Injection Loading Technology:

An Agile Unit Operation for Warheads

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IMAD (1991-2001)

- Dr. R. Bowen, and D. Porada (NAVSEA)
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SERDP/CAME (1993-1997)

- Dr. R. Miller, and Dr. J. Short (ONR)
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- L. Mondy (SNL)

MANTECH (1996-1998)

- NAVSEA (PMO-407)
- J. Brough, and R. Kaczmarek (NSWCIHD)

MANTECH (2002-2005)

- NAVSEA (PMS-529)
- NAVSEA (PMS-500)
- J. Brough (NSWCIHD)

Outline

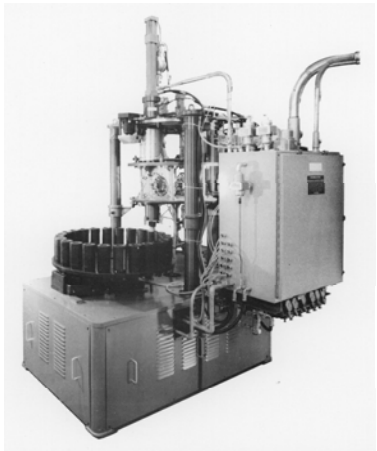
- Introduction
- Submunition Design
- Formulation Considerations
- Process Design
- Process Control
- Benefit
- Conclusion

Introduction

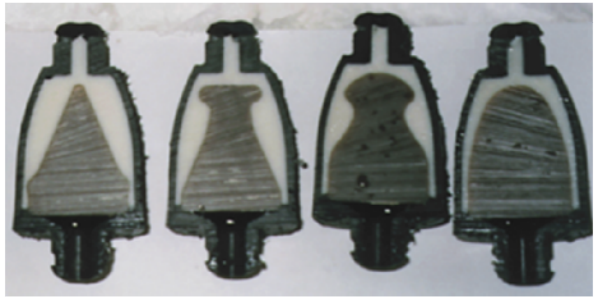
- Injection Loading Technology
  - Initial development under IMAD/HE
  - Demonstrations for ONR, SERDP, MANTECH
- PBX Materials
  - highly filled thermosetting polyurethanes
  - highly filled thermosetting polyacrylates
  - highly filled thermoplastic elastomers

Introduction

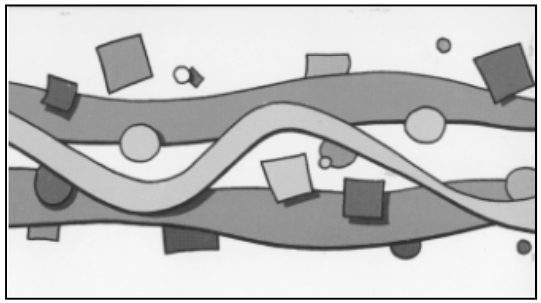
- **Injection loading of PBX into ordnance items requires an integrated approach**



Processing Engineers



Weapons Designers



Formulators

Introduction

- Navy has unique mission
  - Littoral Warfare *"from the sea"*
  - Using *"smart weapons"* from longer range
- Surface Strike issues
  - weapon expense limits number of rounds
  - submunitions provide better coverage (P_H)
  - need greater individual lethality than DPICM
  - considering unitary warheads for better P_K

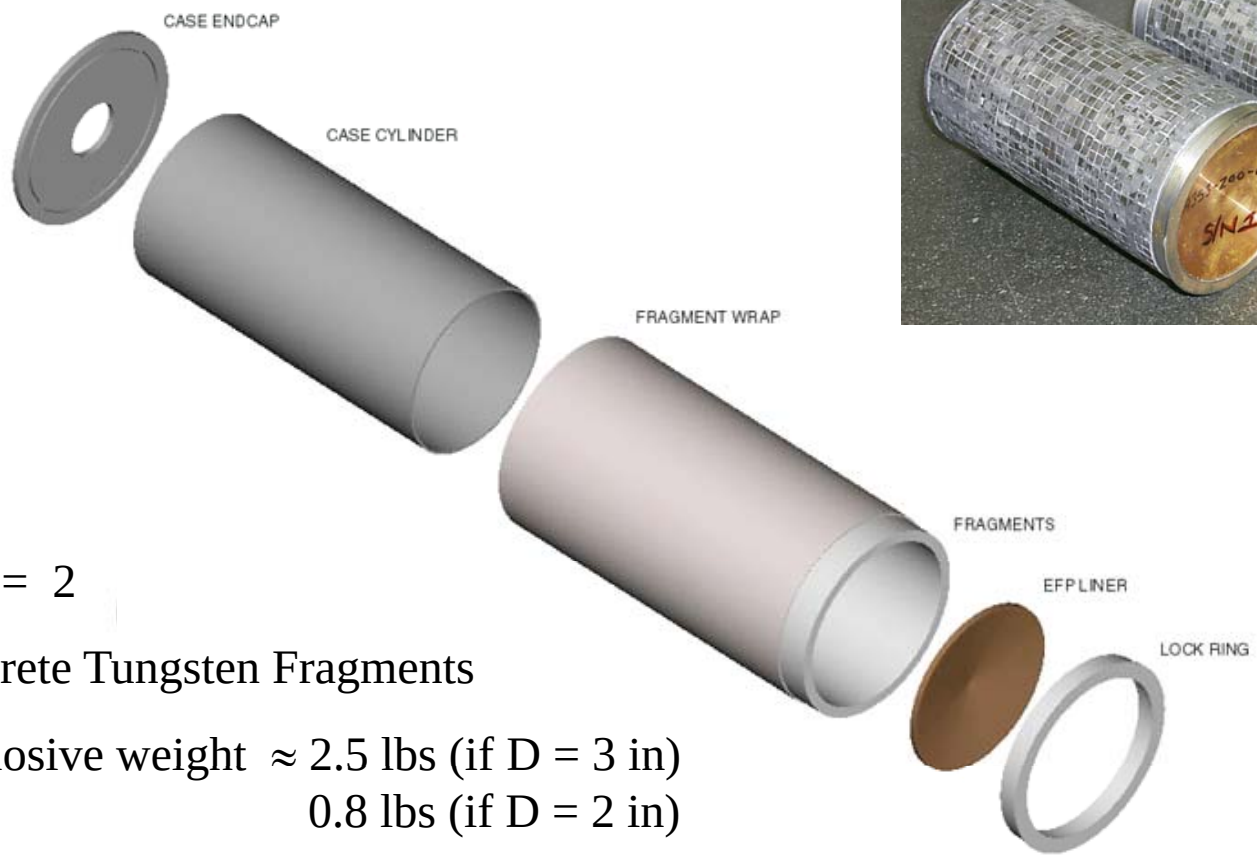
Submunition Design

- Larger submunition than DPICM
- Better fragmentation control
- Proximity fuze
- Long stand-off shaped charge liner
- Reliable and uniform dispense
- Aerodynamic stability during final descent

Submunition Design

- Possible composite construction
- Arrives to the L/A/P facility as one piece
- Small fill port on aft
- Adaptable for multiple port fill manifold
- Final assembly is cylindrical, for easy packaging

Submunition Design



L/D = 2

Discrete Tungsten Fragments

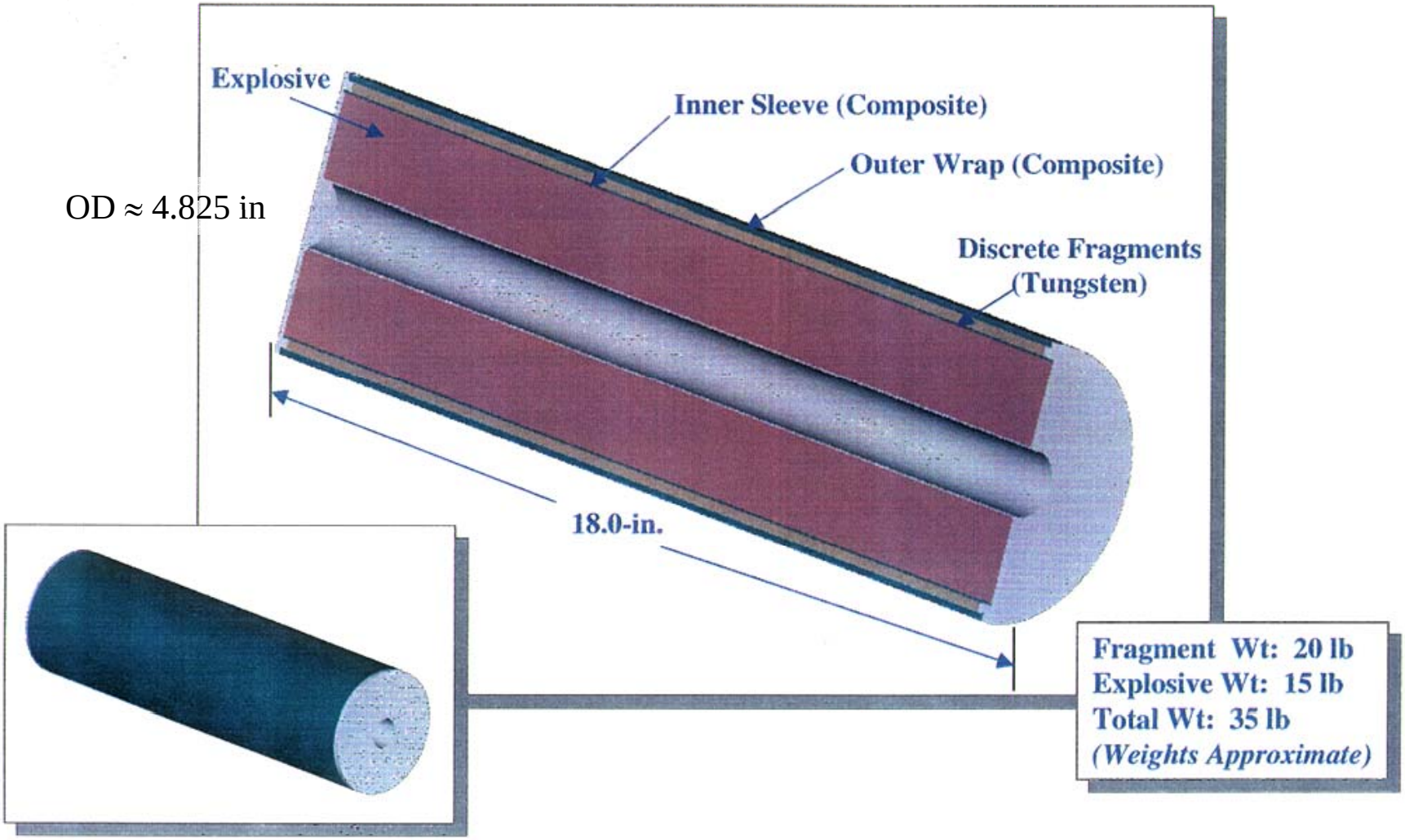
Explosive weight ≈ 2.5 lbs (if D = 3 in)
0.8 lbs (if D = 2 in)

Unitary Warhead Design

- Possible composite construction
- Arrives to the L/A/P facility as one piece
- Small fill port on aft
- Adaptable for multiple port fill manifold
- Large L/D ratio dictates high quality explosive load for safe gun launch

Unitary Warhead Design

OD ≈ 4.825 in



Formulation

- Fragmentation phenomenon is dependent upon shock physics
- Two IMAD/HE reports indicate that aluminized PBX can produce higher fragment velocities than non-aluminized PBX, if optimized

[1] NSWCDD TR-92/569 "Insensitive Munitions Advanced Development High Explosives Project: FY 91 Large-Scale Performance Testing of PBXC-129(Q)", Steve Collignon and Bill Burgess, February 1994.

[2] NSWCDD TR-98/45 "IMAD HE Project- Large Scale Fragmentation and Airblast Testing of Candidate General Purpose and Metal Accelerating Explosives", Bill Burgess, Steve Collignon, and John Leahy, June 1998.

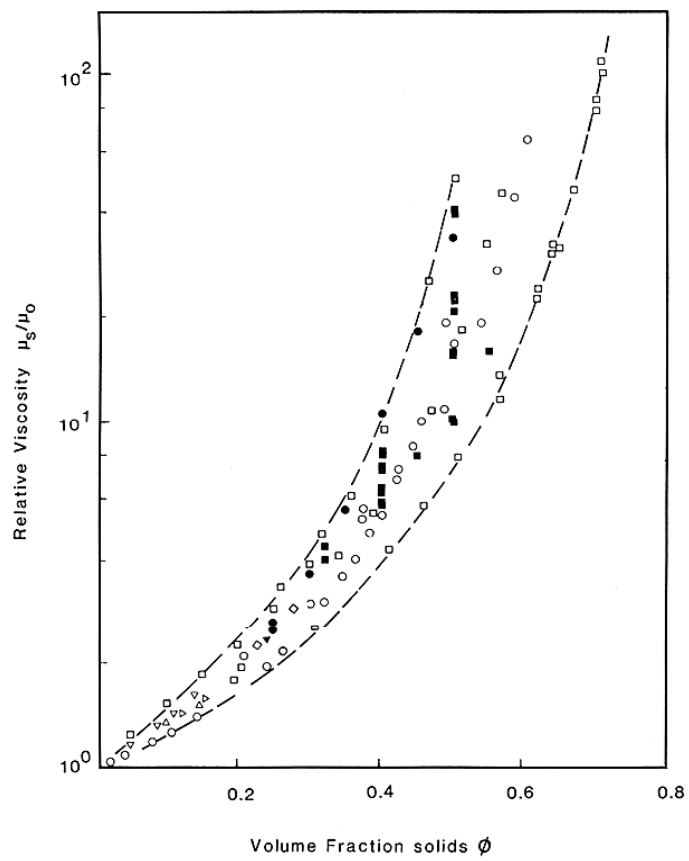
Formulation

- Experimental observation & explanation
  - Aluminum content *versus* fragment velocity
  - Impedance matching
- Approach
  - CYLEX testing of PBX formulations
  - Characterization of “late time event”
- Down-selection and Injection Loading
  - Plasticized polyurethane binder
  - HMX nitramine

Formulation

- We have investigated packing fraction maxima
  - using tri-modal particle size distribution allows a volume fraction of $\phi \geq 0.80$
  - relative viscosity function approaches infinity at maximum packing fraction

$$\mu_r = \mu_s/\mu_o = f(\phi/\phi_m)$$



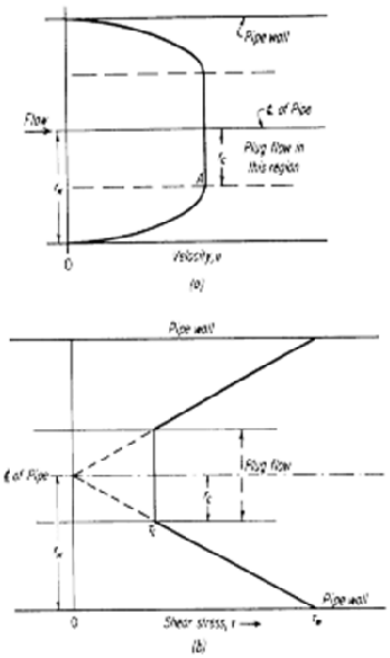
For mono-modal particle size distribution

Formulation

- Taking advantage of previous injection loading work we did for ONR to ensure we have no shear induced particle migration. We want $d\phi/dt \longrightarrow 0$ in the limit as ϕ gets large.

$$d\phi/dt = f(a^2, \dot{\gamma}, 1/\mu_o)$$

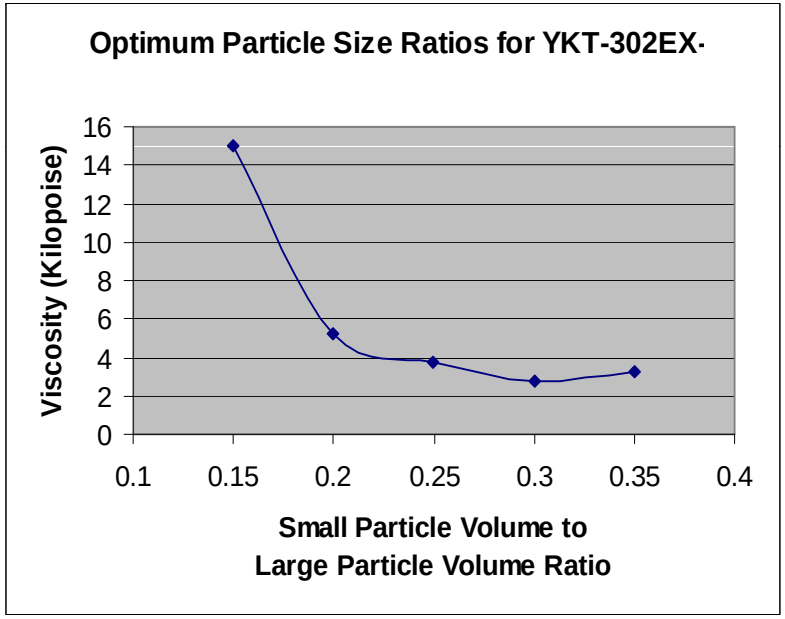
- We also want plug flow behavior, or Bingham plastic profiles



(a) typical Bingham plastic flow profile
(b) typical Bingham shear stress profile

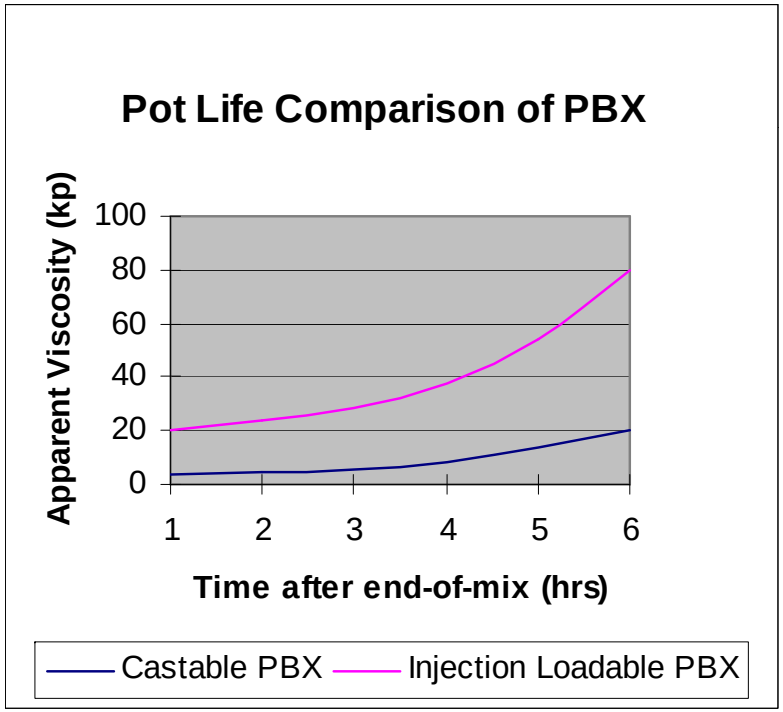
Formulation

- Particle size optimization was performed by evaluating a small particle:large particle volume ratio
  - small = HMX Class 5 + AL
  - large = HMX Class 1
- Minimum apparent viscosity was obtained for a small:large volume ratio = 0.3

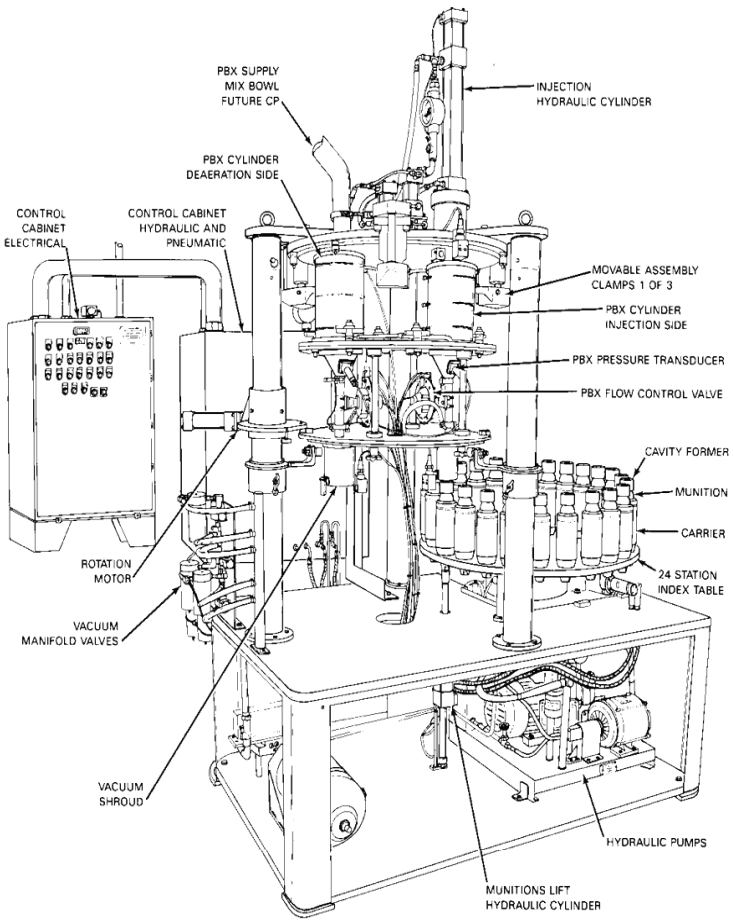


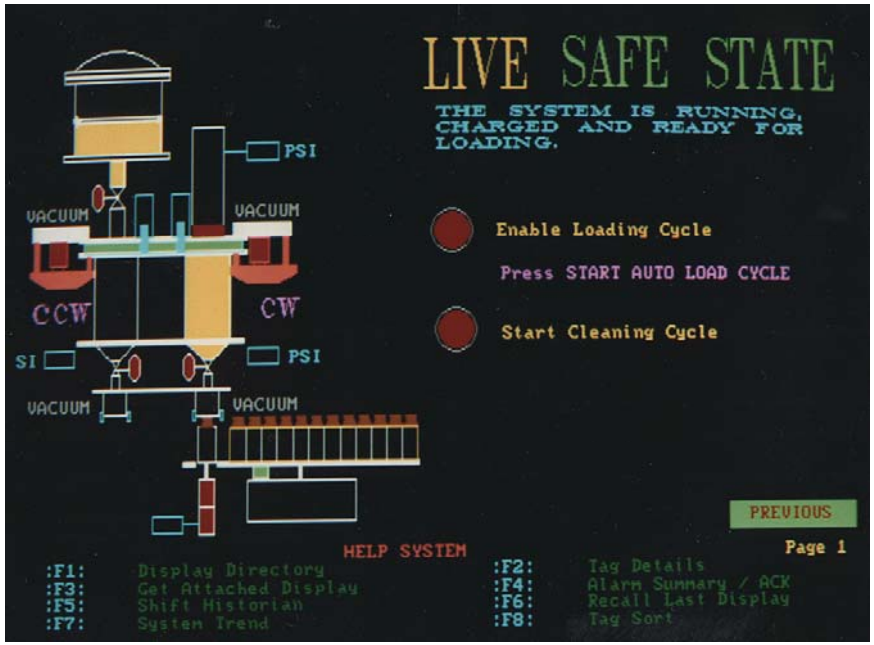
Formulation

- Expect this formulation to have a high end-of-mix viscosity
  - not castable
  - very good injection loadable material
- Processing "pot life" for PBX formulations is different
  - 20 kp limit for casting
  - 80 kp limit for injection loading



Process Design





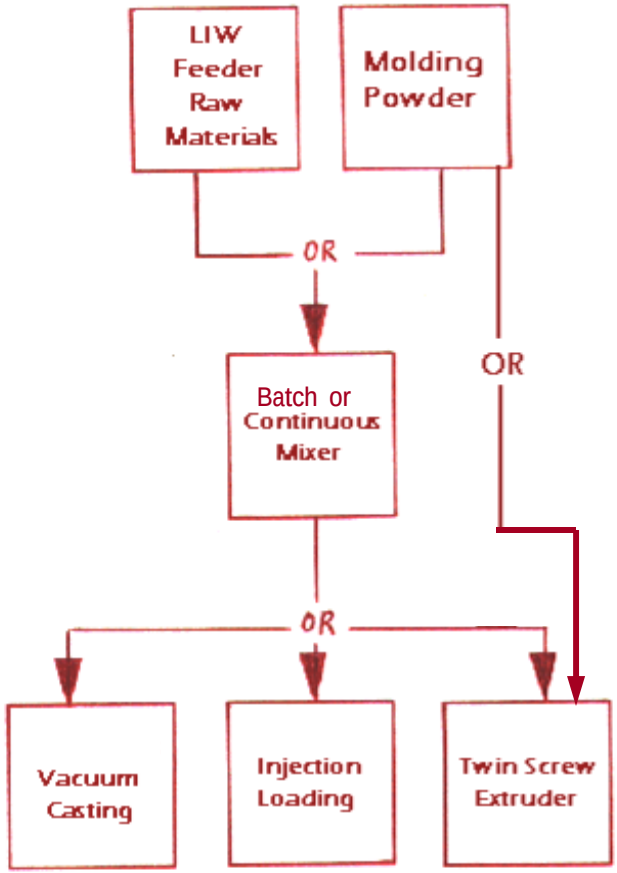
One of the process control and data acquisition screens showing the ability to simultaneously degass PBX (in the CCW chamber) and injection load PBX (in the CW chamber) from a batch mixer bowl into evacuated submunitions.

Process Design

- Minimize the L/D ratio of process plumbing
- Maximize size of process plumbing with respect to particle size (a/R)
- Use low pressure drop splitter plates
- Eliminate corner turns $\geq$ 45 degrees
- Eliminate abrupt contractions
- Use contraction ratios of about 2:1
- Use multi-port manifold to load more than one submunition per cycle

Process Design

- In an agile manufacturing facility, injection loading becomes one of many *unit operations*, depending upon the products being produced.
- Modular design, and possible *miniaturization*, enables injection loading to be utilized as *automated valve assemblies*.
  - Batch
  - Continuous

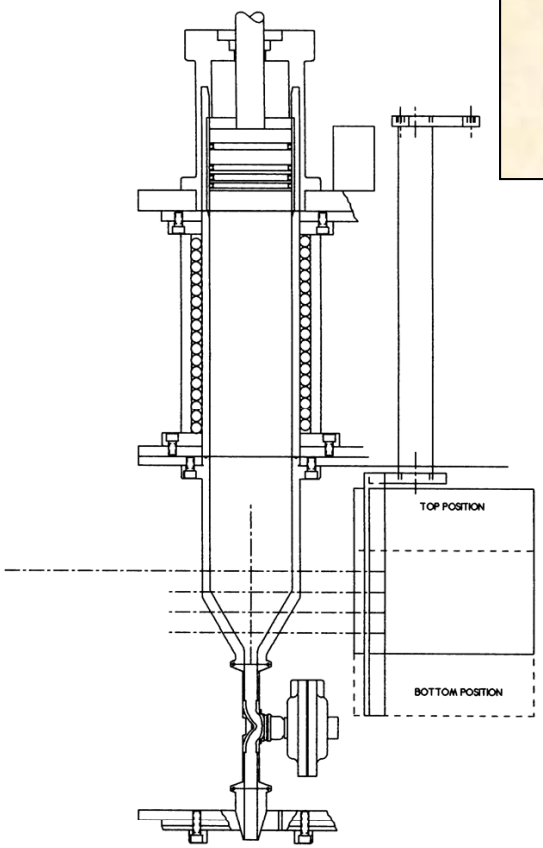


Process Control

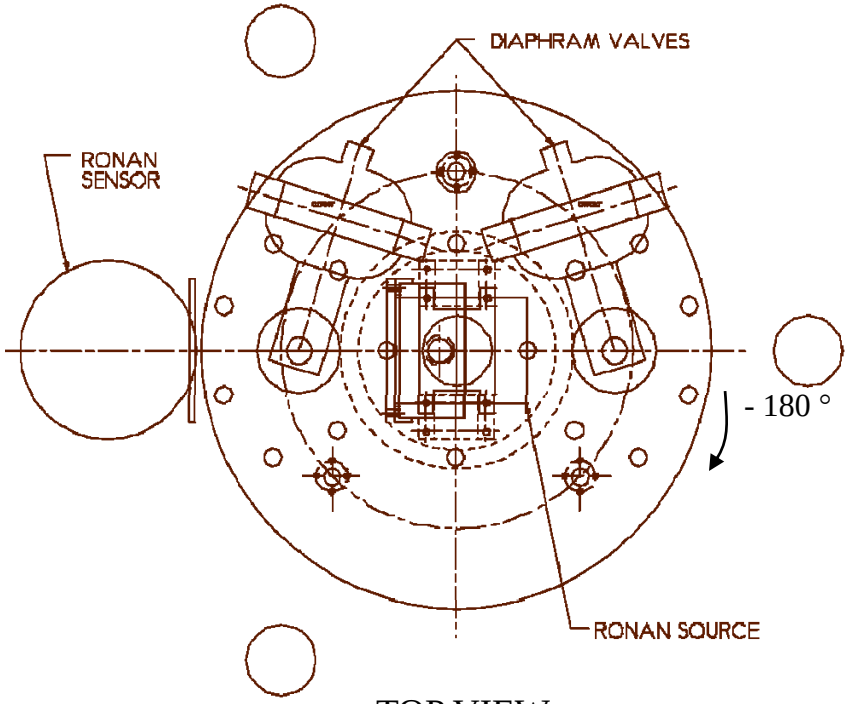
- Calculate flow as a function of ram displacement in time and geometry ($Q = f(u) = f(dx/dt)$)
- Utilize capillary rheometry algorithms to calculate
  - *apparent shear rate* (from flow rate)
  - *apparent shear stress* (from measured pressure)
  - *apparent viscosity*
- Monitor shear rate, and establish a control limit
- Monitor shear stress, and establish control parameters
- Monitor density at the contraction using a densitometer ($\rho = f(dm/dt)$), and establish control parameters
- Manipulative variable is ram displacement

Process Control

- Options for measuring PBX density during loading
  - Cs 137 gamma ray densitometer made by RONAN Engineering
  - measure PBX density near a contraction entrance
  - $d\rho/dt$ information can provide earlier detection of a process disturbance



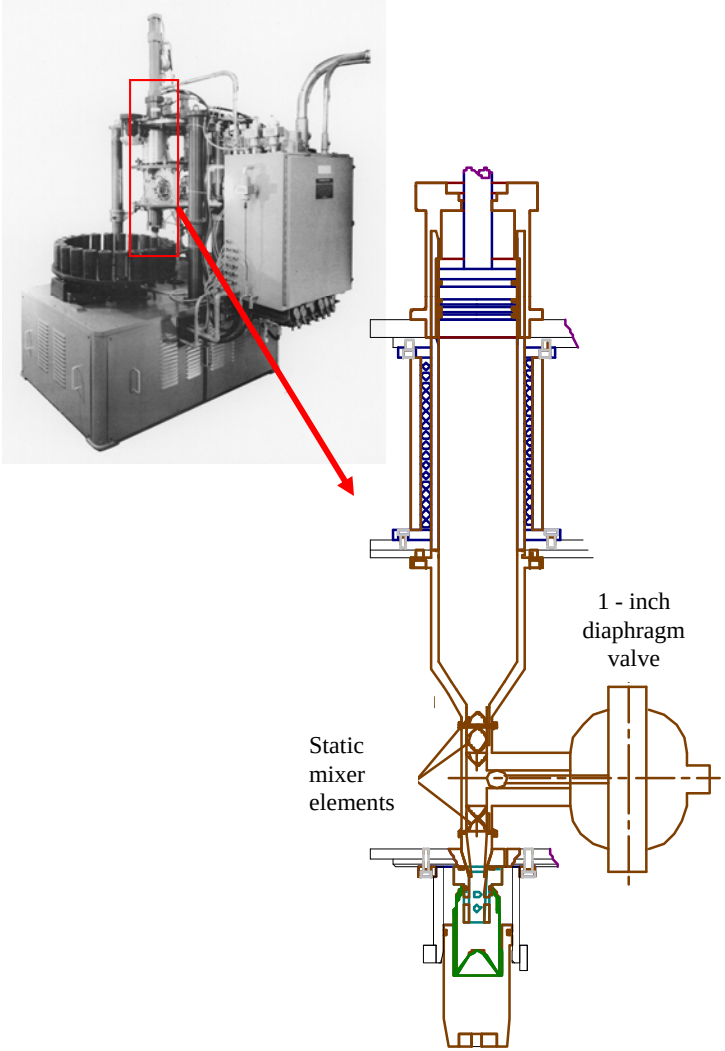
SIDE VIEW



TOP VIEW

Considerations

- For the process engineer
  - injection loading is a high shear operation (400 s^{-1}) requiring
    - » “open” flow channels
    - » no L/D ratios > 12 unless using “in-line” static mixer
    - » no shear induced demixing
    - » “real time” process control



Benefit

- Beneficial Economics
  - injection loading multiple submunitions per cycle
    - reduces unit cost and increases manufacturing rate
    - provides “pressed quality at a cast price”
- *“More Bang for the Buck”*
  - injection loaded PBX has nearly pressed density
  - replacing HMX with AL & improving performance
- Improving *Average* Fragmentation Velocity
  - observe only 4 % increase from PBXN-110 to PBXC-129
  - observe $\geq$ 8 % increase from PBXN-110 to “aluminized PBX”

Conclusion

- Submunitions will continue to be a vital part of the weapon inventory
- Future Navy submunitions will be larger than DPICM
- Future metal accelerating PBX formulations for fragmenting Navy submunitions will probably contain aluminum
- Injection loading is a proven technology that has potential to manufacture high quality PBX filled submunitions or unitary warheads at high rate
- This technology will support RDT&E and production requirements for the surface strike mission