LOX, GOX, and Pressure Relief

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Disclaimer

- You are responsible for the application of the principles and information presented
- Neither NASA, Jacobs Sverdrup, Muniz Engineering Inc., nor the presenter assume any responsibility for your decisions

Why Consider Oxygen Pressure Relief?

Because fires occur

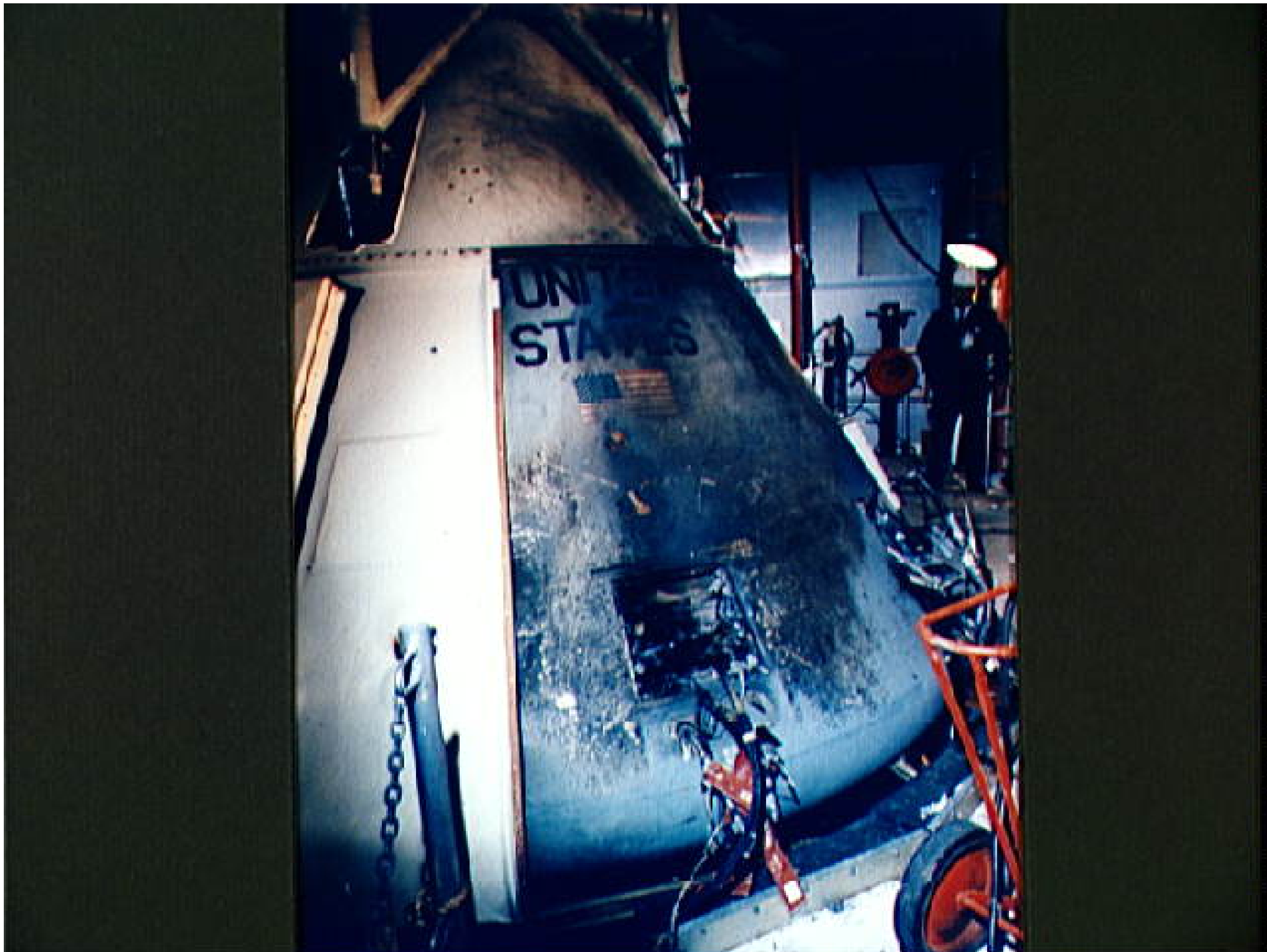
- In liquid oxygen systems
- In gaseous oxygen systems
- In less then 100% oxygen

And the consequences can be severe!

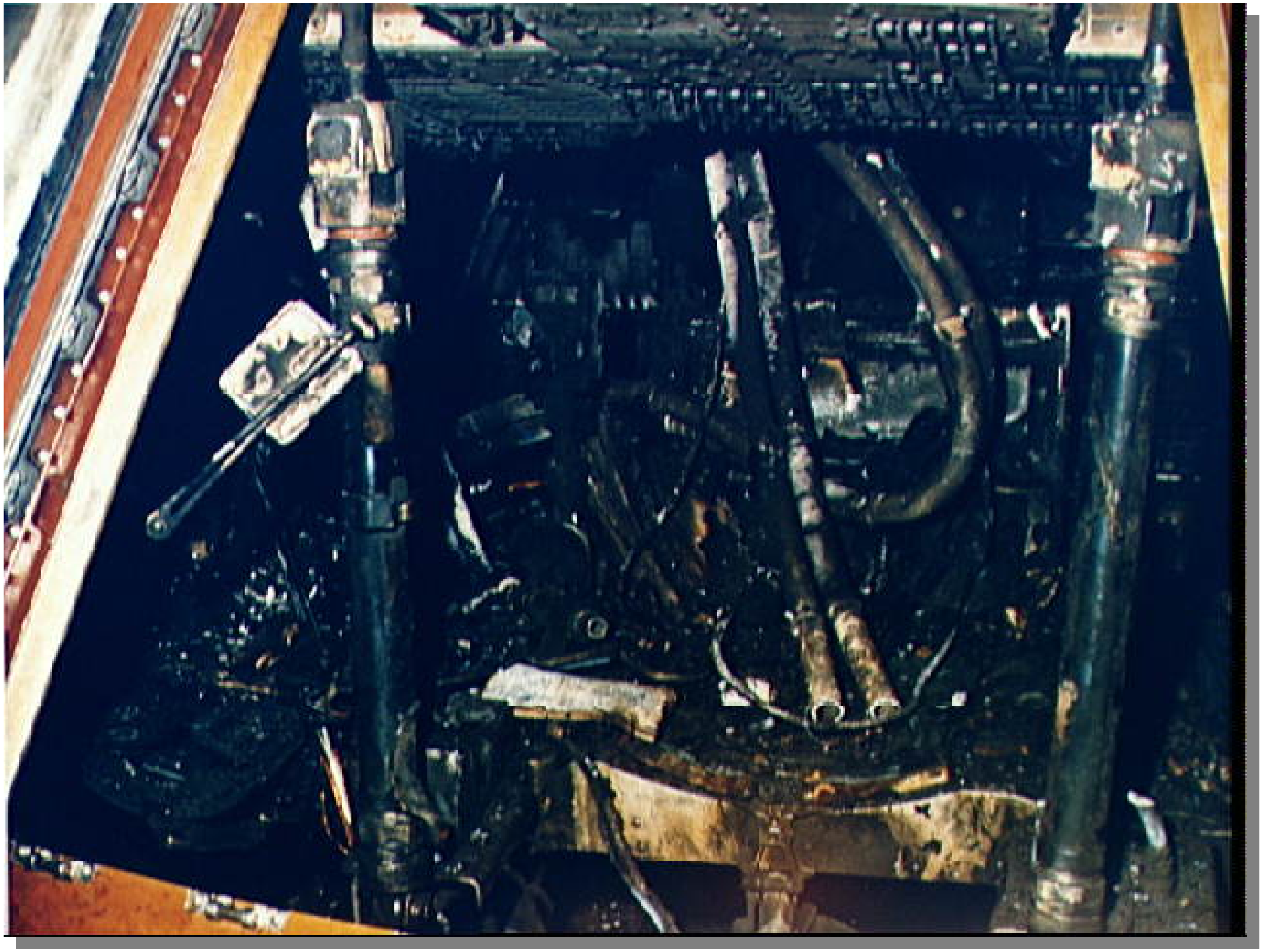
Aluminum O_2 regulator

Aluminum O_2 regulator

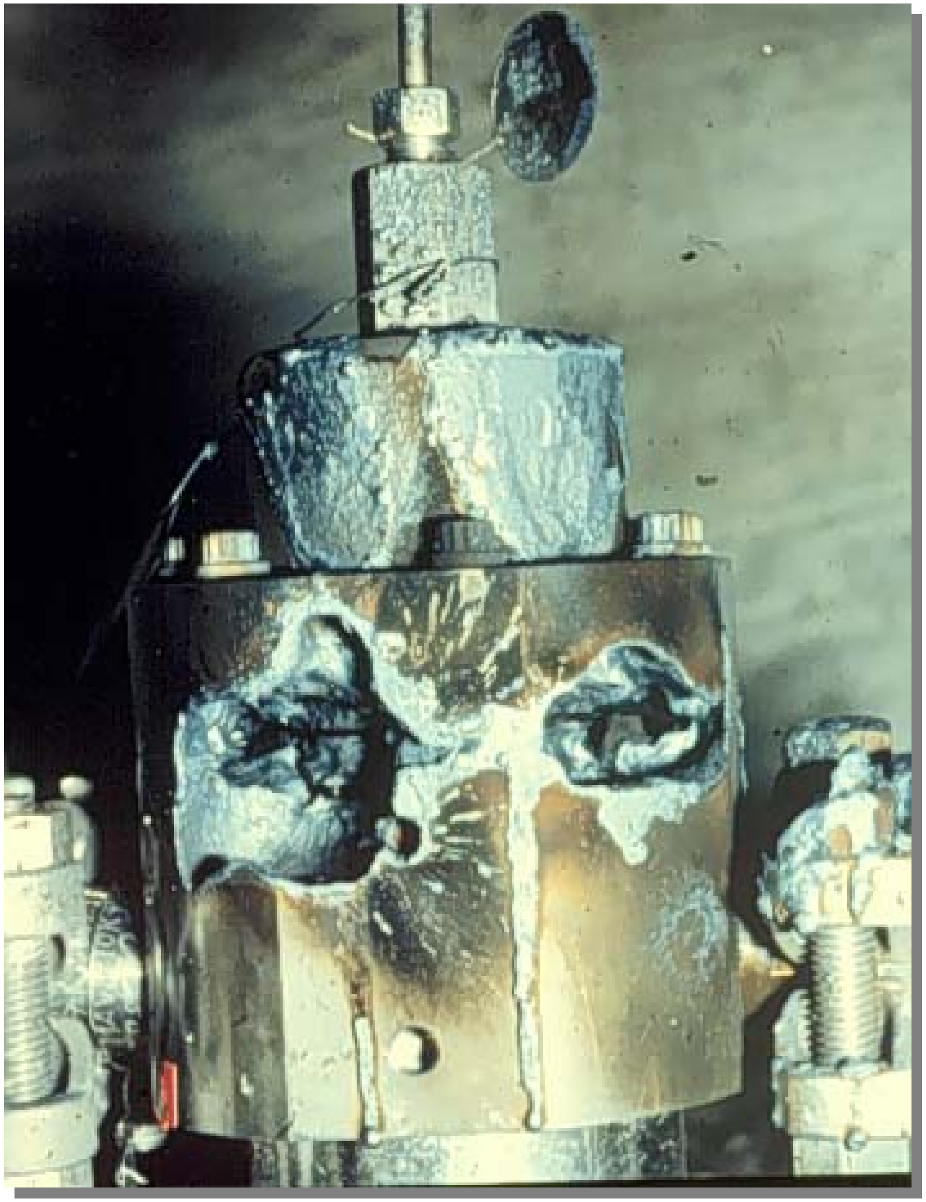
Apollo 204 Fire



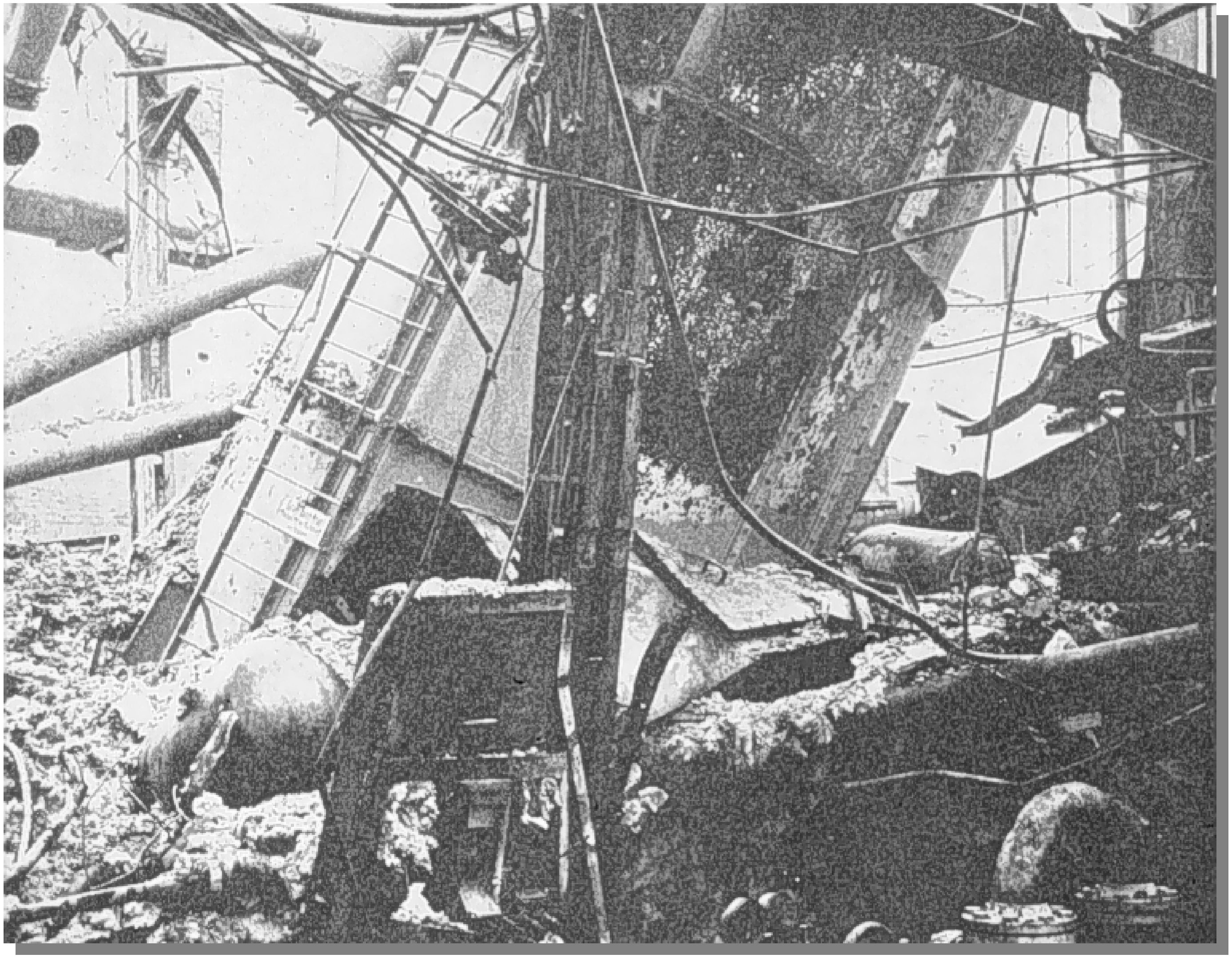
Apollo 204 Fire



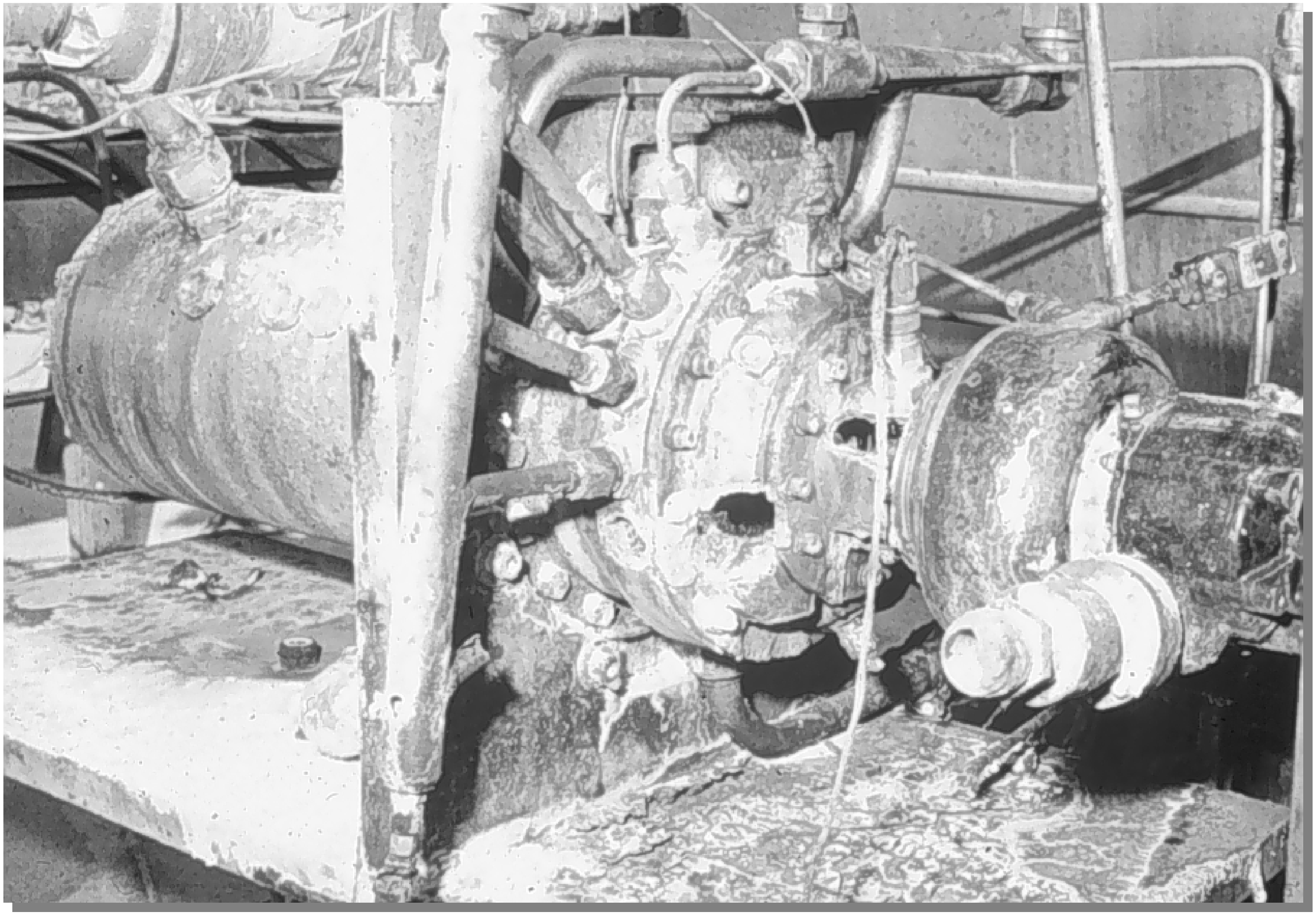
Apollo 204 Fire



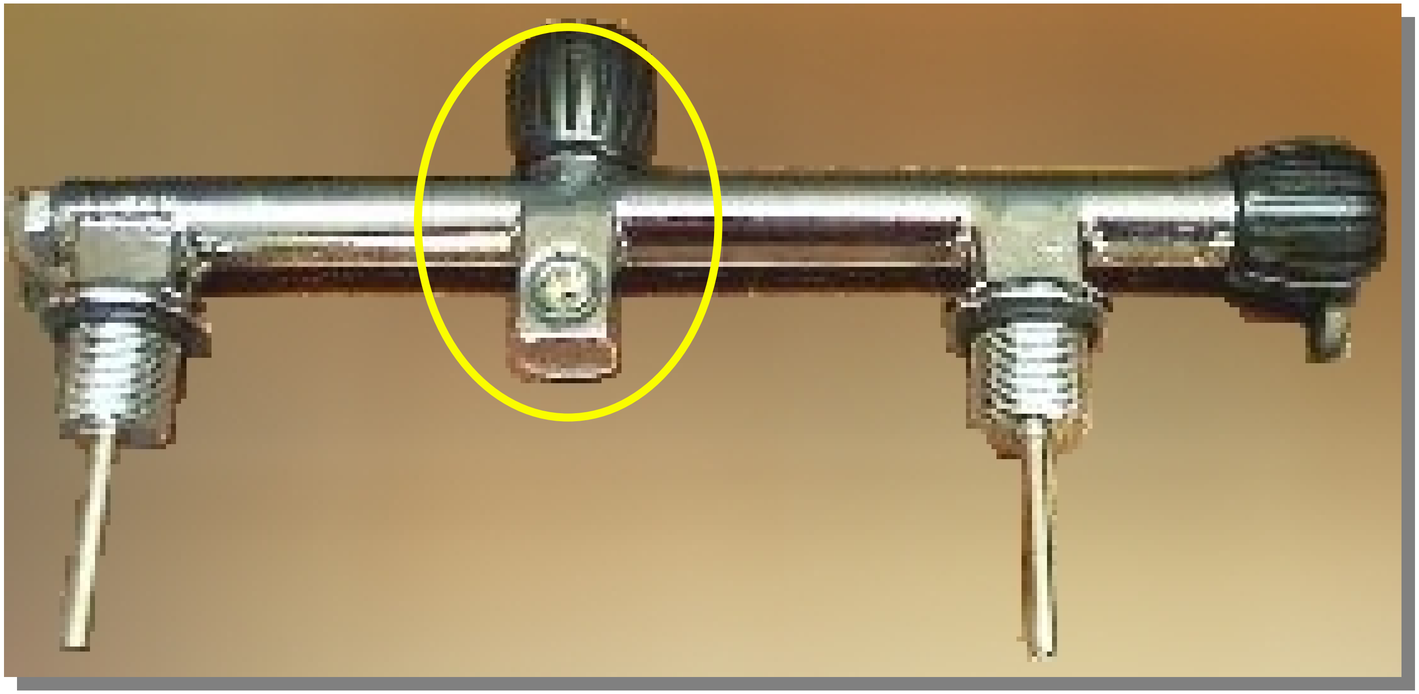
Dome-loaded Regulator Fire



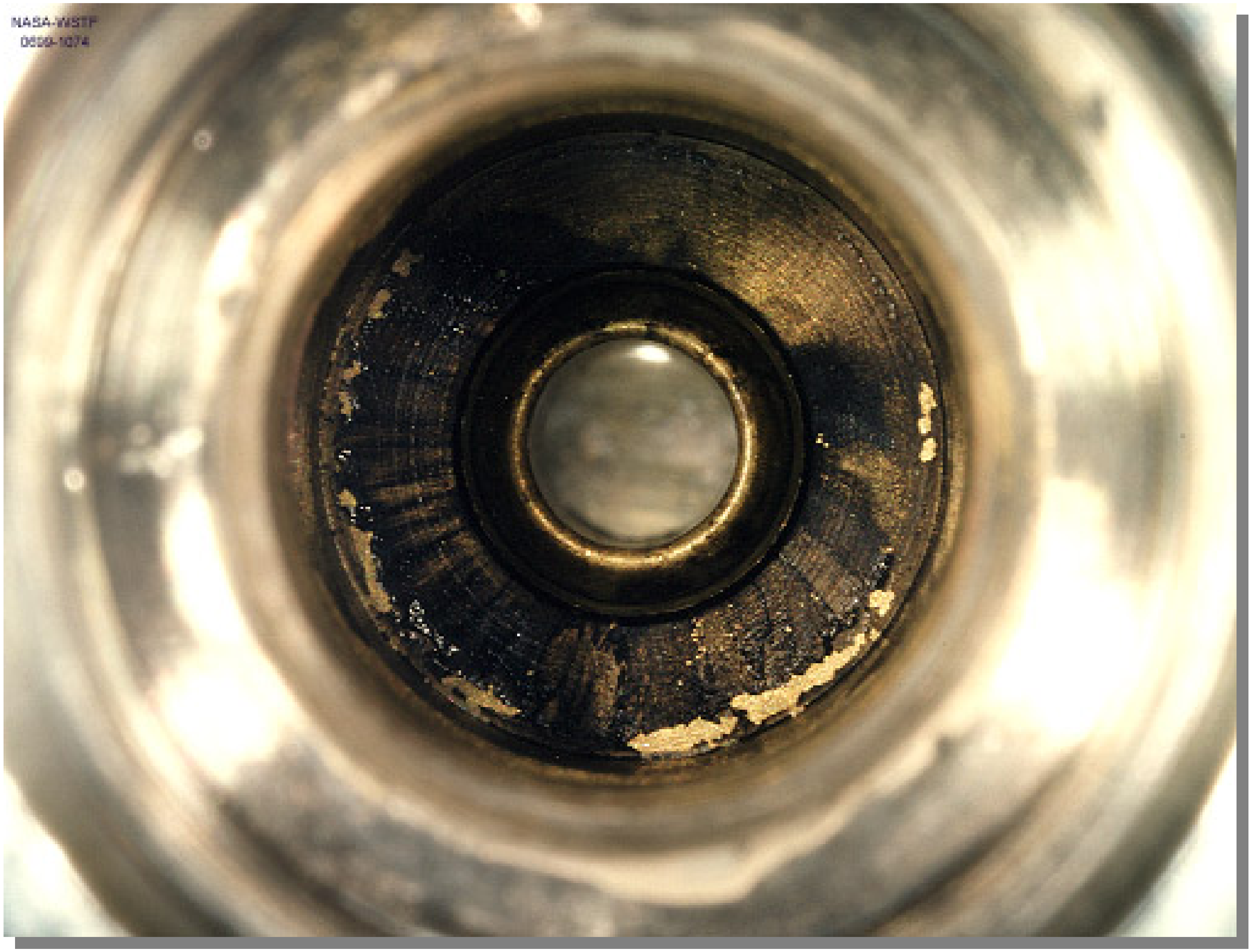
Dortmund ASU Fire



LOX Bearing Tester



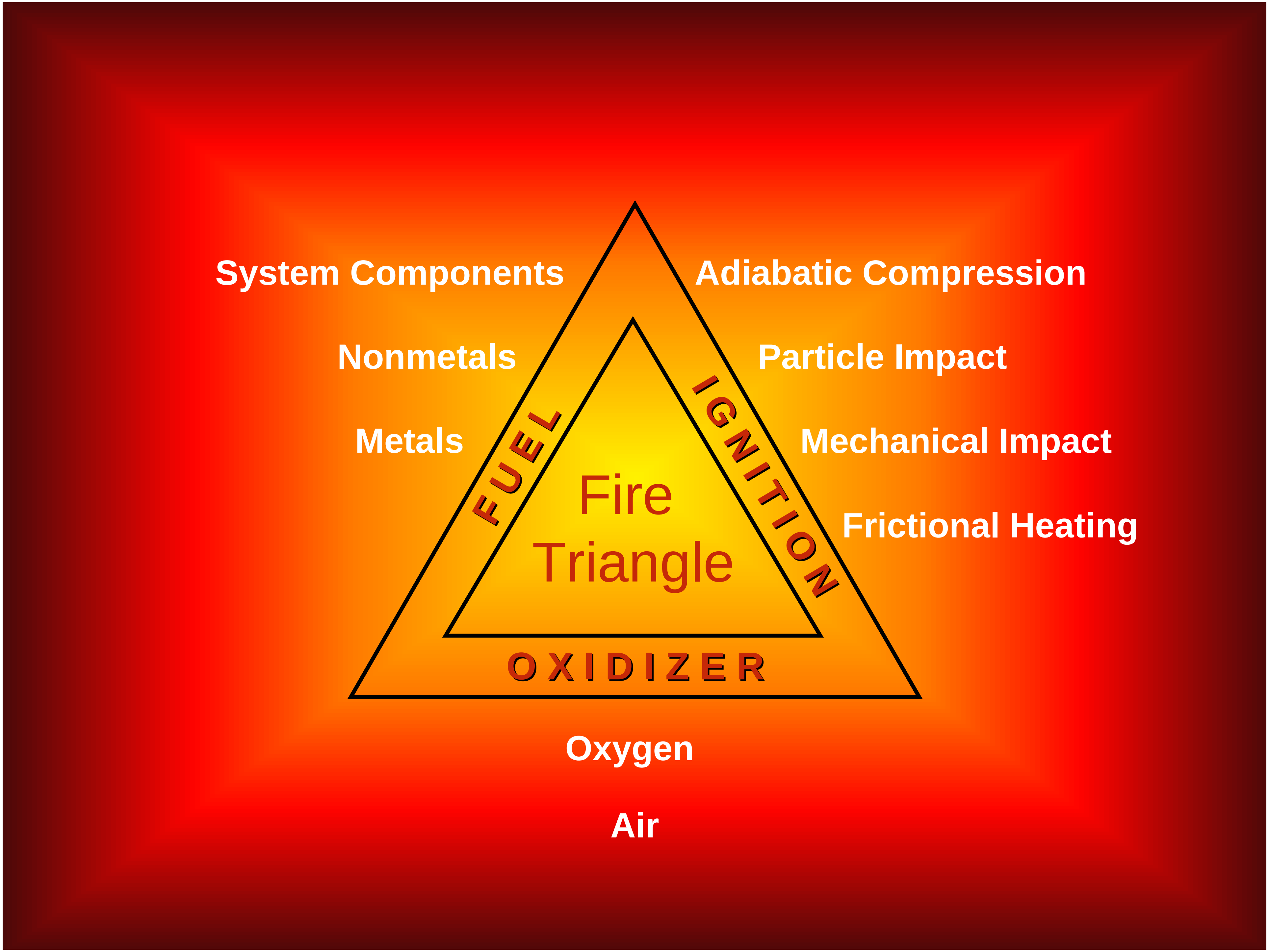
Tank Cylinder Valve



Tank Cylinder Valve

O_2 Fires Occur Industry Wide

- Aerospace
- Industrial gases
- Medical
- Military
- Chemical processing
- Power generation
- Scuba diving
- Metals refining
- Emergency services
- Life support


System Components
Nonmetals
Metals
FUEL
Adiabatic Compression
Particle Impact
Mechanical Impact
Frictional Heating
IGNITION
Fire Triangle
OXIDIZER
Oxygen
Air

The Oxygen System Dilemma

- Can’t remove a leg of the fire triangle
- No comprehensive equations
- No comprehensive modeling packages
- How do we manage the fire hazard?

Risk Management Approach

- Minimize ignition hazards
  - Identify and control ignition sources
- Maximize best materials
  - Ignition resistant
  - Flame propagation resistant
  - Low damage potential
- Utilize good practices
  - Test materials for which there is no data
  - Conduct hazard analysis on every design/change

Ignition Mechanisms

Adiabatic Compression Ignition

Heat generated when a gas is compressed from a low to a high pressure. Also called pneumatic impact or rapid pressurization

Characteristics

- High pressure ratio
- Rapid pressurization
  - Ball valves, cylinder valves, rupture discs
- Exposed nonmetal close to dead end

Adiabatic Compression Ignition

$$\frac{T_f}{T_i} = \left[\frac{P_f}{P_i}\right]^{(n-1)/n}$$

where n = C_p/C_v = 1.4 for oxygen

Final Pressure (psia)	Pf/Pi	Final Temperature (°F)
100	6.8	453
500	34	986
1000	68	1303
2000	136	1688
4000	272	2158

ASTM G88, Table 1

Adiabatic Compression Ignition

- Most efficient direct igniter of nonmetals
- Will not ignite metals directly
- Examples
  - Regulators attached to cylinder valves
  - Components downstream of ball valves
  - Teflon-lined flex hose

Particle Impact Ignition

Heat generated when small particles strike a material with sufficient velocity to ignite the particle and/or the material

Characteristics

- Assume the presence of particles
- High velocity
- Impact point and residence time
- Flammable particle and target

Particle Impact Ignition

(continued)

- Most efficient direct igniter of metals
- Difficult to ignite nonmetals
- Particles can ignite at velocities of 150 ft/s
- Examples
  - First space shuttle flow control valve

Mechanical Impact Ignition

Single or repeated impacts on a material with sufficient force to ignite it

Characteristics

- Large impact or repeated impact loading
- Nonmetal at point of impact

Mechanical Impact Ignition

(continued)

Examples

- Poppet impact on valve or regulator seat
- Chatter on relief or check valve seat
- Special consideration in LOX
  - Hammer fitting on LOX tanker
  - Impacts on porous hydrocarbon materials or surfaces can be "explosion-like"

Galling and Friction Ignition

Heat generated by the rubbing of two or more parts together…

…like the Boy Scout fire-starting trick!

Characteristics

- Two or more rubbing surfaces
- High speed and high loads most severe
- Metal-to-metal contact most severe
  - Destroys protective oxide surfaces or coatings
  - Generates particulate

Flow Friction Ignition

Oxygen leaking across a polymer such that enough heat is generated within the polymer to cause ignition

Characteristics

- High pressure (>1000 psi)
- Leak or "weeping" flow
  - External leaks (seals)
  - Internal leaks (seats)
- Exposed nonmetal in flow path
  - Chafed or abraded surfaces increase risk

Flow Friction Ignition

Examples

- Dome-loaded regulator
- NASA MSFC chamber

Kindling Chain

Ignition of an easily ignited material that, in turn, may release sufficient heat to ignite larger, harder-to-ignite materials

Characteristics

- Active ignition mechanism (adiabatic compression, mechanical impact)
- Ignition of an easily ignited material
- Combustion of the material releases sufficient heat energy to ignite surrounding, harder-to-ignite materials

Increasing Pressure

Increases

- Mechanical stress
- Material flammability
- Compression ignition
- Combustion rates

Decreases

- Energy required for ignition
- Autoignition temperature
- Oxygen index

Independent of pressure

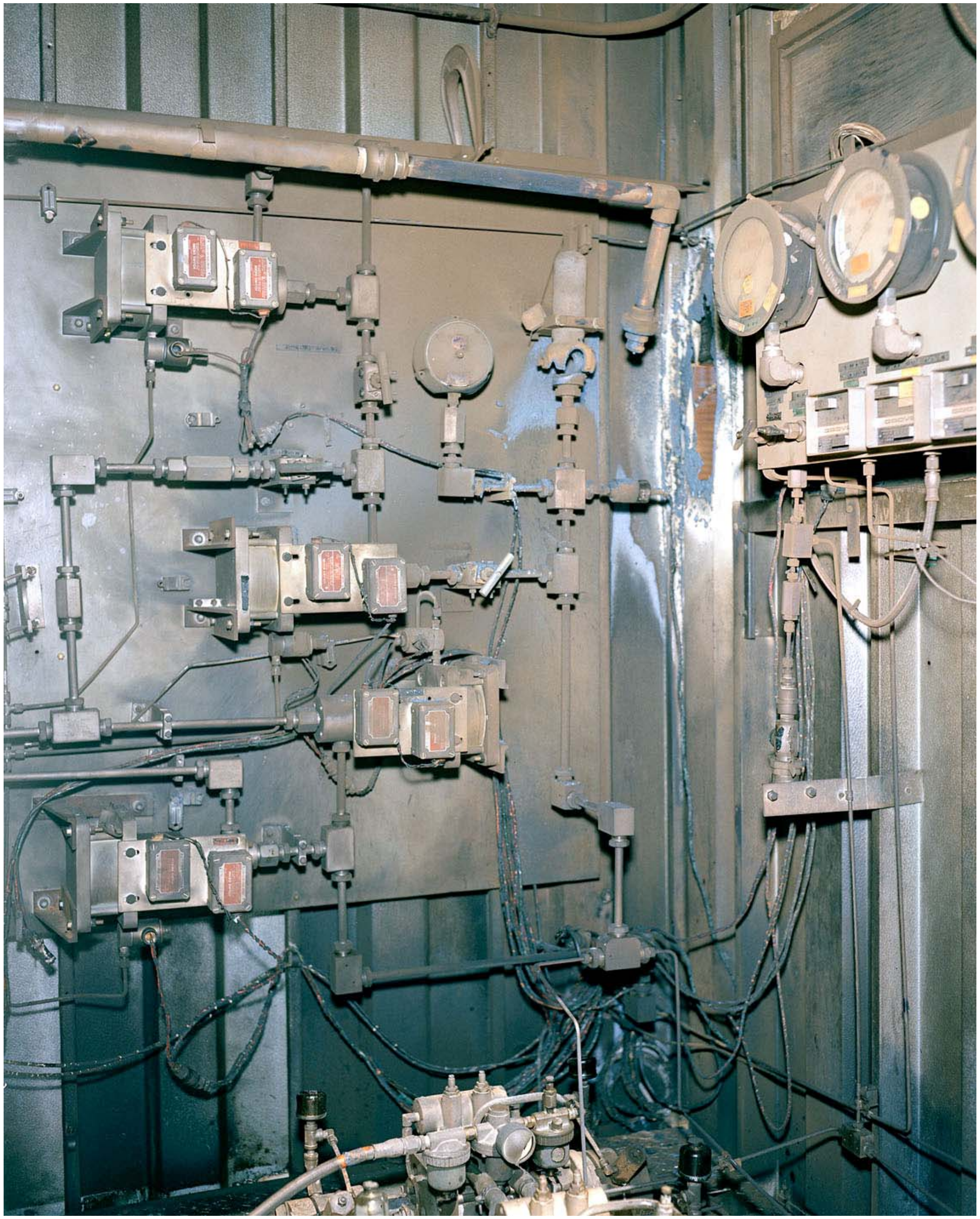
- Heat of combustion (heat release)

So How Do We Protect These Systems?

Relief Valve

Soft seat?

- Flow friction at crack pressure may ignite the seat material kindling a stem and body fire
- Seat cold flow may promote adiabatic compression ignition



Relief Valve

Metal-to-metal seat?

- Valve chatter may generate particles resulting in particle impact ignition of a downstream fitting
- Valve chatter may gall the stem, disc or seat destroying the protective oxide layer

Rupture Discs

All rupture discs produce particles when they burst even “non-fragmenting” discs.

- Rupture disc upstream of a relief valve can result in:
  - Adiabatic compression ignition of PRV softgoods
  - Particle impact ignition of PRV seat, plug, or disc
- Particle ignition of short radius elbows immediately downstream of the disc

Utilize Good Practices

- Design for ballistic flow
  - Long radius elbows instead of standard 90’s
  - “Y’s” instead of Tees
  - Minimum fittings and pipe in discharge line
- Reduce velocity ahead of targets
- Prevent system contamination
  - Insects are extremely flammable
  - Water will freeze
  - Consider a vent cover, such as Enviro-Guard rather than a vent tee with bug screen

Utilize Good Practices

- Treat the vent system with the same care as the process system
- Assemble components using “oxygen clean” techniques
- Thoroughly clean the system and sample the system
  – System must be designed for cleaning

Maximize Best Materials

High Oxygen Pressure and Low Propagation Rate

Material	Initial Pressure psig	Average Propagation Rate in./s
Monel 400	8000	NP
Copper 102	8000	NP
Nickel 200	8000	NP
Yellow brass	7000	NP
Tin bronze	7000	NP
Red brass	7000	NP
Inconel 600	2500	0.16
304 SS	2500	0.44
316 SS	1000	0.44
Ductile cast iron	500	0.14
Nitronic 60	500	0.33
Aluminum bronze	500	1.09
Aluminum 6061	250	1.80

↑ More Compatible

Less Compatible ↓

ASTM G94-05, Table X1.1

Maximize Best Materials

Friction Ignition and Heat of Combustion

Material	Friction Ignition Test $W/m^2 \times 10^{-8}$	Heat of Combustions Cal/g
Nickel 200	2.29	
Copper 102		585
Tin bronze	2.15	655
Red brass		690
Inconel 600	2.00	1300
Monel 400	1.44	870
Yellow brass	0.95	825
Aluminum bronze		1400
304 SS	0.85	1900
316 SS	0.53	1900
Nitronic 60	0.29	
Aluminum 6061	0.061	7524
Ti-6Al-4V	0.004	4710

↑ More Compatible

Less Compatible ↓

ASTM G94-05, Table X1.2, Table X1.5

Maximize Best Materials

Ignitability in Supersonic Particle Impact Test
with 2000 µm Aluminum Particles, Oxygen Pressure 520 to 580 psia

Material	Highest Temperature without Ignition of Target °F	Lowest Temperature with Ignition of Target °F
Monel K500	700	
Monel 400	650	
Copper 102		
Yellow brass	600	
Inconel 600	600	
Tin bronze	550	
Aluminum bronze	500	600
Ductile cast iron	300	400
316 SS	50	100
Nitronic 60	0	250
304 SS	0	100
Aluminum 6061	None	-50

↑ More Compatible

Less Compatible ↓

ASTM G94-05, Table X2.9

Maximize Best Materials

Autoignition Temperature and Heat of Combustion

Material	Autoignition Temperature °F	Heat of Combustion Cal/g
Teflon PFA	795	1250
Teflon A	813	1526
Rulon E (glass filled TFE)	801	1700
Kalrez	671	2090
PCTFE (Kel-F 81)	712	2500
Viton B	554	3089
PVDF (Kynar)	514	3277
Tefzel (ETFE)	469	3538
Viton A	514	3603
Vespel SP-21	649	6100
Zytel (Nylon 6/6)	498	7708
PEEK	581	6665
EPDM	318	11299

↑ More Compatible

Less Compatible ↓

ASTM G63, Table X1.2, Table X1.5

Maximize Best Materials

Mechanical Impact Sensitivity

Material	Impact Sensitivity
	Reactions/tests
Rulon E (glass filled TFE)	0 / 20
PCTFE (Kel-F 81)	0 / 20
PVDF (Kynar)	79 / 100
Viton A	3 / 20
Zytel (Nylon 6/6)	21 / 60

ASTM G63, Table X1.4

Maximize Best Materials

Autoignition Temperature

Material	Autoignition Temperature °F
Brayco 667 (grease)	801
PTFE pipetape	801
Fluorolube GR362 (grease)	801
Fluorolube LG160 (grease)	720
Fomblin RT-15 (grease)	801
Halocarbon X90-15M	801
Krytox 240	801
Oxygen System Antiseize	424
Utility pipe joint compound	421

ASTM G63, Table 1.3

Summary

- Problem
  - Fire hazard risk is real in O_2 Relief systems
  - Fire consequences are often severe
- Solution
  - Use Risk Management Strategy
    - Minimize ignition hazards
    - Maximize best materials
    - Utilize good practices

Summary

- Design relief system for cleanability
- Design relief system for ballistic flow
- Specify the right metals, softgoods, and lubricants
- Specify the best assembly techniques
- Have materials tested if data is not available
- Conduct a full hazard analysis

Summary

Resources

- ASTM
  - Manual 36, Safe Use of Oxygen and Oxygen Systems
  - G 88 - system design
  - G 63 & G 94 - material selection and data
  - G 93 - oxygen system cleanliness
- CGA G04, Oxygen
- NFPA 53, Manual on Fire Hazards in Oxygen-Enriched Atmospheres
- Other options
  - Material testing, NASA White Sands Test Facility
  - Joel Stoltzfus, NASA White Sands Test Facility

Conclusions

- Safe oxygen use and relief is possible
- This is not an exact science
  - Many variables are involved
  - But applicable data and knowledge exist
  - And good principles have been established
- A conservative approach is essential

Key element is judgment!