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HNS IV Powder Characterization to the Updated AOP-7

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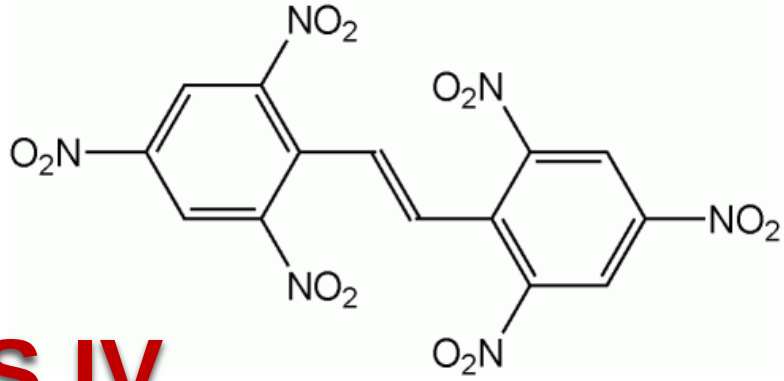
HNS IV Qualification to AOP-7

- This presentation describes qualification testing of HNS IV (2,2',4,4',6,6'-hexanitrostilbene) in accordance with the procedures and tests specified in AOP-7 Manual of Data Requirements and Tests for the Qualification of Explosive Materials for Military Use.
- The test plan incorporated the requirements of AOP-7 Edition 2 and the expected revisions for the safety critical sensitivity tests to be included in Edition 3.
- The requirements for booster explosives were followed since no category specific to detonators is listed in AOP-7.



HNS IV

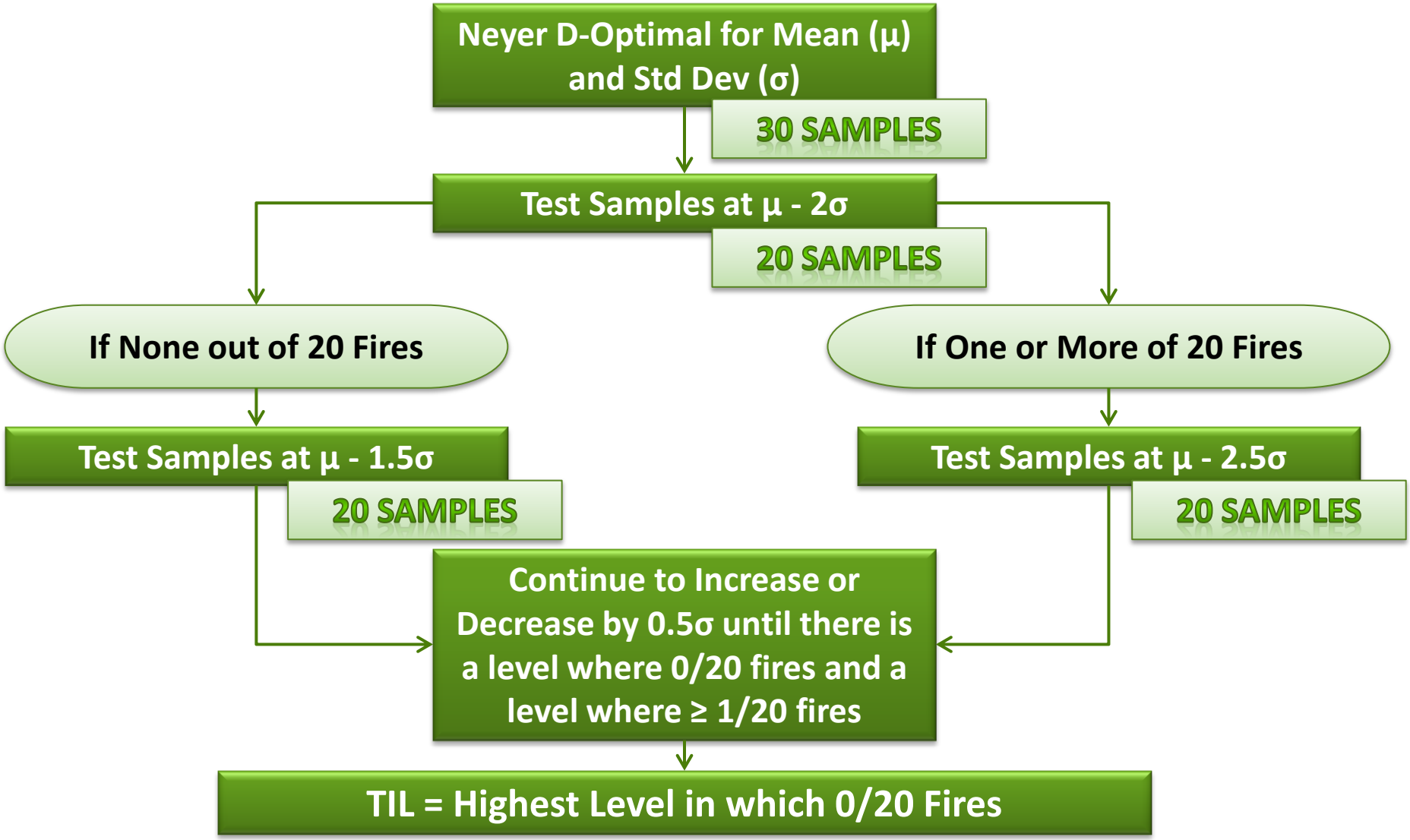
HNS IV Qualification Test Plan

- HNS IV was manufactured in accordance with Excelitas powder specification SP0001 HNS IV Explosive Powder. Excelitas specification SP0001 is based on MIL-E-82903(OS), with the addition of a long term aging test.
- HNS IV, which is also known as small particle HNS, is characterized by high thermal stability and has proven suitable for a wide variety of applications. This HNS IV powder is used extensively in Excelitas Blue Chip® Detonator family.
- Tests that required that the material be tested in a configuration similar to the tactical configuration used parameters and materials consistent with the Blue Chip® Detonator.
- Testing was conducted by an outside source capable of meeting the testing requirements.

HNS IV Qualification Test Plan

- AOP-7 Section 10.7.16.4 defines the mandatory testing and acceptable procedures for booster explosives. Modern test and analysis methods (D-optimal) instead of Bruceton or other primitive methods were used where appropriate. The following properties were evaluated:
  - Impact Sensitivity
  - Electrostatic Sensitivity
  - Friction Sensitivity
  - Shock Sensitivity
  - Ignition Sensitivity/Self-heating
  - Vacuum Thermal Stability
  - Compatibility
  - Exudation and Growth
  - Detonation Velocity
  - Critical Diameter

Threshold Initiation Level (TIL) Proposed Method



HNS IV Impact Sensitivity

- Tests were conducted per procedure:
  - AOP-7 U.S. 201.01.001 – Impact, ERL/Bruceton
- Pass/Fail Criteria: TIL must be greater than or equal to 12 cm to be acceptable. A comparison was run with a Type I, Class 5 RDX standard.

Material Tested	50% Fire Point (cm)	Threshold Initiation Level, TIL (cm)	Result
HNS IV	49.5	23.5	Pass
RDX Type I	19.5	18.5	-

Results out of Twenty (20) Drops per Height until Point of Ignition for HNS IV		
Height (cm)	"Go"	"No Go"
20	0	20
22	0	20
23	0	20
23.5	**0**	**20**
24	2	3
28	2	18
34	3	17
38.8	3	17
40	3	17

Results out of Twenty (20) Drops per Height until Point of Ignition for RDX Type I		
Height (cm)	"Go"	"No Go"
15	0	20
17	0	20
18	1	19
18.5	**0**	**20**
19	6	1
20.2	10	3
21	18	2

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Excelitas HNS IV Passed the Impact Sensitivity Test

HNS IV Electrostatic Sensitivity

- Tests were conducted using procedure:
  - AOP-7 U.S. 201.03.001 – Electrostatic Discharge test, ARDEC method
- Pass/Fail Criteria: TIL must be greater than or equal to 20 mJ. A comparison was run with Type II, Class 5 RDX.

Material Tested	50% Fire Point (mJ)	Threshold Initiation Level, TIL (mJ)	Result
HNS IV	95.9	52.9	Pass
RDX Type II	15.7	9.6	-

Test Level	kV	mJ	HNS IV — The Capacitance used for all trials was 0.02 µF																		
µ-1.0σ	2.5	62.5	o	o	o	o	x														
These levels added	2.4	57.6	o	o	o	o	o	o	x												
	2.3	**52.9**	**o**	**o**	**o**	**o**	**o**	**o**	**o**	**o**	**o**	**o**	**o**	**o**	**o**	**o**	**o**	**o**	**o**	**o**	**o**
µ-1.5σ	2.2	48.4	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o
µ-2σ:	1.9	36.1	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o
Trial			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

Test Level	kV	mJ	RDX Type II Class 5 — The Capacitance used for all trials was 0.002 µF																			
µ-1.0σ	3.2	10.2	o	x																		
This level added	**3.1**	**9.6**	**o**	**o**	**o**	**o**	**o**	**o**	**o**	**o**	**o**	**o**	**o**	**o**	**o**	**o**	**o**	**o**	**o**	**o**	**o**	**o**
µ-1.5σ	2.9	8.4	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o
µ-2σ:	2.6	6.8	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o
Trial			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

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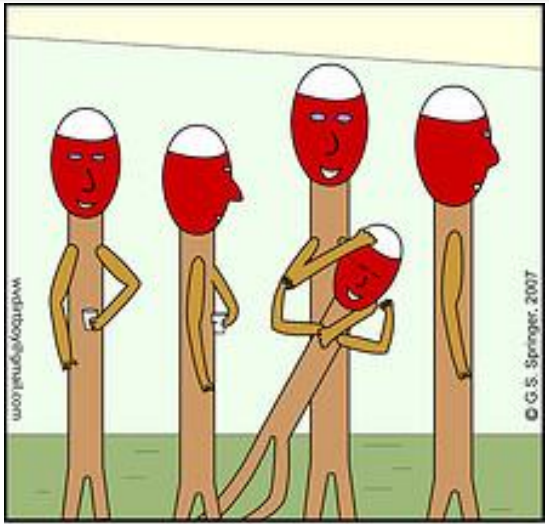
Excelitas HNS IV Passed the Electrostatic Sensitivity Test

HNS IV Friction Sensitivity

- Tests were conducted using procedure:
  - AOP-7 U.S. 201.02.006 – BAM Friction
- Pass/Fail Criteria: TIL must be greater than or equal to 80 N to be acceptable. A comparison was run with a Type II, Class 5 RDX.

Material Tested	50% Fire Point (N)	Threshold Initiation Level, TIL (N)	Result
HNS IV	303	144	**Pass**
RDX Type II	203	84	-



The matchstick party was going great until an ill-advised noogie ignited an inferno.

RDX Type II Class 5 (Newtons)																				
180	X																			
168	O	X																		
160	O	O	O	O	X															
144	O	O	O	X																
128	O	O	O	O	O	O	O	X												
120	O	O	O	O	O	X														
112	O	X																		
108	O	O	O	O	X															
96	O	O	X																	
84	**O**	**O**	**O**	**O**	**O**	**O**	**O**	**O**	**O**	**O**	**O**	**O**	**O**	**O**	**O**	**O**	**O**	**O**	**O**	**O**
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

HNS IV (Newtons)																				
324	O	O	X																	
288	O	X																		
252	O	O	O	O	X															
240	O	O	O	O	O	O	O	X												
216	O	O	O	O	O	O	O	O	O	O	O	O	X							
192	O	X																		
180	X																			
168	O	X																		
160	O	O	O	O	O	O	X													
144	**O**	**O**	**O**	**O**	**O**	**O**	**O**	**O**	**O**	**O**	**O**	**O**	**O**	**O**	**O**	**O**	**O**	**O**	**O**	**O**
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

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Excelitas HNS IV Passed the Friction Sensitivity Test

HNS IV Shock Sensitivity

- Tests were conducted using procedure:
  - AOP-7 U.S. 201.04.003 – NOL Small Scale Gap Test
- Twenty samples were fired using 4.0-decibang attenuators, which corresponds to an input pressure of 12.1 kbar (1.21 GPa).
- Pass/Fail Criteria: The material passes if there are no detonations in 20 consecutive trials. Any reaction causing a dent of 0.002 inch or more in the target plate would have been considered a detonation, failing the test.
- Results: None of 20 trials performed on the material with an attenuator of 4.0 dBg resulted in a dent.

Test No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Explosive Wt. (gm)	1.037	1.049	1.054	1.040	1.024	1.045	1.040	1.046	1.052	1.017	1.046	1.051	1.043	1.033	1.056	1.061	1.051	1.056	1.026	1.060
Diameter (inch)	0.201	0.201	0.201	0.201	0.201	0.201	0.201	0.201	0.201	0.201	0.201	0.201	0.201	0.201	0.201	0.201	0.201	0.201	0.201	0.201
Length (inch)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Density (g/cc)	1.327	1.343	1.349	1.330	1.310	1.337	1.330	1.339	1.346	1.302	1.339	1.345	1.334	1.321	1.352	1.358	1.344	1.352	1.312	1.356
Dent (inch)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

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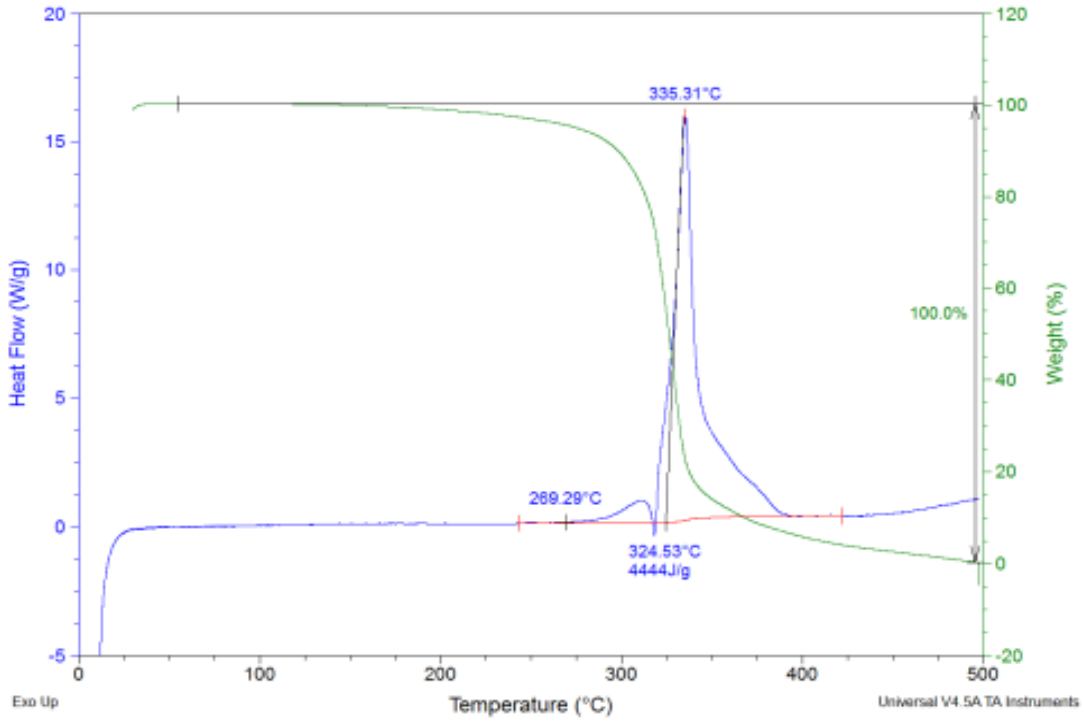
Excelitas HNS IV Passed the Shock Sensitivity Test

HNS IV Ignition Sensitivity / Self-Heating

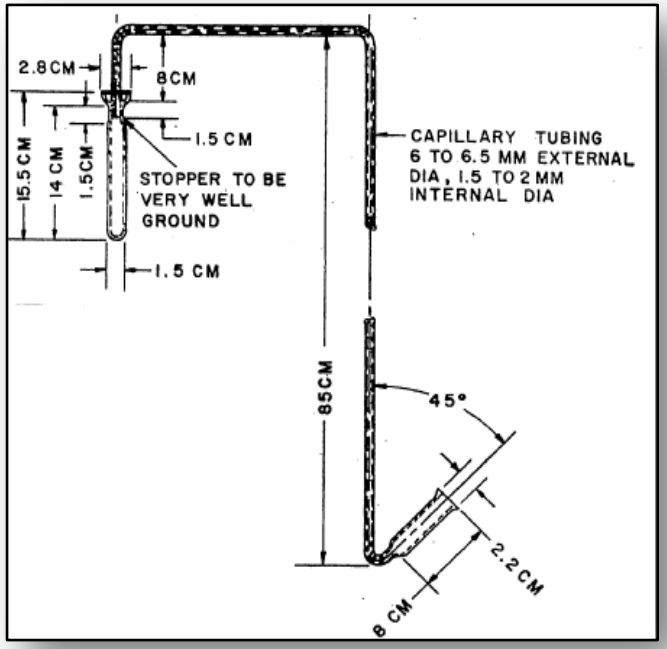
- Tests were conducted using procedure:
  - AOP-7 U.S. 202.01.020 – Differential Scanning Calorimetry (DSC)
- Pass/Fail Criteria: The material passes the ignition sensitivity test if the decomposition exotherm peak / temperature of ignition exceed 180°C for a heating rate of 5°C/minute.
- Results: The exotherm peak temperature for HNS IV is 335.31°C.



Excelitas HNS IV Passed the Ignition Sensitivity Test

HNS IV Vacuum Thermal Stability

- Tests were conducted using procedure:
  - AOP-7 U.S. 202.01.001 – Vacuum Thermal Stability
- Pass/Fail Criteria: The material passes the stability test if no more than 2 ml gas is evolved per gram of HNS IV per 48 hours at 100°C.
- Results: Three samples were tested producing 0.032 ml/gm, 0.033 ml/gm and 0.047 ml/gm of HNS IV over 48 hours at 100°C.



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Excelitas HNS IV Passed the Vacuum Thermal Stability Test

HNS IV Compatibility

- The materials which come into contact with the HNS IV during production and use include only stainless steels (various alloys, primarily 303SS), nickel (UNS2200) and polyimide. Tests were conducted using procedure:
  - AOP-7 U.S. 202.01.020 – Differential Scanning Calorimetry (DSC)

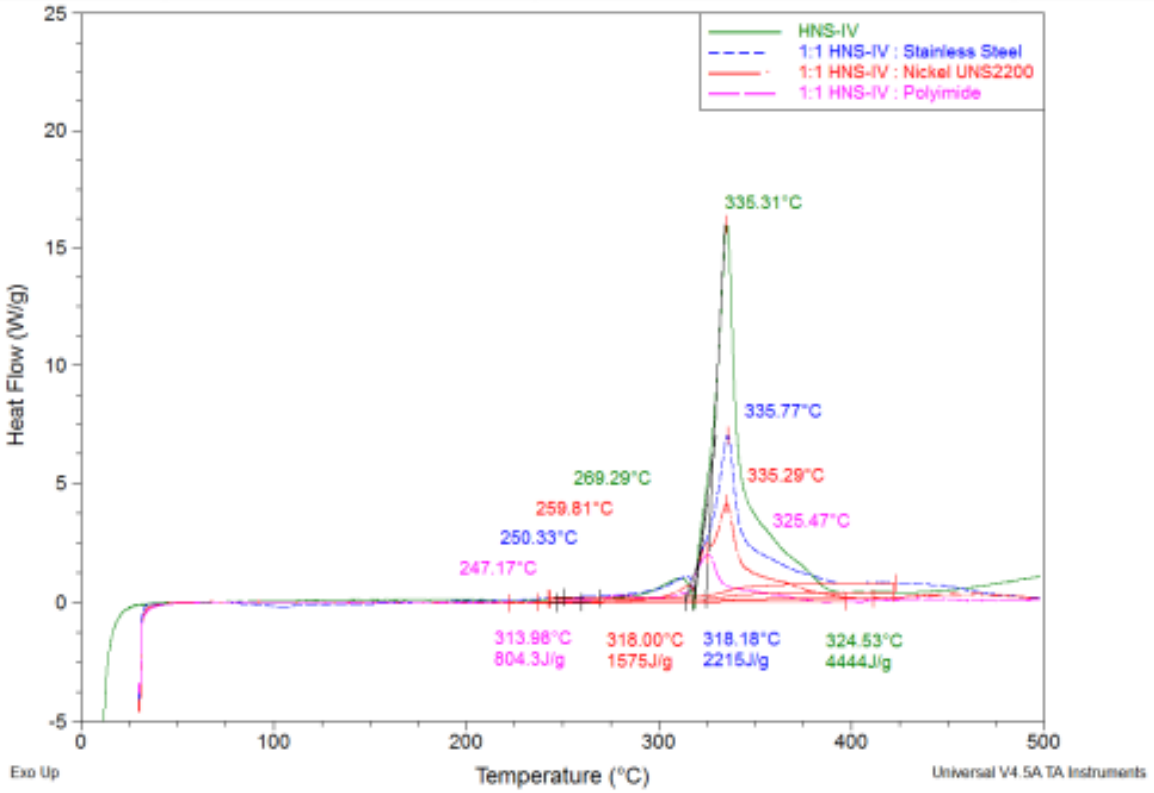
- Pass/Fail Criteria: Acceptance is based on comparing the results with the HNS IV in contact with the mating material versus the results for the HNS IV when evaluated alone. The material passes the compatibility tests if there is a change of no more than 10°C in the exotherm peak temperature for a heating rate of 10°C/minute or less.

- Results: The peak exotherm temperature did not change more than 10°C for 1:1 mixtures of materials.

Excelitas HNS IV Passed the Compatibility Test

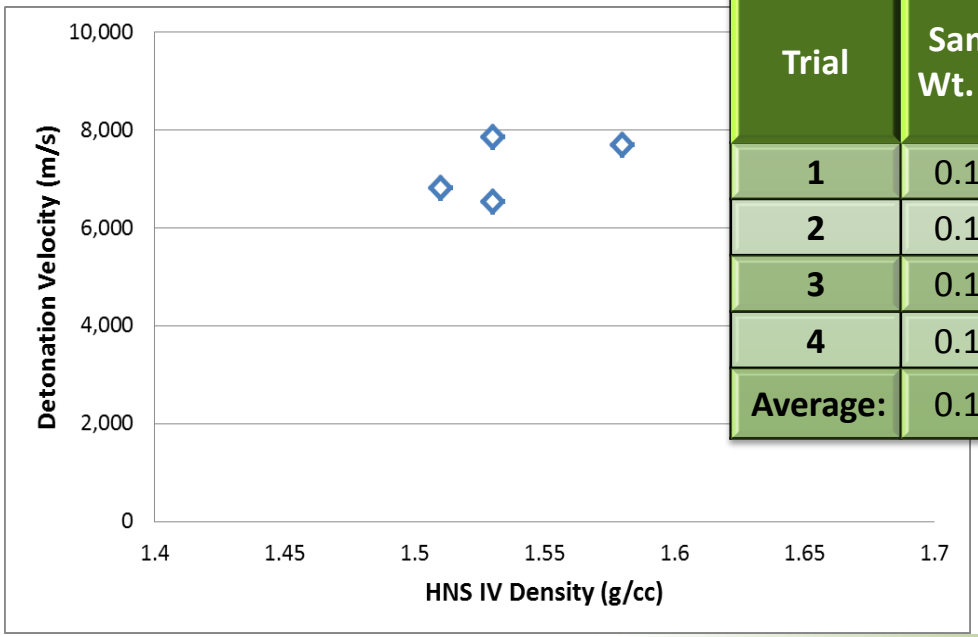
HNS IV Compatibility

Characterization Test	Criteria	Results		Status
Compatibility	Exotherm peak within 10°C of HNS IV baseline	HNS IV: HNS IV & Stainless Steel: HNS IV & Nickel: HNS IV & Polyimide:	335.31°C 335.77°C 335.29°C 325.47°C	**Pass**



HNS IV Detonation Velocity

- Tests were conducted using procedure:
  - AOP-7 U.S. 302.01.001 – Detonation Velocity
- Pass/Fail Criteria: There is no criterion for passing detonation velocity. Measurement is for performance assessment only.
- Results: A Delrin test sleeve, 0.8” in height with a central hole of 0.101” in diameter, was used to contain the test material for testing.



Trial	Sample Wt. (gm)	HNS IV Density (g/cc)	Detonation Length (mm)	Time (µs)	Detonation Velocity (m/s)
1	0.1567	1.53	18.98	2.9	6,545
2	0.1636	1.58	19.23	2.5	7,692
3	0.1552	1.51	19.08	2.8	6,814
4	0.1567	1.53	18.86	2.4	7,858
Average:	0.1581	1.54	19.04	2.65	7,228 m/s

HNS IV Detonation Velocity

- Reference Data: An example from open literature shows that for a sample of HNS II at a density of 1.54 g/cc, the detonation velocity was approximately 6500 m/s. This compares to 7228 m/s for the Excelitas HNS IV.

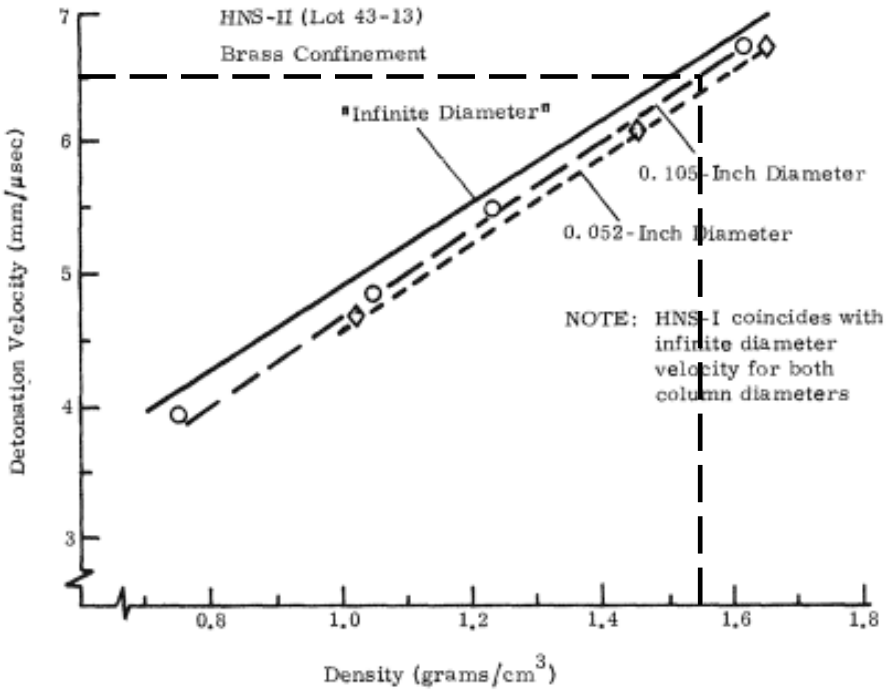


Figure IV-1. Detonation Velocity vs Density of HNS-II

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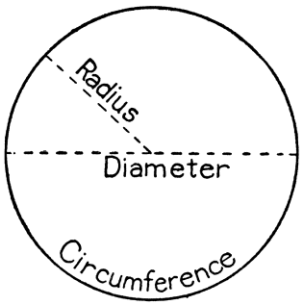
Excelitas HNS IV Detonation Velocity is consistent with historical reference

HNS IV Critical Diameter

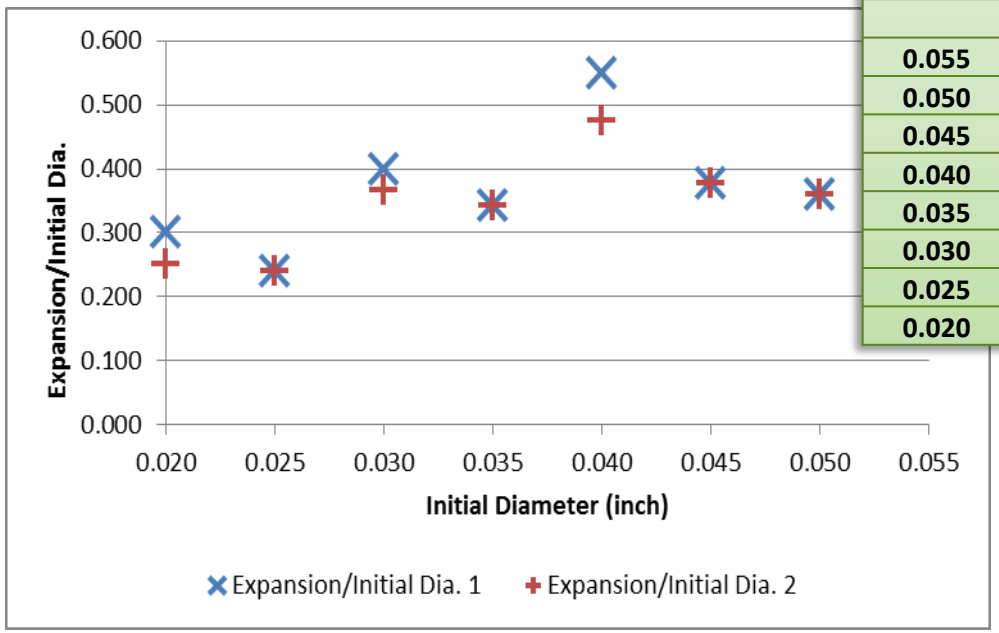
- Tests were conducted using procedure:
  - AOP-7 U.S. 302.01.003 – Critical Diameter
- Pass/Fail Criteria: There is no criterion for passing critical diameter. Measurement is to determine smallest diameter that can support a steady state detonation and is for performance assessment only.
- Results: There was no remaining powder, and expansion of the stainless steel test sleeves occurred at every diameter, indicating the critical diameter is smaller than the smallest test diameter, 0.020 inch (500 µm).
- Reference Data: Open Literature
  - "Redundant tests of HNS rate sticks at diameters of about 250 µm were conducted and the results indicated that a steady detonation was not present at those length scales… it is likely that the failure diameter of this HNS material and density is above a diameter of 250 µm."

Excelitas HNS IV Critical Diameter is consistent with historical reference

HNS IV Critical Diameter



Bushing Dia. (inch)	Explosive Wt. (g)	Bushing Ht. (inch)	Density (g/cc)	Post Test Dia. (inch)	Expansion (inch)
Trial 1					
0.055	0.0135	0.2185	1.59	0.080	0.025
0.050	0.0104	0.2055	1.57	0.068	0.018
0.045	0.0074	0.1800	1.58	0.062	0.017
0.040	0.0053	0.1635	1.57	0.062	0.022
0.035	0.0034	0.1390	1.55	0.047	0.012
0.030	0.0023	0.1240	1.60	0.042	0.012
0.025	0.0012	0.0995	1.50	0.031	0.006
0.020	inaccurate	0.0795	inaccurate	0.026	0.006
Trial 2					
0.055	0.0135	0.2185	1.59	0.076	0.021
0.050	0.0107	0.2070	1.61	0.068	0.018
0.045	0.0070	0.1725	1.56	0.062	0.017
0.040	0.0053	0.1635	1.57	0.059	0.019
0.035	0.0034	0.1390	1.55	0.047	0.012
0.030	0.0023	0.1245	1.60	0.041	0.011
0.025	0.0012	0.1000	1.49	0.031	0.006
0.020	inaccurate	0.0800	inaccurate	0.025	0.005



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Excelitas HNS IV Critical Diameter ≤ 0.020 inch

HNS IV Exudation and Growth

- The methods specified for determination of Exudation and Growth are:
  - AOP-7 U.S. 202.01.010 – Exudation
  - AOP-7 U.S. 202.01.011 – Growth
- AOP-07 Ed 2 states: "No advisory criterion but data from tests performed… are required for TNT based explosives. Tests performed per U.S. 202.01.010 are required for explosives containing energetic plasticizers." Excelitas HNS IV does not contain TNT or plasticizers. Therefore, these tests are not required for Excelitas HNS IV by AOP-07 Ed 2.
- Exudation and growth testing for Excelitas manufactured HNS IV is not required based on analysis.

HNS IV Safety Critical Data Summary

Safety Critical Test	Criteria	Results		Status
		HNS IV Results	RDX Results	
Electrostatic Sensitivity	TIL ≥ 20 mJ HNS > RDX	52.9 mJ	9.6 mJ	**Pass**
Friction Sensitivity (BAM Test)	TIL ≥ 80 N HNS > RDX	144 N	84 N	**Pass**
Impact Sensitivity	TIL ≥ 12 cm HNS > RDX	23.5 cm	17 cm	**Pass**

Excelitas HNS IV Passed the Safety Critical Tests

HNS IV Performance Data Summary

Characterization Test	Criteria	Results		Status
Shock Sensitivity	No detonation	No detonation in 20 trials with 4.0 decibang attenuator		**Pass**
Self Heating	Decomposition > 180°C	Peak exotherm occurred at 335.31°C		**Pass**
Compatibility	Exotherm peak within 10°C of HNS IV baseline	HNS IV: HNS IV & Stainless Steel: HNS IV & Nickel: HNS IV & Polyimide:	335.31°C 335.77°C 335.29°C 325.47°C	**Pass**
Vacuum Thermal Stability	< 2ml gas/gm in 48 hrs	0.037 ml/gm/48 hrs (avg of 3 tests)		**Pass**
Detonation Velocity	Information only	7,228 m/s at 1.53 g/cc (avg of 4 tests)		-
Critical Diameter	Information only	< 0.020 inch (2 trials of 8 diameters)		-
Exudation and Growth	Information only	Completed by analysis		-

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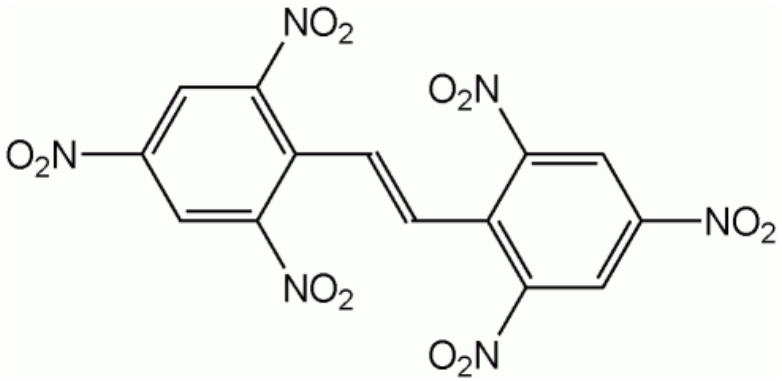
Excelitas HNS IV Passed the Performance Characterization Tests

Excelitas Manufactured HNS IV

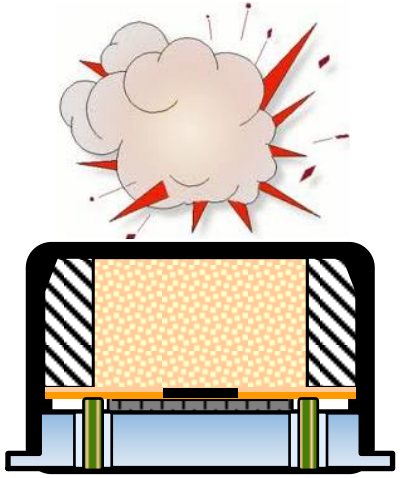
- The test results demonstrate that Excelitas manufactured HNS IV meets all requirements of AOP-7 for both safety critical and performance related testing.



HNS IV

HNS IV Application - Excelitas Blue Chip® Detonator

- **Blue Chip® Detonator utilizes HNS IV**
  - Qualified design (MIL-DTL-23659 Appendix A) with over 200,000 produced.
- **Throw flying plate that "slaps" into HNS IV**
  - Large current (> 1000 amps) explodes thin flat foil bridge
  - Expanding plasma (metal vapor) accelerates cover layer
  - Flying plate slaps into explosive
  - Shock wave directly detonates explosive
  - Explosive accelerates lid
  - Lid slaps into next explosive assembly

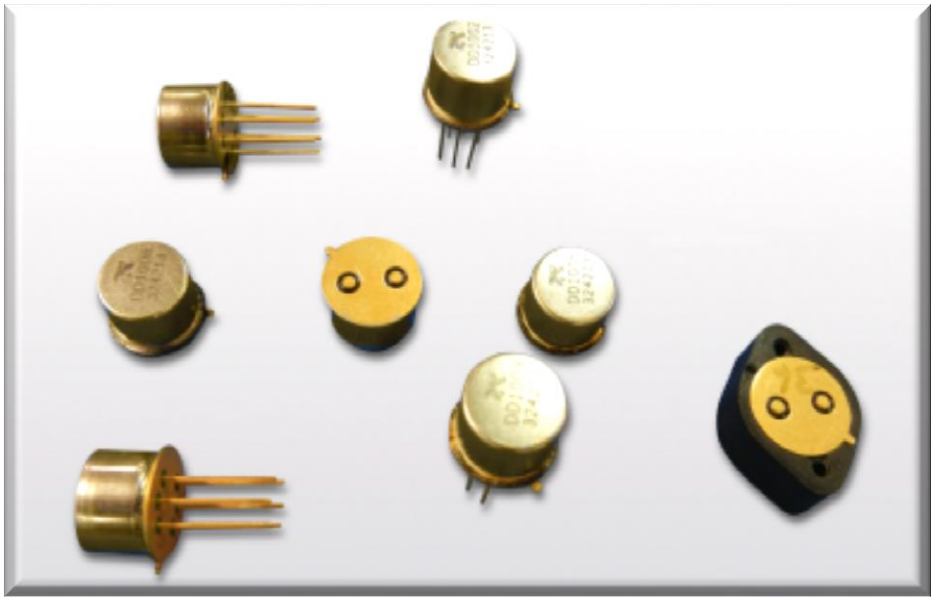


- **Hard to initiate accidentally**
  - Require capacitor discharge
  - Firing system must have low inductance (capacitor must be closely coupled)
  - Require high energy switch
- **Function times of less than one microsecond**
- **Can initiate many types of secondary explosives**

Excelitas Blue Chip® Detonator Family

- Surface mount
- Strip Line
- Plug in

- Standard and Low Energy
- Standard and Dual Load (High Output)
- Low Output for TBIs
- Shock Hardened
- High Temperature (> 200° C)



- Designs qualified to MIL-DTL-23659 (or predecessor for older designs)

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