Pyrotechnic Initiator Research

IsoVac Engineering is providing a copy of the following publication as a piece of research that IsoVac considers to be of substantial value to all individuals with interest in the field of automotive airbag and restraint systems. This research deals with the hermeticity problems associated with airbag firing mechanisms, ("Initiators" &" Squibs"), and is directly supportive of IsoVac research findings over the past fifteen years.

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Pyrotechnic Initiator Research at the University of Idaho

D.V. Gunter, M.K. Klein, K.K. Rink*
Department of Mechanical Engineering
*karlrink@uidaho.edu

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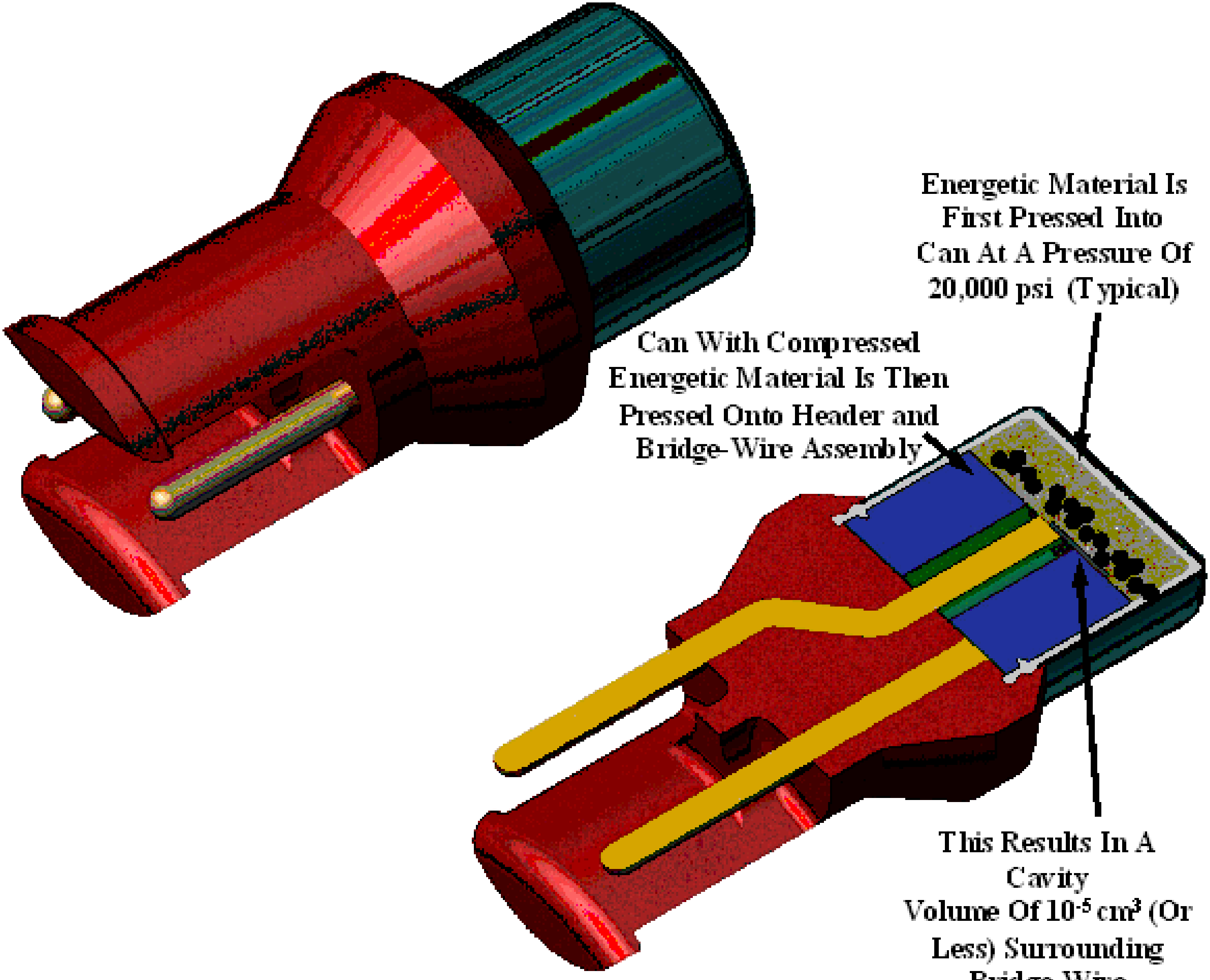
Hermetic Behavior and Failure Mode Analysis

Pyrotechnic initiators are commonly used in a number of potentially life-saving applications including inflatable restraint systems (i.e. airbags) intended for supplemental occupant protection in automobiles. The use of these devices continues to expand rapidly as world wide production of driver, passenger, side impact, and curtain inflation systems exceeds 100 million units yearly. Additional automotive safety applications include seat belt pretensioners, inflatable seat belts, knee bolsters, hood lift systems, and fire extinguisher systems. In these systems, it is critical that the initiators operate reliably without failure or diminished performance for the intended service life of the vehicle – typically specified as 15 years. Recent research at the University of Idaho indicates that these devices are often not able to meet the stringent quality control requirements specified for other electrical elements of the ignition system. This research program involves the use of radioactive krypton (^{85}Kr) to identify leak paths and quantify leak rates into pyrotechnic initiators. Ultimately, this work will provide and understanding of initiator failure modes, establish firm engineering specifications for allowable leak rates into initiator devices, and allow improvements in initiator design and function.

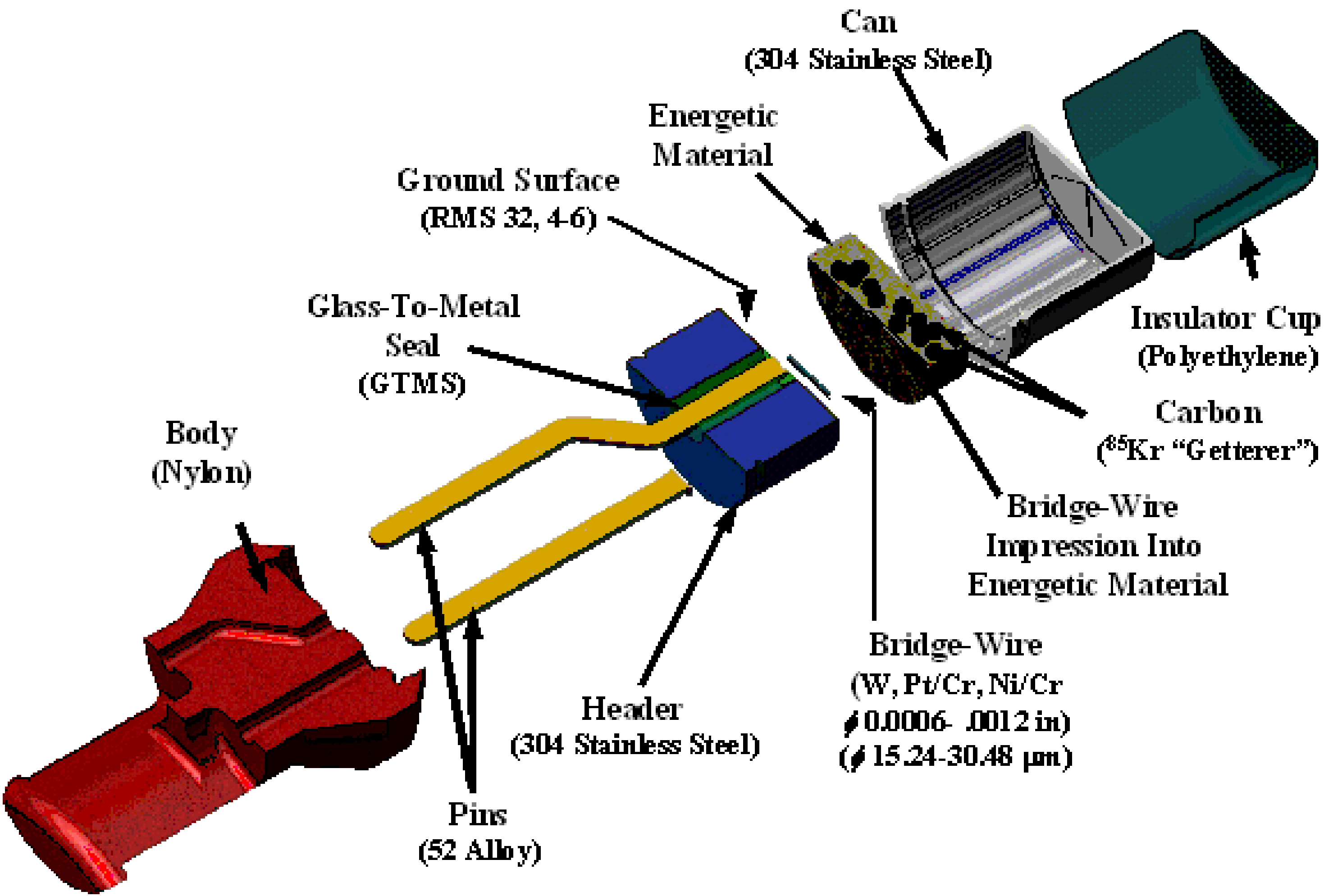
Typical Initiator Design, Components, And Materials Of Construction



Energetic Material Is First Pressed Into Can At A Pressure Of 20,000 psi (Typical)

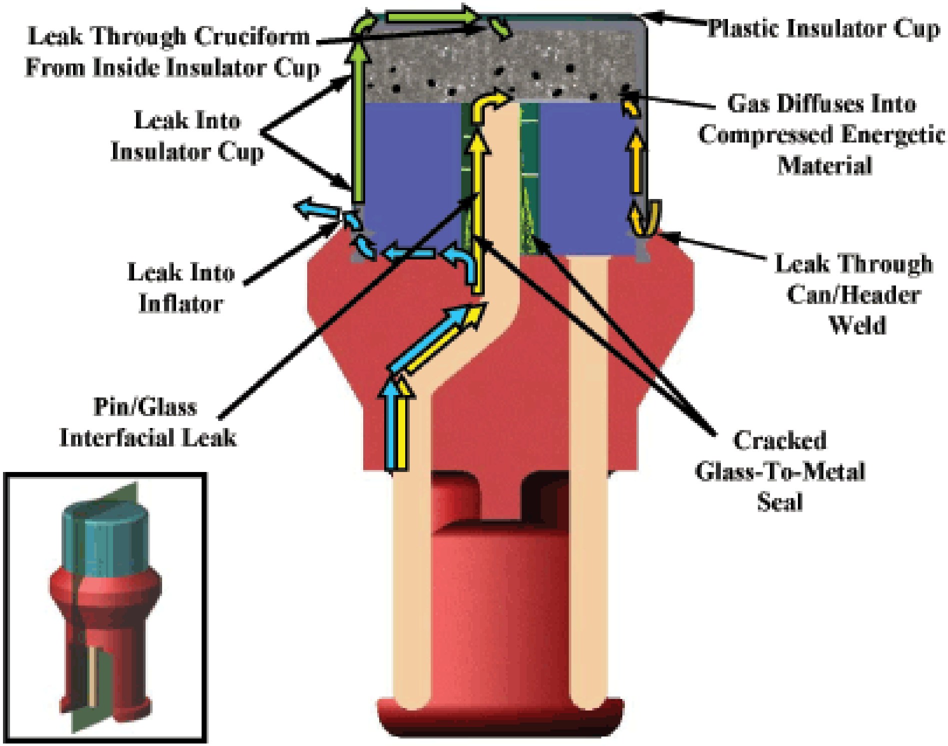
Can With Compressed Energetic Material Is Then Pressed Onto Header and Bridge-Wire Assembly

This Results In A Cavity Volume Of 10^{-5} cm^3 (Or Less) Surrounding Bridge-Wire


Can
(304 Stainless Steel)
Energetic
Material
Ground Surface
(RMS 32, 4-6)
Glass-To-Metal
Seal
(GTMS)
Insulator Cup
(Polyethylene)
Carbon
(^{85}Kr "Getterer")
Bridge-Wire
Impression Into
Energetic Material
Body
(Nylon)
Bridge-Wire
(W, Pt/Cr, Ni/Cr
ϕ 0.0006- .0012 in)
(ϕ 15.24-30.48 μm)
Header
(304 Stainless Steel)
Pins
(52 Alloy)

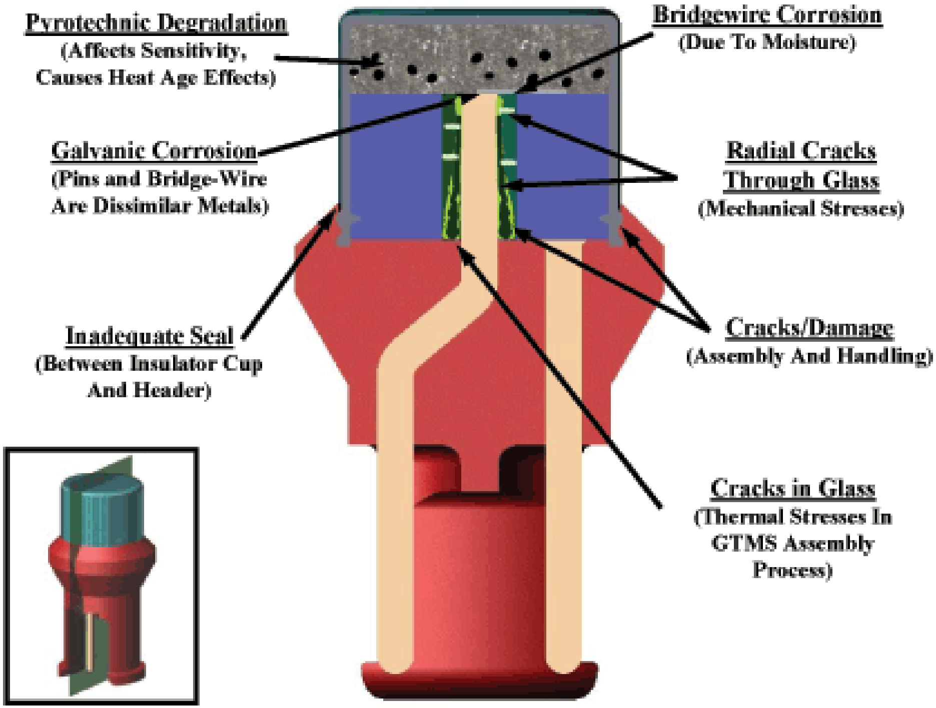
Problems In Ensuring Hermetic Behavior

To ensure proper operation, the initiator is designed to protect the bridge-wire from the possibility of a leak of gas from the external atmosphere into this region. Leak rates as low as 10^{-8} atm-cm^3/s are specified, but the extremely small internal volumes characteristic of this region (10^{-3} cm^3 to 10^{-5} cm^3, or less) make accurate leak rate determination extremely difficult. Without additional design precautions, leak detection using typical helium tracer gas technologies is futile. Powdered coconut charcoal is an effective krypton-85 adsorbent (known as a “getterer” material) that, when added to the pyrotechnic materials, is proven to overcome this problem.



Initiator Failure Modes Associated With Leaks

The leak of moist gases into an initiator assembly can lead to deleterious and potentially catastrophic degradation of performance. The most serious failure – one that has been observed in ordnance systems – is corrosion and failure of the bridge-wire. Corrosion may occur due to ingestion of moisture, or it may also arise from moisture inherent to the pyrotechnic or plastic materials. Galvanic corrosion (related to the use of dissimilar metals) is a common finding. The causes of many failures can be linked to specific design features coupled with a general misunderstanding of engineering principles needed to ensure hermetic behavior. These areas are a primary concern of the University of Idaho initiator research program.



Pyrotechnic Degradation
(Affects Sensitivity, Causes Heat Age Effects)

Bridgewire Corrosion
(Due To Moisture)

Galvanic Corrosion
(Pins and Bridge-Wire Are Dissimilar Metals)

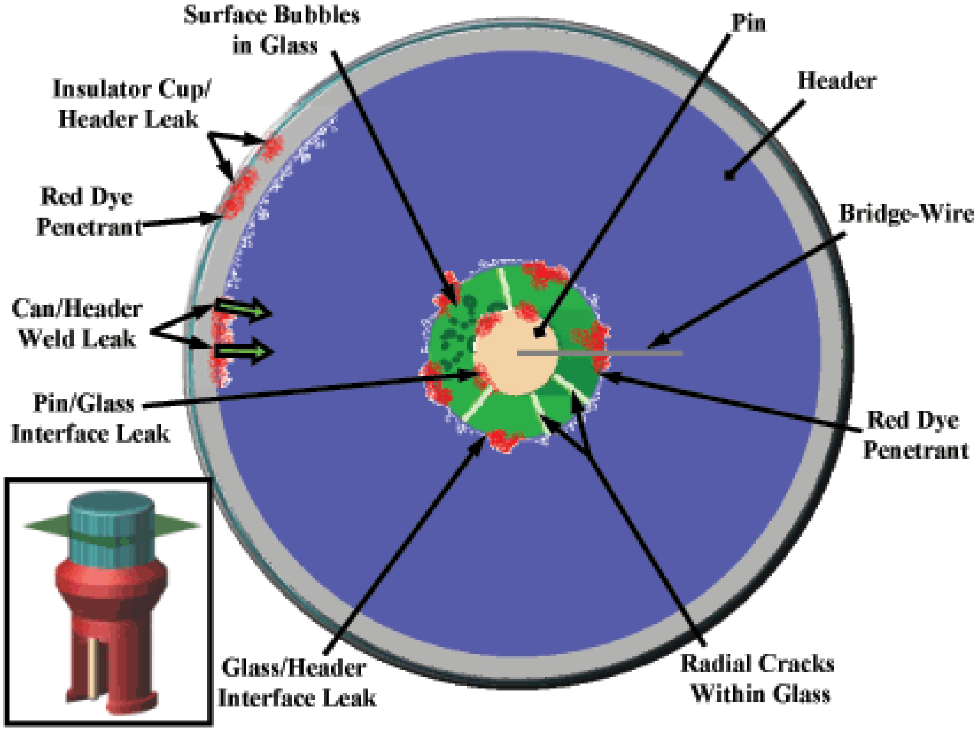
Radial Cracks Through Glass
(Mechanical Stresses)

Inadequate Seal
(Between Insulator Cup And Header)

Cracks/Damage
(Assembly And Handling)

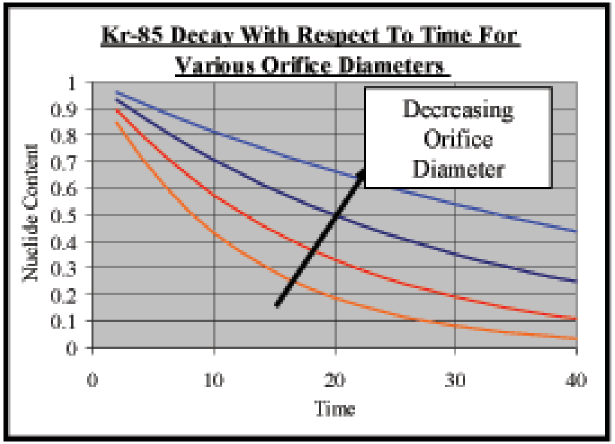
Cracks in Glass
(Thermal Stresses In GTMS Assembly Process)

Commonly Observed Leak Paths

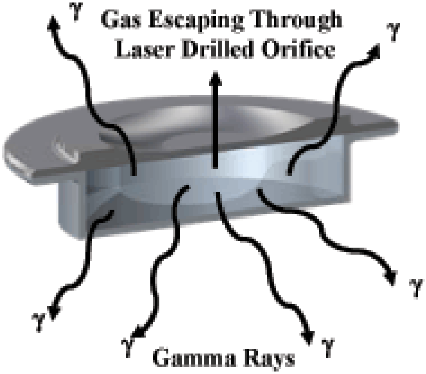


The integrity of the glass-to-metal-seal (GTMS) is of particular concern in initiator design, manufacture, and installation. A number of different failure mechanisms can lead to leaks into the bridge-wire cavity. Commonly observed flaws include radial cracks emanating from the pin through the glass to the header body. These cracks usually do not leak in the header stage of manufacture, but are made to leak when the output can is welded in place and when the part goes through handling, thermal cycling, crimping, and assembly. Large cracks can often be demonstrated through the use of red dye penetrant. This is a common weakness in headers.

Hermeticity Failure Mode Analysis: Selected Work-in-Progress



Kr-85 Decay With Respect To Time For Various Orifice Diameters



Device Geometry Matrix

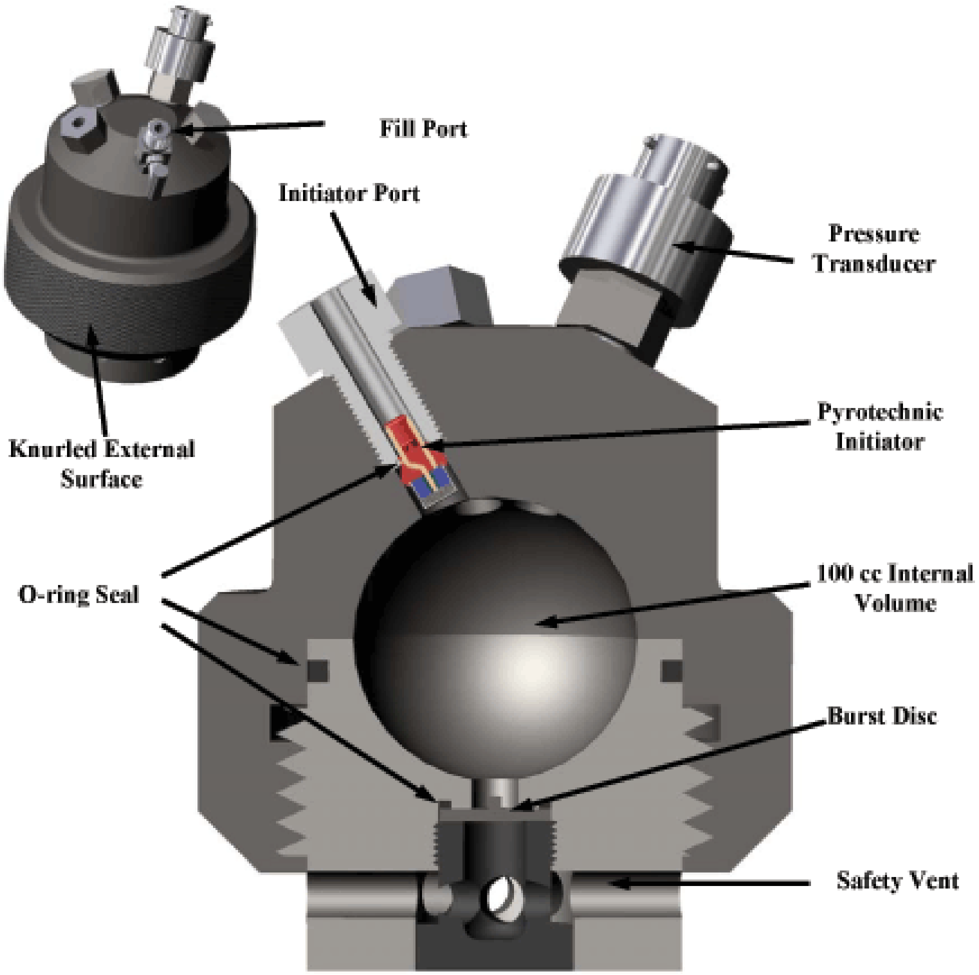
Internal Cavity Volumes	Orifice Diameter (μm)				
1.0 cm^3	100	50	25	10	1
0.1 cm^3	100	50	25	10	1
0.01 cm^3		50	25	10	1
0.001 cm^3			25	10	1
0.0001 cm^3					1

Literature detailing the leak rates from small cavity devices is scarce due to the proprietary nature of the technologies involved and the difficultly of producing devices with well-defined leak path geometries. In this work, a population of specially-designed standards has been manufactured and leak rate analysis performed using a Radiflo® leak detection system. In these tests, small cavity devices are first subjected to high pressure ^{85}Kr/air mixtures. Then the reduction in nuclide content within the devices is continuously monitored using a scintillation crystal detection apparatus. Since the nuclide content is directly related to the mass in each device, experimental results can be compared to accepted flow theories.

Ballistic Characterization and Modeling

Many types of pyrotechnic initiators of different design are currently in use in a multitude of engineering applications. Since initiators feature different types and quantities of pyrotechnic materials, it is important to be able to characterize, predict, and model the ballistic response of the devices in closed vessels and vented enclosures. Therefore, the specific goals of this work include the determination of the apparent energy released during initiator function, and device variability given different conditions of temperature, pressure, and composition of the environment. Proper instrumentation, data sampling rate, signal conditioning and processing are necessary to accurately determine the ballistic characteristics of an initiator. This situation is made more complex when initiators are discharged into reactive gas mixtures or multi-phase fluid mixtures. Once the ballistic response is accurately determined initiator variability can be properly studied. Recent research has shown that the lack of hermetic behavior in initiators and anomalies in ballistic response are often intricately coupled. Careful study and analysis are required to understand the separate effects or pyrotechnic variability and hermetic failure in initiator performance. The goal of this work is to quantify the effects of failures from non-hermetic behavior in terms of the ballistic response of initiators.

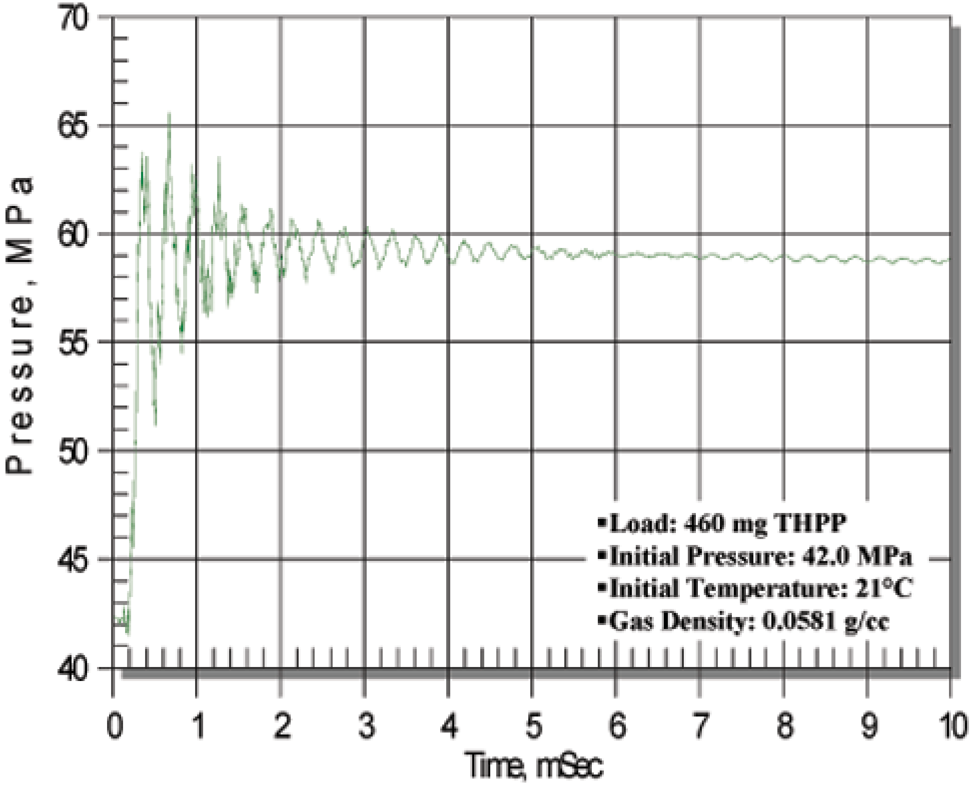
Ballistic Test Fixture



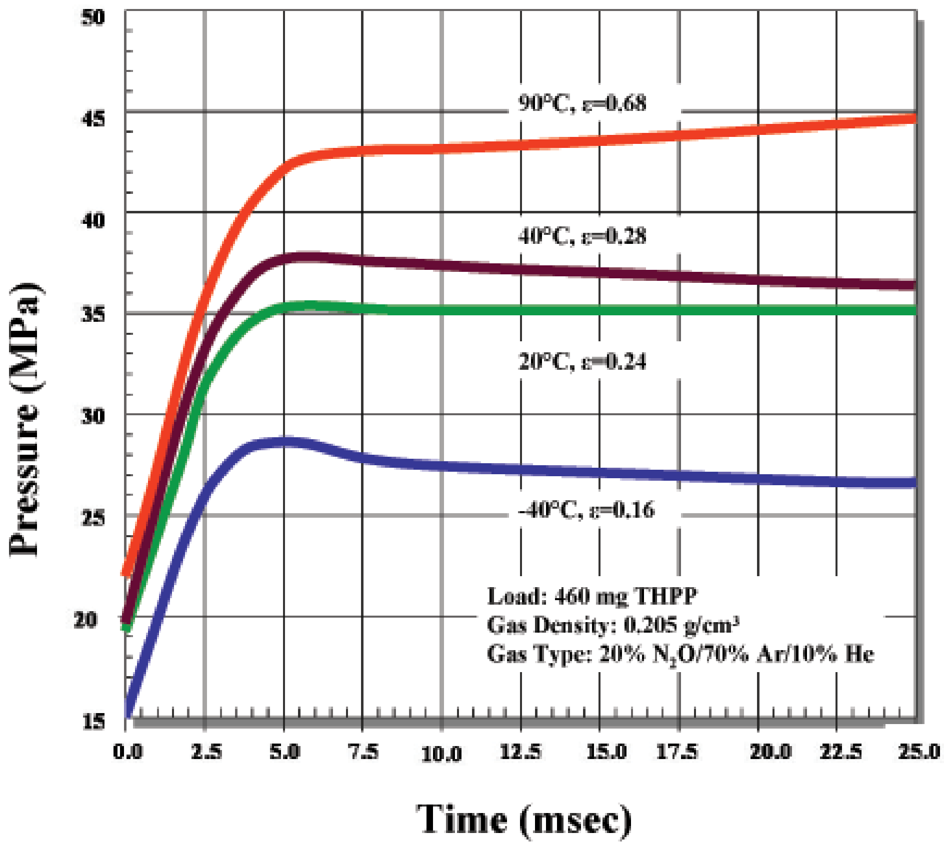
The ballistic test fixture is a thread together device intended for multiple uses, rapid assembly, and multiple initiator (pyrotechnic or optical) configurations. It is constructed of 17-4 PH stainless steel and features an internal spherical volume of 100 cm^3. To prevent galling, a coarse thread (ANSI 3.50-6 UN) is used and the threads are fully nitrided to increase surface hardness. The fixture has proven insensitive to seizing at routine operating pressures of 241 MPa (35,000 psia) and is capable of withstanding pressures in excess of 689 MPa (100,000 psia). Pressures are monitored using piezo-resistive or piezo-electric transducers, and gases may be withdrawn through a valve for analysis by FTIR/GTMS.

Typical THPP Initiator Response In Inert Enviroment

Ballistic work has focused on two specific pyrotechnic formulations and loads: 275 mg of zirconium potassium perchlorate (ZPP), and 460 mg of titanium hydride potassium perchlorate (THPP). These initiators were chosen because they are widely used in current automotive airbag applications. This figure illustrates the typical unfiltered response of a 460 mg THPP initiator discharged into a pure helium environment. Initiators were fired into pure helium environments and the apparent energy release was then calculated using the measured pressure combined with the well-defined value of the specific heat of the gas. Apparent energy release asymptotically approached a maximum value as pressure was increased.



Typical Initiator Response In Nitrous Oxide Bearing Environments



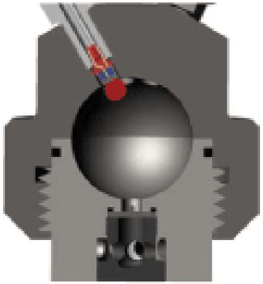
When pyrotechnic initiators are discharged into N_2O bearing gas mixtures, only a fraction "ε" of the N_2O will dissociate, as described by the simplified relation

$$N_2O \rightarrow \varepsilon\, N_2 + 1/2\, \varepsilon\, O_2 + (1-\varepsilon)N_2O$$

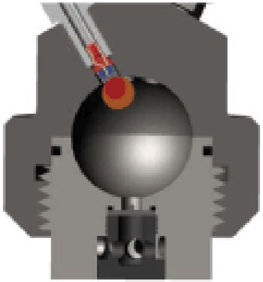
The value of the extent of dissociation "ε" depends on many factors including: the initial N_2O concentration, the mixture density, the quantity of energy deposited in the mixture, and the initial temperature of the mixture. Because of international shipping regulations, most airbag inflation systems are limited to 20% N_2O, and the extent of dissociation is often about 20%. This figure illustrates the extent of N_2O dissociation for a constant density mixture conditioned at different ambient temperatures.

Ballistic Characterization Modeling Selected Work-in-Progress

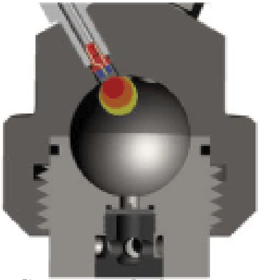
For the initiators currently under study, a simple closed vessel (CV) reactor model will accurately describe nitrous oxide dissociation for conditions of low gas density. For mixtures consisting of 20% N_2O, below pressures of 1.75 MPa, essentially all of the N_2O will dissociate. However, as the initial gas density is increased further, the extent of N_2O dissociation begins to decrease. Dissociation only occurs locally where the high temperature combustion products of the initiator adequately heat the mixture. At the highest densities tested (29 MPa), only 5 to 10% of the nitrous oxide will dissociate. An initiator discharge model has been incorporated into the CV reactor model to describe this incomplete dissociation process. This model continues to be improved to include radiation and convective heat transfer effects.



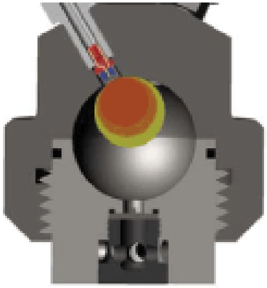
Initiator discharges into high density N_2O bearing gas mixture. Adiabatic flame temperature approaches 4000K



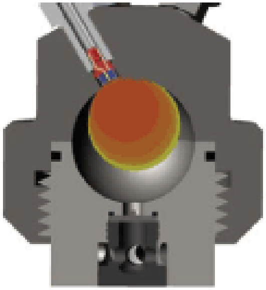
As initiator combustion products expand into vessel, N_2O dissociation occurs in high temperature regions.



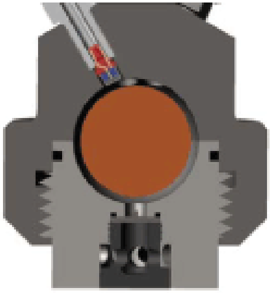
Some heat is liberated through N_2O dissociation, but heat is also transferred to the cool reactants and through radiation to the walls.



Heat losses begin to dominate and rate of dissociation decreases.



Average temperature throughout the vessel is inadequate for N_2O dissociation.



Reaction terminates, and N_2O dissociation is incomplete.