Smokes: The How And The Why

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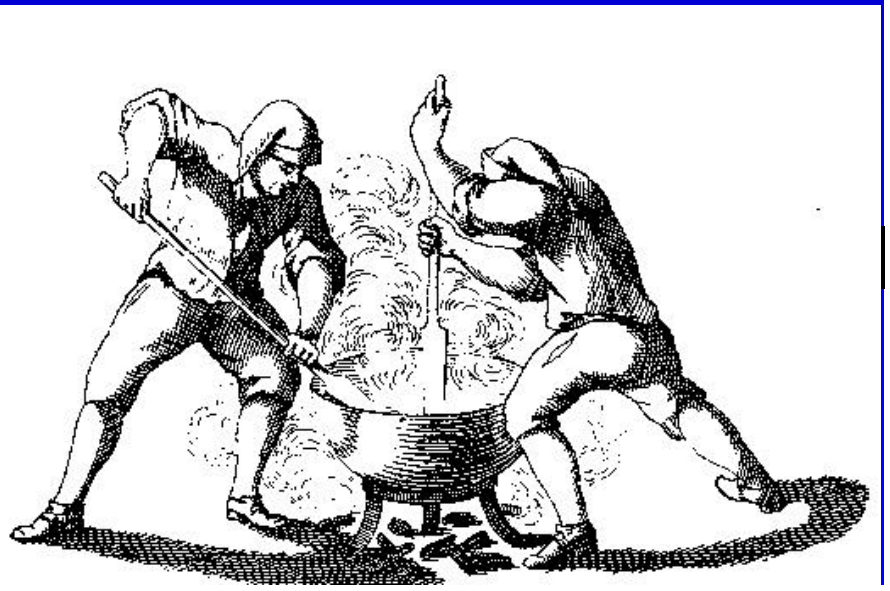
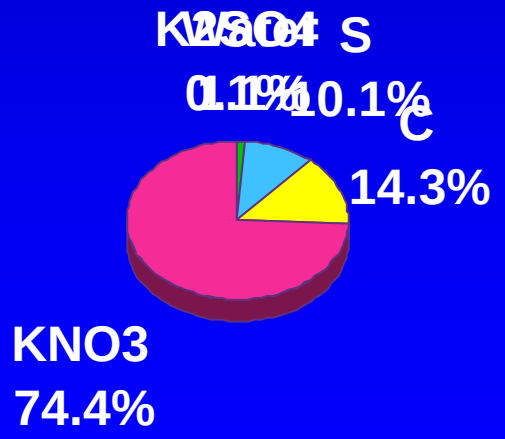


Who Was That Masked Man?

- Crackerjacks, Inc.
  - Vice President for Publications
  - Webmaster : www.crackerjacks.org
- Department of the Army
  - Chief, Pyrotechnics Team (26 years)
  - LTC Maryland Army National Guard

Typical Black Powder Analysis

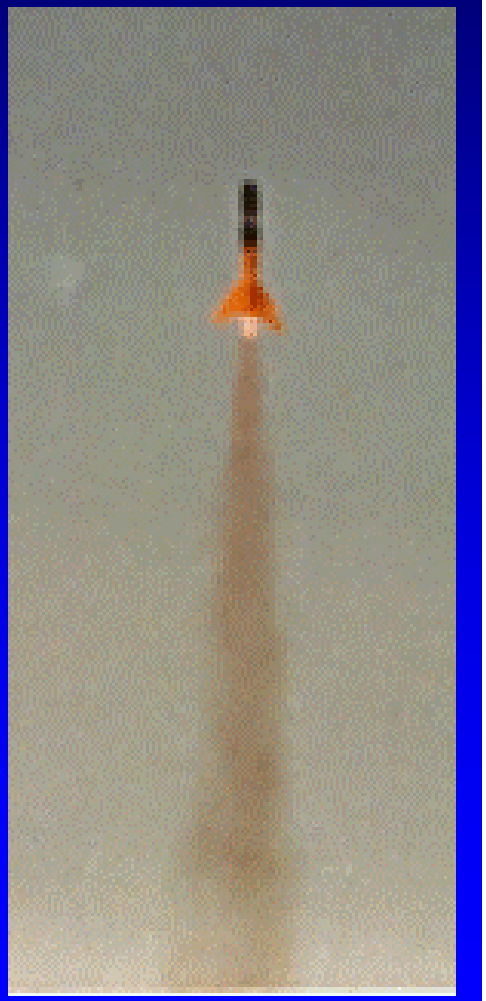
Potassium Nitrate	(KNO3)	74.43
Charcoal	(C)	14.29
Sulfur	(S)	10.09
Water	(H2O)	1.06
Potassium Sulfate	(K2SO4)	0.13



Typical Black Powder Analysis

It's hard to believe that less than **50%** of the combustion products are gases.

Combustion Products	Weight%
Solids	55.91
Gases	42.98
Water	1.11



Typical Black Powder Analysis

ny doubts of the composition of the white residue?

Solids		Weight%
Potassium Carbonate	K2CO3	61.03
Potassium Sulfate	K2SO4	15.10
Potassium Sulfide	K2S	14.45
Sulfur	S	8.74
Potassium Nitrate	KNO3	0.27
Potassium Sulfur Cyanide	KSCN	0.22
Ammonium Carbonate	(NH4)2CO3	0.08
Carbon	C	0.08

Smokes were developed for **what** reason???

Arthasastra

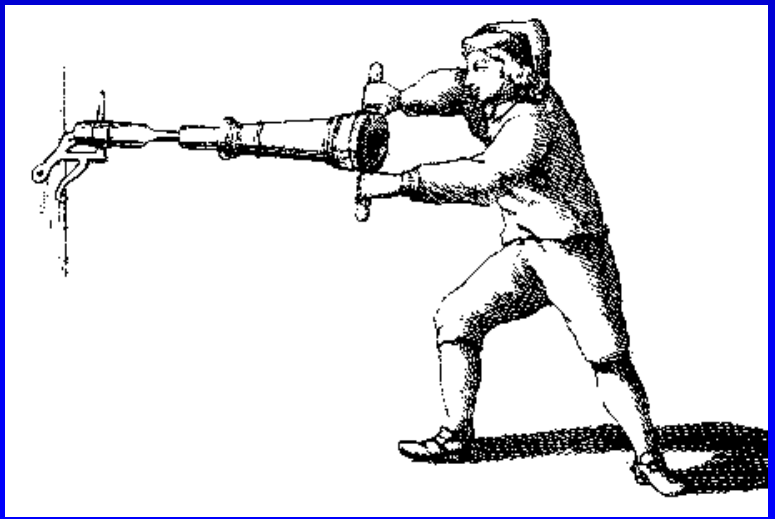
Published 300 BC by Kautilya

- Provides formulas for poisonous smokes
- Made from Green Vitriol (arsenic sulfides)
  - plants
  - insects
  - animals
  - reptiles

Wu Pei Chih
(Records of War Preparations)

80 volumes of 240 chapters

- **To make a powder producing much smoke:**
  - 1 pound saltpeter
  - 1 pound shih huang
  - 4 ounces of sulfur
    - boiled in human urine
  - 4 ounces p'ishuang
  - 1 ounce ch'ang nao
    - (deer brains)
  - 1/10 ounce ch'ing fan

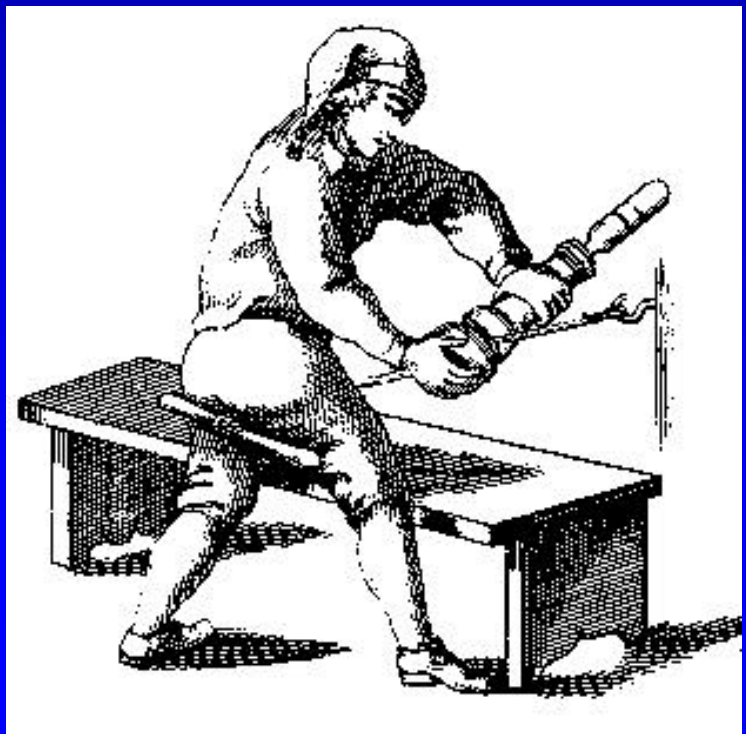


Pyrotechnic Smoke Mixture for Defending Thick Walls Against Attack.

An apple sized ball is dropped into the excavation tunnel built by the enemy.

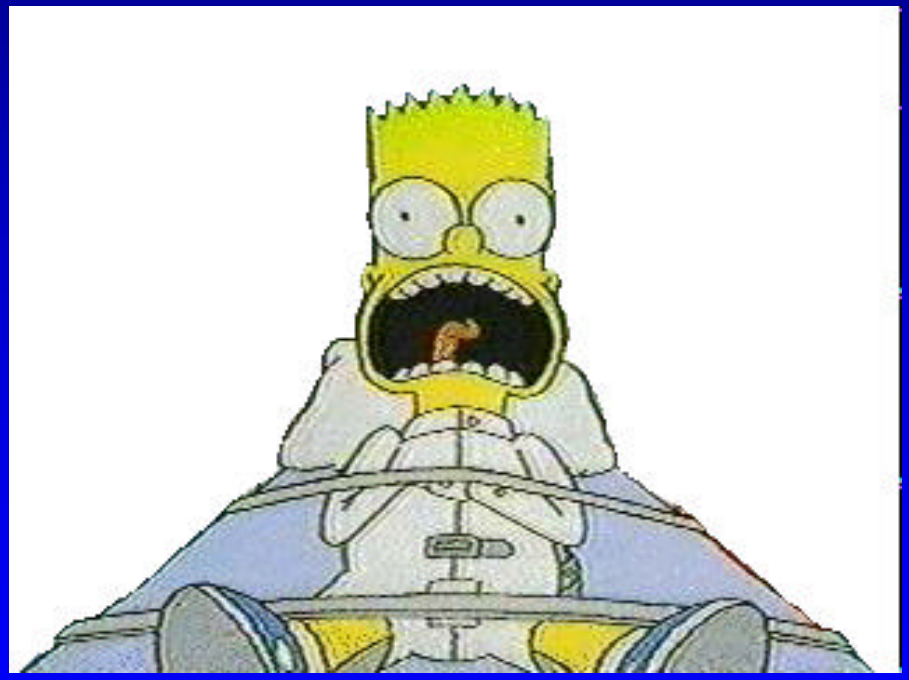
Formula given as :

30 lb resin
30 lb saltpetre
10 lb sulfur
6 lb charcoal
10 lb arsenic



Dialogus oder Gesprach zweier Personen...
Published 1573 by Samuel Zimmerman

- Describes "amusement" smokes consisting of:
  - Saltpeter
  - Sulfur
  - Mercury



British Old Smoke Ammo Design

- **Candle, Smoke, M1, Type S**
  - **3 5/8" diameter**
  - **5" high**
  - **2 1/2 lbs payload**
    - **Potassium Nitrate**
    - **Sulfur**
    - **Pitch**
    - **Borax**
    - **Glue**

3 min burn time

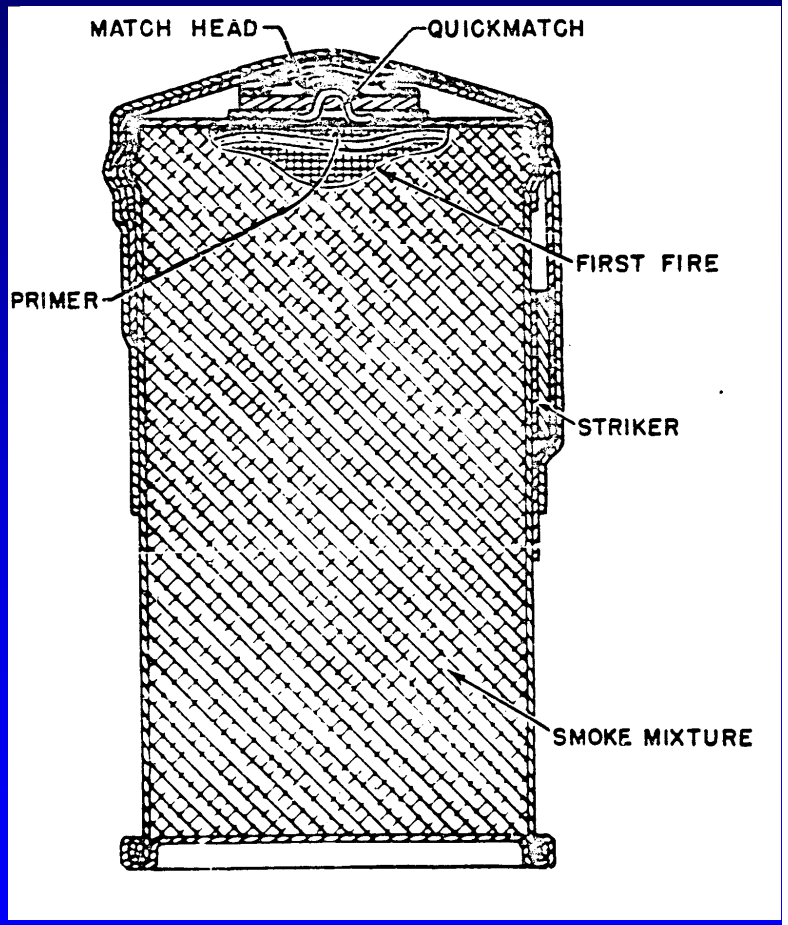
Yellowish brown smoke

Torch, Smoke, M1

White smoke with a "tinge" of yellow

4 min burn time

Composition	PBW
Potassium nitrate	47.4
Pitch	29.2
Borax	10.6
Calcium carbonate	4.9
Sand	4.0
Sulfur	3.9



188,102 of the 500,000 ordered were ever made.

Edgewood Arsenal 1920

- Hexachloroethane now cheap to make
- Needed solid ingredients only
  - BM candles @ 60 deg C die in 5 weeks

	M-III mix	BM mix
Zinc powder	32.8	35.4
Carbon tetrachloride		41.6
Hexachloroethane	39.8	
Sodium chlorate	17.0	9.3
Ammonium chloride	7.4	5.4
Magnesium carbonate	3.0	8.3

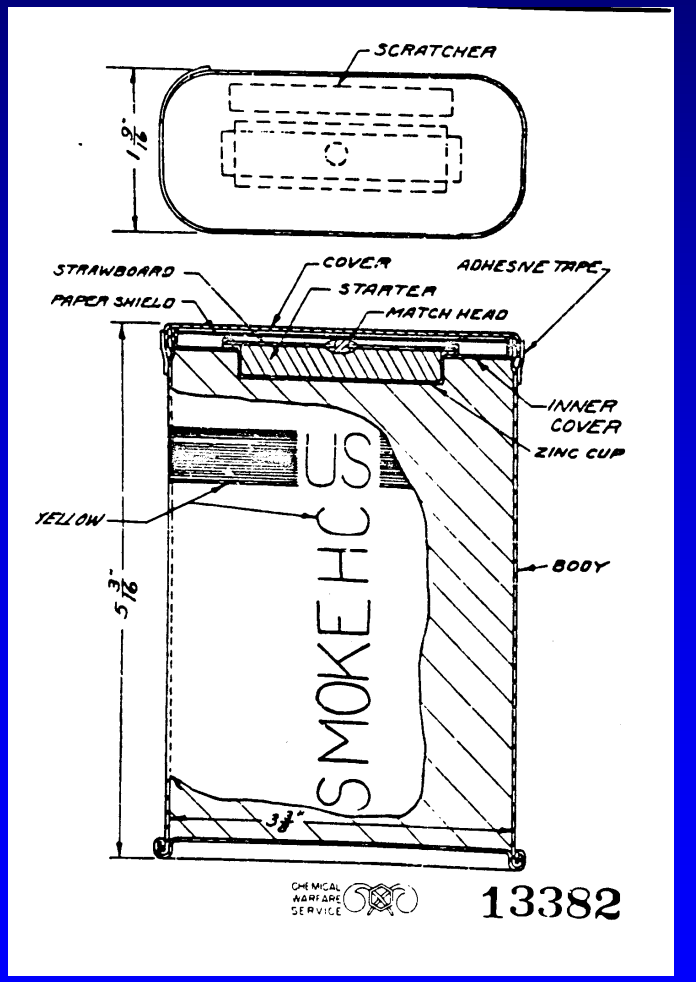
Blend 7:1 with carbon tetrachloride and let evaporate

Edgewood Arsenal 1920 Candle, Smoke, HC, M1

- 600,000 obsolete canisters
  - Let's use 'em for smoke!
  - now pressed hydraulically
  - Could not seal the can properly
  - continued development using.....
    - ..... the old gas mask canister!!!

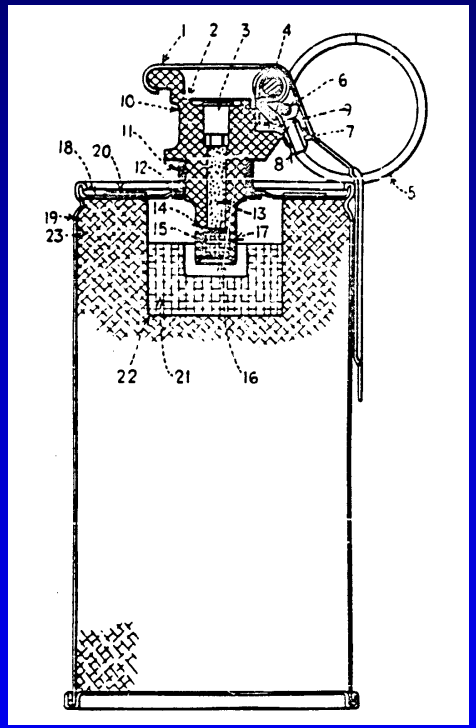
Hexachloroethane	50
Zinc powder	28
Zinc oxide	22

1 lb 13 oz



Edgewood Arsenal 1926 Grenade, Hand, Smoke, HC, M8

- Chief of Infantry speaks out
  - Standardize the cans
    - 3/4 to 1 3/4 lb
    - 2 1/8" to 2 3/8" diameter
    - 4" to 5" long



	Fast 50 gm	Slow 535 gm
Zinc dust	36	36
Hexachloroethane	43	44
Ammonium perchlorate	15	10
Ammonium chloride	6	10

1933, Chief or Ordnance renames Candle Smoke, HC MII to Grenade, Hand, HC, M8

HC Smoke Mixes

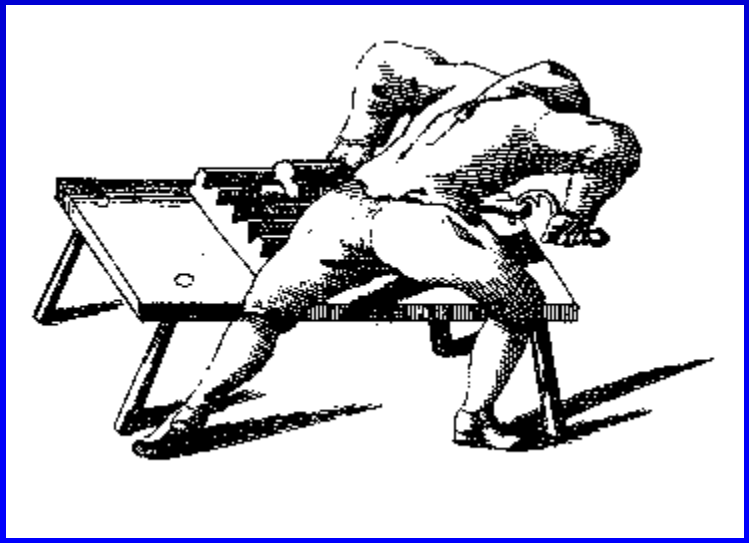
	M3	M1	Slow	Fast	Type C	Type D
Zinc	32.8	28	36	36		
Zinc Oxide		22			46.5	43.4
Ammonium Chloride	7.4		10	6		
Sodium Chlorate	17.0					
Magnesium Carbonate	3.0					
Hexachloroethane	39.8	50	44	43	46.5	50.6
Ammonium Perchlorate			10	15		
Aluminum					7.0	6.0

HC Smoke Mixes

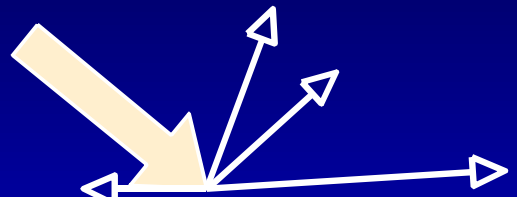
	Type D
Zinc Oxide	43.4
Hexachloroethane	50.6
Aluminum	6.0

Classes of Particulate Clouds

- Dusts - formed by mechanical disintegration
  - 0.1 - 100 microns
- Mists - formed by condensation of liquids 5-10 microns
- Fogs - high concentration of mist droplets
  - (must be visible to naked eye)
- Smokes - any particle suspension
- not classified as a dust or mist
- (0.01 to 5.0 microns)

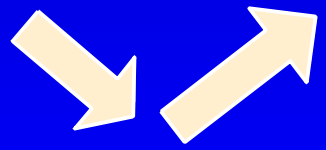


Optical Properties



Scatter

Absorption



Reflection

Smoke Cloud Destruction

Evaporation/Condensation

- **Droplet size is critical**
- **Droplets smaller than critical diameter will evaporate because their vapor pressure is higher than the partial pressure in the vapor phase.**
- **Droplets larger than the critical diameter will grow as a result of condensation.**
- **Also applies to small solid particles.**

Zinc / Sulfur Smoke

Zinc / Sulfur / Potassium Chlorate

Zinc / Ammonium Perchlorate

Smoke Uses

Signalling

Color

Visibility

Duration

Persistence

Volume

Smoke Uses

Target Acquisition

- **Identify specific targets on the battlefield**

Smoke Uses

- Specific chemicals for types of smoke
  - Insecticides
  - Reforestation
  - Plant coatings (smudge pots)
- Riot control agents
- Toxic agents

Smoke Uses

- In combat for deception
- In movies for special effects

Smoke Uses

Nuisances

- **Undesirable for cannons/guns due to lack of gas production and as heat sink**
- **Gives away firing position**
- **Unable to see civilian fireworks during displays**

Magnesium / Hexachloroethane

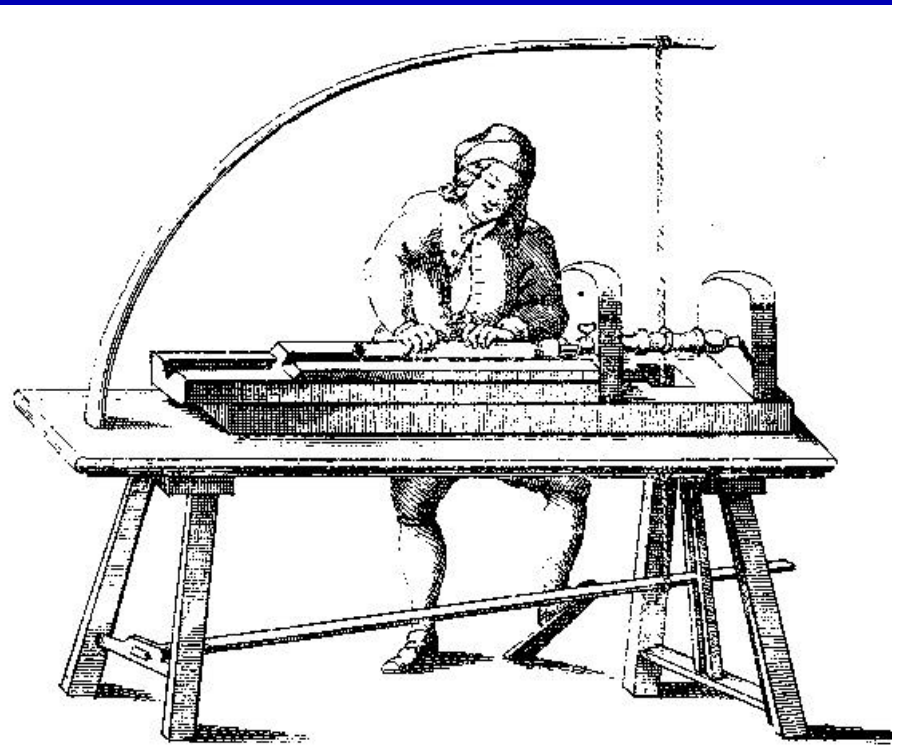
Magnesium / HC / NP

Loading Force vs Burn Time

Compacted devices fall into two basic categories,

1) Pressed devices
2) Cast devices.

Compacted pyrotechnic compositions are universally loaded with the use of a hydraulic ram instead of the older "hammer wack" technique. By keeping increments small in relation to the container height, the cross sectional density of the material will be more uniform and the resulting device more reliable.



Loading Force vs Burn Time

Loading Pressure (pounds)	Burn Time (seconds)	Efficiency (percent)
0	2.0	100
5,000	5.0	183
10,000	9.0	226
15,000	9.5	219
20,000	10.0	256

BT Versus Fuel:Oxidizer Ratio

Fuel	Oxidizer	Burn Time
1.0	1.0	17 sec
1.0	1.75	14 sec
1.0	2.5	10 sec

Sucrose: Potassium Chlorate System

Burn Time vs Exit Orifice Diameter

Orifice Diameter (inches)	Burn Time (seconds)	Smoke Efficiency (percent)
.172	7.6	104
.190	8.5	104
.205	9.3	106
.250	12.2	115

Burn Times vs Granule Size

Mesh Size	Granule Diameter (microns)	Burn Time (seconds)	Smoke Efficiency (percent)
325	45	10	93
60	250	7	100
10	2000	5	93

Catalyst Effects vs Burn Time

Catalyst	Burn Time (seconds)	Efficiency (percent)
None	10	100
Copper Chloride	9	101
Iron Sulfide	8	96
Iron Acetate	7	102
Red Iron Oxide	7	105

Sucrose: Potassium Chlorate System

Colored HC Smoke

Magnesium	16
Hexachloroethane	14
Red Iron Oxide	36

HEXACHLOROETHANE BASED ORANGE SMOKE

Colored HC Smoke

Magnesium	16
Hexachloroethane	14
Red Iron Oxide	36
Magnesium Carbonate	+10

HEXACHLOROETHANE BASED ORANGE SMOKE

2 Component Black Smoke

Polystyrene	
Potassium Chlorate	

Inorganic Based Colored Smoke

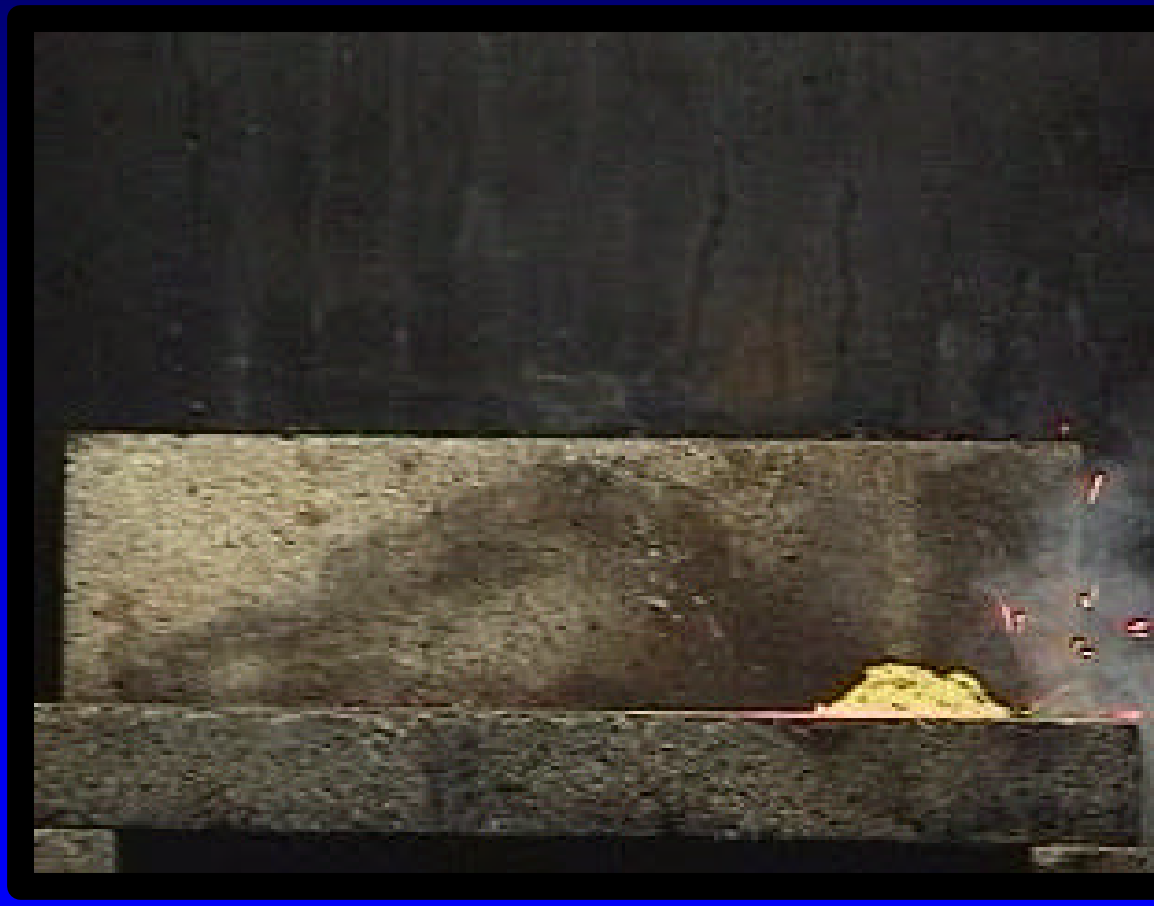
	Yellow	Orange	Brown
Magnesium	14	15	15
Potassium Dichromate	66	35	
Bismuth Tetroxide	20		
Lead Dioxide		50	35
Cupric Oxide			50

Inorganic Based Colored Smoke

	Yellow
Magnesium	14
Potassium Dichromate	66
Bismuth Tetroxide	20

Inorganic Based Colored Smoke

	Yellow
Magnesium	14
Potassium Dichromate	66
Bismuth Tetroxide	20
Magnesium Carbonate	+10



Inorganic Based Colored Smoke

	Orange
Magnesium	15
Potassium Dichromate	35
Lead Dioxide	50

Inorganic Based Colored Smoke

	Orange
Magnesium	15
Potassium Dichromate	35
Lead Dioxide	50
Magnesium Carbonate	+10

Inorganic Based Colored Smoke

	Brown
Magnesium	15
Lead Dioxide	35
Cupric Oxide	50

Inorganic Based Colored Smoke

	Brown
Magnesium	15
Lead Dioxide	35
Cupric Oxide	50
Magnesium Carbonate	+10

Red Dye Based Colored Smoke

	CARCINOGENIC RED SMOKE	STANDARD RED SMOKE	RED SMOKE III	NEW SAFER RED SMOKE
Wheat Flour	15.0 pbw			
Sulfur			9.0 pbw	
Lactose		18.0 pbw		
Sucrose				17.5 pbw
Potassium Chlorate	25.0 pbw	29.5 pbw	26.0 pbw	17.5 pbw
Rhodamine B	24.0 pbw			
Para Red	36.0 pbw			
Red Dye		47.5 pbw	40.0 pbw	
Dye, Disperse Red 11				6.8 pbw
Dye, Solvent Red 1				34.2 pbw
Sodium Bicarbonate			25.0 pbw	
Magnesium Carbonate		5.0 pbw		10.0 pbw
Terephthalic Acid				14.0 pbw

Safer Red Dye Based Colored Smoke

Yellow Dye Based Colored Smoke

	STANDARD YELLOW SMOKE	YELLOW SMOKE IV	NEW SAFER YELLOW SMOKE
Wheat Flour			
Sulfur		8.5 pbw	
Lactose	16.0 pbw		
Sucrose			15.0 pbw
Potassium Chlorate	26.5 pbw	20.0 pbw	22.0 pbw
Benzanthrone	32.0 pbw	24.5 pbw	
Yellow Dye	14.0 pbw	14.0 pbw	
Dye, Solvent Yellow 33			33.0 pbw
Sodium Bicarbonate	33.0 pbw	33.0 pbw	
Magnesium Carbonate			21.0 pbw

Safer Yellow Dye Based Colored Smoke

Green Dye Based Colored Smoke

	CARCINOGENIC GREEN SMOKE	OLD STANDARD GREEN SMOKE	GREEN SMOKE IV	NEW SAFER GREEN SMOI
heat Flour	15.0 pbw			
lfur			10.4 pbw	
ctose		18.0 pbw		
crose				16.5 pbw
tassium Chlorate	28.0 pbw	31.5 pbw	27.0 pbw	24.5 pbw
ramine	10.0 pbw			
ethylene Blue	17.0 pbw			
digo Pure	30.0 pbw			
nzanthrone		9.4 pbw	8.0 pbw	
een Dye		32.9 pbw	28.0 pbw	
llow Dye		4.7 pbw	4.0 pbw	
ve, Solvent Yellow 33				12.5 pbw
ve, Solvent Green 3				29.5 pbw
dium Bicarbonate			22.6 pbw	

Safer Green Dye Based Colored Smoke

Violet Dye Based Colored Smoke

	CARCINOGENIC VIOLET SMOKE	STANDARD VIOLET SMOKE	NEW SAFER VIOLET SMOKE
Wheat Flour	15.0 pbw		
Sulfur			
Lactose		24.0 pbw	
Sucrose			19.1 pbw
Potassium Chlorate	26.0 pbw	22.0 pbw	18.4 pbw
Indigo Pure	22.0 pbw		
Para Red	21.0 pbw		
Rhodamine B	16.0 pbw		
Violet Dye		46.0 pbw	
Dye, Disperse Red 11			38.0 pbw
Dye, Disperse Blue 3			4.4 pbw
Sodium Bicarbonate			
Magnesium Carbonate		7.0 pbw	20.1 pbw

Safer Violet Dye Based Colored Smoke

Unusual Dye Smokes

Guanidine Nitrate Based

Guanidine Nitrate	40
Celluloid Powder	35
Dye	25

2 Component Smoke

Polybamo	50
Dye	50

Plastic Bonded Colored Smoke

Sucrose	18.0
Potassium Chlorate	23.0
Dye	51.0
Potassium Dichromate	8.0
Polyvinyl Acetate	2.2
Dichloromethane	5.8

Smoke Fuel Mix

UNIVERSAL SMOKE FUEL MIX

Sucrose	28
Potassium Chlorate	40
Magnesium Carbonate	32

Granulate 50/50 with 92/8 nitrocellulose in acetone.

Use with experimental material to be vaporized.

Fast Smoke Fuel Mix

UNIVERSAL SMOKE FUEL MIX

Sucrose	28
Potassium Chlorate	40
Magnesium Carbonate	5

Granulate 50/50 with 92/8 nitrocellulose in acetone.

Use with experimental material to be vaporized.

Slow Smoke Fuel Mix

Sucrose	28
Potassium Chlorate	40
Magnesium Carbonate	15

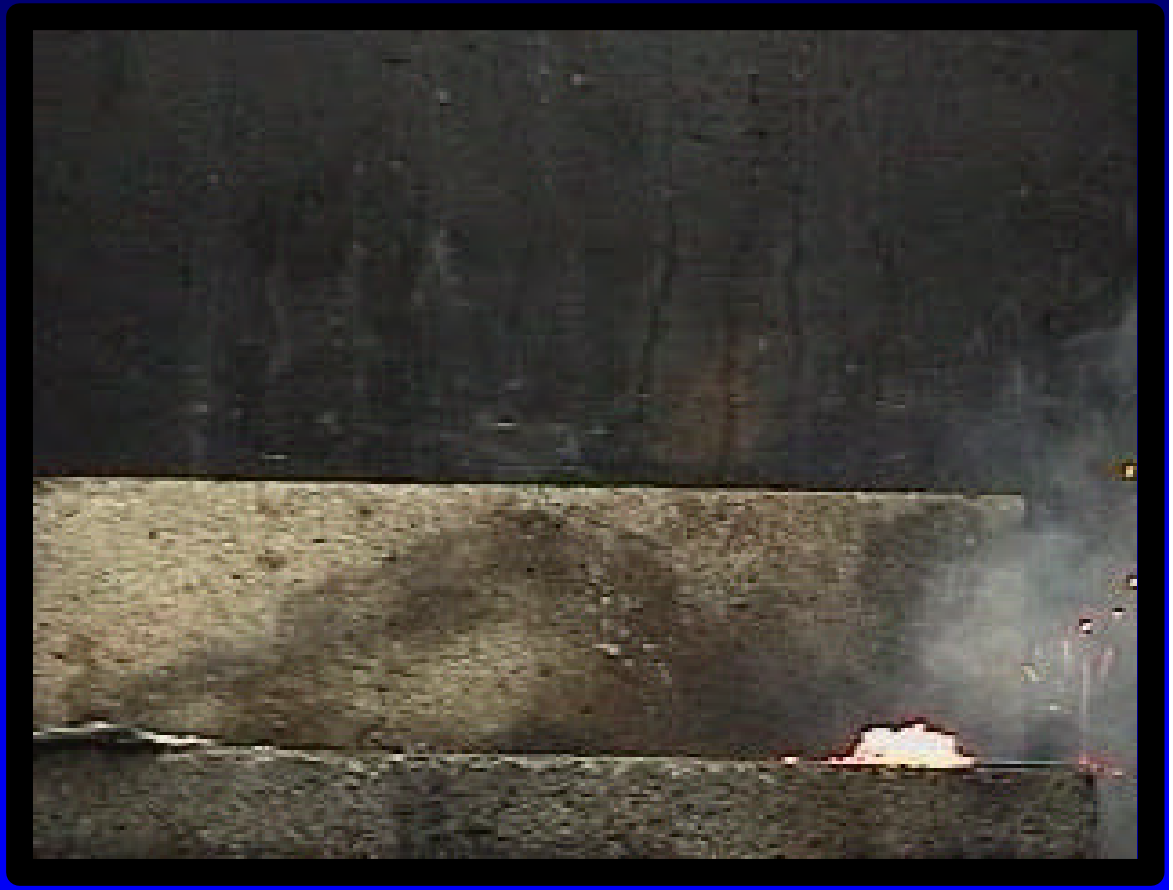
Granulate 50/50 with 92/8 nitrocellulose in acetone.

Use with experimental material to be vaporized.

Sucrose / Potassium Chlorate

Straight Binary Mix

Sucrose	28
Potassium Chlorate	40



Granulate 50/50 with 92/8 nitrocellulose in acetone.

Use with experimental material to be vaporized.

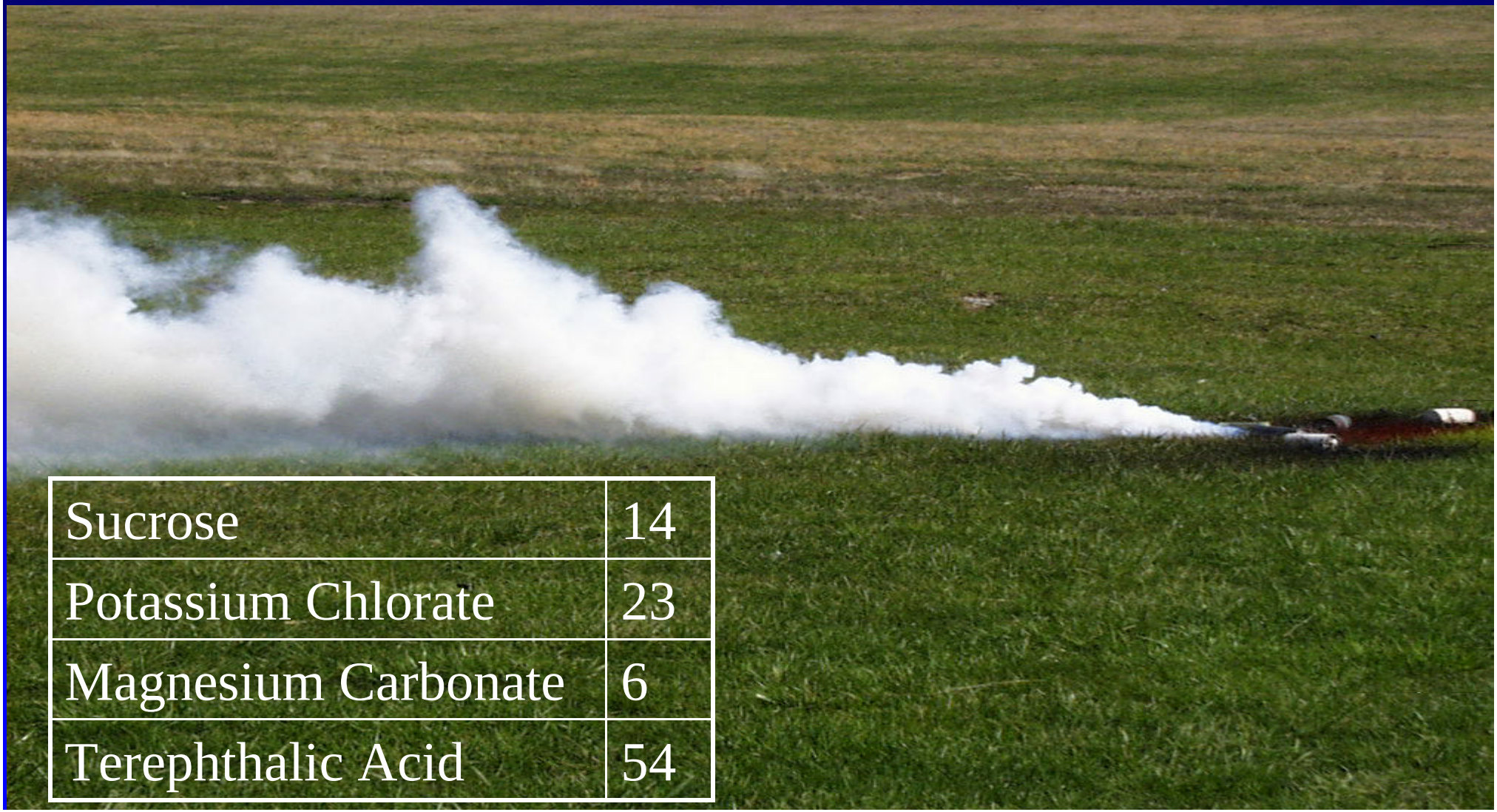
Vaporized Wax Smokes

Sucrose	19
Potassium Chlorate	29
Magnesium Carbonate	6
Synthetic Wax	46

Vaporized Wax Smokes

Sucrose	19
Potassium Chlorate	29
Magnesium Carbonate	6
Synthetic Wax	46

Future Low Toxicity Smokes



Sucrose	14
Potassium Chlorate	23
Magnesium Carbonate	6
Terephthalic Acid	54

Future Low Toxicity Smokes

Sucrose	14
Potassium Chlorate	23
Magnesium Carbonate	6
Terephthalic Acid	54

Where is the Peanut Butter Smoke ???

Peanut Butter

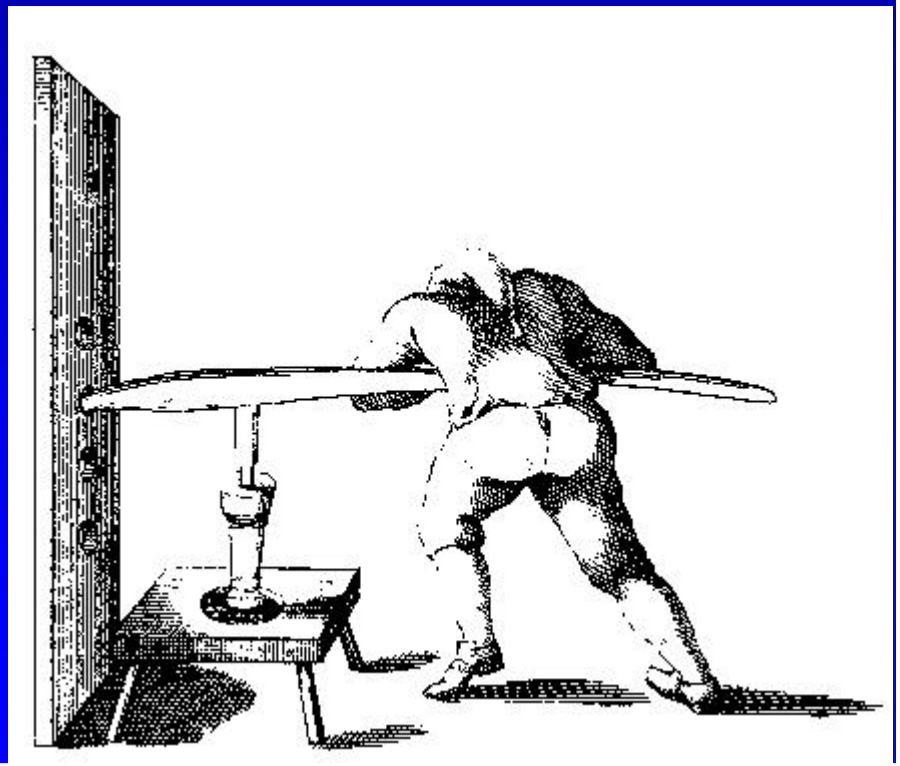
Popcorn

Sucrose	28
Potassium Chlorate	40
Magnesium Carbonate	32

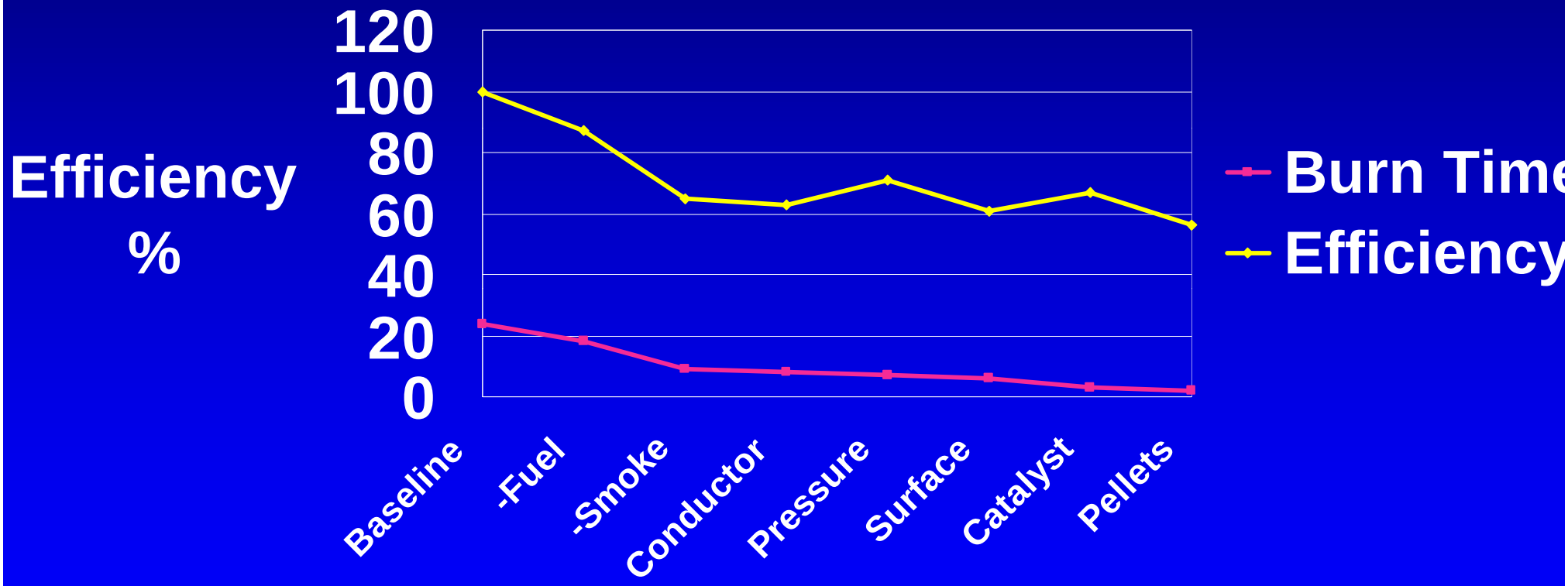
Coffee

Chocolate

Fast Burning Smoke Item Design

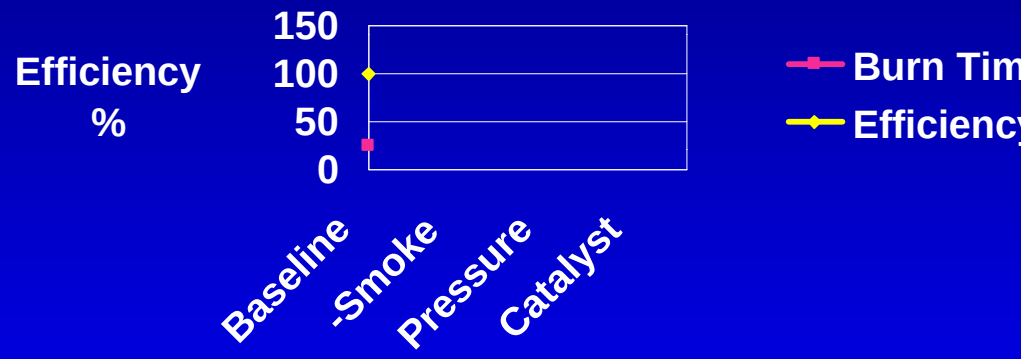


Fast Burning Smoke Item Design



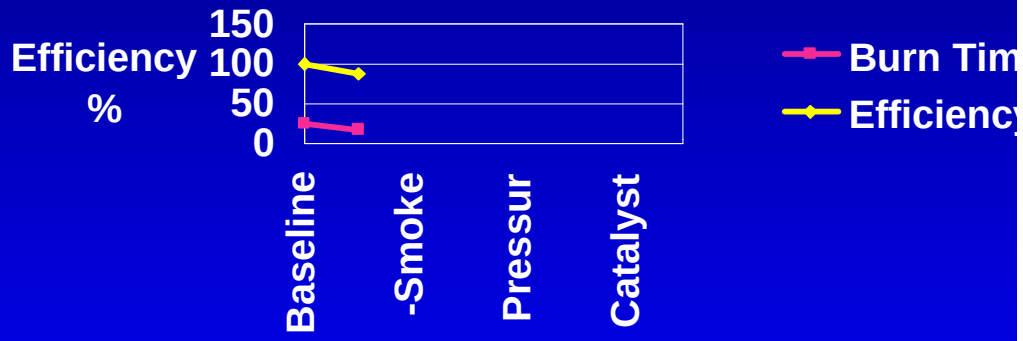
Fast Burning Smoke Item Design

- The stoiometric blended composition begins at a burn time of 24 seconds for a hand sized device.



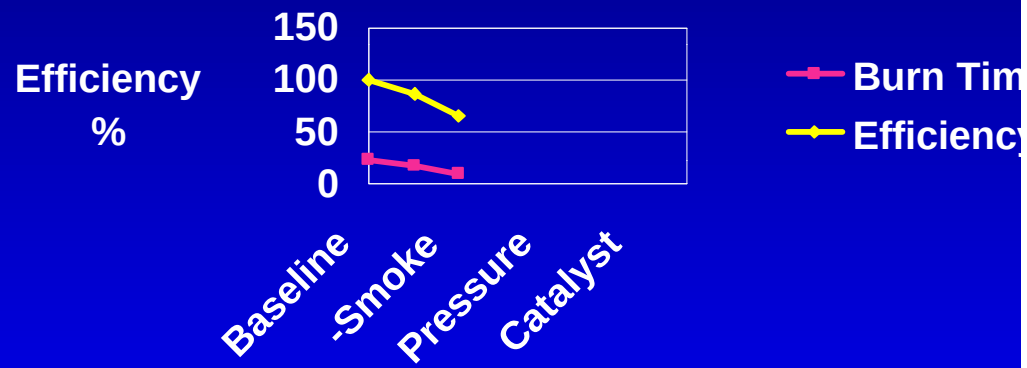
Fast Burning Smoke Item Design

- By decreasing the fuel / oxidizer ratio the burn time is reduced to 18 seconds. This increases the available oxygen to the fuel due to brute force.



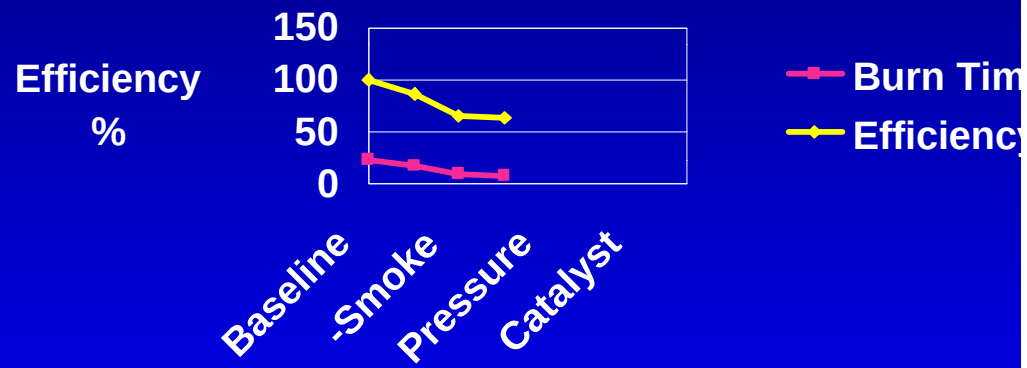
Fast Burning Smoke Item Design

- A burn time of 9 seconds is then achieved by reducing the smoke material in the composition. This works well as there is now less of a "heat sink" material in the device.



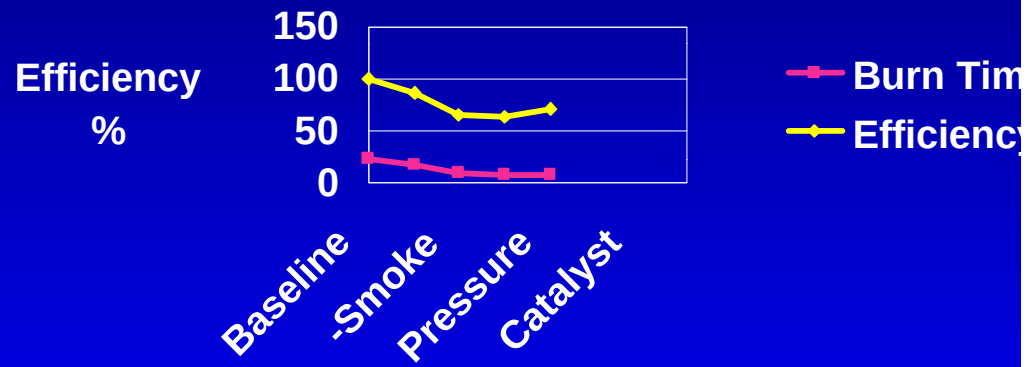
Fast Burning Smoke Item Design

- A one second drop in burn time to 8 seconds is possible with the addition of ten percent by weight of fine powdered aluminum. This improves the thermal conduction of the composition while providing a highly energetic fuel.



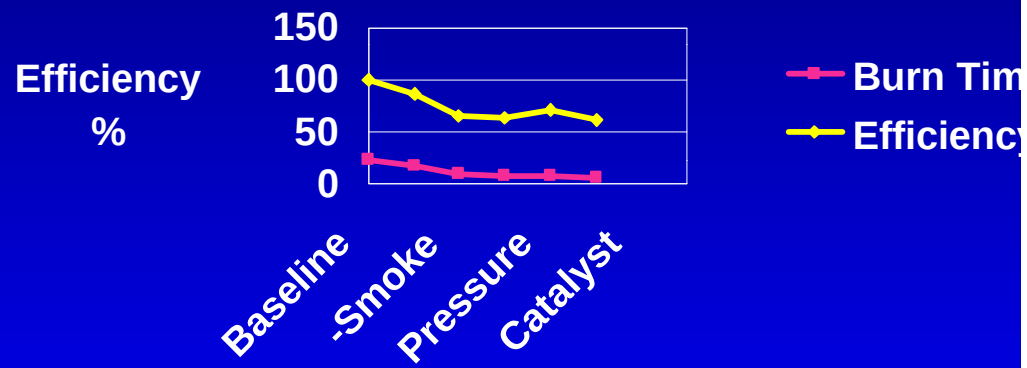
Fast Burning Smoke Item Design

- A burn time of 7 seconds is possible when the exit orifice diameter is reduced from 0.3125" to 0.1875" in diameter. The increased back pressure increases the rate of reaction.



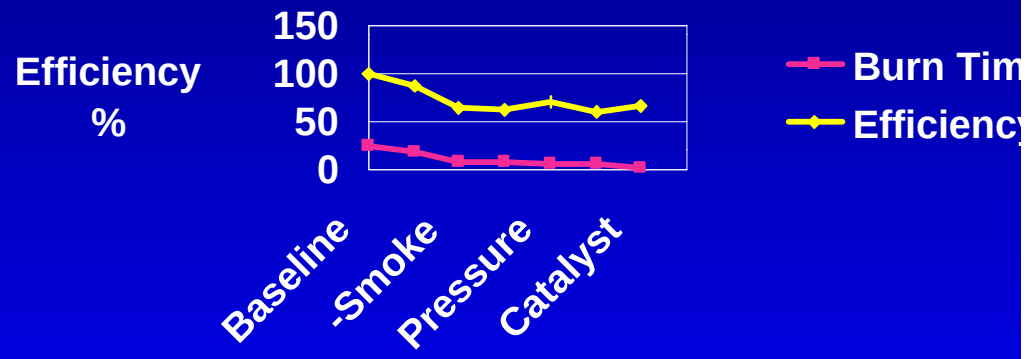
Fast Burning Smoke Item Design

- A 6 second burn time is achieved by increasing the amount of material ignited at the beginning of the burn. The center core diameter is enlarged from 0.312" to 0.500 inches in diameter.



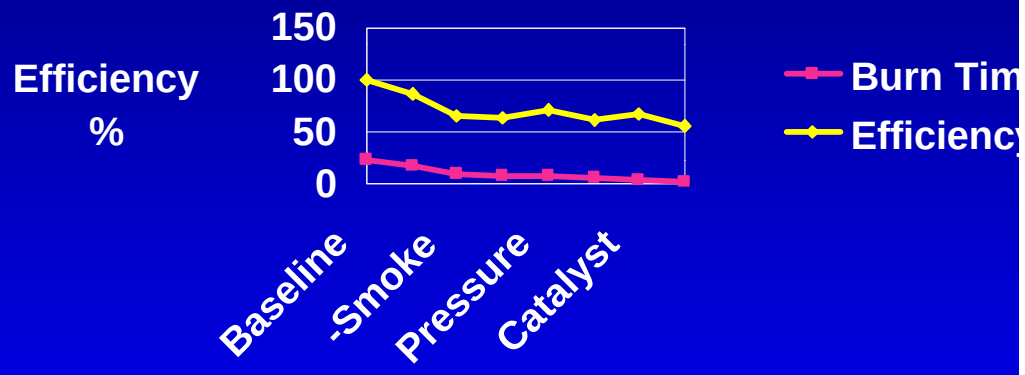
Fast Burning Smoke Item Design

- By adding 2 percent of iron oxide the burn time drops to 3 seconds. The catalytic effect causes a 50% reduction in the burn time.



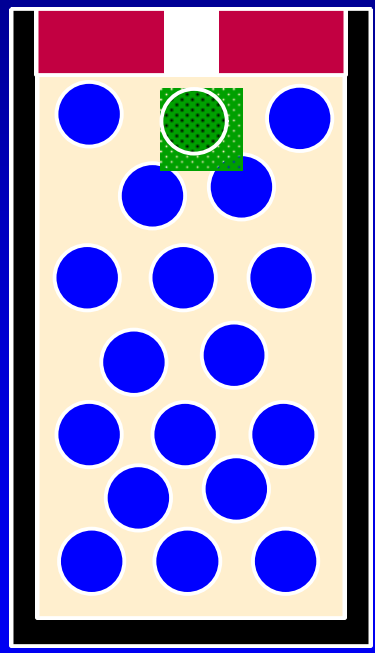
Fast Burning Smoke Item Design

- Finally, by pressing the composition into 1/8" by 1/8" pellets and placing them in the same container, the burn time drops to a low of 1.8 seconds. Any additional drop in the burn time will destroy the integrity of the canister.



Fast Burning Smoke Item Design

Modification	Burn Time (seconds)	Efficiency (percent)
Basic Mix	24.0	100
Decrease Fuel	18.0	87
Decrease Smoke	9.0	65
Thermal Conductor	8.0	63
Pressure	7.0	71
Surface Area	6.0	61
Catalyst	3.0	67
Particle Size	1.8	53



Cast HTPB Propellants

Cast HTPB Colored Flames

Red

Purple

Cast HTPB Based Smokes

White Smoke

Black Smoke

Accident Summary

for Pyrotechnic Mixtures*

Type	Number	Percentage
Primers	12	2.0
Flares	21	3.6
Smokes	385	66.8
Gas	35	6.0
Noise	7	1.3
Heat	59	10.3
Delays	2	0.3
End Items	56	9.7

40% of all accidents were during pressing

Go, Make Smoke, and Stay Green!