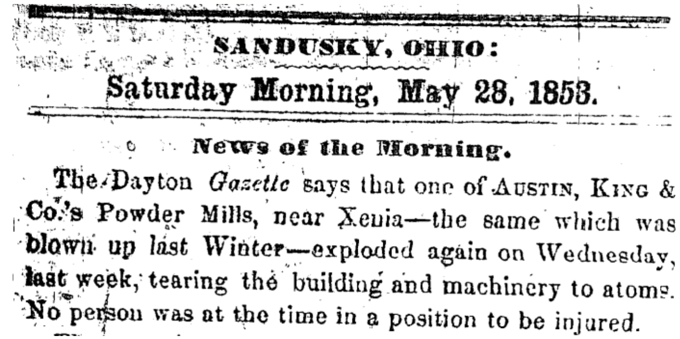
The ExCEED facility for beryllium dust explosions

Paul Humrickhouse
Idaho National Laboratory

Virtual Laboratory for Technology conference call
20 February 2013

Dust explosions- a long standing safety issue

- Dust explosions became an issue when large scale milling of grain began in the 1700s; the earliest known: a flour warehouse explosion in Turin, Dec. 14 1785
- They continue to be a problem: three incidents involving metal dust and hydrogen explosions killed five and injured three at the Hoeganaes facility in Gallatin, TN in 2011
- Legislation (H.R.522) was (re)introduced last week to compel OSHA to issue a standard on dust explosions
- We know dust is created by plasma-surface erosion in tokamaks; this safety concern has to be addressed for devices that may generate large quantities of dust



SANDUSKY, OHIO:

Saturday Morning, May 28, 1853.

News of the Morning.

The Dayton *Gazette* says that one of AUSTIN, KING & Co.'s Powder Mills, near Xenia—the same which was blown up last Winter—exploded again on Wednesday, last week, tearing the building and machinery to atoms. No person was at the time in a position to be injured.

Dates	Incidents	Deaths	Injuries
Pre-1922	217		
1900-1952	769	464	1229
1980-2005	281	119	718

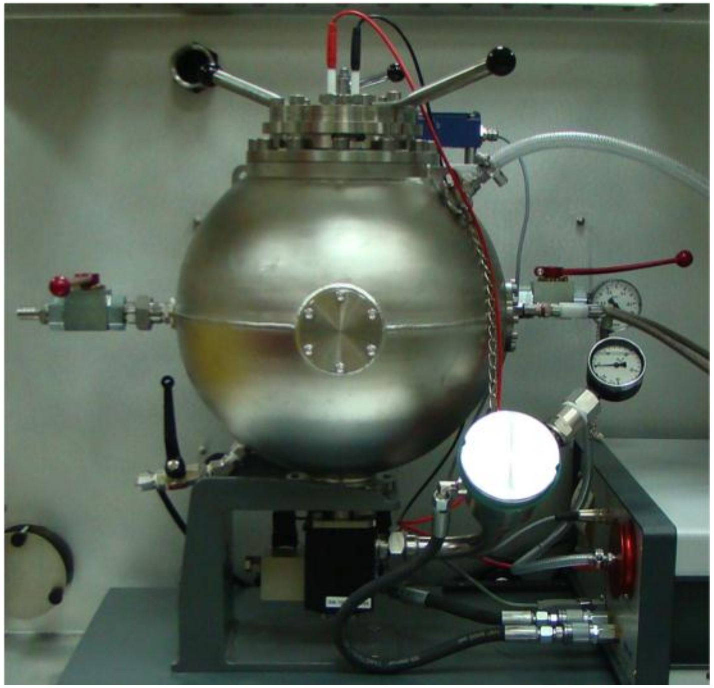
Imperial Sugar, GA, 2008 (14 dead)

Relevant questions

- Is the dust explosive?
  - This is the “explosibility”- established by igniting dust clouds over a wide range of concentrations- the dust is not explosive if it fails to ignite
- In what concentrations is it explosive?
  - The Lower Explosion Limit (LEL) identifies the minimum concentration necessary for an explosion
- How much oxygen is needed to permit a dust explosion?
  - The Limiting Oxygen Concentration (LOC) is that below which a dust explosion cannot occur
- How violent is the explosion?
  - The explosion indices (P_{max}, K_{max}) are the maximum pressure and maximum rate of pressure rise for a particular dust

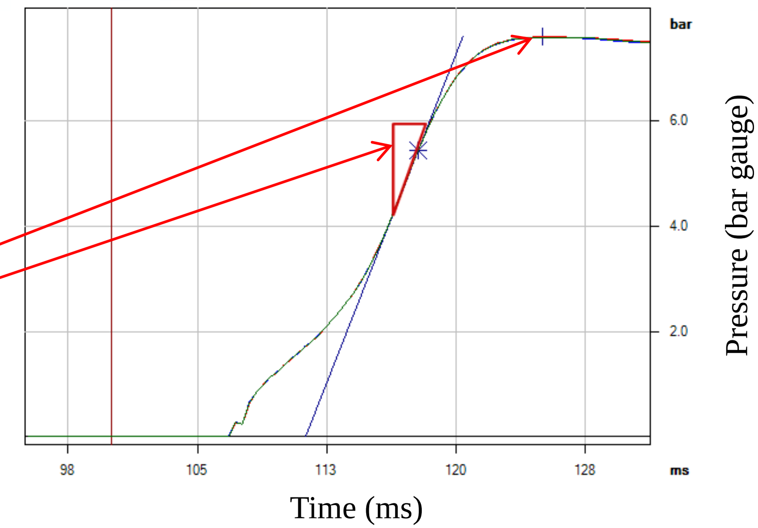
Kühner 20 liter sphere

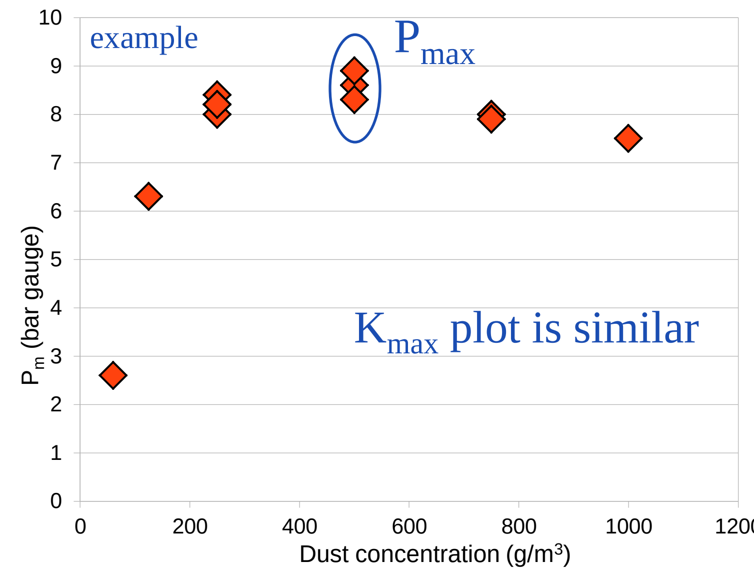
- Standard device for determination of explosion indices (cf. ASTM E1226)
- 0.6 liter, 21 atm dust/air mixture combines with:
- 20 liter, 0.4 atm air volume
- Timed ignition with 2 chemical igniters (5 kJ each for measurement of the explosion indices)
- Pressure rise measured and recorded as function of time
- Double walled vessel has a water jacket for rapid cooling, constant initial temperatures



Explosion Indices of Combustible Dust

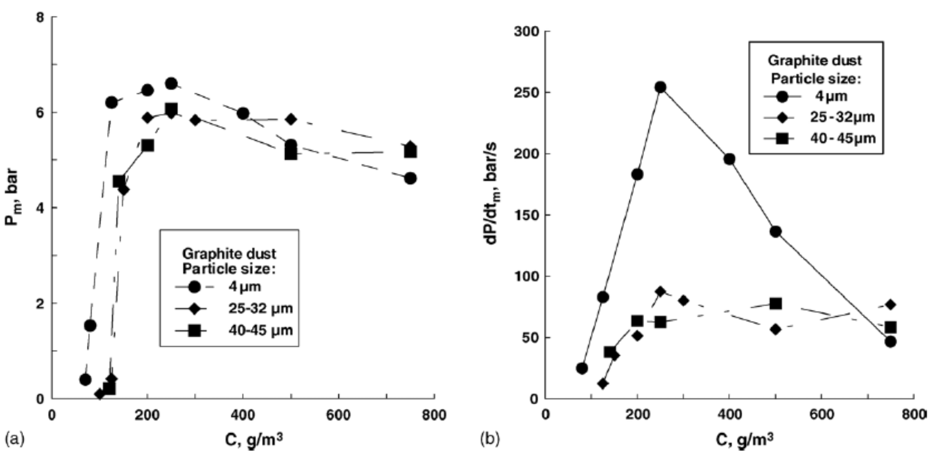
- Explosion indices are determined by conducting a series of explosions at increasing dust concentrations in air under standardized conditions
- Each explosion has a maximum pressure (P_m) and maximum rate of pressure rise (dP/dt_m) identifiable on the pressure trace
- Plotting P_m and dP/dt_m for each explosion versus the dust concentration identifies the P_{max} and dP/dt_{max} characteristic of that dust
- dP/dt_{max} is further corrected to be volume independent: $K_{max} = V^{1/3}\left(\partial P/\partial t\right)_{max}$
- **P_{max} and K_{max}** are the **explosion indices** of the dust in question
- K_{max} is an indication of the explosion violence and is grouped into the classes:
  - St 1: 0 < K_{max} < 200 [m·bar/s] **(Weak)**
  - St 2: 201 < K_{max} < 300 [m·bar/s] **(Strong)**
  - St 3: K_{max} > 300 [m·bar/s] **(Very Strong)**

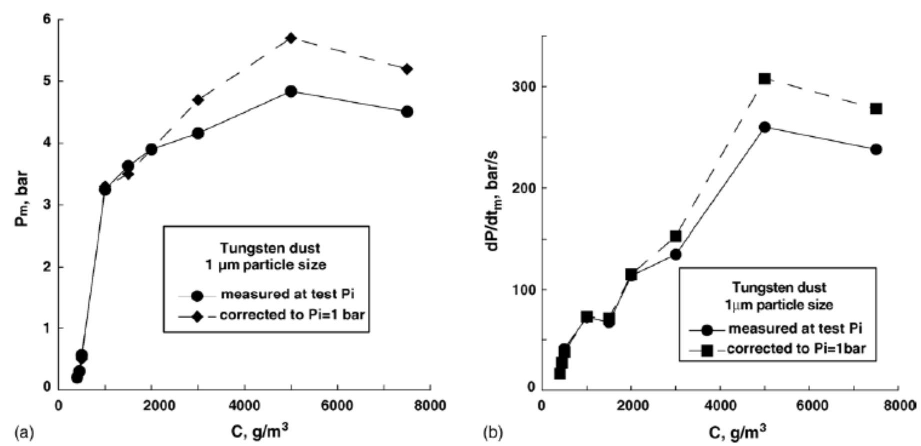




KIT facility - DUSTEX

- To address the explosion risk for fusion, KIT has carried out numerous tests (also with a Kühner sphere) on graphite and tungsten dusts
- These were found to be at most weakly explosive (class St 1)

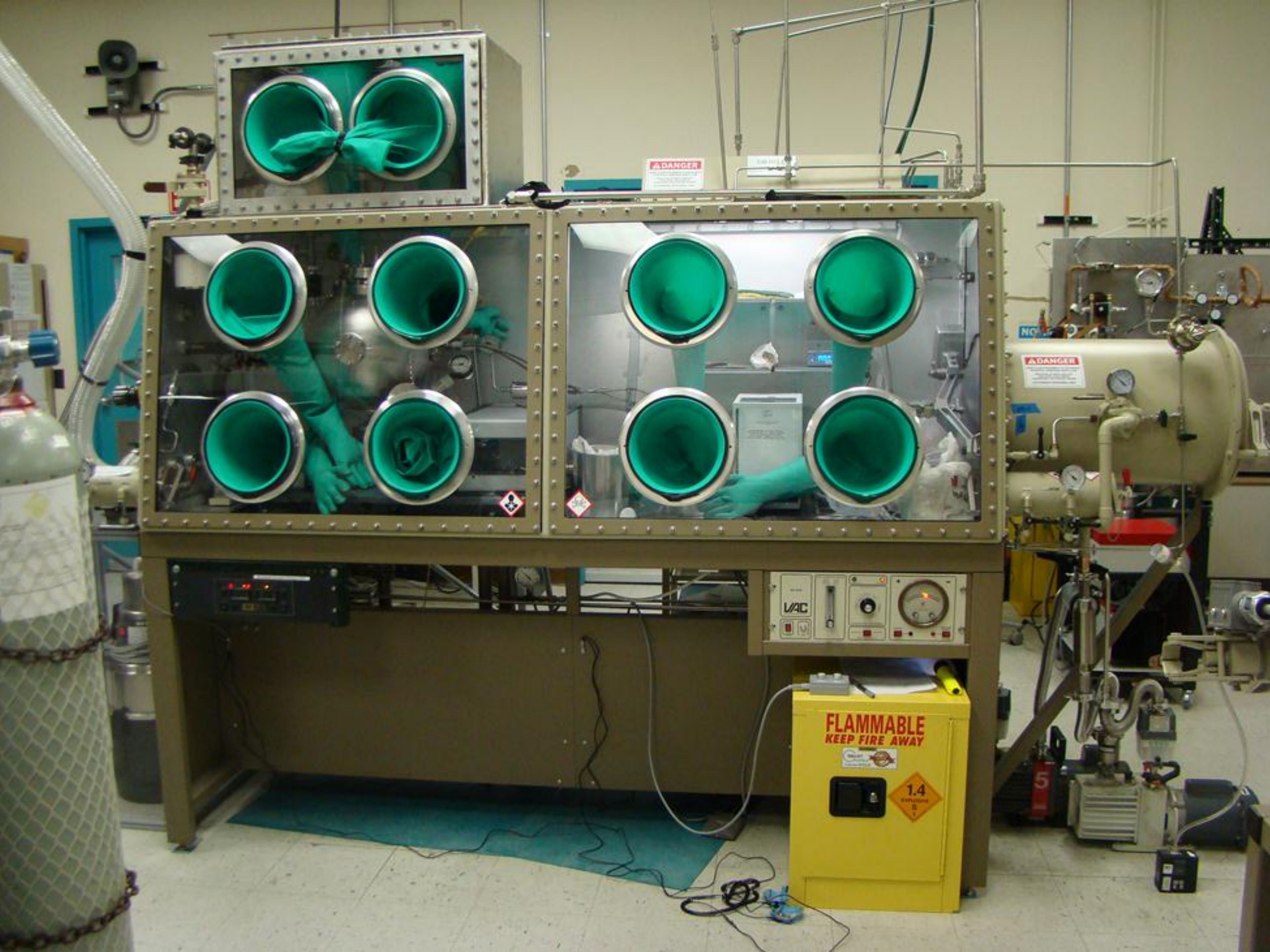




Dust	P_{max} (bar)	K_{max} (bar·m/s)	Class	Description	Reference
C	6.6	68	St 1	Weak Explosion	Denkevits, Fus. Eng. Des. **75-79** (2005) 1135
W	4.7	71	St 1	Weak Explosion	Denkevits, Fus. Eng. Des. **75-79** (2005) 1135
Wood	9.4	208	St 2	Strong Explosion	Bartknecht 1989
Niacin	8.1	243	St 2	Strong Explosion	Kühner report
Al	10-12.5	500-650	St 3	Very Strong Explosion	Numerous

Beryllium data is needed

- Beryllium oxidation is more energetic than tungsten or graphite, may dominate explosion risk if present as a PFC
- To address this need, we have commissioned the Experimental Chamber for Evaluation of Exploding Dust (ExCEED)
- Testing in the Kühner sphere requires ~100s of grams of material
- This is a real challenge considering that exposure to as little as 0.2 µg/m^3 can cause chronic beryllium disease
- Our Kühner sphere is housed in a glovebox for complete containment of beryllium

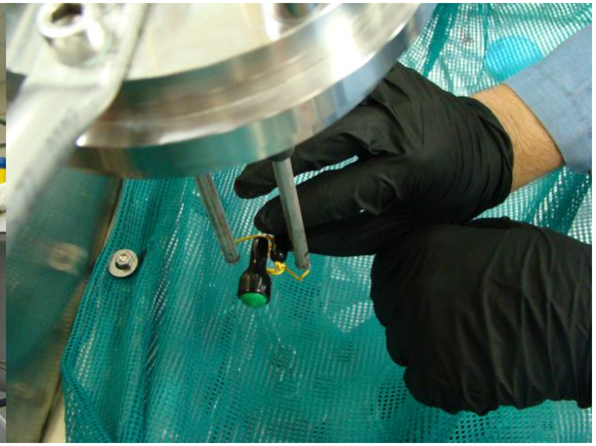

DANGER
DANGER
VAC
FLAMMABLE
KEEP FIRE AWAY
1.4

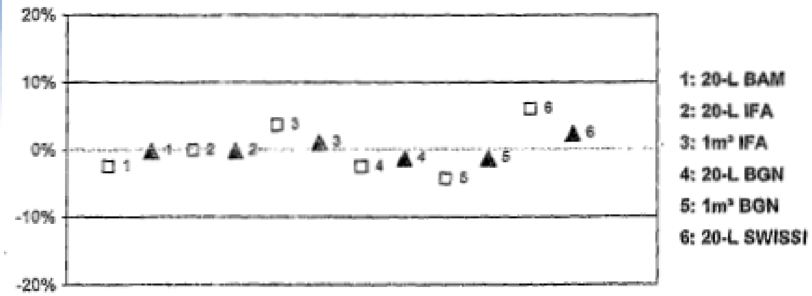
Safety Analysis and Controls

- Pressure vessel analysis
  - Kühner sphere has a MAWP of 30 bar; tested to 42 bar
  - Established Code equivalency between European Pressure Equipment Directive 97/23/EC and ASME section VIII for the sphere
  - Installed ASME section VIII U-stamped safety relief valve
- Glovebox integrity
  - Inert (N_2) atmosphere for fire and explosion prevention
  - Pressure relief and HEPA filtration
  - Pressurization scenarios considered; no threat to the glovebox is evident
- Igniter handling
  - Anti-static controls include pulsed DC ion bar, grounded mats and wrist straps, grounding of all devices, anti-static glovebox gloves
  - Accidental ignition not a threat to glovebox integrity

Igniters

- We use Simex igniters because of their superior safety characteristics

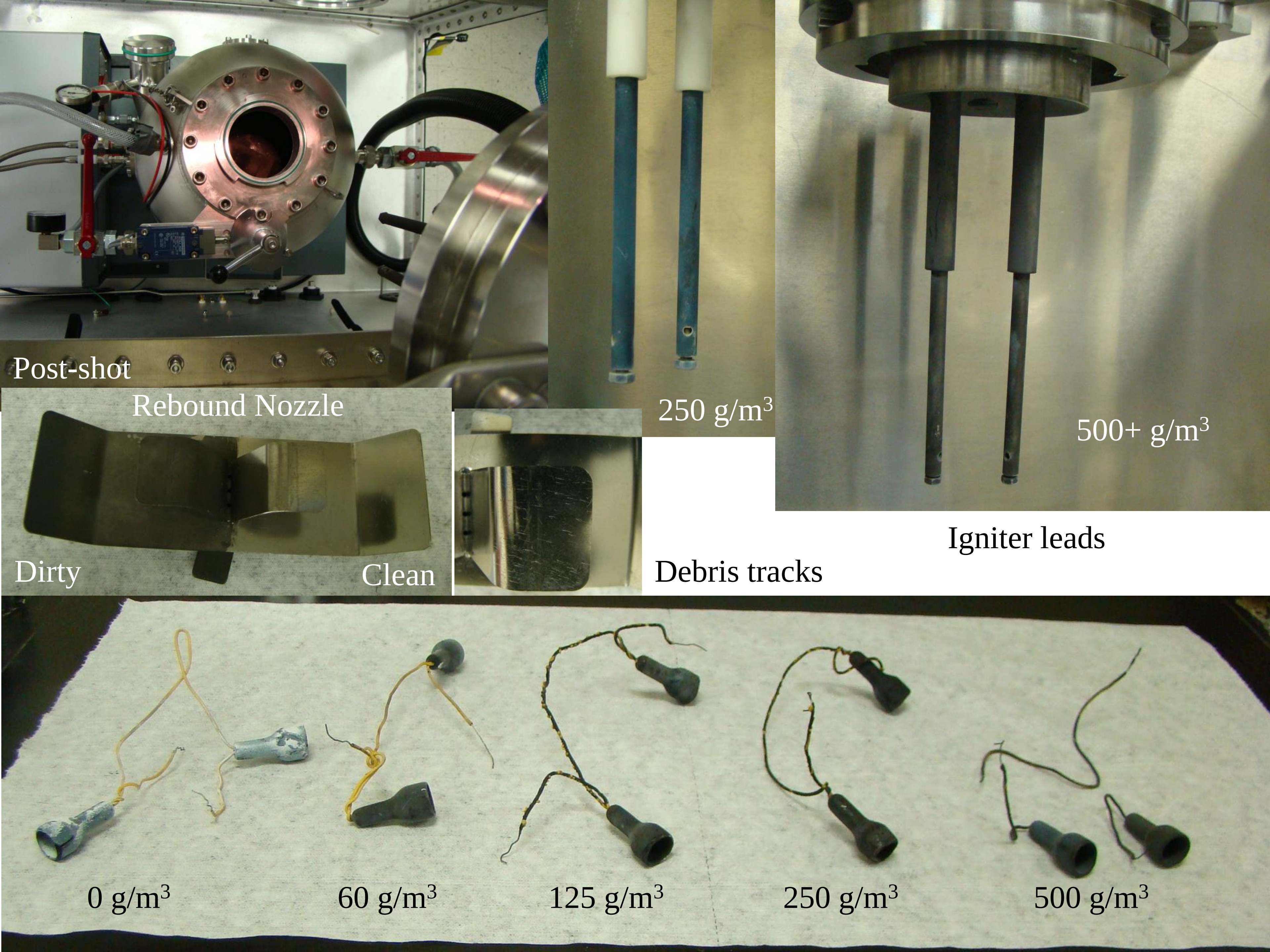




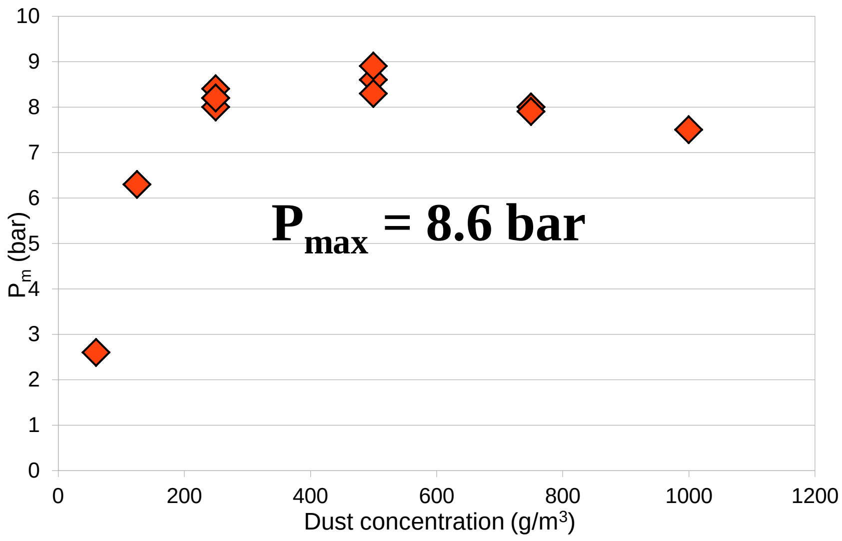
Parameter	Standard 5kJ Igniters	New SIMEX NPI® 5kJ Igniters
Content of Toxic Compounds	YES	NO
ESD Sensitivity	10-20 mikro J	10-20 mili J
Friction Sensitivity	200 gms	4 000 gms
Safety Current	0,18 Amps	0,4 Amps
Function time delay and accuracy	7,5 ± 2,5ms	1,5 ± 0,5ms
Calculated Combustion Temperature	3800 ± 200 °C	3800 ± 200 °C
Results of P_{max} and K_{max} Evaluation (CaRo-07, Al, Coal, Lycopodium etc.)	Mean value ± 10%	Mean value ± 10%
Caloricity	5 kJ	5 kJ
Ballistic output (20lt)	0,9 to 1,3 Bar	0,9 to 1,3 Bar

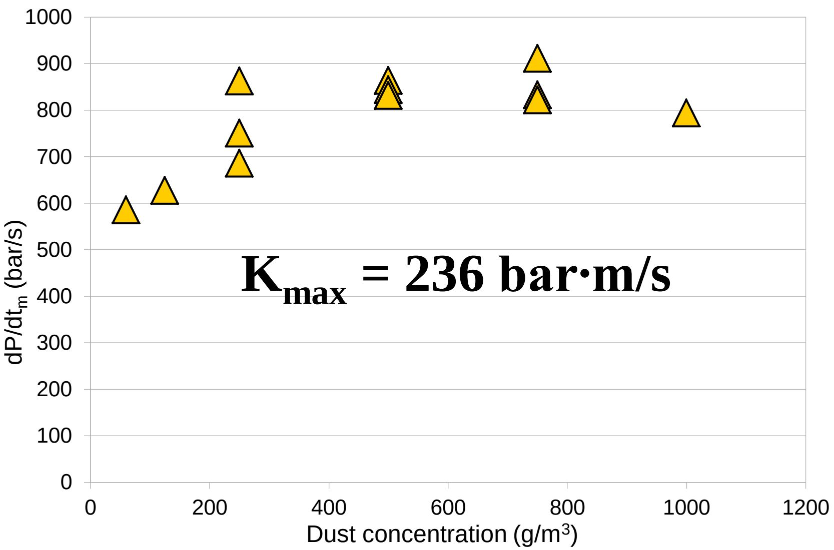
Calibration Testing

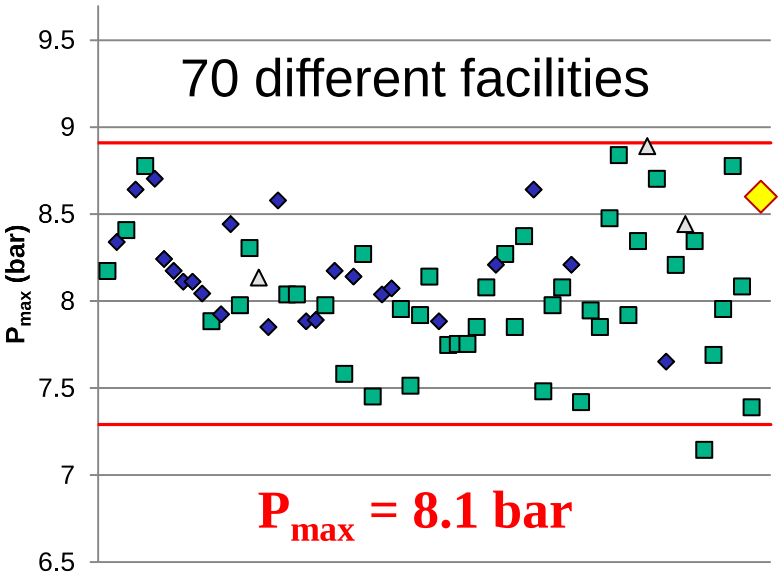
- Kühner provides a powder (Niacin, a.k.a. vitamin B_3, $C_6NH_5O_2$) and test protocol for calibration of the sphere
- Purpose is to compare results for a standard dust against all other facilities
- Results within 10% of mean are acceptable
- 3 test series are required; each series consists of explosions at 60, 125, 250, 500, 750... g/m^3 (1.2, 2.5, 5, 10, 15... g in the 20 liter sphere) continuing until the peak in the curve P_{max} (or K_{max}) vs. concentration is identified
- This testing has been completed in ExCEED
  - We were able to do so without the glovebox sealed as there is no need for strict confinement of niacin

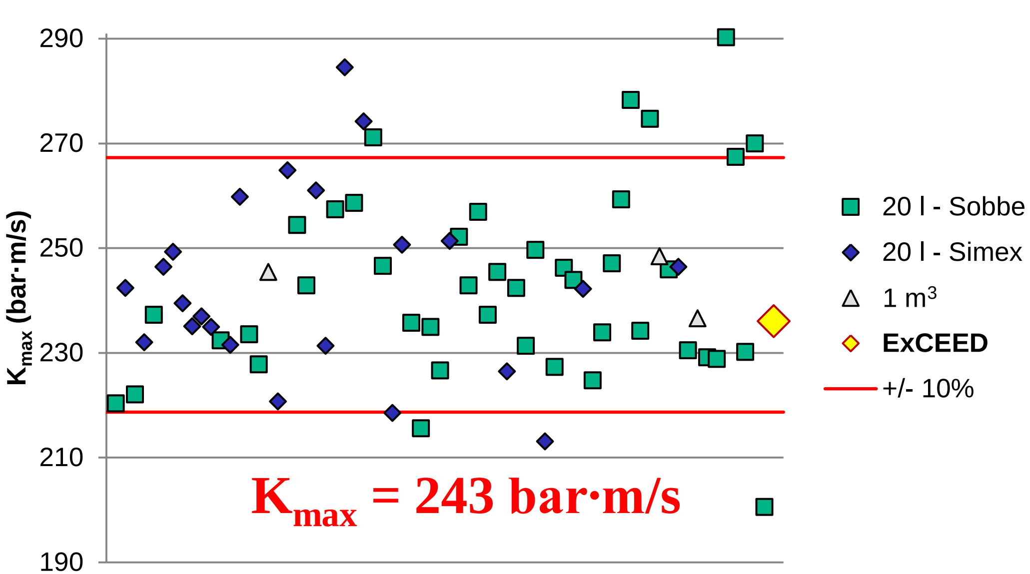

Post-shot
250 g/m3
500+ g/m3
Rebound Nozzle
Dirty
Clean
Debris tracks
Igniter leads
0 g/m3
60 g/m3
125 g/m3
250 g/m3
500 g/m3

Niacin Calibration



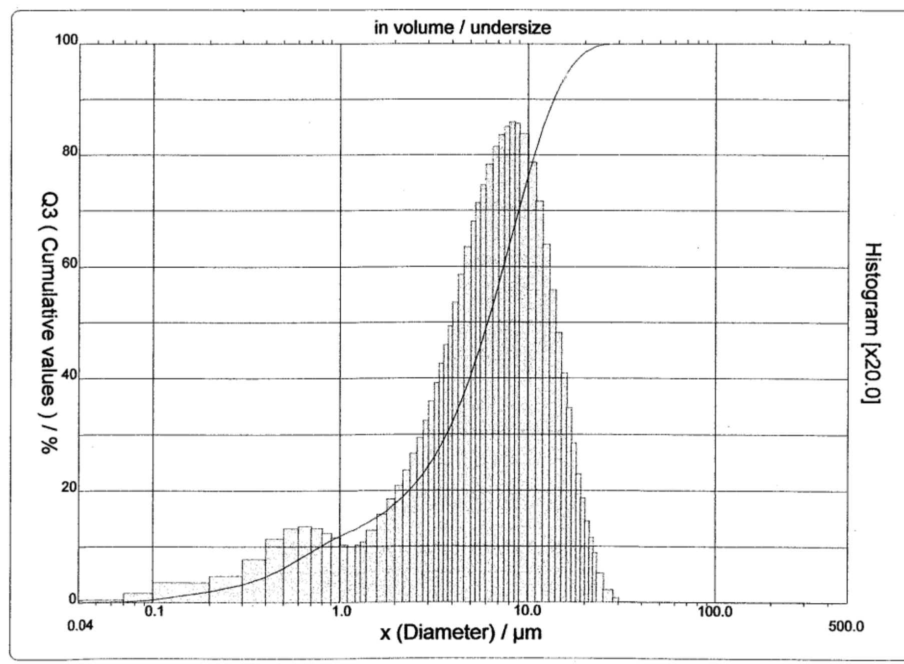






Beryllium Testing – Powder Specifications

- Powder representative of tokamak dust has been purchased from Materion Brush Beryllium and Composites (1 kg) and is well characterized
  - Size distribution contains primarily <10 µm and some < 1 µm particles
  - BET surface area: 4.67 m^2/g



Status and Future Work

- Explosion Indices of beryllium dust have been measured
- Some possible future work:
  - Standard tests for Limiting Oxygen Concentration, Minimum Ignition Energy, or Lower Explosion Limit
  - Testing of larger beryllium particle sizes
  - Identification and testing of surrogates for beryllium with similar explosion characteristics (for larger scale tests)
  - Explosion indices of mixed dusts (e.g. including beryllium, tungsten, and/or others)
  - Inclusion of hydrogen in the gas mixture (some additional safety reviews and equipment will probably be required)
  - Analysis of product gases (e.g. oxygen content) for benchmarking of combustion models