Experimental Support of a Slow Cookoff Model Validation Effort

Weapons Division
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Technical Challenge

- **To generate a set of experimental data that can be used to validate cookoff models currently under development**

Prediction capability for not only time to reaction but reaction violence

Why Bother?

Cookoff hazard - Four Carriers

USS Oriskany (1966)	**44 killed, 156 injured, 3 aircraft destroyed, $63.6M**
USS Forestal (1967)	**134 killed, 162 injured, 21 aircraft destroyed, 43 aircraft damaged, $758M**
USS Enterprise (1969)	**28 killed, 343 injured, 15 aircraft destroyed, 17 aircraft damaged, $554M**
USS NIMITZ (1981)	**14 killed, 48 injured, 3 aircraft destroyed, $150M**

220 killed, $1525.6M - None under attack

Needs

- Ship Commanders need information
  - How long sailors have to fight fire?
  - What are the most vulnerable munitions?
  - Can munitions load-out reduce vulnerability?
  - What are the consequences of cookoff reaction?

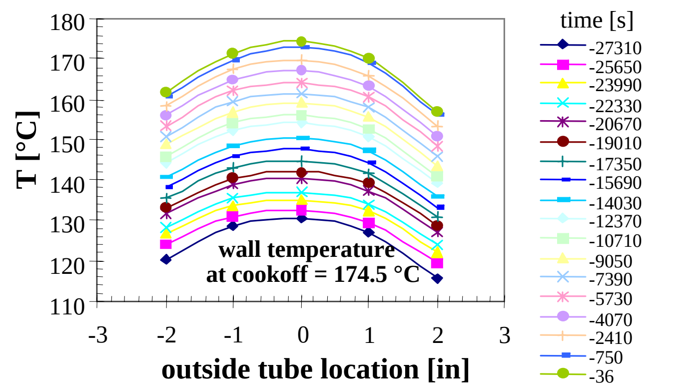
Leveraged Program

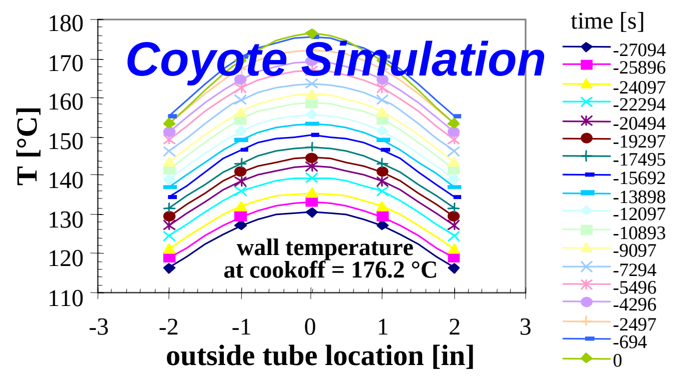
- Joint effort between Navy and DOE
  - Navy working under ONR
    - NAWCWD-CL
    - NSWC - IH
  - DOE working under MOU
    - LLNL
    - SNL
    - LANL (partial)

Approach

- **Three year project initiated by DOD Office of Munitions based on meeting success criteria**
  - **Time to reaction ± 10 %**
  - **Temperature at reaction ± 10 %**
  - **Degree of reaction violence**
  - **Location of reaction**
  - **Extent of reaction**
- **Phase I (FY00)**
  - **Simple geometry**
  - **Single sample**
- **Phase II (FY01/02)**
  - **Increased geometric complexity**
  - **Different materials**
- **Phase III (FY02/03)**
  - **Predict ordnance item in cookoff**

NAWC Experiment (5/10)



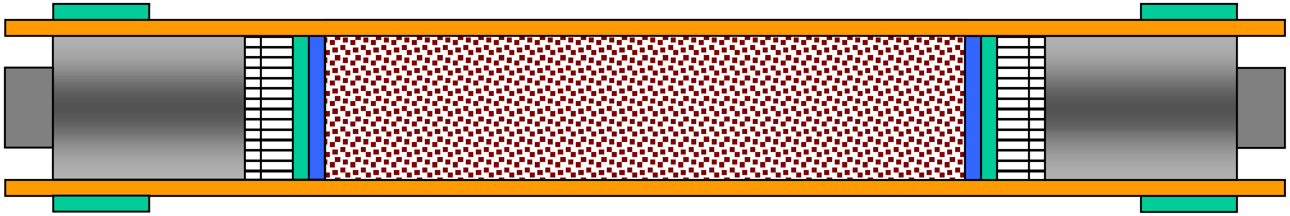


Phase I

–Simple geometry

–Single sample

Phase I Test Fixture



Type 4130 Steel
Tube Length ~ 229 mm
Explosive Length ~ 102 mm

Experimental Variables
- **Confinement**
- **Ullage**
- **Heating profile**

FORMULATION OF PBXN-109

COMPOSITION ANALYSIS

- **Mix 991206**

INGREDIENT	WEIGHT PERCENT
RDX	64.94
BINDER	14.09
ALUMINUM	20.97

Only mild reactions observed in all conditions tested

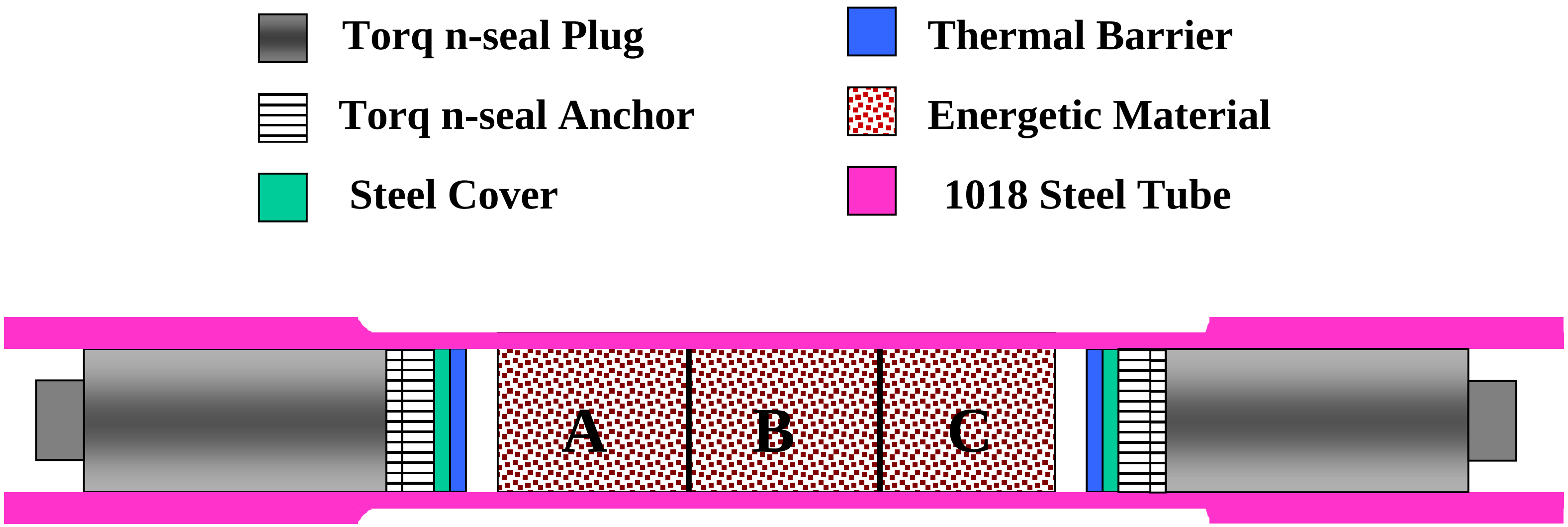
Phase II

- Increased geometric complexity
- Different materials

Phase II Energetic Materials

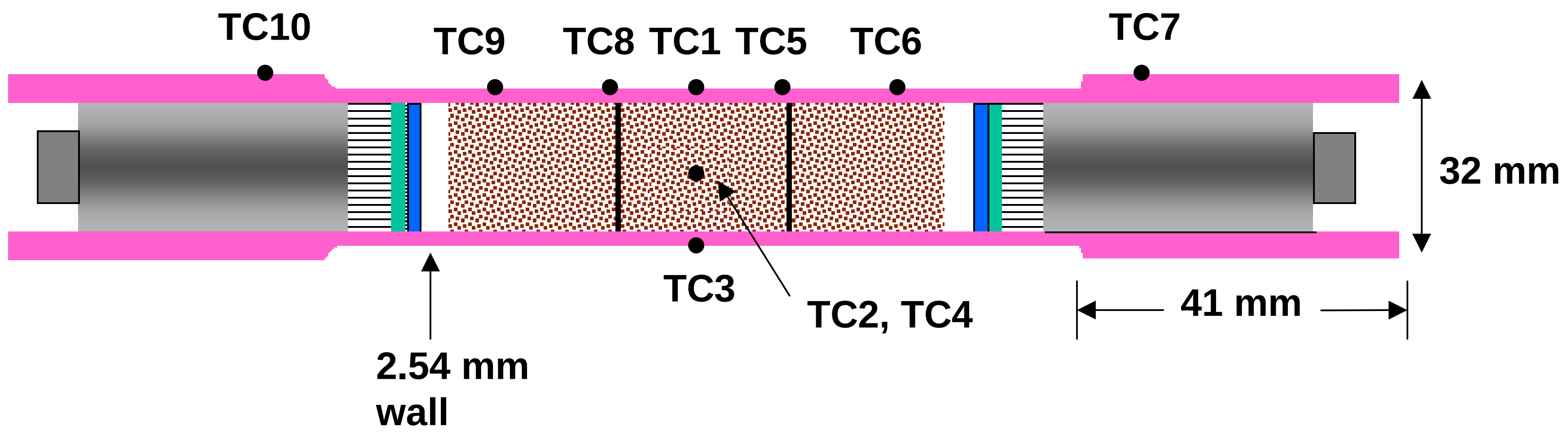
Energetic Material	Composition – Wt %
PBXN-109	65% RDX, 15% HTPB, 20% Al
LX-10	95% HMX, 5% VitonA
PBX9501	95% HMX, 2.5% BDNPF/A, 2.5% Estane
PS-1	70% AP, 10% HTPB, 20% Al

Type 1018 Steel Test Fixture

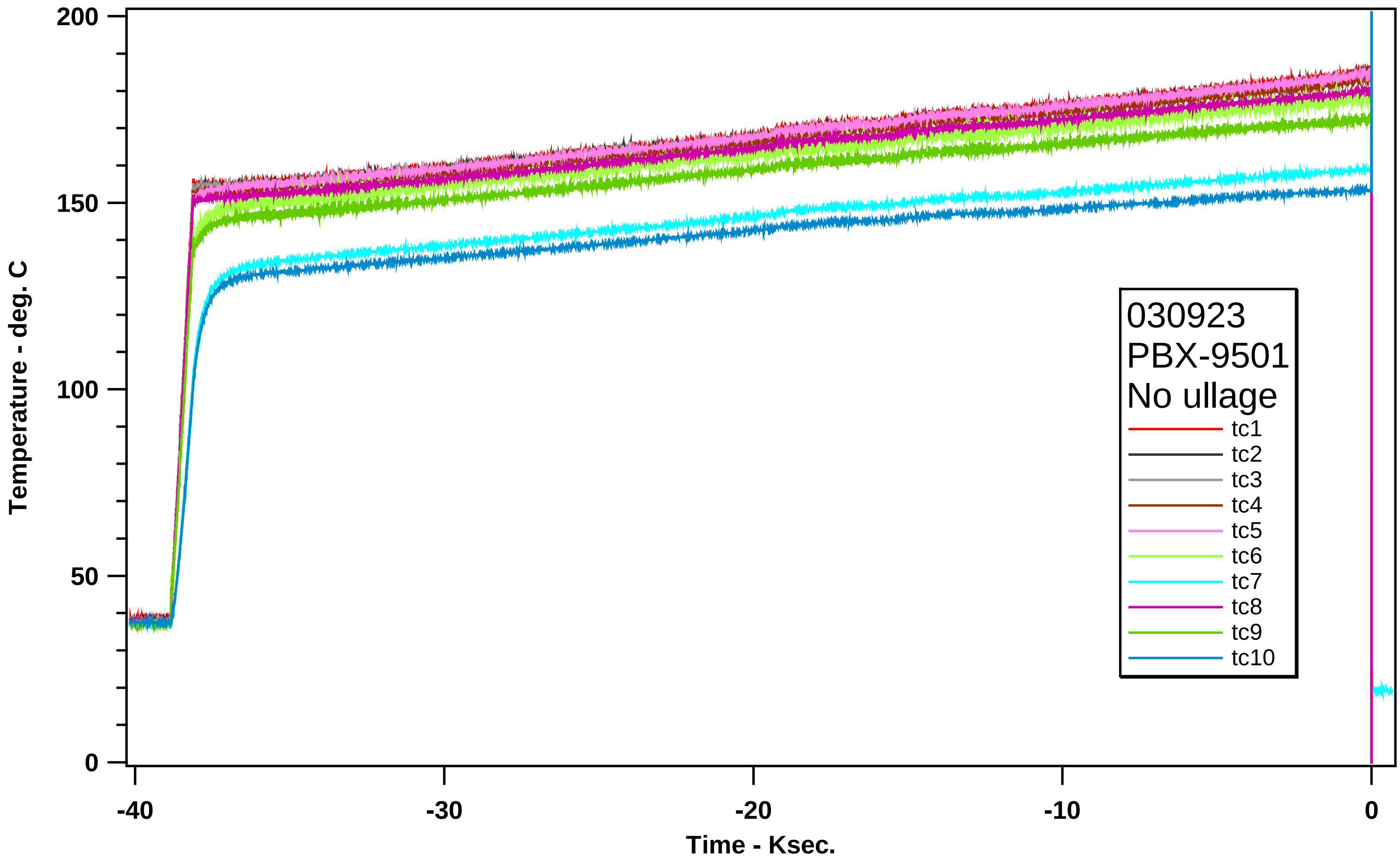


ID ~ 22 mm
Tube Length = 250 mm
Center wall = 2.54 mm
Explosive Length ~ 102 mm
65-95 grams energetic

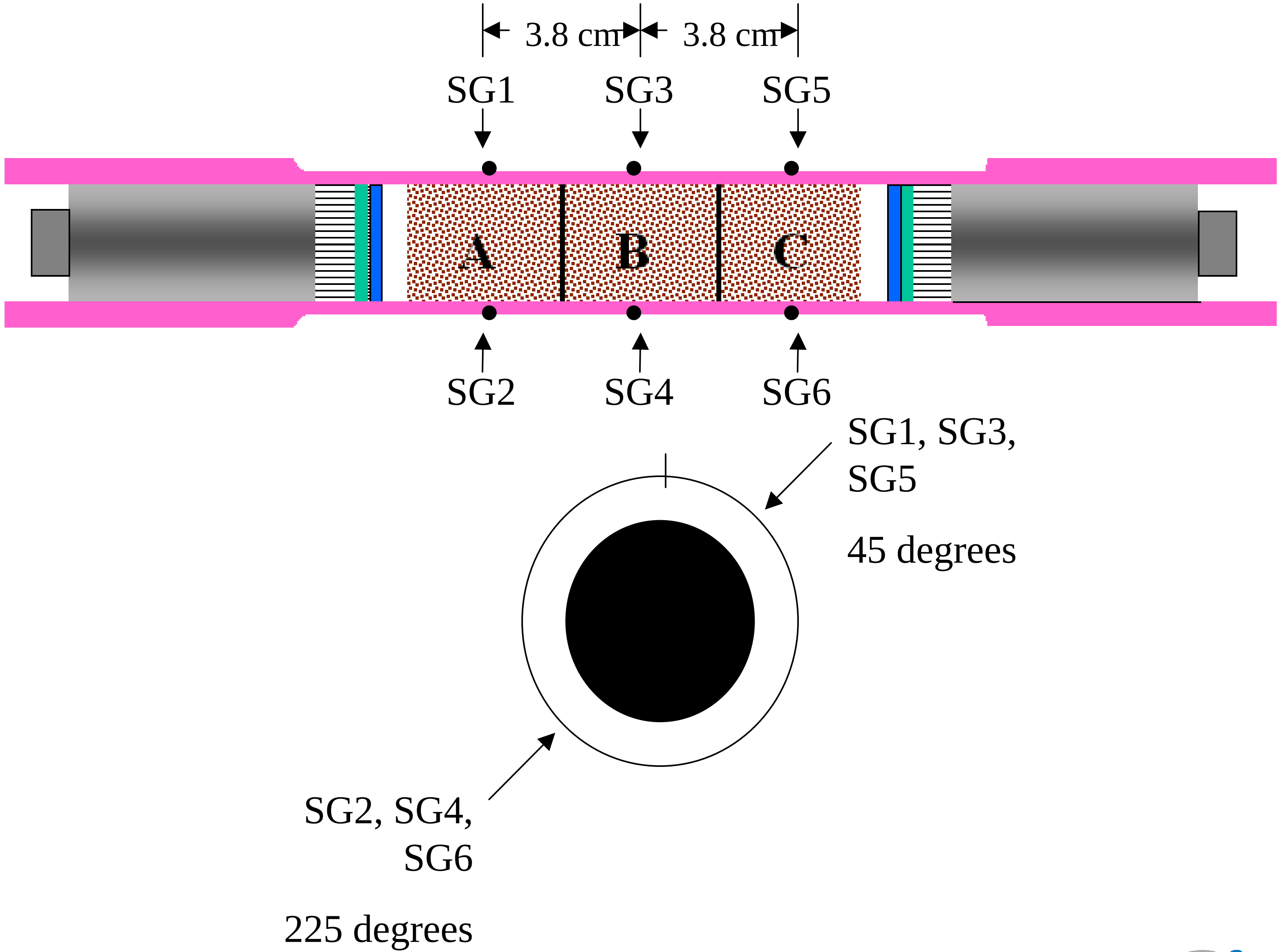
Thermocouple Placement



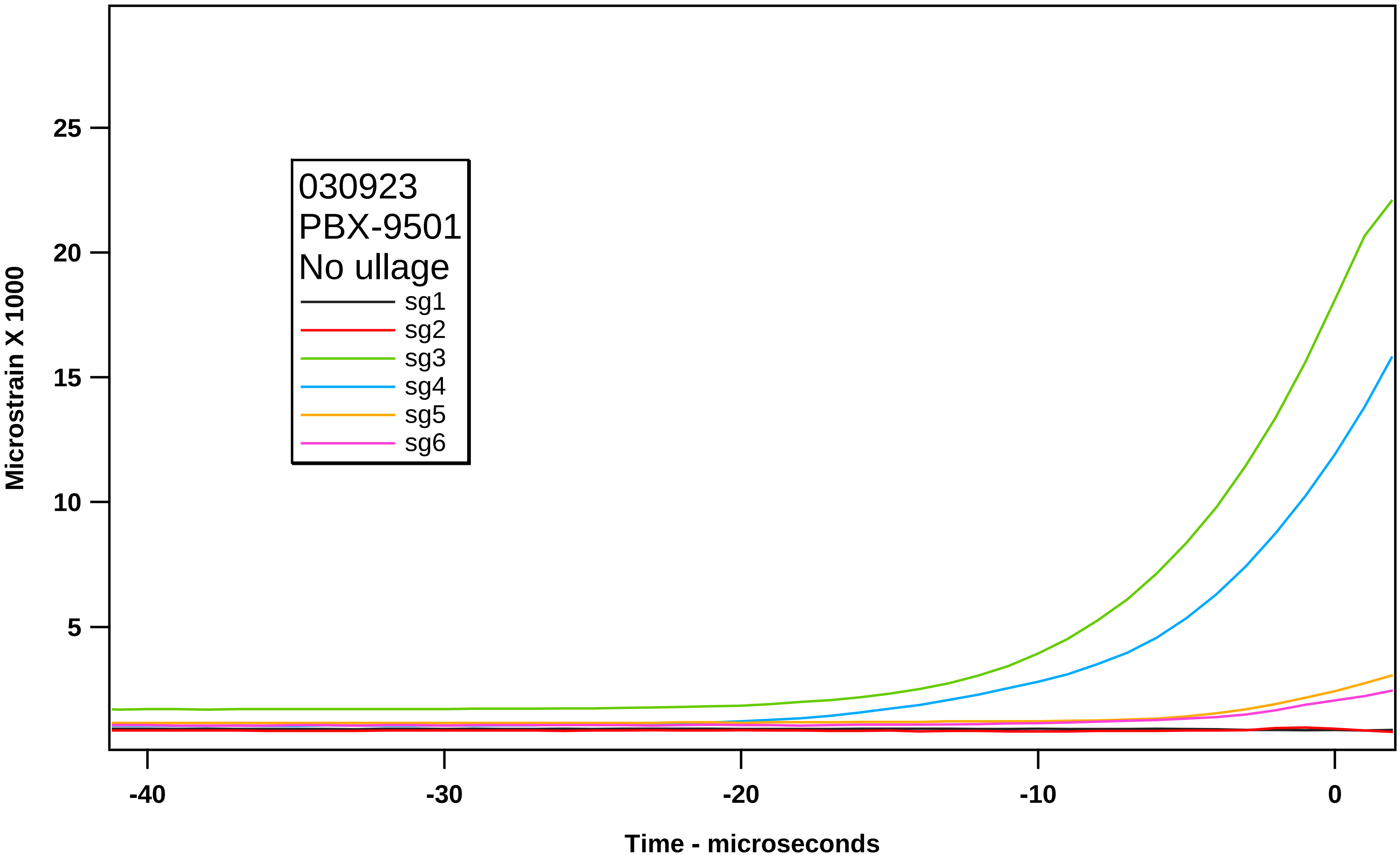
Thermocouple Data



Strain Gage Placement



Strain Gage Data



Phase II Results

Material	Free Volume - CC	Reaction Temperature, C	Fragments
PBXN-109	4	169.0	1
LX-10	6	205.0	9
LX-10	1	197.1	7
PBX9501	4	185.0	15
PBX9501	1	185.6	108
PS-1	4	238.0	3

Fragmentation

PBXN-109

PBX9501

Phase II Porosity Study

LX-10

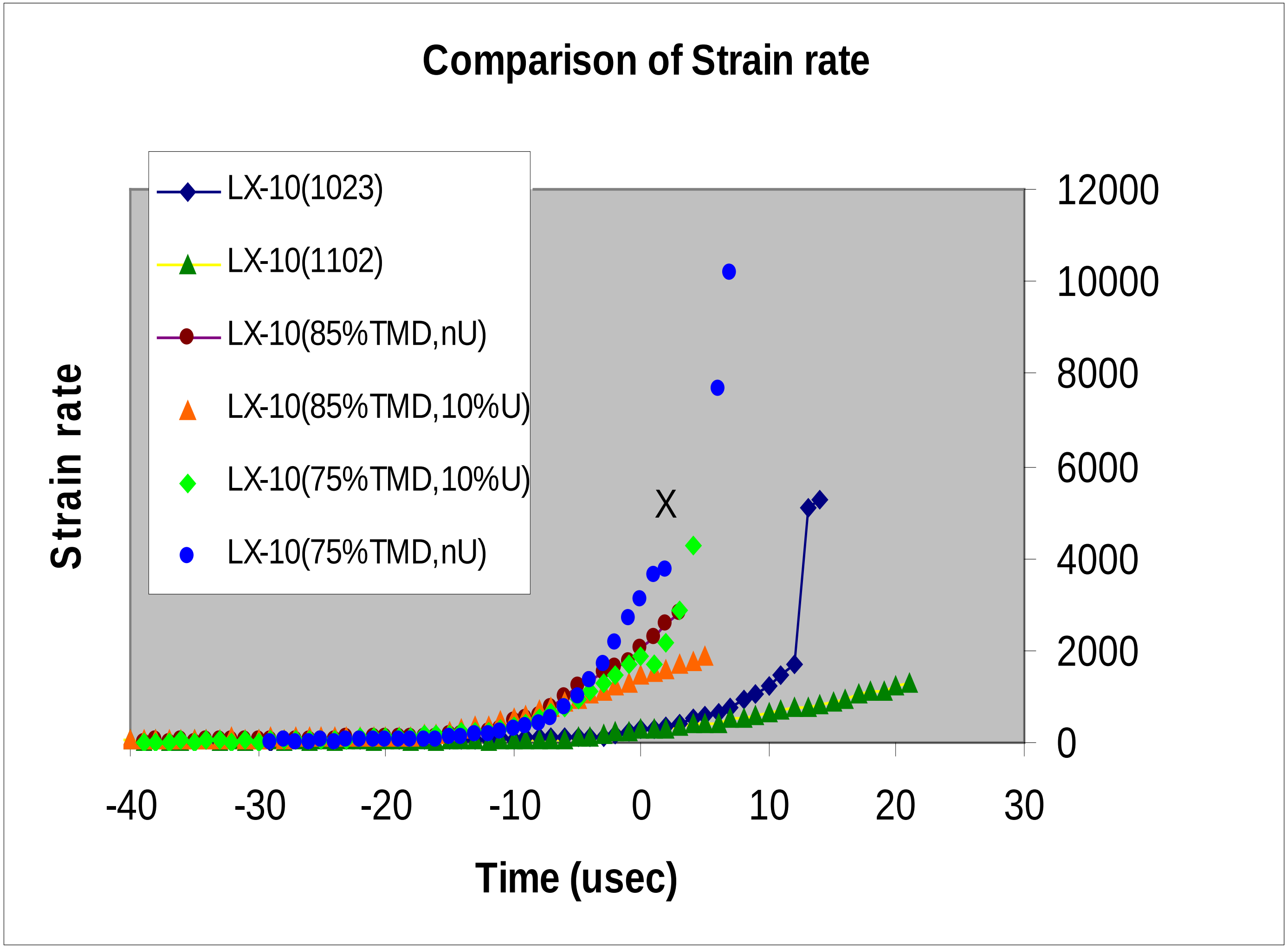
Percent TMD	Free Volume - CC	Reaction Temperature, C	Fragments
98	1	197	7
99	6	205	9
85	10	204	15
85	15	202	5
75	20	202	208
75	25	203	15

LX-10 Porosity Study

98 %TMD, 1 cc free volume

75% TMD, 20cc free volume

LX-10 Strain Rate Comparison



Phase III

– Predict ordnance item in cookoff

Phase III
Heavywall Penetrator (HWP)

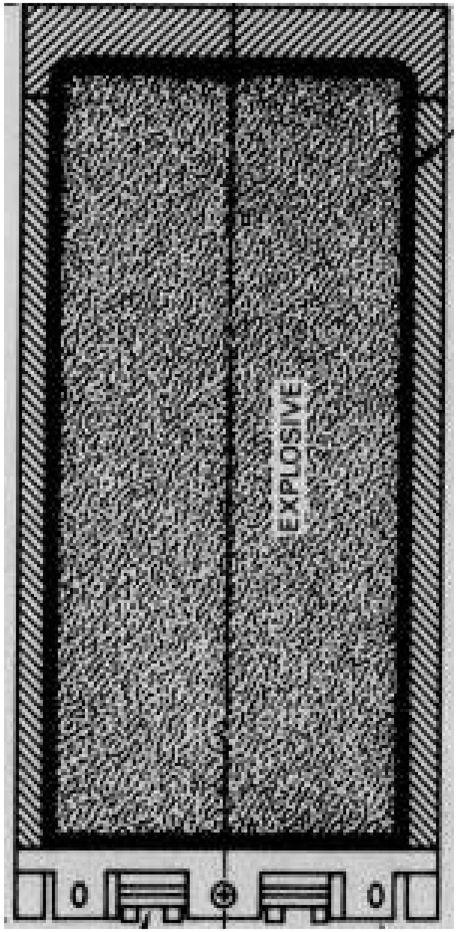
- **Dimensions**

Total Length	17.8"
Outer Diameter	8.0"
Wall	0.5"
Aft Plate	0.5"
Nose Plate	1.5"
Liner	0.06"
Interior Volume	573.6 in^3

- **Weights**

Empty	81.2 lb
Typical Load	33.8 lb
Total	115.0 lb

- **Material** 4130 steel

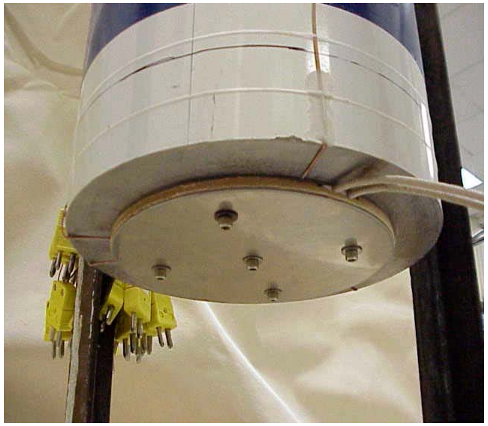


Modified HWP Aft Closure

HWP - Two heating configurations

Configuration 1

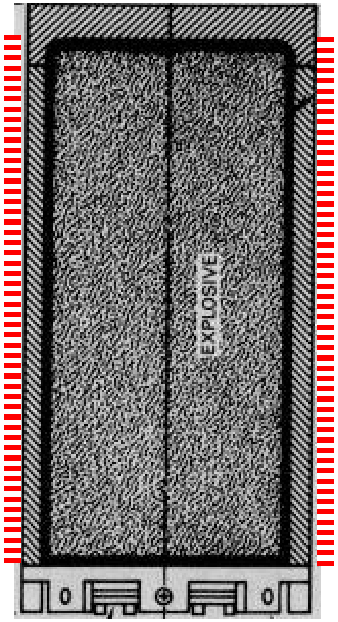
End heating

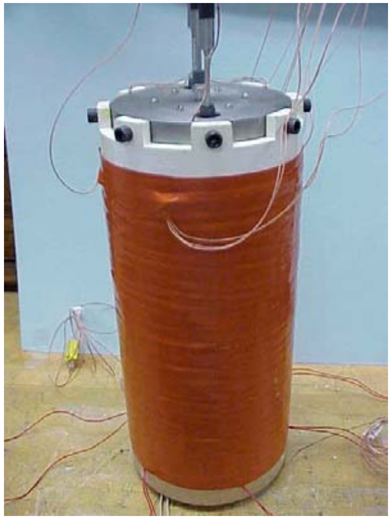


Mica

Configuration 2

Side heating





Silicon Rubber

<u>Configurations 1 and 2</u>

Quick ramp to 150 deg C

side = 3.3 deg C/min

end = 2.6 deg C/min

Soak 5 hours

Slow ramp at 0.05 deg C/min

Sample

- Inert Explosive – one HWP cast

Ingredient	Weight percent
Glass beads	71.3
Binder	28.69
Blue dye	0.01

- PBXN-109 – two HWP cast

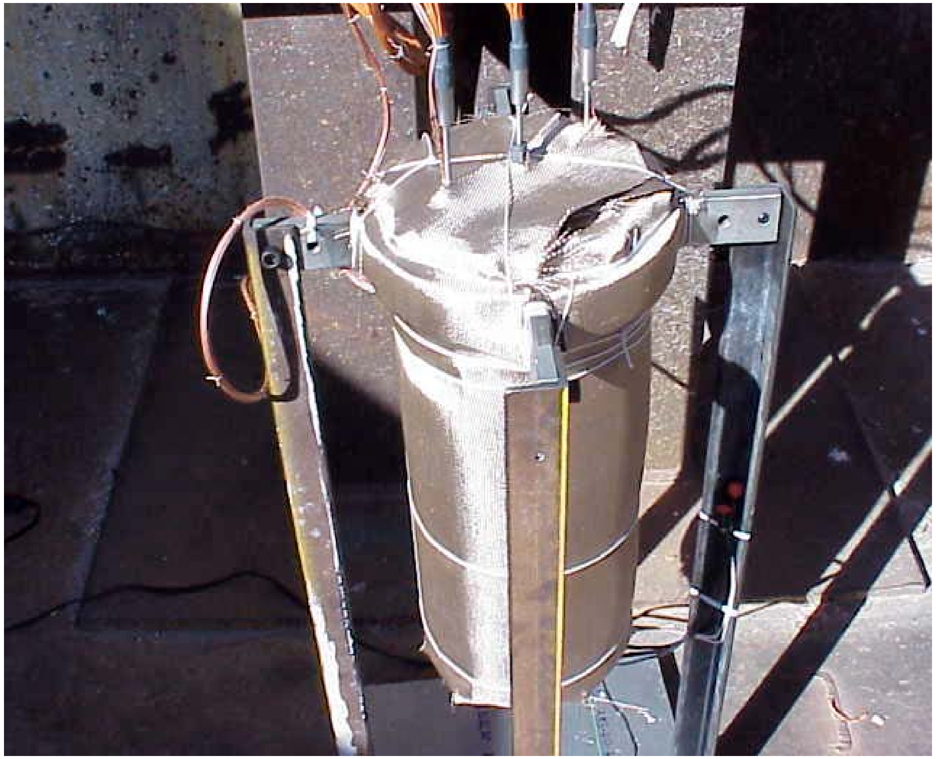
Ingredient	Weight percent
RDX	64.87
Binder	15.62
Aluminum	19.51

HWP Results

- **End heated**
  - **Cookoff at 1015.0 min (16.9 hr)**
  - **Maximum temperature of 181.4 ºC at control TC (184.8 ºC predicted)**
    - **Externally mounted on down facing forward end**
    - **Ignition at center of forward end (as predicted)**
- **Side heated**
  - **Cookoff at 654.4 min (10.9 hr)**
  - **Maximum temperature of 176.6 ºC at internal TC in center about one inch from wall**
    - **External control TC at 163.8 ºC (165.5 ºC predicted)**
    - **Ignition off center near wall (as predicted)**

End Heated HWP

End Heated HWP

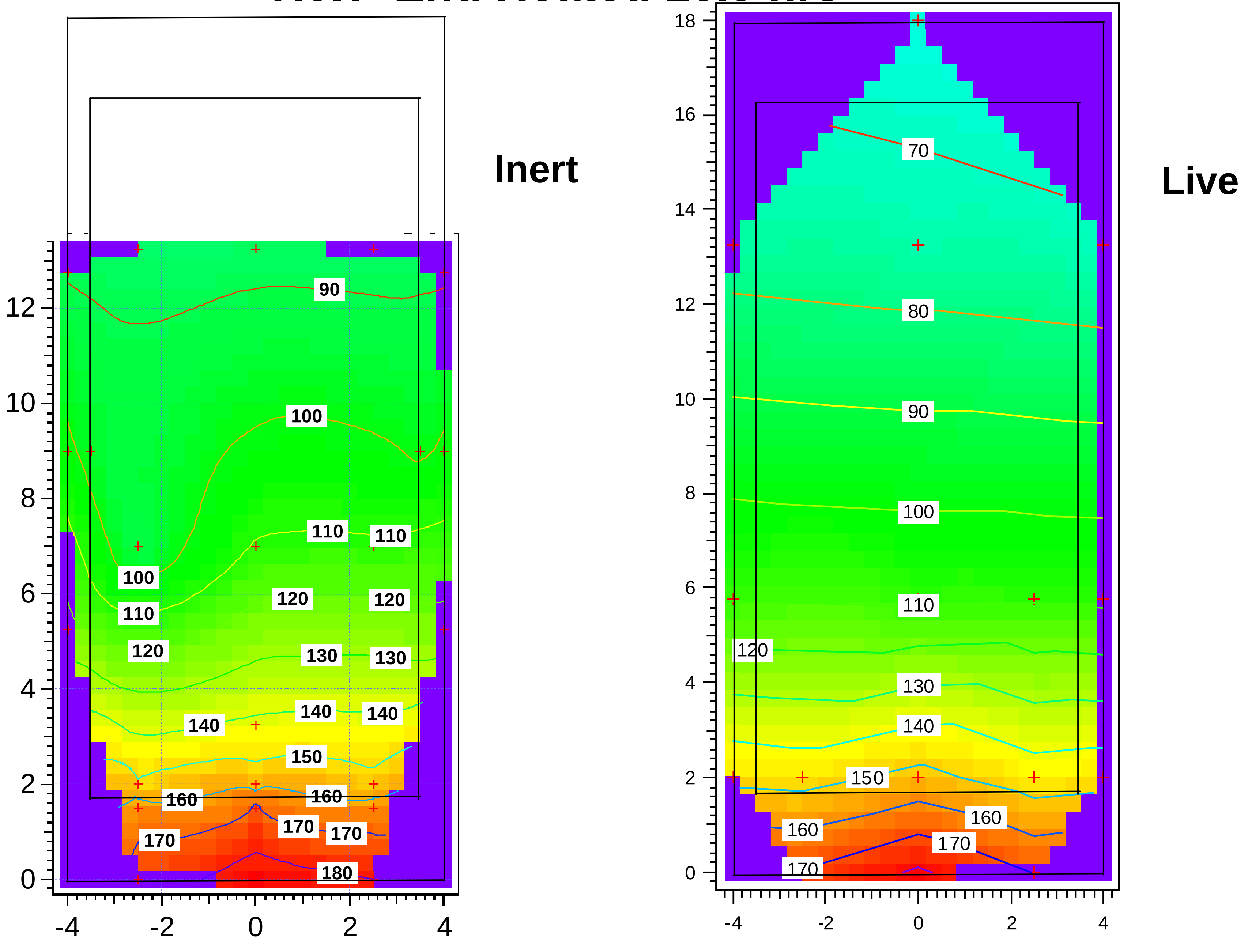


Mica Heater

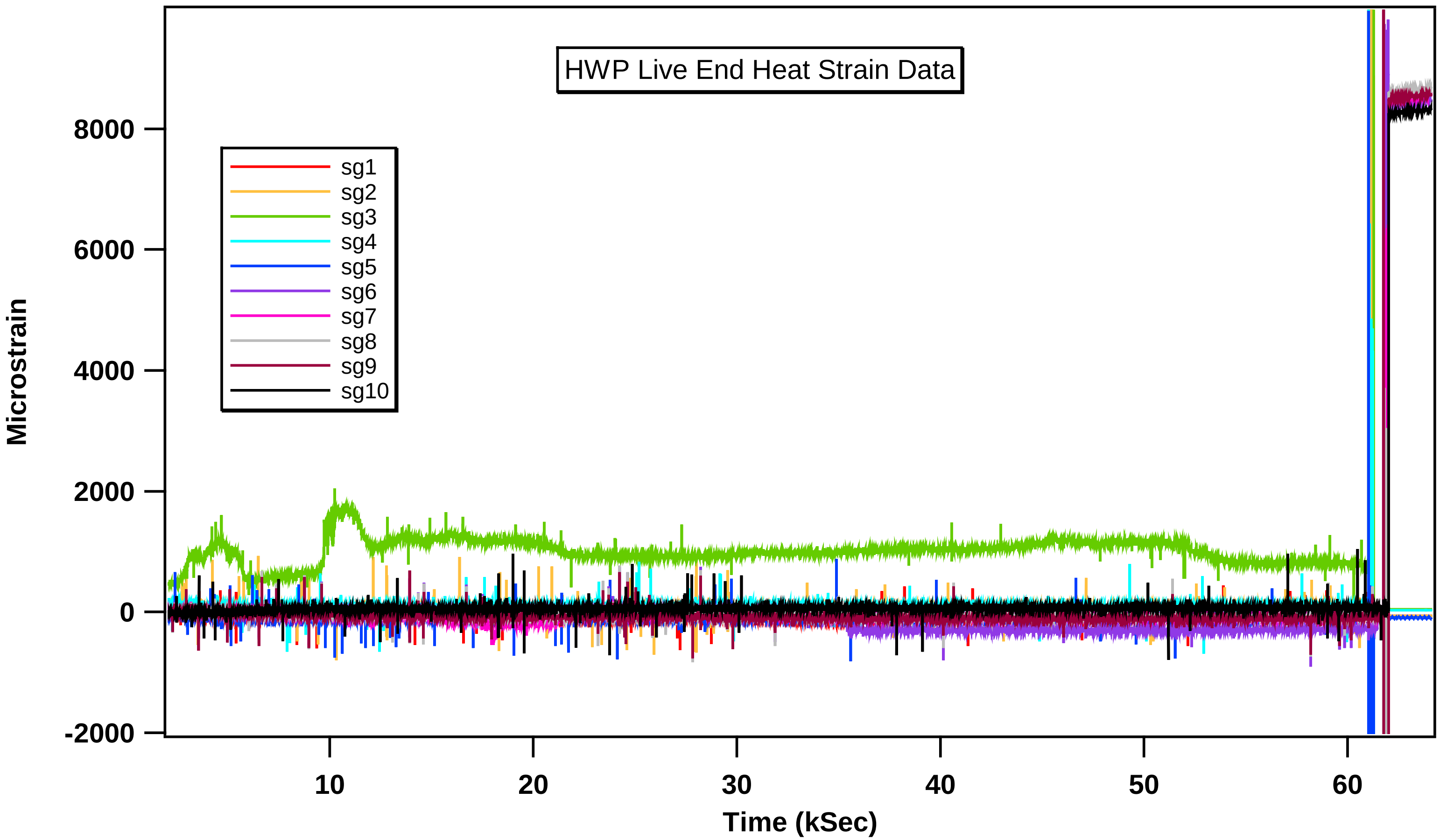
HWP End Heated PBXN-109

HWP at test site

HWP End Heated 16.9 hrs



Strain Gage Data

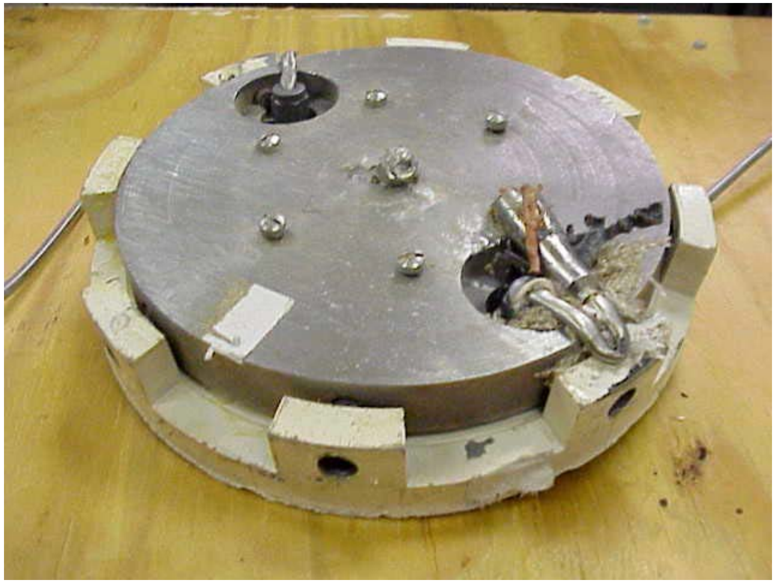


HWP End Heated PBXN-109

Post test

HWP End Heated PBXN-109

Recovered cylinder

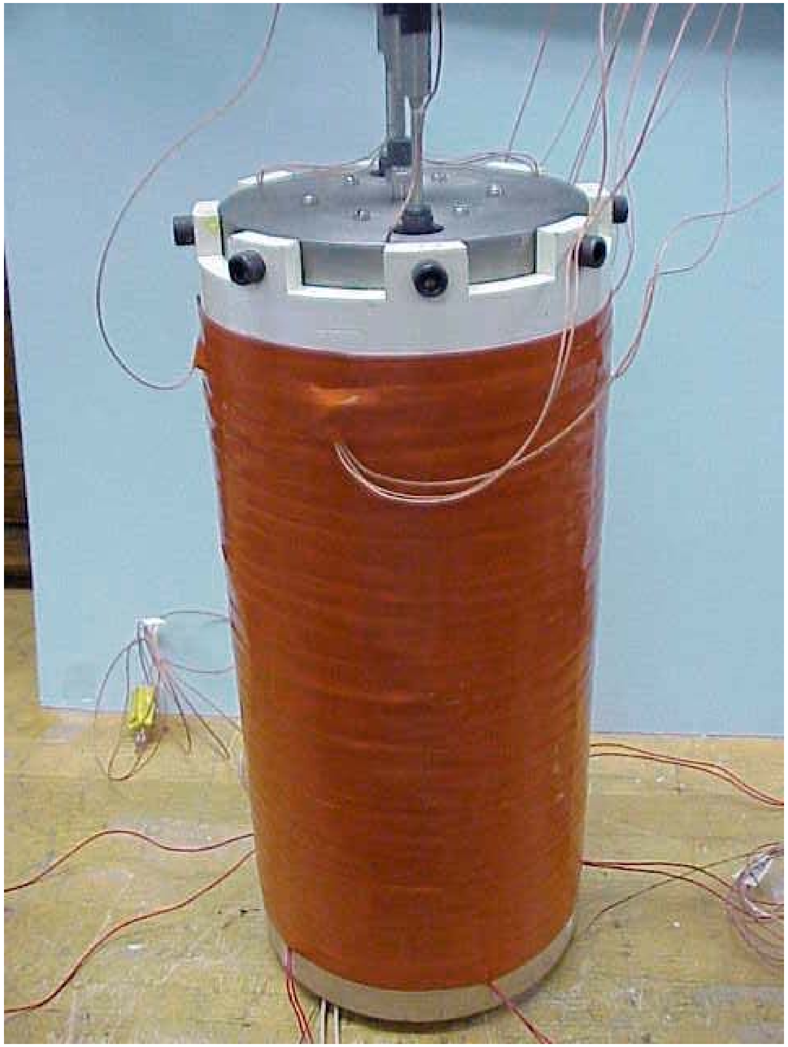


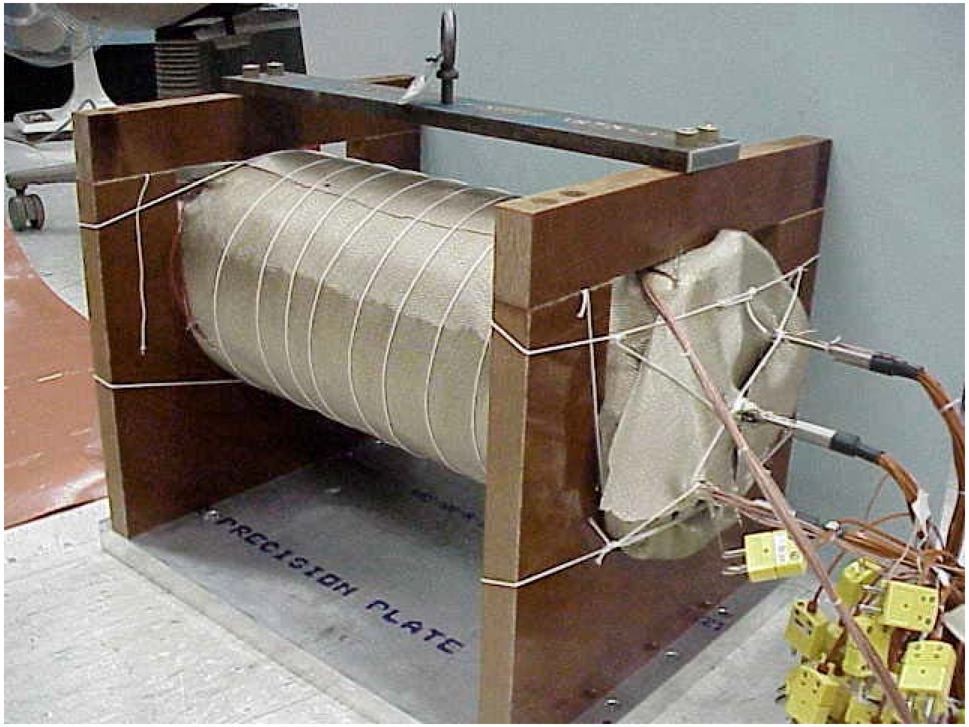
Exterior of aft end fragment
End plate in place - bolts sheared

30.56 lbs explosive recovered

Side Heated HWP

Side Heated HWP





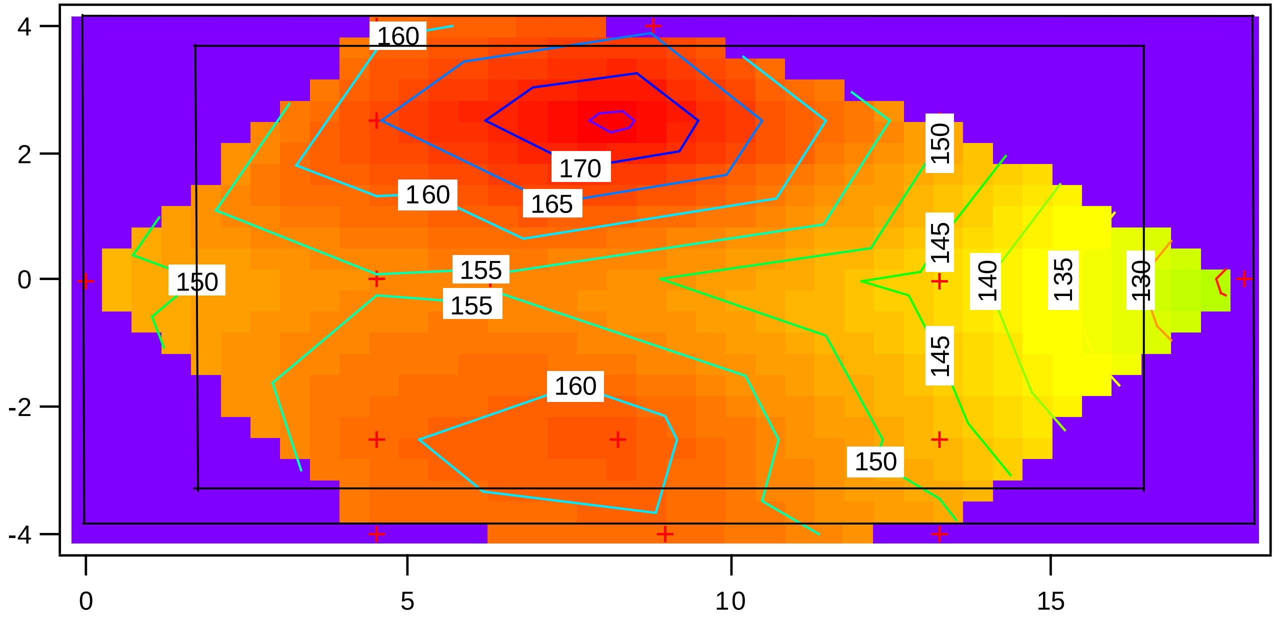
Silicon rubber heater

HWP Side Heated PBXN-109

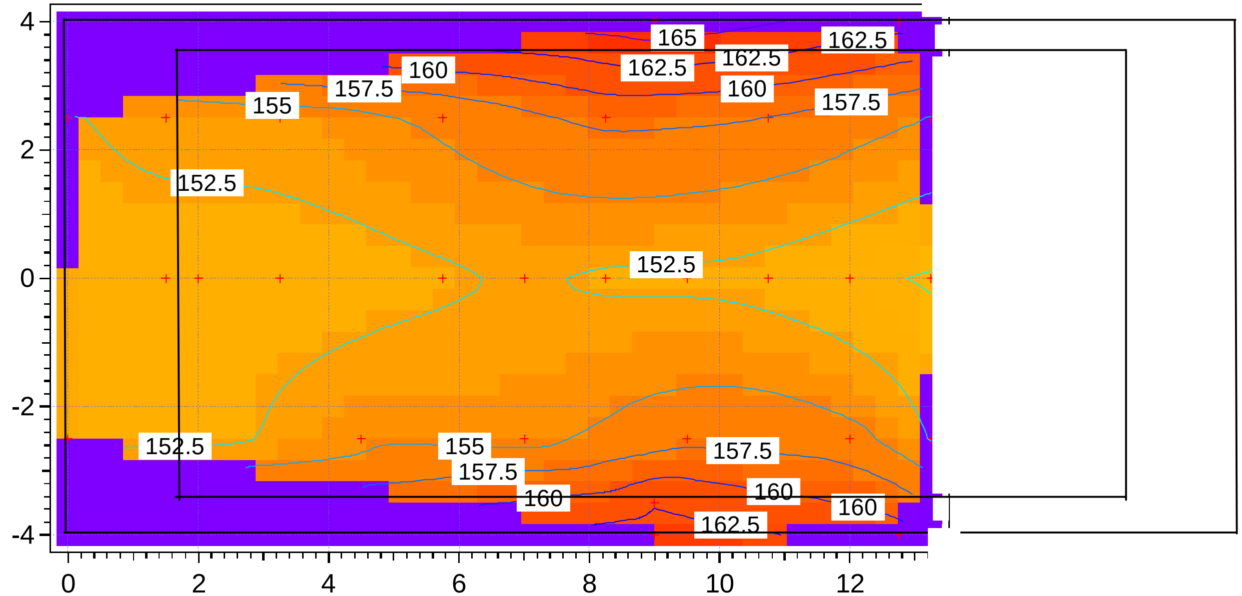
HWP at test site

HWP Side Heated 10.9 hrs

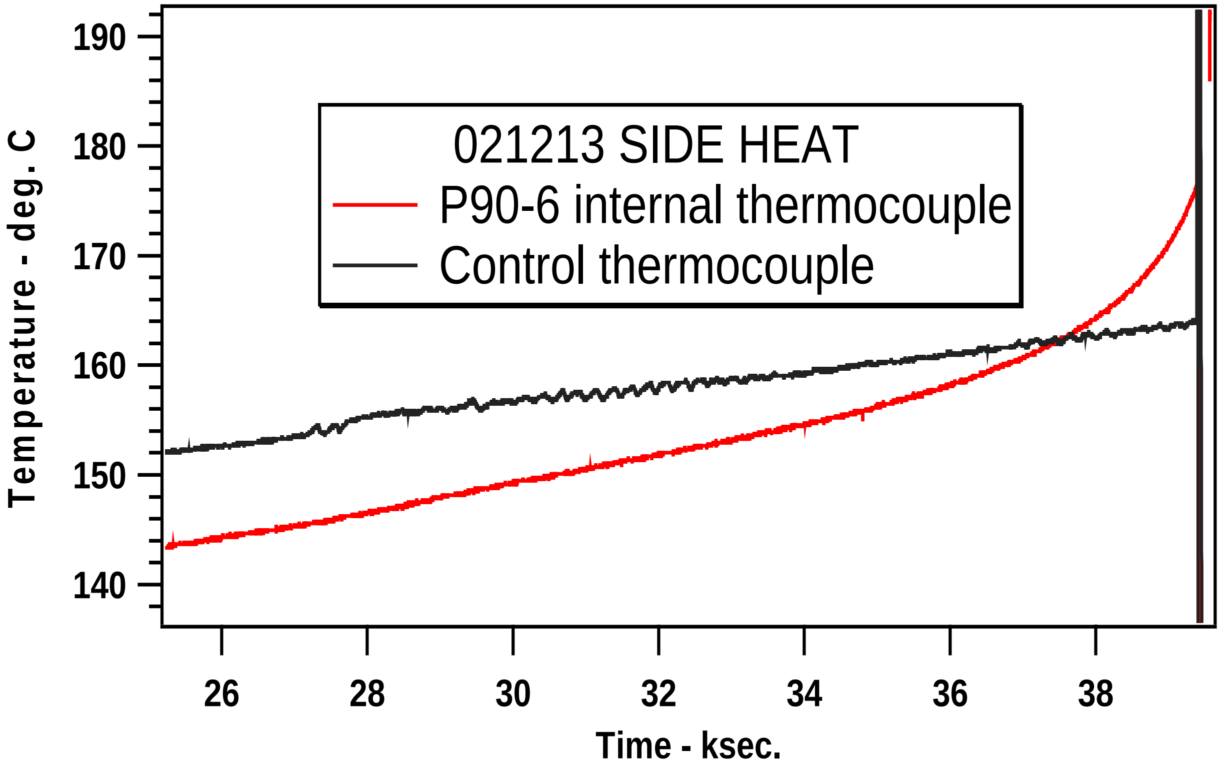
Live



Inert



Side Heated HWP

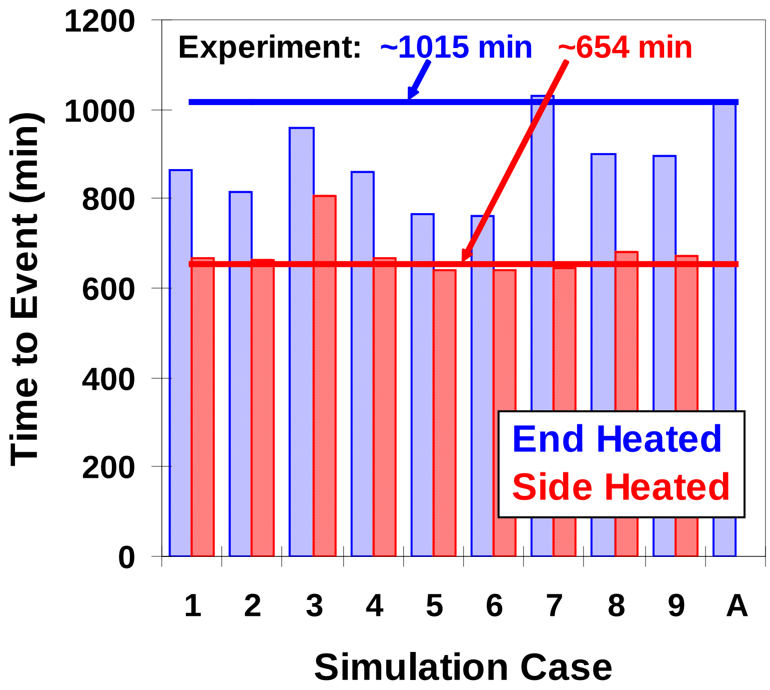


HWP Side Heated PBXN-109

Cylinder located 550 feet from test pad
Aft end fragment located 415 feet from test pad
9.44 lbs explosive recovered

HWP: Simulation vs. Experiment

Comparison with Simulation Results



Note: Cases 1-9 were *a priori* simulations, case A (end heated) was done afterwards.

- **Simulations were real predictions**
  (Inert tests were used to estimate heat loss BC's for live tests)
- **Data fell within range of predictions**
- **Improvements can be made with more thorough knowledge of boundary conditions**

Sandia National Laboratories

Accomplishments

- Slow cookoff model validation effort contributed to development of protocol for slow cookoff
- Platform for collaboration
  - Small scale experimental design
  - Placement of thermocouples and strain gages
- Range of reaction violence was demonstrated in small scale experiment
  - HMX containing explosives were most violent
  - Porosity contributes to reaction violence
- Full scale experiments demonstrated importance of geometry and boundary conditions
  - Initial ambient air conditions

Where do we go from here?

- Apply experimental and analytical tools to real problems and realistic heating profiles
  - Ordnance design
  - Fire fighting tactics
  - Magazine design
  - Captive carry
  - Development of a sub-scale bonfire test - TB700-2