PROGRAM EXECUTIVE OFFICE

AVIATION

U.S. Army Hand Held Extinguisher Environmentally Acceptable Replacement Agent Development

Dr. J. Douglas Mather – U.S. Army Contractor

CGI Federal (Stanley Associates, Inc.)

Replacement for the 2.75 Lb. Halon Handheld Fire Extinguisher in Army Rotary Wing Weapon Systems

- United States (U.S.) Army Program Executive Office (PEO) Aviation initiated agent and hardware replacement effort.
- The U.S. Army Aviation Ground Support Equipment (AGSE) Product Manager Office (PMO) was tasked with finding acceptable agent and hardware to replace Halon 1301 HHFE.
- Project was initiated July 2008 and testing continued through April 2013.
- Aberdeen Test Center (ATC) performed all agent testing, hardware development and Special Sodium Bicarbonate (SBC_S) processing optimization.

Initial Project Goals and Strategy Were To Develop An Extinguisher With:

- Form, Fit and Function equivalent to current Halon 1301 HHFE (“Drop In Replacement” no changes to mounting bracket, no allowance for a larger or heavier cylinder.)
- Firefighting performance equivalent to current Halon 1301 HHFE performance (Hardware and agent configurations underwent concurrent development.)
- New agent to be commercially available and environmentally and toxicologically acceptable.
- The project was initially tasked to optimize four commercial agents and compare their pan fire performance to that of the existing Halon 1301 extinguisher.

Environmentally Acceptable Commercial Clean Extinguishing Agents Included in Development Effort

- HFC-227ea (FM-200), boiling point -16 °C (2.3 °F)
- HFC-236fa (FE-36), boiling point -1.4 °C (29 °F)
- Halotron-I (HCFC-123), boiling point 27 °C (81 °F)
- Novec 1230, boiling point 49 °C (120 °F)

Final Optimized Agent/Hardware JP-8 Pan-fire Performance Comparison

Agent	Largest Pan Fire size (SQ FT)/attempts	Number of Extinguishments for Largest Pan Fire	Average Discharge Time Fire Out (sec.)
HFC-227ea	10/8	6	4.5
HFC-236fa	10/7	6	2.4
Halotron-I	12.5/6	6	3.0

NOTE: These are the three agents that we were able to optimize

Final Optimized Agent/Hardware N-Heptane Pan-fire Performance Comparison

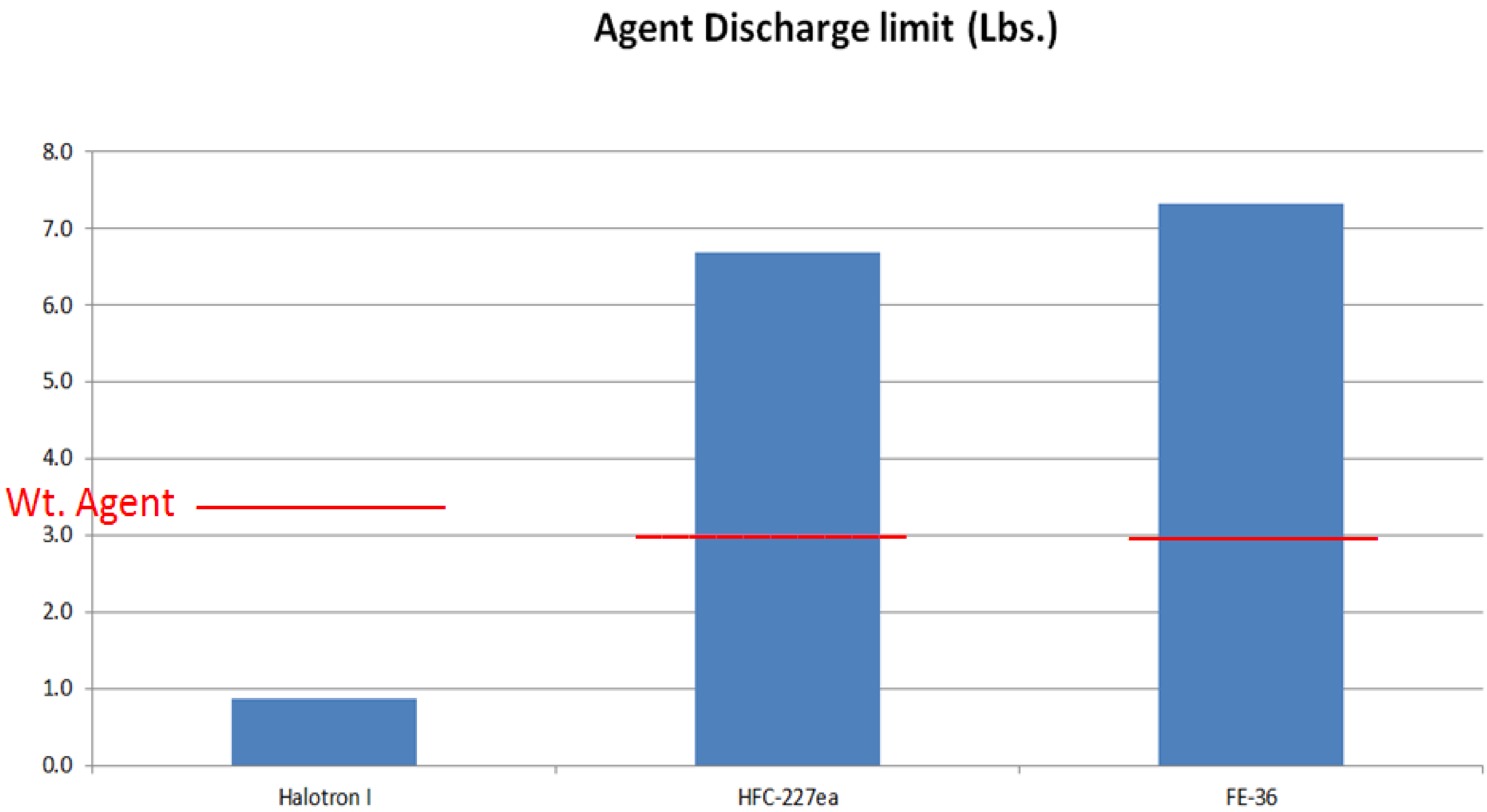
Agent	Largest Pan Fire size (SQ FT)/attempts	Number of Extinguishments for Largest Pan Fire	Average Discharge Time Fire Out (sec.)
HFC-227ea	5/2	2	3.8
HFC-236fa	5/2	0	---
Halotron-I	5/2	0	---

Guidance for Agent Selection
Federal Aviation Administration Advisory Circular (AC) 20-42D

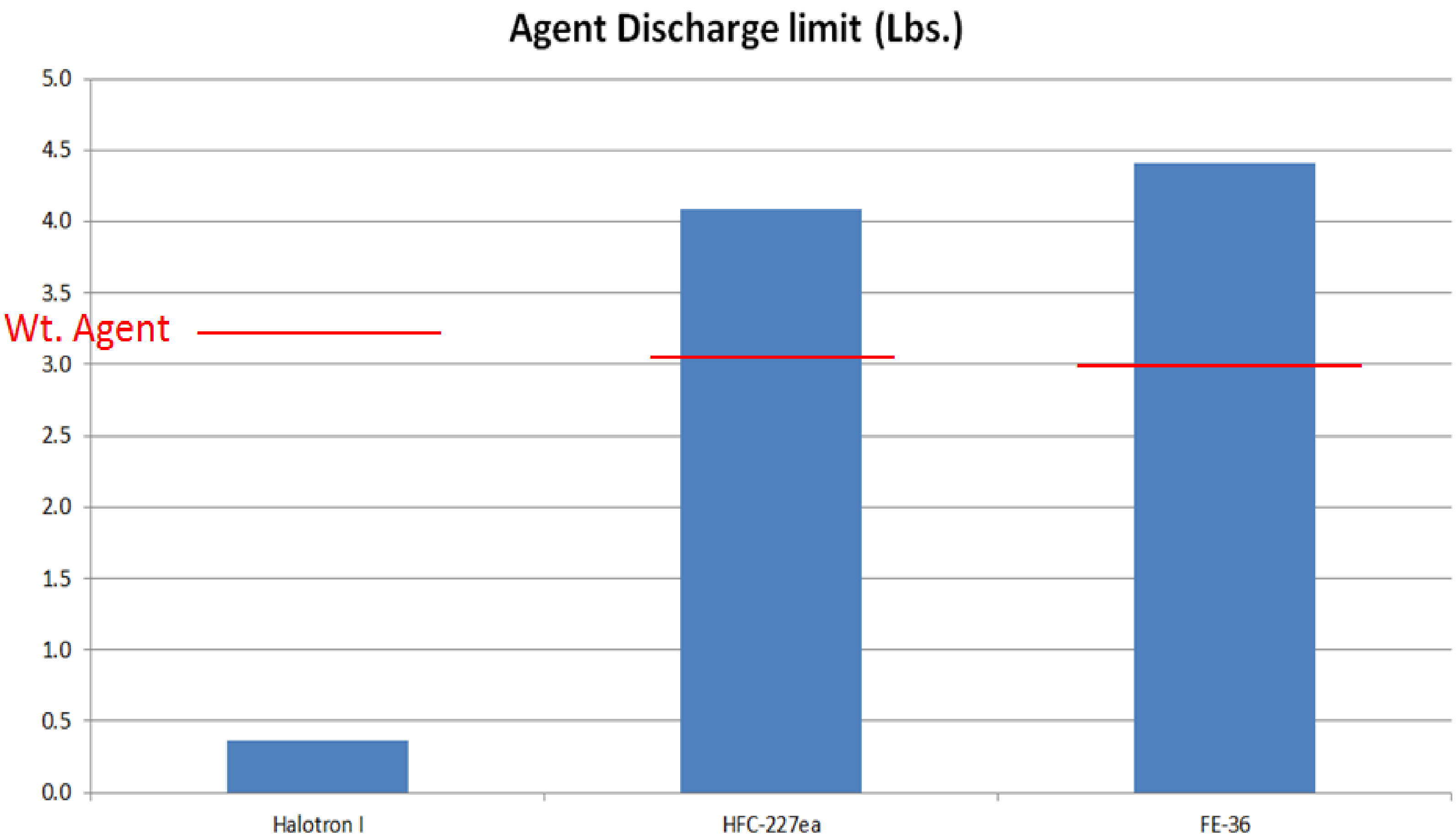
- FAA AC 20-42D gives guidance for the fire-fighting effectiveness, selection and safe-use of hand fire extinguishers in airplanes and rotorcraft.

- Safe-use (*Wt./Vol.)* guidance for various air change times, assuming perfect mixing, is presented in appendix 4, paragraph 2 of AC 20-42D

FAA Draft Circular AC 20-42D - Agent Discharge Limit (OH-58D 1 Minute Agent Clearance)



FAA Draft Circular AC 20-42D – Agent Discharge Limit, (OH-58D 6 Minute Agent Clearance)



Optimized HFC-227ea and Baseline Halon 1301 JP-8 Pan-Fire Performance

Agent	Test Phase	Largest Pan Fire SQ FT/attempts	# Extinguishments for Largest Pan Fire	Average Discharge Time Fire Out (sec.)
Halon 1301	Baseline	12.5/5	3	7.5
HFC-227ea	Final	10/8	6	4.5

NOTE: Down-select to HFC-227ea was made at this juncture

Optimized HFC-227ea and Baseline Halon 1301 n-Heptane Pan-Fire Performance

Agent	Test Phase	Largest Pan Fire SQ FT/attempts	Number of Extinguishments for Largest Pan Fire	Average Discharge Time Fire Out (sec.)
Halon 1301	Baseline	7.5/6	4	7
HFC-227ea	Final	5/2	2	3.8

NOTE: Down-select to HFC-227ea was made at this juncture

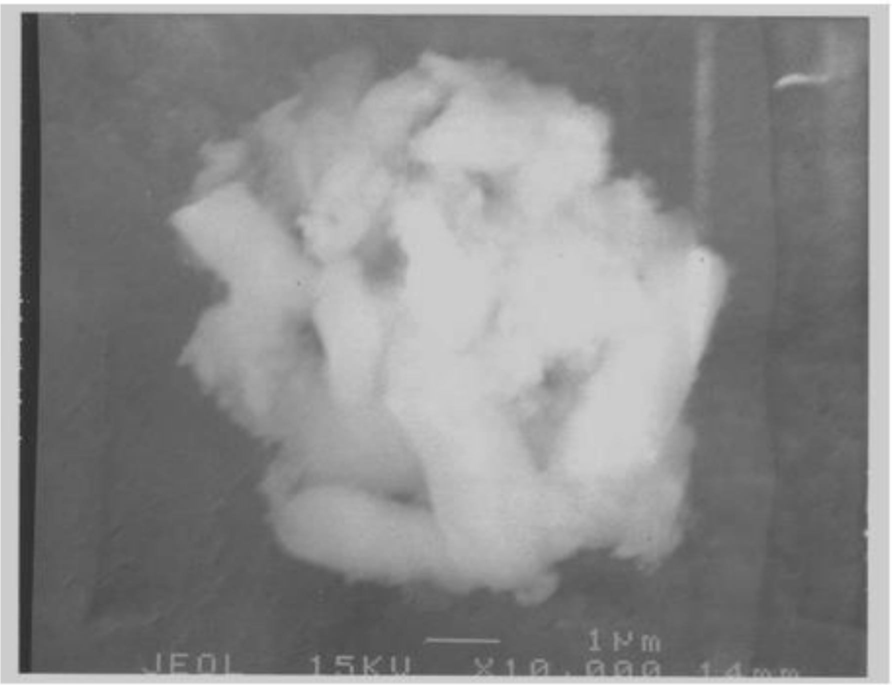
Options to Improve HFC-227ea Pan Fire Extinguishment Performance

- In Dec 2009, HFC-227ea w/ Special Sodium Bicarbonate (SBC_S) powder was added to determine if this blend could meet or exceed the performance of the Halon 1301 configuration.
- Preliminary tests of SBC_S powder in HFC-227ea were very successful leading to a need to expand the development effort. Initial agent testing included:
  - Pan fire trials of various HFC-227ea/SBC_S blends
  - Characterization of obscuration effects on discharge in crew areas
  - Ease of cleanup of agent residue post discharge

NOTE: Preliminary trials with standard SBC was performed in the late summer of 2009.

SBC_S Powder Suppliers - Initial Testing

Quickfire USA



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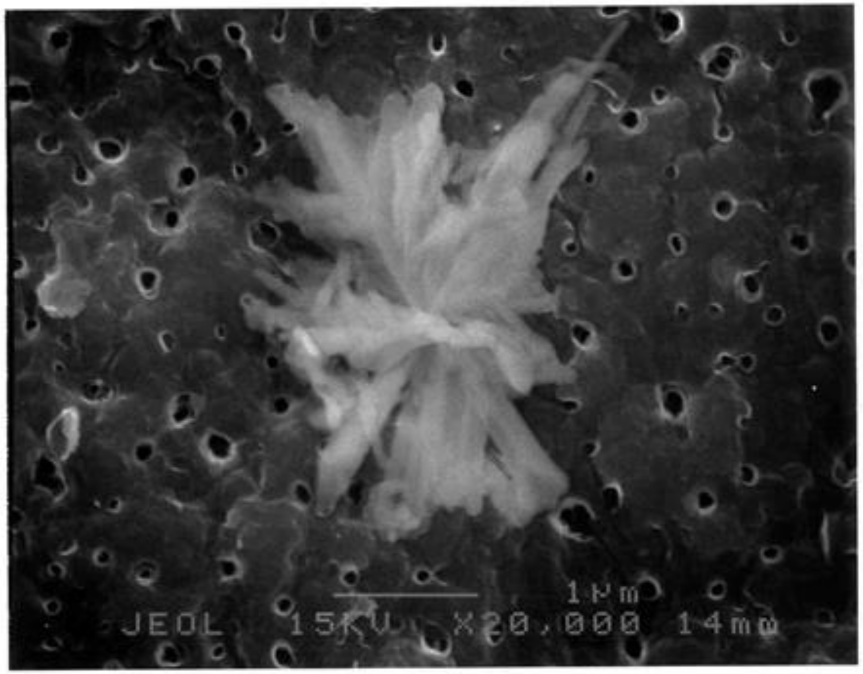
Nanomaterials Company



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Development of Optimal SBC_S Powder Continued and Expanded to:

- Minimize the SBC_S loading required to improve HFC-227ea pan fire performance to be equivalent with the Halon 1301 HHFE.
- Develop SBC_S that suspend to fill the entire HFC-227ea liquid column.
- Develop new or identify existing commercial sources of optimal SBC_S powders.
- Evaluate long term stability of HFC-227ea/SBC_S agent (accelerated aging studies based on extended temperature cycling).
- Develop a reliable SBC_S moisture content characterization method having a low water quantification limit and establish a specification for SBC_S moisture content.
- Obtain SBC_S physical characterization information for use in procurement (particle size, morphology & surface area).
- Assist agent HFC-227ea/SBC_S health hazard assessments

SBC_S Commercial Process Options and Evaluations Performed

- Jet Milling of SBC_S:
  Initial process development testing and production performed by Sturtevant Inc. (Fluid Energy Corporation did limited process testing)

- Wet Milling of SBC_S:
  This is a potential method for producing very small SBC_S particles in suspension unfortunately equipment was not available for use in SBC_S powder development.

- Spray Drying of SBC_S dissolved in water:
  Early testing was performed at Buchi Instruments. SBC_S powders produced had excellent suspendability in HFC-227ea.
  Limited scale up testing occurred at GEA Process Engineering with promising results.

- Proprietary methods of SBC_S nano-particle production:
  SBC_S powder process development was performed by Nanomaterials Company yielding SBC_S powders whose blends with HFC-227ea demonstrated very effective fire suppression in pan fire tests.

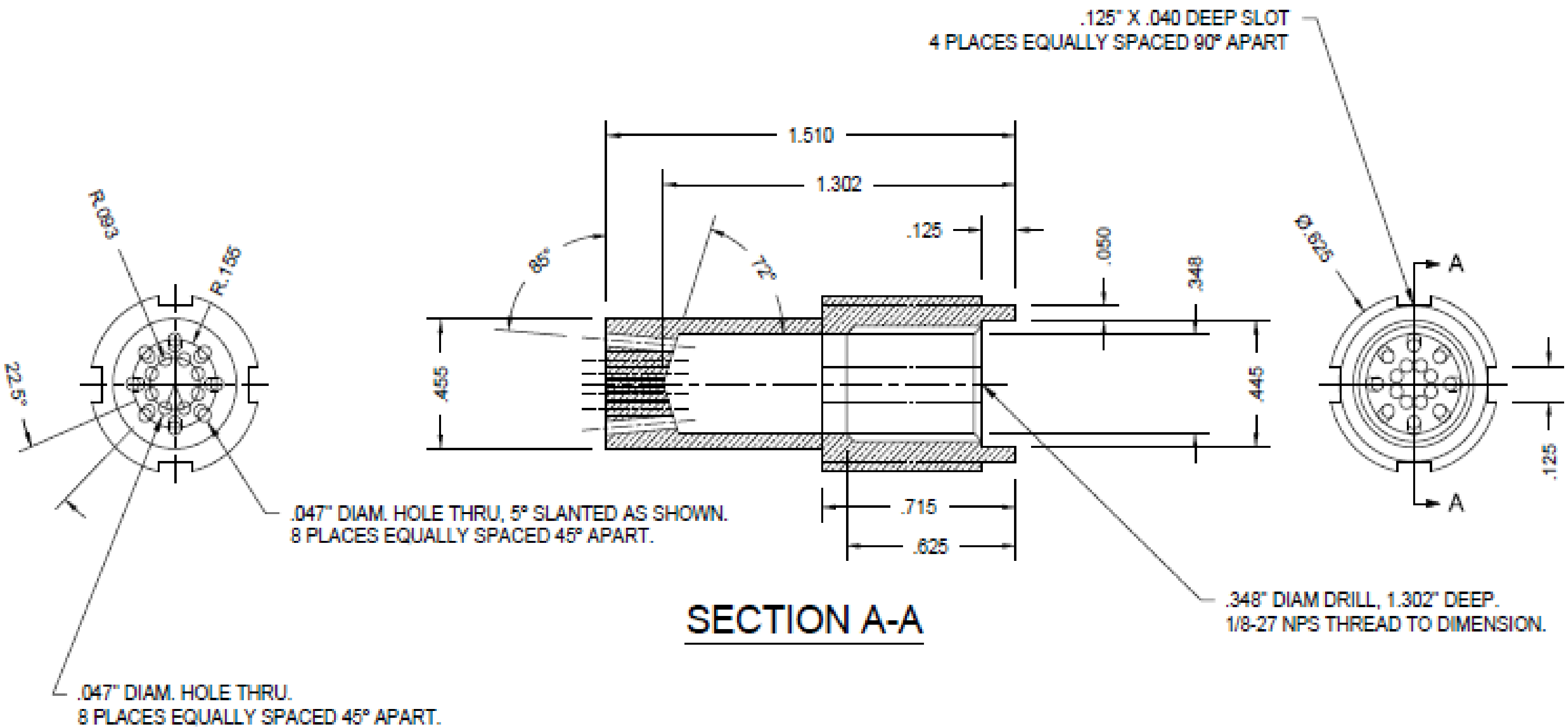
HFC-227ea/SBC_S Pan-Fire Performance of Sturtevant, Inc. and Nanomaterials Company SBC_S powders

JP-8 fuel

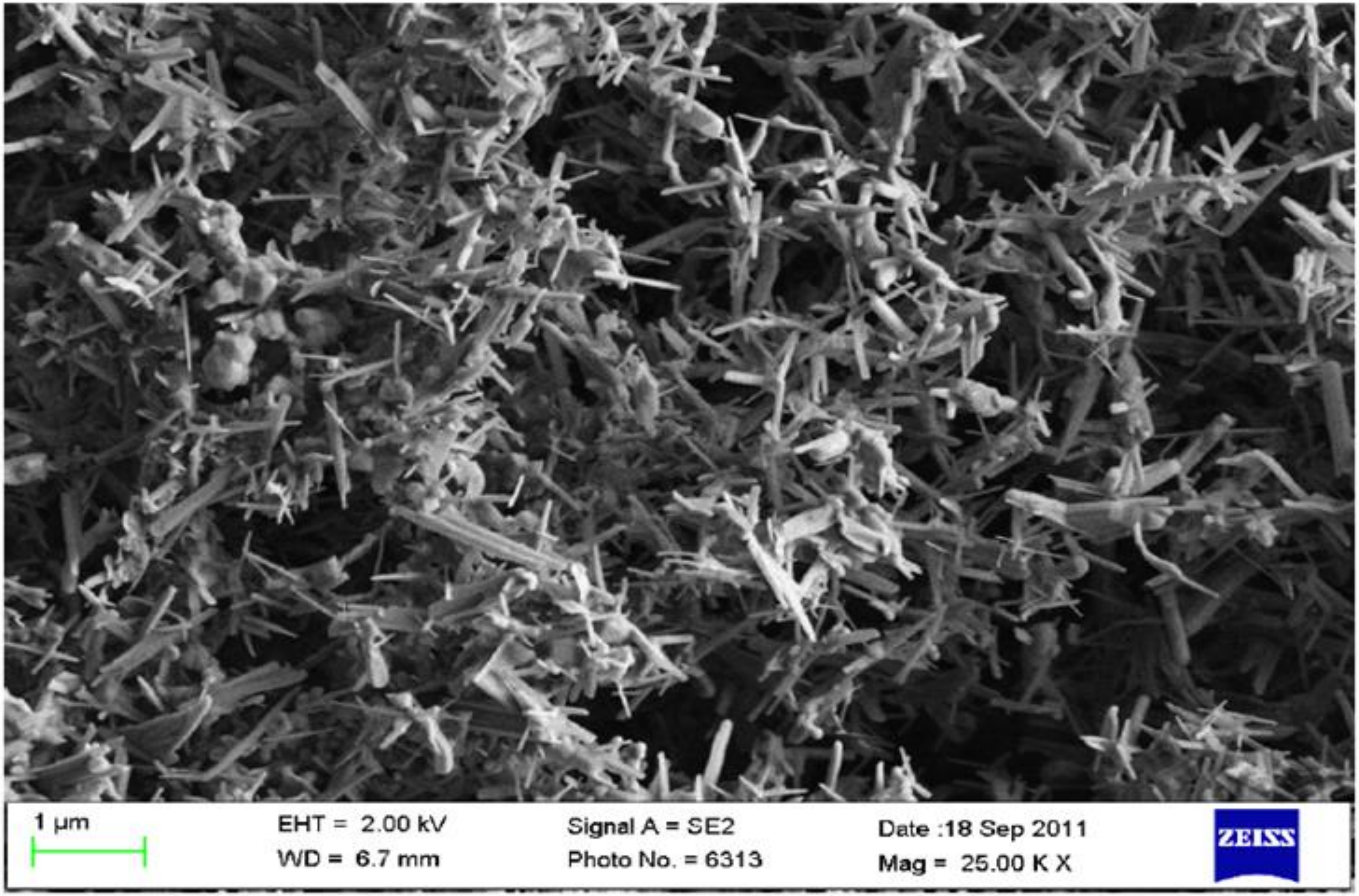
Agent	Max Pan Fire (SQ FT)/attempts	Max Pan Fire (SQ FT)/ Fire out	Pan Fire Attempt Success (Y or N)/grams						Average Discharge Time - Fire Out (sec.)
Halon 1301	12.5/5	12.5/3	Y	N	N	Y	Y	-	7.5
HFC-227ea	12.5/6	12.5/1	N	Y	N	N	N	N	4.5
HFC-227ea/SBC_S (Sturtevant)	12.5/4	12.5/3	Y/70	Y/35	Y/21	N/21	-	-	3.8
HFC-227ea/SBC_S (Nanomaterials)	12.5/2	12.5/1	Y/20	N/35*	-	-	-	-	3.2

*** Test Compromised**

Nozzle Developed for Halotron-I and HFC-227ea/SBC$_S$ Blended Agents



Nanomaterials Company SBC_S Powder
Field Emission Scanning Election Microscopy (FESEM)



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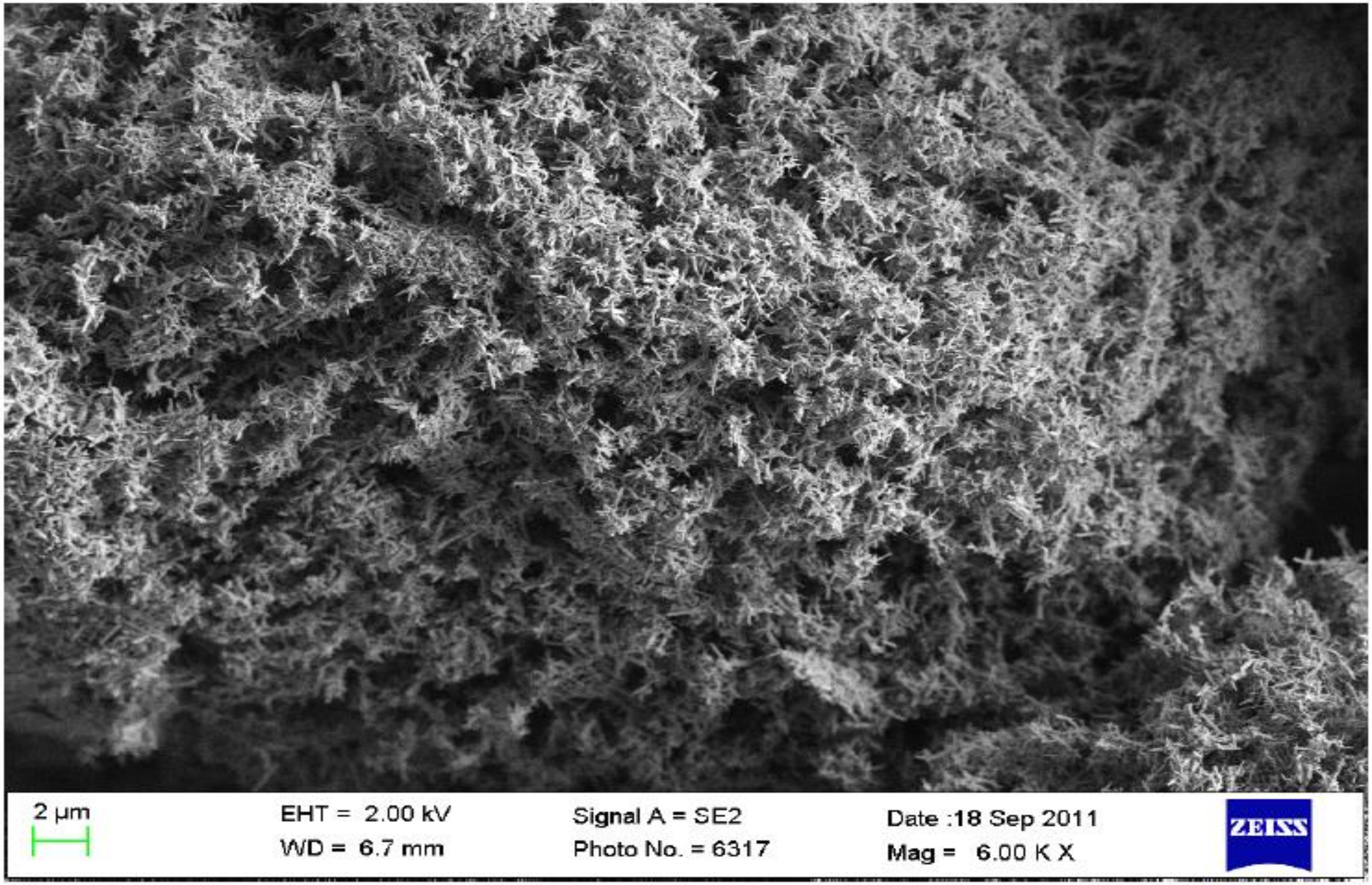
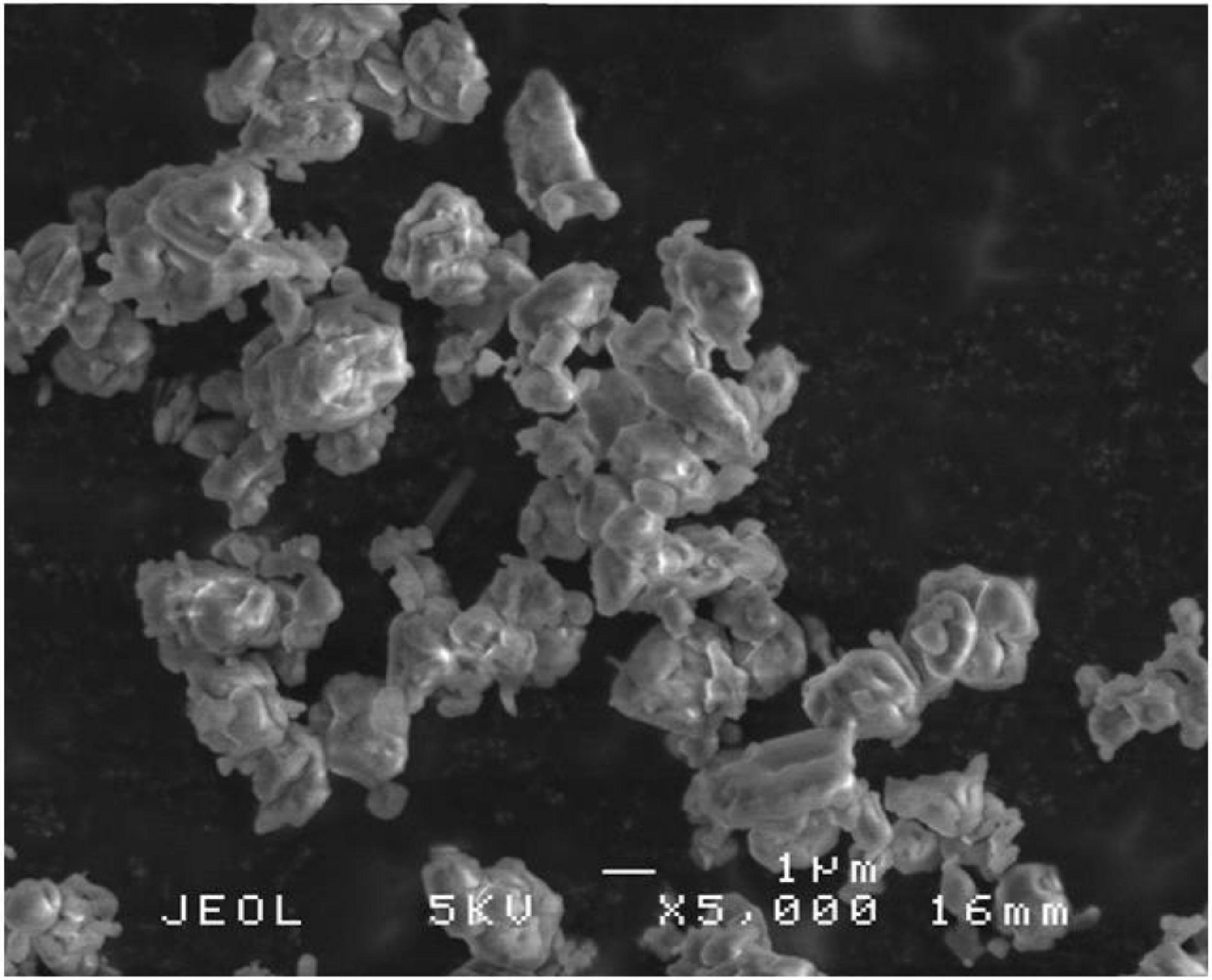
Nanomaterials Company SBC_S Powder FESEM



Sturtevant, Inc. SBC_S Powder FESEM



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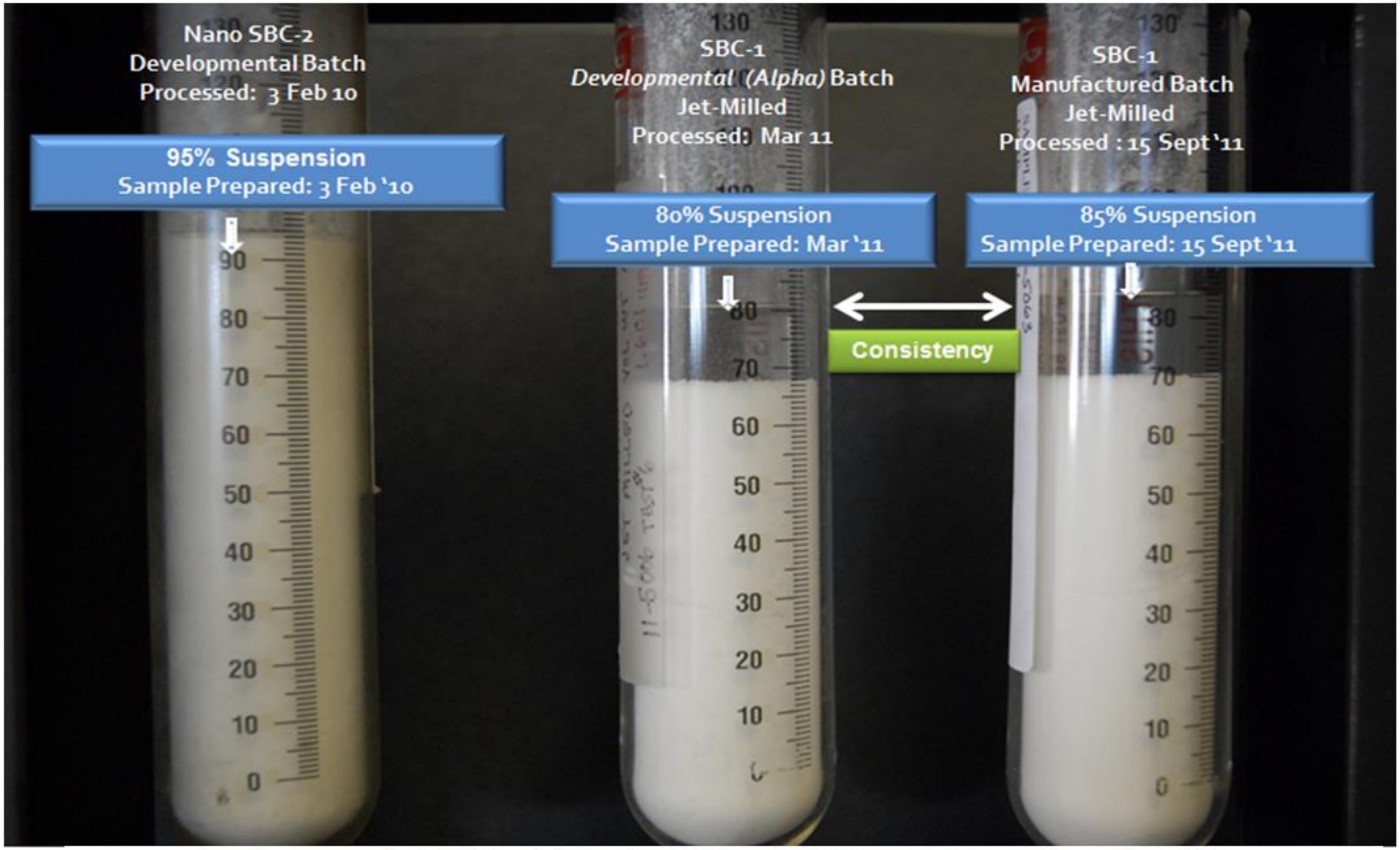
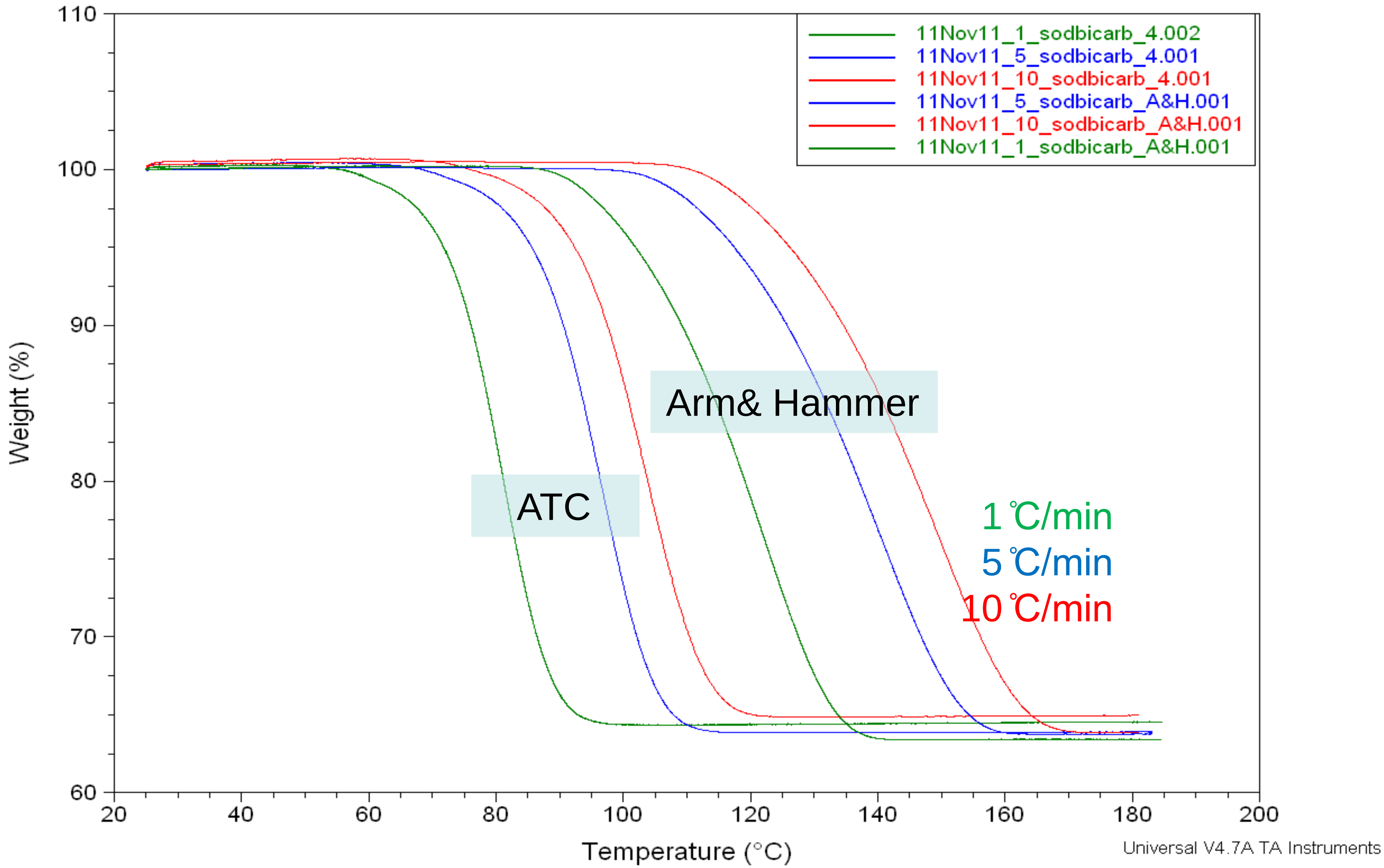
SBC$_S$ Suspendability in HFC-227ea



Samples prepared at ATC Fire Lab for observation of SBC suspension properties and stability.
SBC mixed with HFC-227ea at 5% by weight and ultrasonicated at 40Khz (250 watts/gal.) for 5 minutes.

~36% SBC_S Weight Loss on Heating



Thermo gravimetric analysis performed @ ATC 14 Nov 2011

Post Accelerated Aging HFC-227ea/SBC$_S$ Slurry Flow Check (Nanomaterials Company, SBC$_S$ Sample Tube 14 Thermal Cycling)

HFC-227ea/SBC_S Slurry
Post Accelerated Aging Observations

- Post thermal cycling agent SBC_S suspension levels had decreased
- Following repeated inversion (shaking by hand) each tubes SBC_S levels recovered to near original levels
- HFC-227ea/SBC_S slurries showed no change in their flow characteristics
- No SBC_S clumping or caking was observed in any of the test samples.

Additional HFC-227ea/SBC_S Testing Performed and Agent Evaluations Supported

- SBC_S water content. A solvent extraction and gas chromatography analysis based water content analytical method was developed by Galbraith Laboratories under a contract with Aberdeen Test Center. The analytical method number is AP GLI-Army C101.
- An SBC_S surface area. A measurement method based on Proton Nuclear Magnetic Resonance (NMR) allowing characterization of SBC_S powders was developed.
- SBC_S particle imaging (morphology). FESEM methods for imaging SBC_S powders and characterizing particle morphology were developed.
- Toxicity Clearances were provided by the U.S. Army Institute of Public Health for SBC-1 (March 2012) and SBC-2 (May 2012).

Additional HFC-227ea/SBC_S Testing Performed, Agent Evaluations Supported and Documentation - continued

- A Health Hazard Assessment Report (HHAR) for the SBC-1 and SBC-2 was provided by the U.S. Army Institute of Public Health; June 2012.
- DuPont Fluorochemicals Analytical Laboratory Wilmington, DE performed a materials compatibility evaluation. The ANSI/ASHRAE Standard 97 was used as a testing guide.
  The report conclusion: “for a highly critical application, further testing at more aggressive test conditions may be needed. However, from the test conditions prescribed herein, signs of significant deterioration were not evident.”
- A report detailing the HFC-227ea/SBC_S agent development effort is being drafted. It is expected to be publicly available early 2014.
- MIL-DTL- 32412 titled “HFC-227ea Fire Extinguishing Agent Enhanced with Special Sodium Bicarbonate Powder (HFC-227ea/SBC_S)” was published. Class I and Class II SBC_S powders are defined within the specification. This document is accessible via the internet.

MIL-DTL- 32412 - Individual Specification Requirements for Class I (SBC1) and Class II (SBC2) Agents and Test Methods

- Moisture Content Limits for SBC_S
- Caking and Lumping Check Method
- HFC-227ea/SBC_S Slurry Flow Check
- SBC_S Suspendability in HFC-227ea
- Average Particle Aspect Ratio (width/length) Limits
- SBC_S Powder Surface Area Acceptable Range
- Particle Size Requirement (Longest Dimension)
- SBC_S Concentrations in HFC-227ea in Weight %
- Color
- SBC_S Water Content (ppm) Range
- Surface Area Characterization - Instrumentation and Method
- FESEM Sample Preparation and Analysis Technique

Program Leads and Key Contributors

Alivio Mangieri – *AGSE PM Technical Branch*

Timothy Helton – *U.S. Army Aviation and Missile Command (AMCOM) G-4*

Kevin Dowell and Leonard Lombardo – *Aberdeen Proving Ground*

Acknowledgements

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Technical Management – Aviation Ground Support Engineering (AGSE)

<u>Supporting Organizations</u>

Aberdeen Test Center (ATC), Intermediate Fire Lab
Tyndall AFB - Air Force Research Laboratory (AFRL)
US Aberdeen Proving Ground, Army Institute of Public Health

Special Thanks – The support staff at the Intermediate Fire Lab, ATC

DuPont Company – contributed FM-200 and FE-36 agents and performed materials compatibility testing of HFC-227ea/SBC_S agent with HHFE hardware components

Quickfire USA – contributed powdered agent for crucial initial HFC227ea and SBC evaluations

3M Corporation – contributed Novec 1230

American Pacific Corporation – contributed Halotron-I

Questions

Any presentation related questions should be addressed to:

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Backup Slides

ATC Pan Fire Test

OH-58D HFC-227ea/SBC_S Initial Testing of Visual Obscuration Photo at ~4.5 seconds from start of HHFE discharge

Aircraft Doors and Windows Closed During and Post Discharge

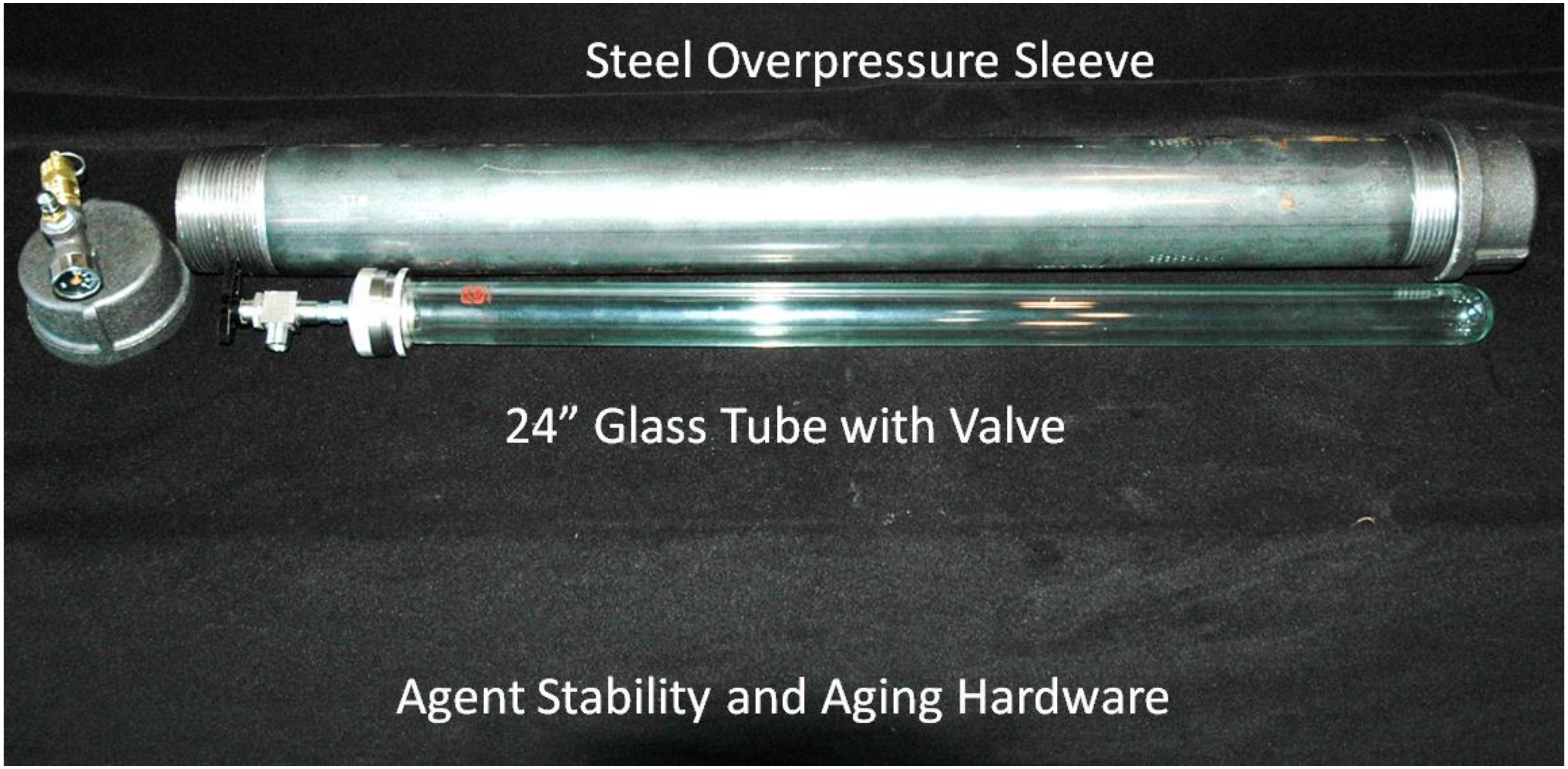
SBC_S supplied by Quickfire USA

OH-58D HFC-227ea/SBC$_S$ Visual Obscuration Discharge Photo ~1 second after discharge completion

Aircraft Doors and Windows Closed During and Post Discharge

Total Discharge Time ~8.0 Seconds

24" High Pressure Glass Tube and Pipe Over-Pressure Sleeve (glass tubes manufactured by Andrews Glass Company)



Tubes Kept Vertical During and After Accelerated Aging Thermal Cycling

Thermal Cycling Test Chamber

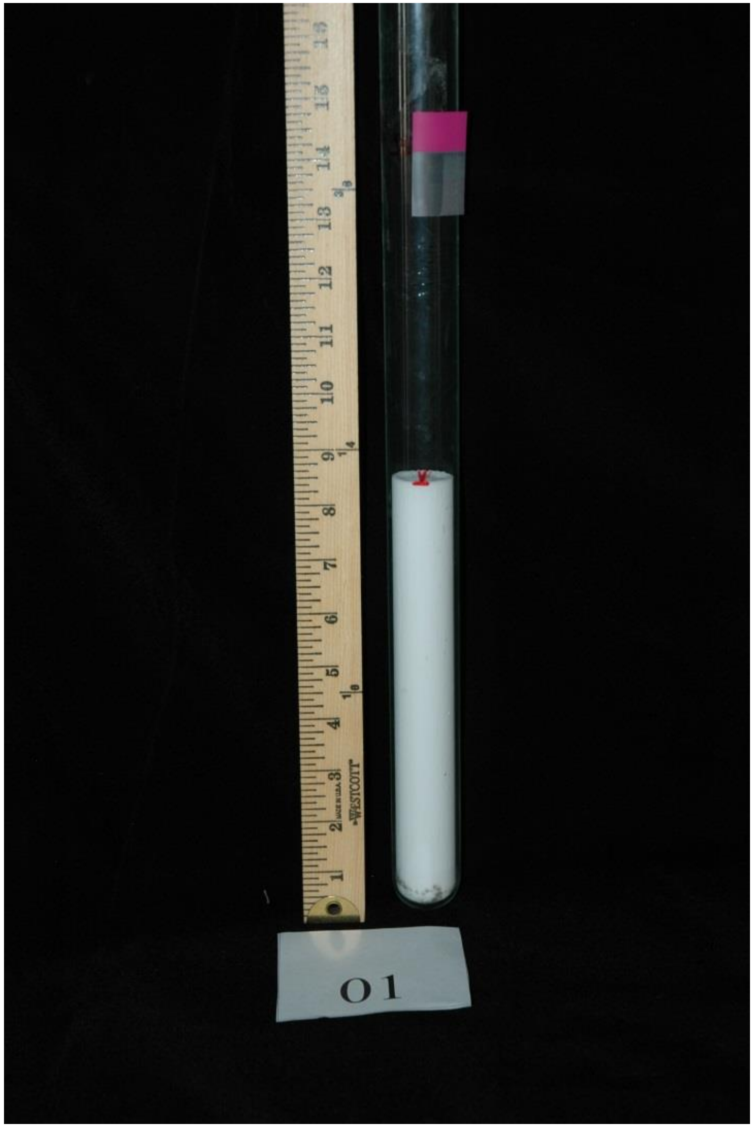
Accelerated Aging Sample Compositions

Pressure Tube label #	Sample Description	Sample type
1	SBC-1/Dry 1	Control
2	SBC-1/Dry 2	Diurnal sample
3	SBC-1/Dry 3	Diurnal sample
4	SBC-1/AR 1	Control
5	SBC-1/AR 2	Diurnal sample
6	SBC-1/AR 3	Diurnal sample
7	SBC-1/300 1	Control
8	SBC-1/300 2	Diurnal sample
9	SBC-1/300 3	Diurnal sample
10	SBC-1/600 1	Control
11	SBC-1/600 2	Diurnal sample
12	SBC-1/600 3	Diurnal sample

Accelerated Aging Sample Compositions - continued

Pressure Tube Label #	Sample Description	Sample type
13	SBC-2/Dry 1	Control
14	SBC-2/Dry 2	Diurnal sample
15	SBC-2/Dry 3	Diurnal sample
16	SBC-2/AR 1	Control
17	SBC-2/AR 2	Diurnal sample
18	SBC-2/AR 3	Diurnal sample
19	SBC-2/300 1	Control
20	SBC-2/300 2	Diurnal sample
21	SBC-2/300 3	Diurnal sample
22	SBC-2/600 1	Control
23	SBC-2/600 2	Diurnal sample
24	SBC-2/600 3	Diurnal sample
25	SBC-2 Slurry As Rec.- CONTROL	Control
26	SBC-2 Slurry As Rec.	Diurnal sample
27	SBC-2 Slurry As Rec.	Diurnal sample
28	SBC-2 Slurry 0.3ml water	Diurnal sample
29	SBC-2 Slurry 0.1ml water	Diurnal sample

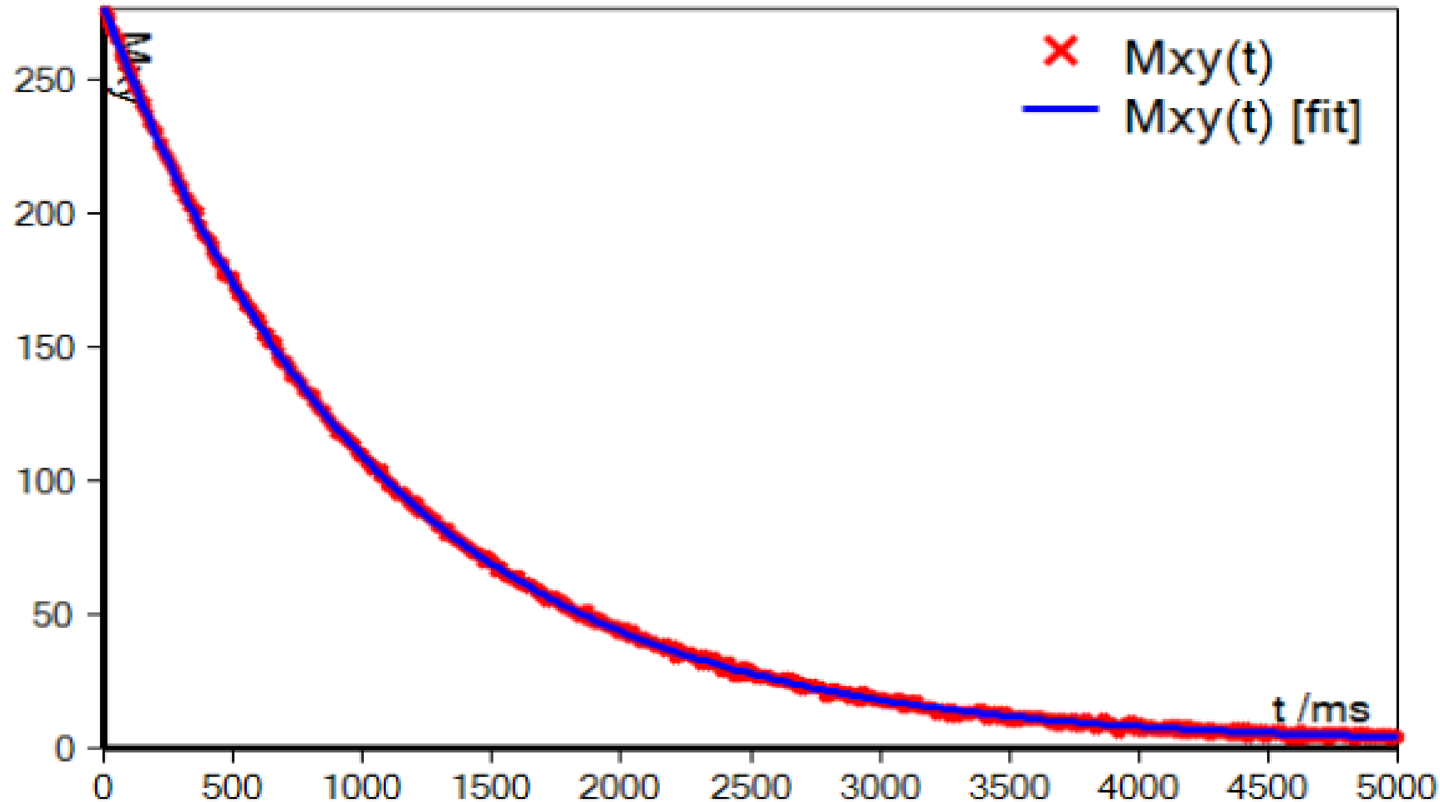
Accelerated Aging SBC-1 (Tube 01) and SBC-2 (Tube 13) Control Samples



NMR relaxation time plot – H^1 resonance decay rate is used to calculate surface area (testing performed by XiGo Nanotools, Inc.)

Sample 1: AA4

The specific surface area is estimated to be 14.2m²/g. This is based on a T_2 value of 1064ms, a specific surface relaxivity, k_a of 0.0026g/m²/ms, a bulk fluid relaxation time of 1319ms and a volume ratio of 0.049.



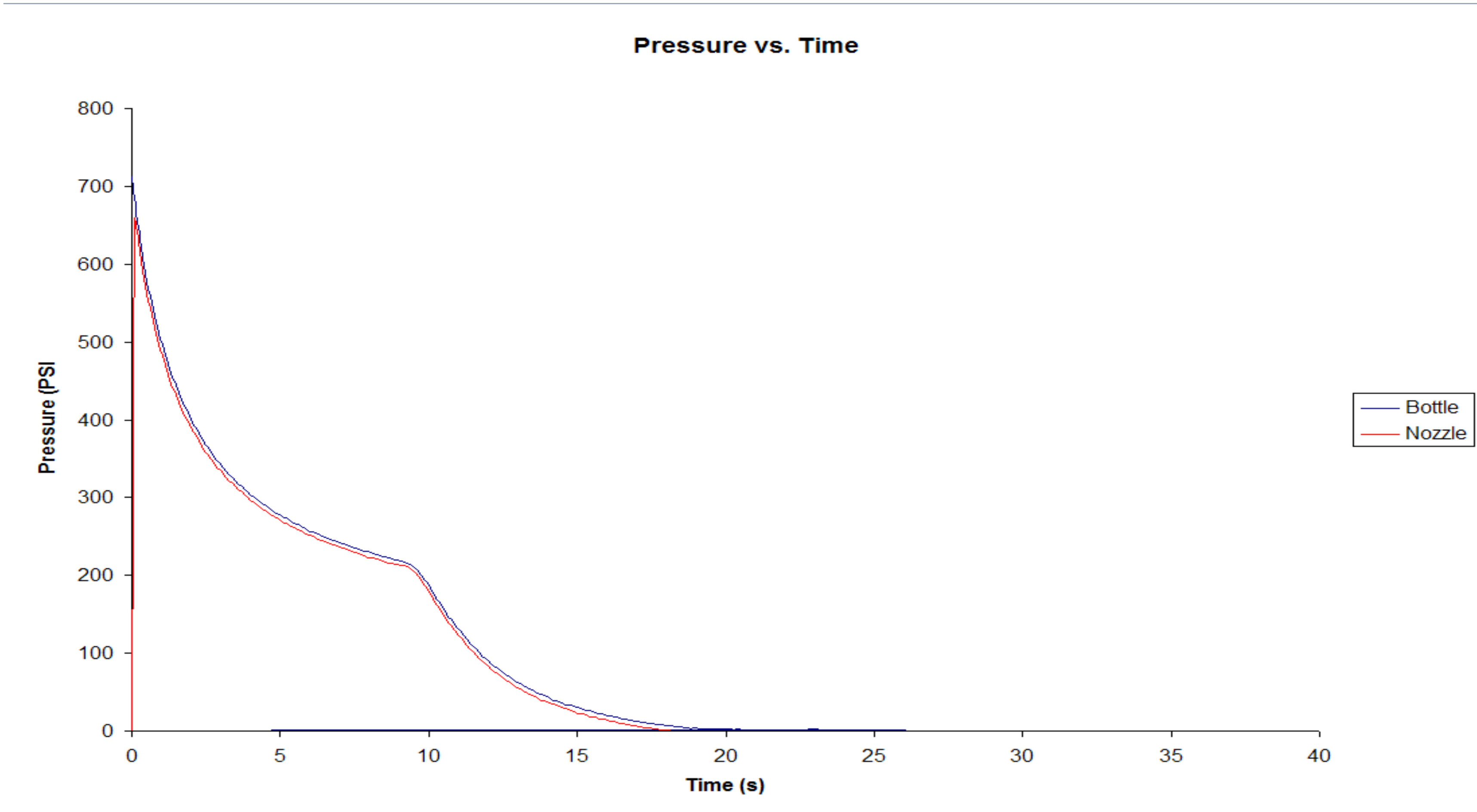
Surface area by NMR relaxation time (testing performed by XiGo Nanotools, Inc.)

Sample	Average T2 (ms)	Surface Area (m^2g^{-1})
AA4	1064 (stddev: 14.5; cov: 1.4%)	**14.3**
AA5	1141 (stddev: 70.1; cov: 6.1%)	**10.9**
AA15	1065 (stddev: 21.6; cov: 2.0%)	**19.3**
AA16	1081 (stddev: 27.2; cov: 2.5%)	**19.9**
AA17	1048 (stddev: 4.5; cov: 0.4%)	**17.4**
XO2	1119 (stddev: 9.7; cov: 0.9%)	**39.5**

PEO Aviation
Cradle to Grave Lethality!

Hardware used in agent development

Pressures (Cylinder and at Nozzle) During Discharge (Test 27)



Testing and Test Equipment

Development testing included evaluation of operational temperature limits

- Qualification Testing as per DTP (Fire testing, Ambient, High/Low Operation Temp)

Production representative
HHFE @ 70 ºF
FM-200/SBC-2 Agent
12.5 S.F. JP-8-fueled Pan Fire
15 Feb 2012

Production representative
HHFE @ 160 ºF
FM-200/SBC-2 Agent
12.5 S.F. JP-8-fueled Pan Fire
15 Feb 2012

Production representative
HHFE @ -60 ºF
FM-200/SBC-2 Agent
5 S.F. JP-8-fueled Pan Fire
15 Feb 2012

PEO Aviation
Cradle to Grave Lethality!

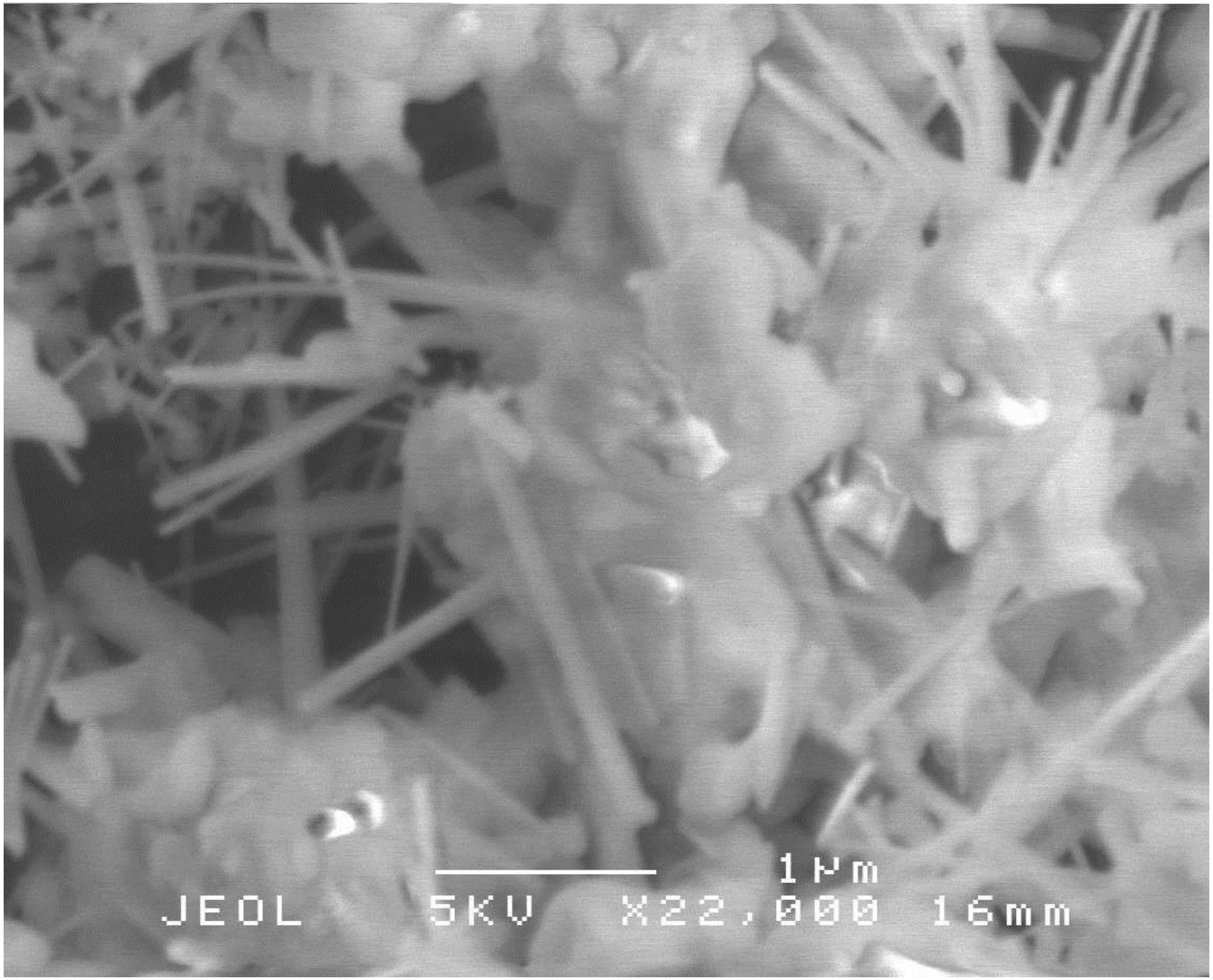
SBC handling employed a dry box kept at < 1% RH using 3A molecular sieve

SBC in Glove Box

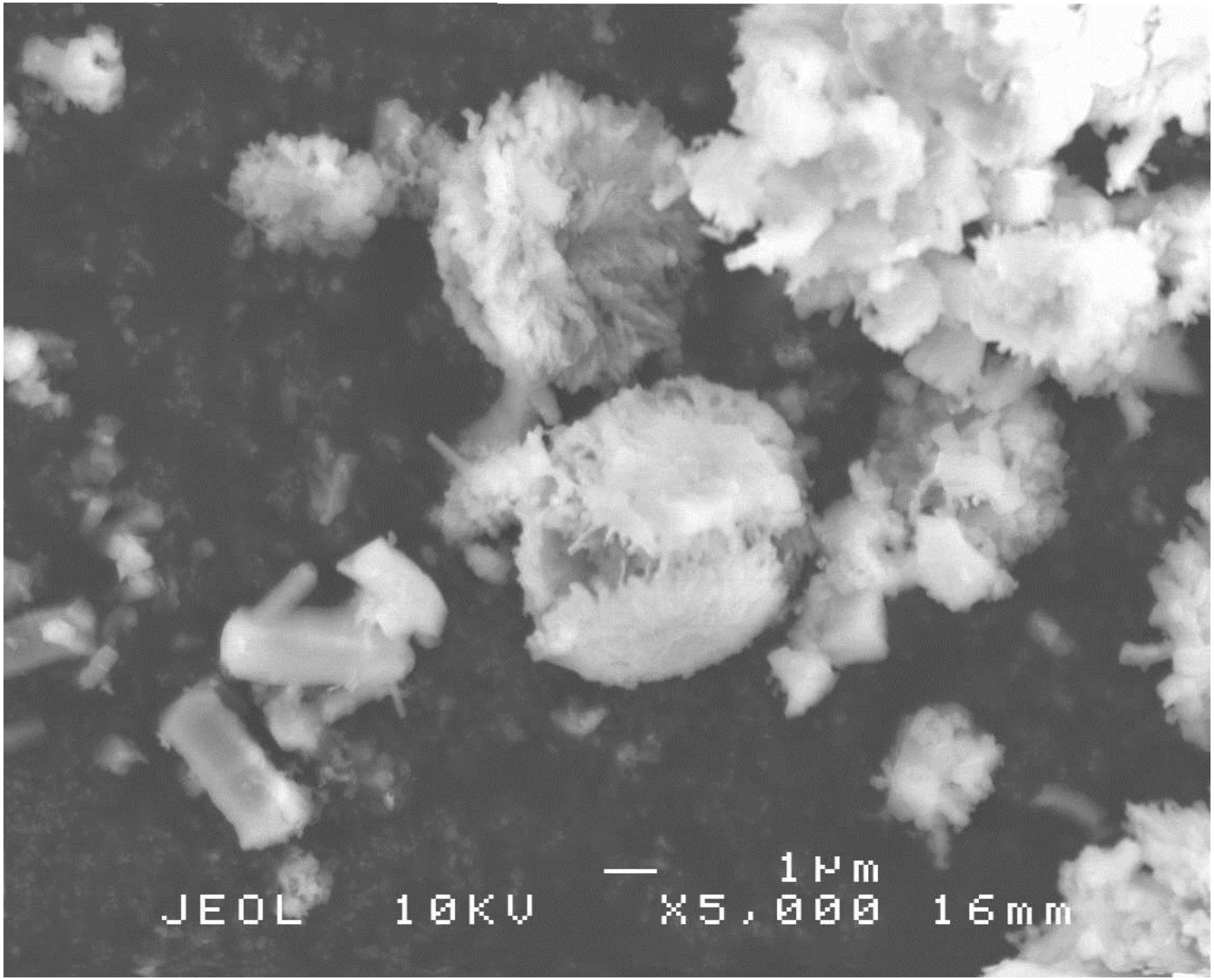
Buchi – B290 bench scale spray dryer test

Buchi - B90 bench scale spray dryer test

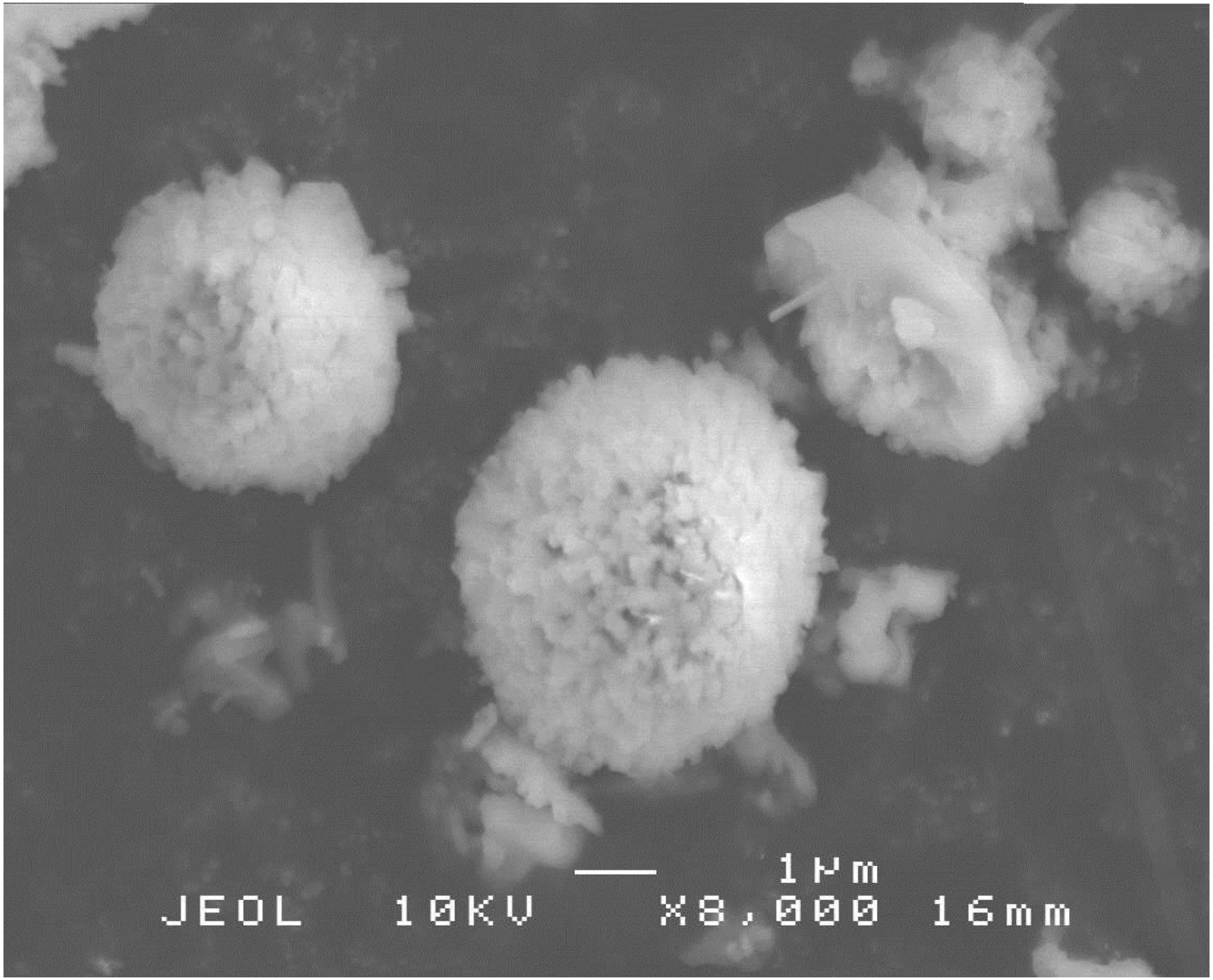
Buchi B90 Powder FESEM (Spray Drying of SBC Solution)



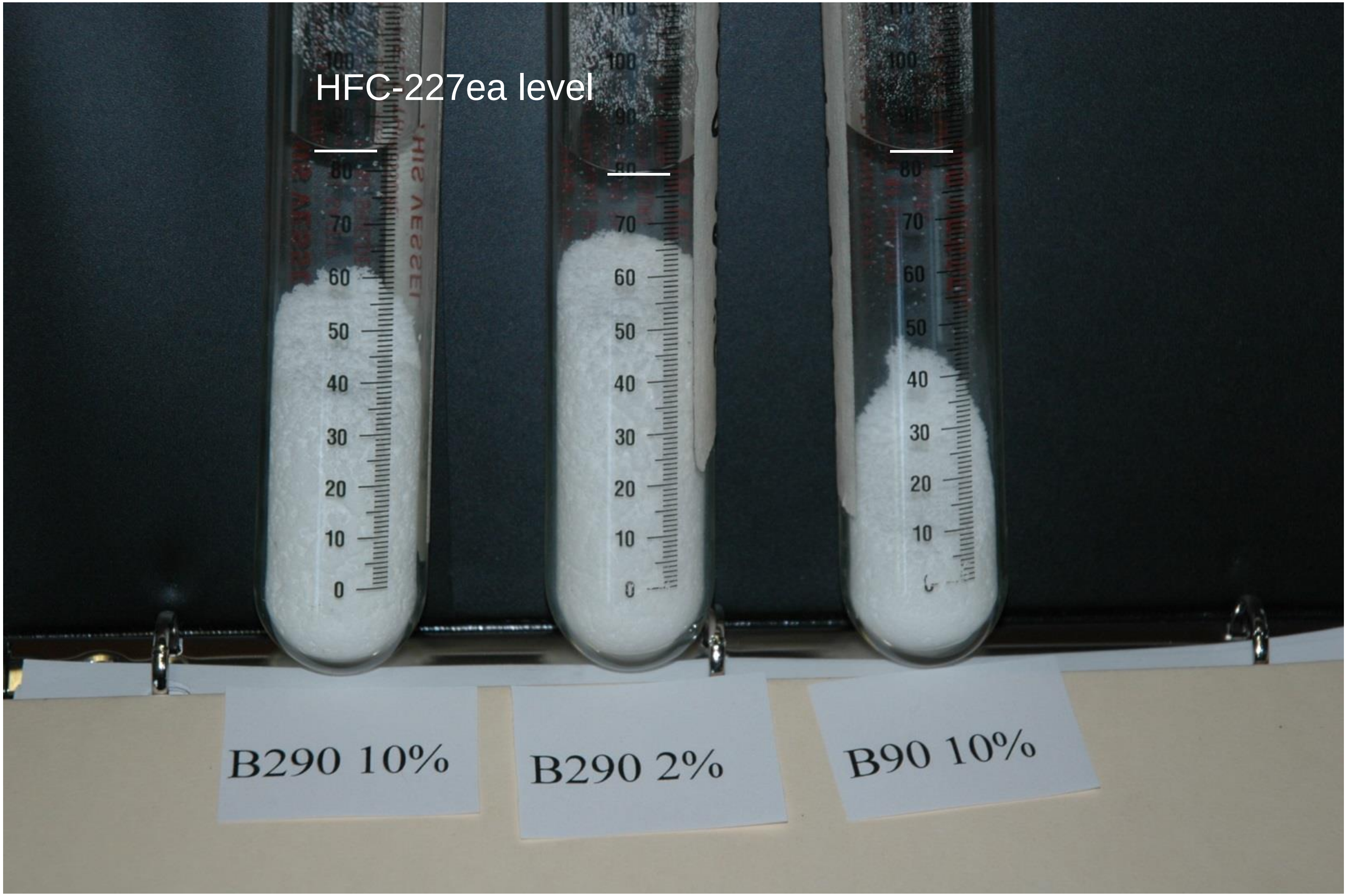
Buchi B290 Powder FESEM
(Spray Drying of SBC Solution)



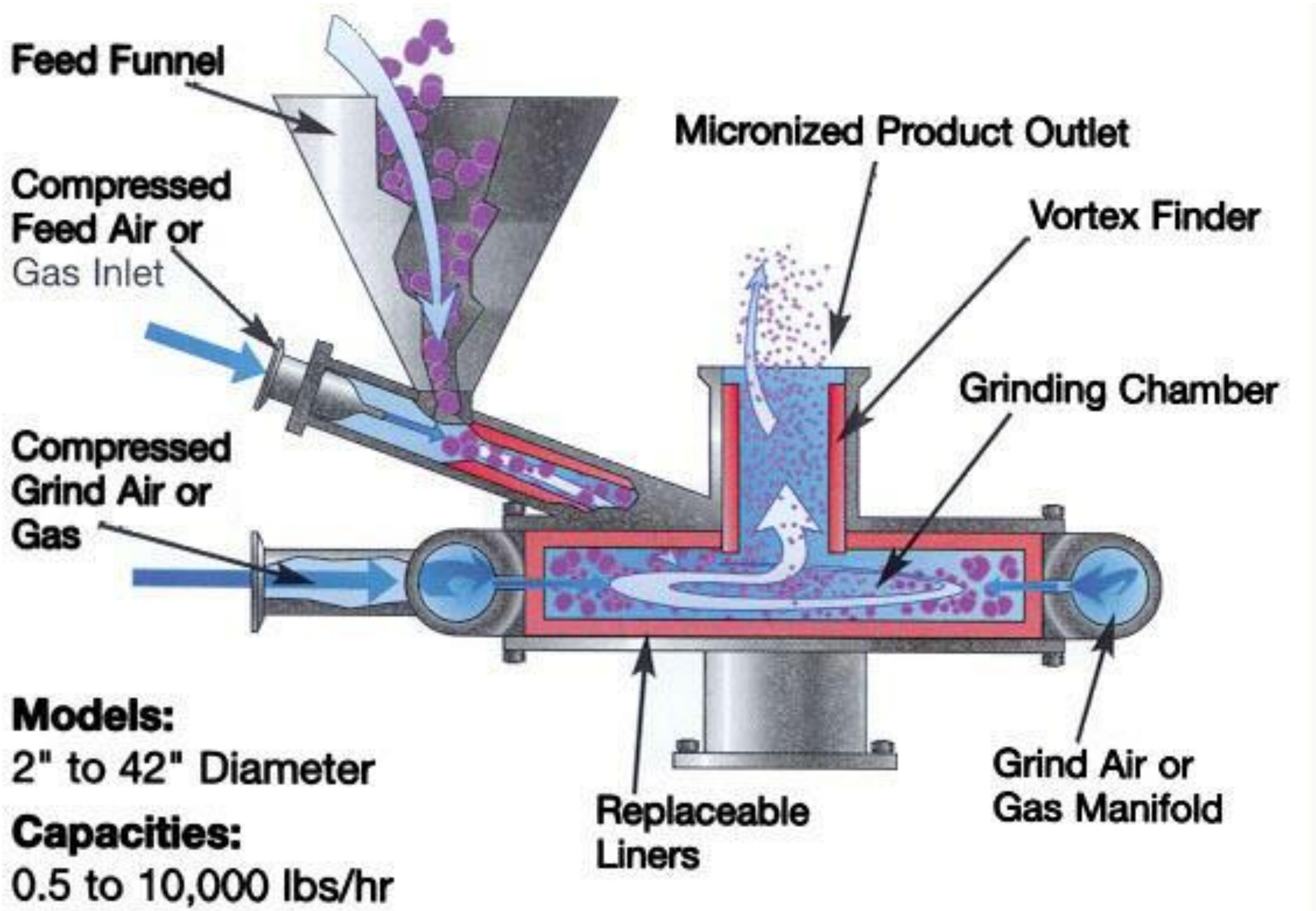
Buchi B290 Powder FESEM (Spray Drying of SBC Solution)



Buchi B290 and B90 spray dryer generated SBC samples suspended in HFC-227ea



Micronizer Jet Mill



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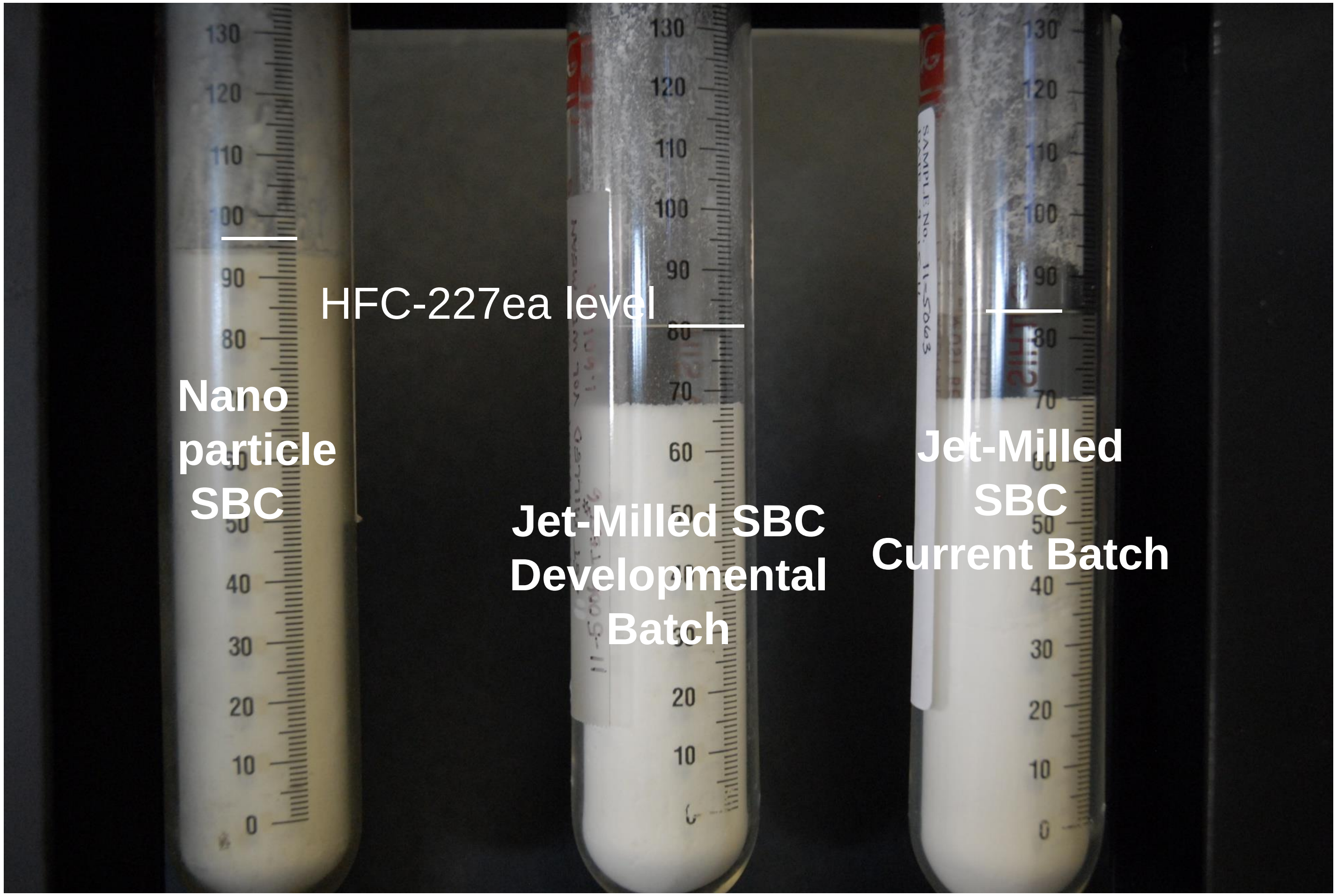
SBC suspendability in HFC-227ea



Laser Illumination of HHFE Spray