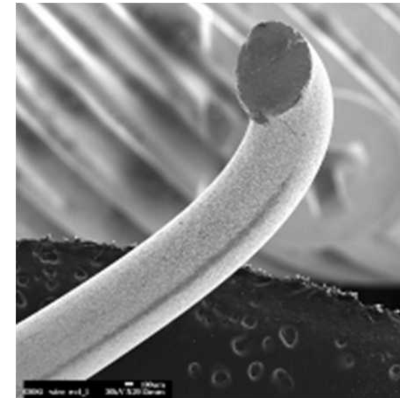


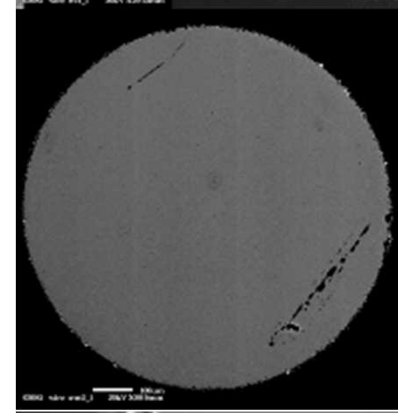


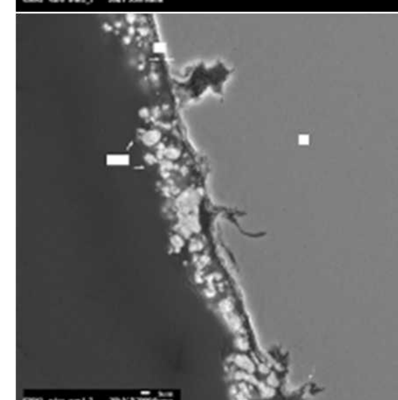




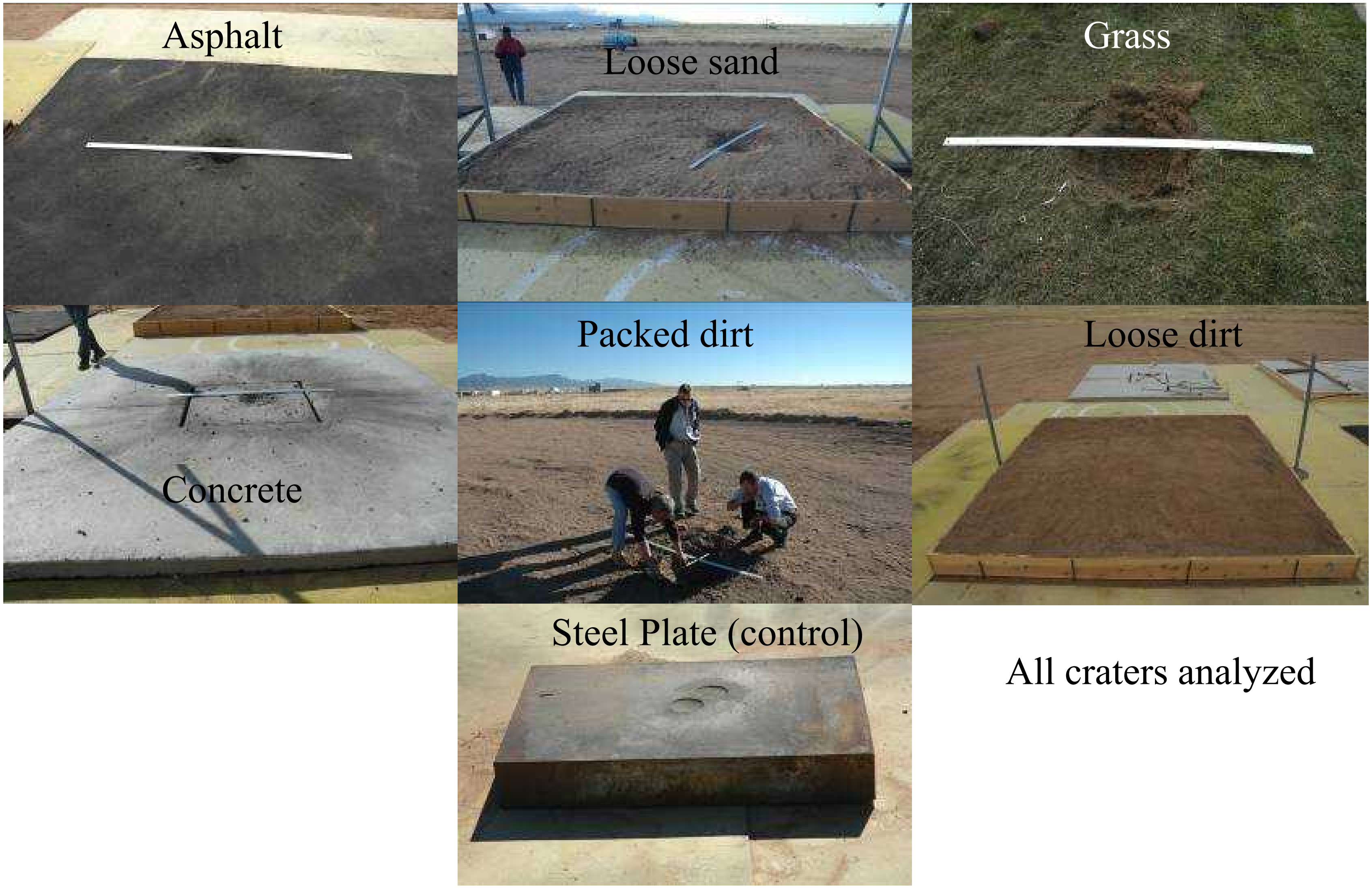








Dirt entrainment/plume behavior tests performed on several urban surfaces



All craters analyzed


2006-11-02 17:37:08.999000
Plume
T49 Plate Top 5lb
Thu Nov 02 2006 17:37:09.085 232 utc S


2006-11-02 17:37:08.999000
Fireball-4
Fireball-3
Fireball-1
Fireball-2
T49 Plate Top 5lb
Thu Nov 02 2006 17:37:09.085 232 utc S

Afterburn and fireball comparisons: 1 lb, det on top, different surface conditions

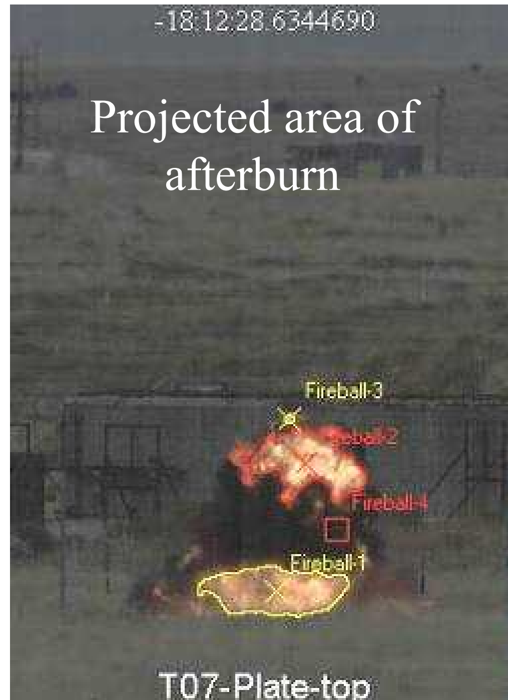
Steel plate

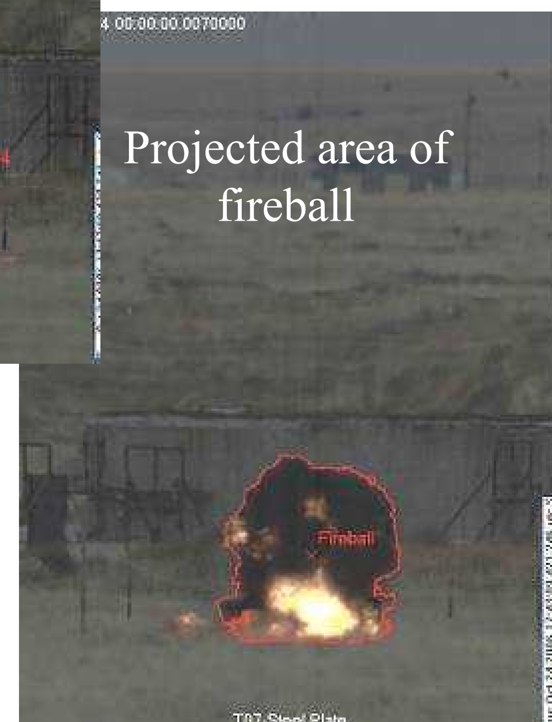
Grass

Steel plate, 1 m high

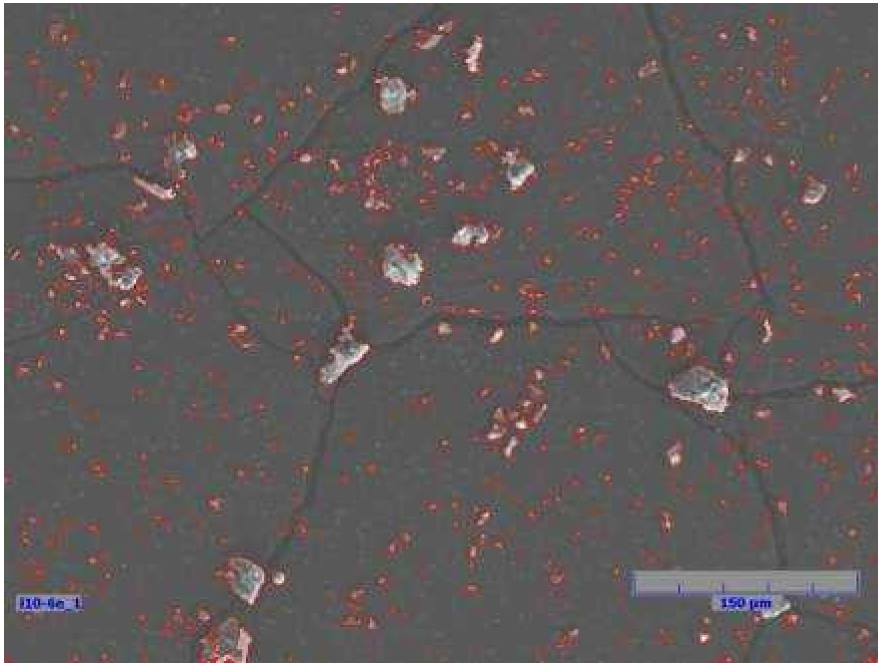
Normalized mass of material in fireball early time

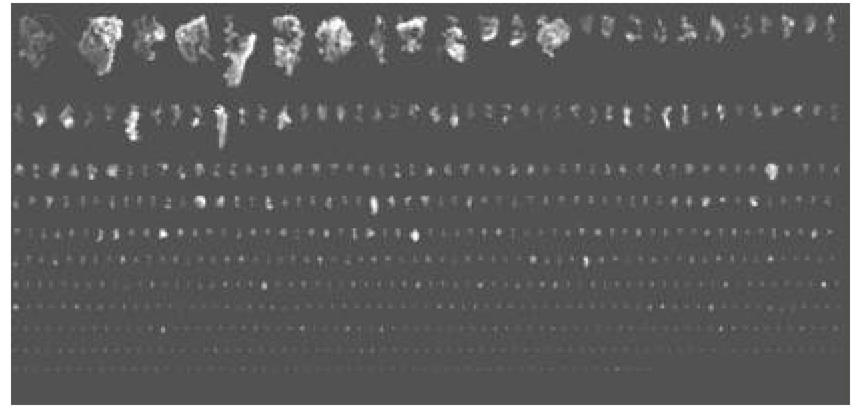
Surface	Mass of inert material in Fireball (kg)
Mixed sand	1
Loose dirt	1
Concrete	0.08
Grass	0.07
Packed dirt	0.03
Asphalt	0.02 (Late burn)
Steel plate	0



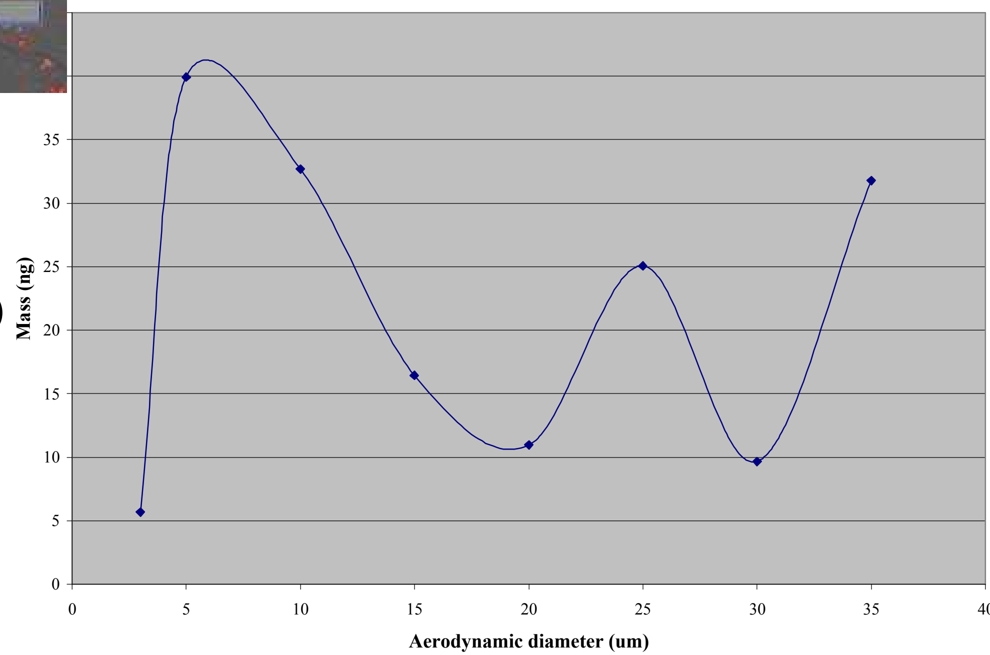


Dirt entrainment particle size analysis





Mass vs aerodynamic diameter (from electromicrograph field of view)



Consistent with bimodal size observations
From Pinnick, Fernandez, and Hinds
(Explosion dust particle size measurements)

Observed peaks at 7 and 70 µm irrespective of soil or explosive type
(Clay soil from LA, sandy clay soil from AL, and sandy soil from NM)

Some Simple Fireball Physics

- Det wave in explosive
- Shock wave in particles (ΔP acceleration of particles)
- Expansion of det products (acceleration of particles by det products)
- Stagnation when det products reach atmospheric pressure (drag – deceleration of particles)
- Particles > ? µm escape influence of fireball and det products – inertia > drag (simple calculations and experimental observations show that escape velocities achieved for particles > 100 µm aero)
- Shock wave in air, influence of neighbor particles (reduced drag)
- Afterburn if O_2 available, Temperature not suppressed, soot and CO available
- C4 and TNT produce a lot of soot and CO
- TNT has an O_2 balance of – 74 %, while HMX and RDX have an oxygen balance of about -20 % (more energy in initial detonation, less in afterburn)
- More than half of the energy from TNT comes from the afterburn if the products burn to completion
- Shape of fireball dependent on det location, shape of explosive, material interactions

Additional Basics Needed Here

- Settling Velocity
  - 1 μm – .0035 cm/s
  - 10 μm – .31 cm/s
  - 100 μm – 24.8 cm/s
  - 1000 μm – 386 cm/s
- Force of Drag $F_D = C_D \frac{\pi}{8} \rho_g d^2 V^2$
- Aerodynamic diameter $d_a = d_{phys} \rho_p^{1/2}$

$$Re = \frac{\rho_g V d}{\eta_g}$$

(or in cgs units)

$$Re = 6.6 V d$$