Apollo Spacecraft & Saturn V Launch Vehicle Pyrotechnics / Explosive Devices
Objectives

- Identify critical performance, design requirements and safety measures used to ensure quality, reliability and performance of the pyrotechnic/explosive devices.

- List and understand the major components and functions of a typical Apollo pyrotechnic/explosive device:
  - Initiators
  - Cartridge Assemblies
  - Detonators
  - Core charge

- Identify the major locations/uses for the devices on:
  - Command & Service Module (CSM)
  - Lunar Module (LM)
  - Launch Vehicle (all stages)
More than 210 pyrotechnic devices per Apollo Mission

Automatically or commanded from the Apollo spacecraft systems
- Onboard
- In-flight
- Timed
- Controlled

All devices required high reliability and safety

Most devices were classified as either crew safety critical or mission critical
Common Uses of Pyrotechnic Devices

Pyrotechnic devices had a wide variety of applications:

- Launch Escape Tower (LET) separation
- Separation rocket ignition
- Booster stage/Lunar Module separation
- Forward heat shield jettison
- Spacecraft/Lunar Module Adapter panel separation
- Lunar Module landing gear deployment
- Lunar Module propulsion systems pressurization and activation
- Parachute deployment and release
- Electrical circuit opening and closing
- Line/cable cutting – timed & delayed-time
- Spacecraft vehicle destruction, if loss of control or other catastrophe
Locations - Apollo Spacecraft

See slides under References for detail view
- Saturn V Launch Vehicle Pyrotechnics components
  - Stage separation
    - Retrorockets
    - Ullage rockets
    - Detonator blocks
    - Firing Units
  - Propellant Dispersion System
    - Not shown – discussed later

See slides under References for detail view
Requirements, Design/ Safety Philosophy

- The high specific energy of pyrotechnic materials provides a large energy source in a small package.
- Functions were accomplished reliably and safely with minimum weight and space limitations.
- These properties made wide acceptance of pyrotechnics in the Apollo Program a natural result.
- Conventional electrical and mechanical components were used, when possible, to minimize potential design problems.
- The quality of explosive materials was crucial - only newly-manufactured, specification-controlled Cyclotrimethylenetritritramine (RDX), Hexanitrostilbene (HNS), and Lead Azide were used to ensure consistent quality of the high-explosive materials.
To ensure non-interchangeability of similarly-shaped cartridges, an indexing technique which provided special keyway combinations was developed, and different size threads were used on the output ends of the cartridges.

When complete system redundancy was not possible, redundant cartridges or single cartridges with dual initiators were used.

Typically, two separate and electrically independent systems operated in parallel and provided complete redundancy in the firing circuitry.

Apollo pyrotechnic devices ranged from low-energy charges for puncturing gas bottles to high-energy charges for cutting 0.153-inch-thick steel.
The pyrotechnic safety design reliability goal was established to be 0.9999 at the 95 % confidence level.

Tests of the initiators were performed in all applicable types of environment & storage conditions to obtain information on the safety aspects or the no-fire capabilities of a particular device.

No failures of any pyrotechnic device were ever detected during any of the Apollo missions.
A typical Apollo explosive device system (or “train”) generally consisted of:

- **Initiators** - started “first fire”
  - Apollo Standard Initiator & Single Bridgewire Apollo Standard Initiator

- **Cartridge assemblies** - increased the power of the initiator
  - Electrically Initiated & Spacecraft/LM Adapter Thruster

- **Detonator** - initiated the core charge
  - Apollo Standard Detonator, End-Detonating Cartridge, & Long-Reach Detonator

- **Core charge** - completed the explosion started by the detonator (big explosion)
  - Mild Detonating Fuse, Confined Detonating Cord, & Linear Shaped Charge
Initiators

- The Apollo Standard Initiator (ASI), was originally developed/qualified for Apollo electrically-initiated pyrotechnic devices - electrical sensitivity problems with the double-bridgewire design were discovered.

- In response, the Single-Bridgewire Apollo Standard Initiator (SBASI) was developed/qualified in 1966 as the initiating element for all electrically-initiated pyrotechnic devices.

- The SBASI is a two-pin, electrically-activated, hot wire, explosive – translates an electrical stimulus into a pyrotechnic action or “train”.

- The SBASI was adopted and used as the NASA Standard Initiator (NSI) on the Space Shuttle, Shuttle payloads, & other NASA programs.
Initiators

Single Bridgewire Apollo Standard Initiator (SBASI)
Cartridge Assemblies

- Typical applications
  - Actuating electrical circuit interrupters and disconnects
  - Thruster operation
  - Parachute deployment
  - Valve operations
  - Served as separation systems component parts
Cartridge Assemblies

- Most cartridge assemblies were similarly constructed, but differed in thread size and in amount of output charge
  - Cartridges with different outputs had different thread size to prevent installation in the incorrect pyro train
  - Cartridges with the same output, but located close together and fired at different times, were keyed (or indexed) differently
- Most were electrically initiated by an SBASI (exception noted on next slide)

Electrically-Initiated Cartridge
Cartridge Assemblies

- The only non-electrically initiated cartridge was initiated by Confined Detonating Cord (CDC)
- Use to operate the Spacecraft/Lunar Module Adapter (SLA) panel adapters
Type 1 - Apollo Standard Detonator (ASD) –
typical uses:
- LES tower-separation
  frangible nut
- CM/SM guillotine
- Tension-tie cutter
- Lower LM guillotine
- SLA-panel separation
- LM/SLA separation
Type 2 - End-Detonating Cartridge (EDC)

- Used for high-temperature applications where a directional shock was needed to initiate high-explosive elements.
- Had an intermediate charge of lead azide and an output charge of HNS.
Type 3 – Long Reach Detonator (LRD)

- The Long-Reach Detonator (LRD) was only used in the docking ring assembly
- This configuration was necessary to extend the output charge to an interface area not accessible with either the Apollo Standard Detonator (ASD) or the EDC (previous slide)
Core Charges

- Mild Detonating Fuse (MDF) – two primary uses
  - On the SLA and for CM/docking separation
  - As the explosive element that drove the guillotine blades when cutting umbilicals
- Linear-Shaped Charge (LSC)
  - Sever tension ties connecting the SM and CM
- Confined Detonating Cord (CDC)
  - Detonation transfer in the SLA separation system

![Diagram](a) Mild detonating fuse.  
(b) Confined detonating cord.  
(c) Linear-shaped charge.)
Reefing Line Cutters

- Time-delay line cutters were used for:
  - Deploying recovery aids (e.g. VHF and HF antennas and the recovery beacon)
  - Cutting parachute reefing lines (drogue and main chutes)
Launch Escape System (LES) Explosive Devices

- **Purpose of LES explosive devices:**
  - Separate the Command Module (CM) from the Launch Vehicle (LV) in the case of a Pad Abort or 1st Stage Abort

- **Emergency separation:**
  - The LES was activated immediately before an abort was initiated to ensure crew was clear of explosive debris or an out-of-control launch vehicle

- **Nominal separation:**
  - If no abort declared, the Launch Escape Tower (LET) was separated from the CM at L/O + 2:50 and approximately 260K ft/79K m altitude
  - Accomplished by switch throws by the crew - the tower jettison motor and the frangible nuts at that base of each tower were ignited simultaneously
Command & Service Module (CSM) Pyro Systems

- Major Command (CM) & Service Module (SM) pyrotechnic devices/uses
  - CSM and Spacecraft/Lunar Module Adaptor (SLA) separation
  - Lunar Module Separation System
  - Adapter Panel Explosive Train System
  - SLA Panel separation
  - SLA and Lunar Module (LM) separation
  - Docking probe retraction
  - Docking ring retraction
  - CM and SM separation
  - Circuit interruption in the CM and SM
  - Fuel and oxidizer dump/purging functions
CSM Pyrotechnic Circuit Interrupters

Command Module

Service Module

Electrical Circuit Interrupters
CSM Pyrotechnically Operated Valves

- These pyrotechnically operated valves were used to control the distribution of helium & propellants.
- Each valve (normally closed) was actuated by an electrically-initiated cartridge.
- Upon firing, the valves remained open permanently.
CSM Structural Separation System & Guillotine

- Tension ties connecting the SM & CM were cut with linear shaped charges
- The CM/SM guillotine cut the umbilical between the CM & SM thus allowing CM/SM separation
- Apex cover was jettisoned when the spacecraft had descended to 24,000 ft (7315 m)
- Drogue parachute deployment followed two seconds after apex cover jettison
- At 10,000 feet (3048 m) the drogue parachutes were released by severing the risers with cartridge-actuated guillotines
- The main parachutes were deployed in the reefed condition using mortar ejected pilot parachutes
- Immediately after splashdown, the main parachutes were released by cartridge-actuated blades
Lunar Module (LM) Pyrotechnic Systems

LM pyro devices/uses:

- Landing gear deployment
- Valve opening to pressurize descent, ascent, & RCS propellant tanks
- Descent propellant tank venting
- Electrical circuit interruption
- Interstage umbilical severance
- Ascent & descent stage separation

See slides under References for detail view
Landing gear uplock detonators were fired, driving a blade to sever the strap - this allowed deployment mechanism springs to extend the LM landing gear.
LM Pyrotechnically Operated Valves

- LM pyrotechnic valves operated instantaneously by firing self-contained explosive charges for valve functioning.
- Upon firing, the valves remained open permanently.
- Allowed descent propellant tank pressurization/venting, ascent propellant tank pressurization, & RCS propellant tank pressurization.
**LM Ascent Stage Pyrotechnic Separation**

Separation of the LM ascent & descent stages has three steps (all involving pyrotechnics):

**Step 1 - Break all interstage electrical circuits**

**Step 2 - Separate all four interstage nuts & bolts**

LM Electrical Circuit Interrupter

LM Interstage Nut & Bolt Assembly

Before firing

After firing
**LM Ascent Stage Pyrotechnic Separation, cont’d**

**Step 3** – Sever the umbilical and water line between the ascent & descent stages with the interstage umbilical guillotine

![Cross Section of LM Interstage Umbilical Guillotine](image1)

![Installed View of LM Interstage Umbilical Guillotine](image2)
Saturn V Pyro Systems
Saturn V Launch Vehicle Range Safety Operations

- The Saturn V Launch Vehicle had a predetermined launch trajectory.
- If it deviated from this trajectory, to the degree that it could endanger life or property (shown in the blue band)...
- The Range Safety Officer (RSO) would send a command to the vehicle's Propellant Dispersion System (PDS) to destroy the vehicle.
- PDS is described per stage on the following slides.
- This operation was never needed during the Apollo Program.
Stage S-IC (also called 1st Stage) had two pyrotechnic systems:

- Propellant Dispersion System (PDS) provided for flight termination (vehicle destruction) if the Launch Vehicle trajectory deviated beyond the prescribed limits of its flight path (previous slide).

- Retrorocket System had 8 rockets to provide separation thrust (deceleration) after S-IC burnout to support staging to Stage II.
Stage S-IC Ordnance

- Stage S-IC Propellant Dispersion System (PDS) - Overview

PROPELLANT DISPERSION

See slides under References for detail view
Stage S-IC Ordnance

- Safety & Arming Device
  - All Stages
    - Serves as the arm portion of the “arm and fire” technique used for all critical commands to manned space vehicles
    - Used for all Saturn V Propellant Dispersion Systems (PDS) stages
    - The PDS is the system used to destroy the vehicle in case of trajectory diversion or other catastrophic event
Stage S-IC Retrorockets

- The 8 retrorockets provide separation thrust after Stage S-IC burnout.
- Propels Stage S-IC away from the rest of the launch stack as it progresses to Stage II.

See slides under References for detail view.
Stage S-II (also 2\textsuperscript{nd} Stage) had four pyrotechnic systems:

- **Propellant Dispersion System (PDS)** provided for flight termination (vehicle destruction) if the Launch Vehicle trajectory deviated beyond the prescribed limits of its flight path (previous slide)

- **Separation System** was a dual-plane separation system used to dead face umbilicals, interrupt electrical circuits, etc

- **Retrorocket System** had 8 rockets to provide separation thrust (deceleration) after S-II burnout to support staging to Stage IV-B

- **Ullage Rocket System** to ensure stable flow of propellants into the J-2 engines by providing a small forward acceleration to “settle” the propellants
Stage S-II Ordnance

- Stage S-II Propellant Dispersion System (PDS) - Overview
Stage S-II Separation Systems

See slides under References for detail view
Stage S-II Ordnance

Stage S-II Retrorockets and Ullage Systems

S-II ULLAGE AND RETROROCKETS

Stage S-II Retrorockets

Stage S-II Ullage System
Stage S-IVB (also called 3rd Stage) had four pyrotechnic systems:

- **Propellant Dispersion System (PDS)** provided for flight termination (vehicle destruction) if the Launch Vehicle trajectory deviated beyond the prescribed limits of its flight path (previous slide).

- **Separation System** was a single-plane separation system used to dead face umbilicals, interrupt electrical circuits, etc.

- **Ullage Rocket System** uses 2 ullage rockets during J2 engine start to ensure stable flow of propellants into the J-2 engine by providing a small forward acceleration to “settle” the propellants.

- **Ullage Rocket Jettison System** jettisons the 2 ullage rockets & fairings following the J2 engine start to reduce weight.
Stage S-IVB Ordnance

Stage S-IVB Component Locations
### Abbreviations & Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>AFETR</td>
<td>Air Force Eastern Test range</td>
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<tr>
<td>ASD</td>
<td>Apollo Standard Detonator</td>
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<tr>
<td>ASI</td>
<td>Apollo Standard Initiator</td>
</tr>
<tr>
<td>CM</td>
<td>Command Module</td>
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<tr>
<td>CDC</td>
<td>Confined detonating cord</td>
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<tr>
<td>CDF</td>
<td>Confined Detonating Fuse</td>
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<td>CSM</td>
<td>Command Service Module</td>
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<td>EBW</td>
<td>Exploding Bridgewire</td>
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<td>ED</td>
<td>Explosive Device</td>
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<tr>
<td>EDC</td>
<td>End Detonating Cartridge</td>
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<td>EDS</td>
<td>Explosive Devices Subsystems</td>
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<tr>
<td>ELS</td>
<td>Earth Landing System</td>
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<td>EMI</td>
<td>Electromagnetic interference</td>
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<tr>
<td>FLSC</td>
<td>Flexible linear shaped charge</td>
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<tr>
<td>HNS</td>
<td>Hexanitrostilbene</td>
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<td>IU</td>
<td>Instrument Unit</td>
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<td>LES</td>
<td>Launch-Escape System</td>
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<td>LM</td>
<td>Lunar Module</td>
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<td>Long Reach Detonator</td>
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<td>LSC</td>
<td>Linear-shaped charge</td>
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<tr>
<td>LVDC</td>
<td>Launch Vehicle Digital Computer</td>
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<tr>
<td>MDF</td>
<td>Mild detonating fuse</td>
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<tr>
<td>NSI</td>
<td>NASA Standard Initiator</td>
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<tr>
<td>PDS</td>
<td>Propellant Dispersion System</td>
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<tr>
<td>PIC</td>
<td>Pyrotechnic Initiator Controller</td>
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<tr>
<td>RDX</td>
<td>Cylotrimethylenetrinitramine</td>
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<td>RFI</td>
<td>Radio frequency interference</td>
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<tr>
<td>RSO</td>
<td>Range Safety Officer</td>
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<tr>
<td>S&amp;A</td>
<td>Safety &amp; Arming Device</td>
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<tr>
<td>SBASI</td>
<td>Single bridgewire Apollo standard initiator</td>
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<tr>
<td>SLA</td>
<td>Spacecraft/Lunar Module Adaptor</td>
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<tr>
<td>SM</td>
<td>Service Module</td>
</tr>
<tr>
<td>ZPP</td>
<td>Zirconium-potassium perchlorate</td>
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</tbody>
</table>
The Apollo Standard Initiator, October 1963
NASA TMX 50602, N65-88832
William H. Simmons, NASA Manned Spacecraft Center


Apollo Spacecraft Pyrotechnics, October 1969
NASA TM X-58032
William H. Simmons
http://ntrs.nasa.gov/search.jsp?R=42259&id=10&qs=Ntt%3Dapollo%252Bpyrotechnics%26Ntk%3Dall%26Ntx%3Dmode%2520matchall%26N%3D0%26Ns%3DHarvestDate%257c1

Apollo Experience Report - Spacecraft Pyrotechnic Systems, March 1973
NASA TN D-7141
Mario J. Falbo & Robert L. Robinson, NASA Manned Spacecraft Center
http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19730011151_1973011151.pdf

Propellant for the NASA Standard Initiator, October 2000
NASA/TP-2000-210186
Carl Hohmann, Bill Tipton, Jr., Maureen Dutton, NASA Manned Spacecraft Center