Mechanical Integrity: Reducing the Hidden Risk Multiplier

Mechanical integrity (MI) is a core element of OSHA's Process Safety Management (PSM) regulation. The CSB frequently identifies inadequate MI, aging infrastructure, and poor preventive maintenance as root causes of catastrophic chemical releases, fires, and explosions.



In process industries, major accident risk rarely comes from a single bad decision. More often, risk accumulates quietly.

- An inspection gets deferred.
- A repair is pushed to the next turnaround.
- A piece of equipment continues operating beyond its expected service condition.
- A temporary repair becomes a long-term solution.
- An overdue inspection enters a backlog—and eventually becomes part of the normal operating landscape.

None of these decisions necessarily feels like a major safety event. But collectively, they can change the risk profile of an entire facility. That is why mechanical integrity

should be viewed by management not simply as a maintenance activity, but as a ***major accident risk control.***

Inspection and maintenance backlogs are common realities in complex process facilities. Resources are limited. Production demands are high. Turnarounds are expensive. Equipment must remain available.

Mechanical Integrity: The Hidden Risk Multiplier

Not that every overdue inspection or deferred maintenance item represents an imminent catastrophic failure. A deferred repair on a non-critical piece of equipment may have little impact on major accident risk. A similar deferral involving containment of a highly hazardous material could have consequences that extend far beyond equipment reliability.

The management question therefore should not simply be:

> ***How large is our maintenance backlog?***

It should be:

> ***Which elements of our backlog are degrading our barriers against a major accident?***

Mechanical integrity is a barrier—not just a maintenance function. Process safety depends on layers of protection working as intended. Pressure vessels, piping, relief systems, tanks, instrumentation, rotating equipment, safeguards, and other critical assets form part of those layers. When their condition deteriorates, the facility can gradually lose the reliability of those protective barriers.

Consider a simple progression, often identified from a PHA scenario:

Corrosion → wall thinning → loss of containment → flammable or toxic release → ignition or exposure → major event.

The mechanical degradation may develop over months or years. The major accident can develop in seconds. That difference is important for management. By the time a failure occurs, the organization may perceive the event as sudden. In reality, the conditions that allowed the failure may have been developing for a very long time.

<u>Deferred maintenance can multiply risk</u>

The term “risk multiplier” is important. A single degraded asset does not necessarily create a major accident. But degraded equipment can interact with other weaknesses.

For example, an organization may have:

* an overdue inspection on aging piping;

* incomplete information about corrosion rates;

* a temporary repair that has remained in service;

* limited operating margin;

* changes in process conditions;

* reduced maintenance resources; and

* safeguards that have also experienced testing or maintenance delays.

Each issue may appear manageable in isolation. Together, they can create a significantly different risk picture. *This is where management visibility becomes critical.* The risk is not necessarily the individual backlog item. *The risk is the accumulation of degraded or uncertain barriers.*

“Deferred” does not mean “low risk”

Identification is not the same as risk control

If an inspection or maintenance is overdue, the organization needs to understand what is known about the equipment condition, what failure mechanisms are credible, what safeguards remain available, and what operating limitations may be appropriate until the inspection or repair is completed.

In other words:

A backlog is a list. Risk management requires understanding what the list means.

This distinction becomes particularly important when production pressures compete with maintenance requirements. If an inspection cannot be completed during the planned window, the decision should not simply become “move the date.”

It should become a conscious risk decision:

* What could fail?

* How could it fail?

* What are the consequences?

* How much uncertainty exists about the equipment condition?

* What safeguards remain?

* What temporary controls are in place?

* How long can the equipment safely remain in its current condition?

* Who has accepted the residual risk?

These are management questions, not merely maintenance questions.

The hidden danger of normalization

There is another risk that develops over time: normalization.

An overdue inspection that remains open for several weeks attracts attention. An overdue inspection that remains open for several months can begin to feel normal. The same can happen with temporary repairs, operating restrictions, recurring equipment deficiencies, and extensions to inspection intervals. Eventually, the organization can become accustomed to operating with degraded conditions. The absence of an incident reinforces the perception that the risk is acceptable. But nothing has necessarily become safer. The organization may simply have been fortunate.

This is particularly dangerous in high-hazard operations because major accidents are low-frequency events. A facility can operate for years with latent weaknesses without experiencing a catastrophic failure. That does not prove the controls are effective. It may simply mean the initiating event has not occurred.

CSB Investigations and Recommendations

The CSB Fact Sheet, "*Drivers of Critical Safety Change*" cites the following examples of failed MI:

- **Chevron Richmond Refinery Fire (2012)**: A corroded carbon steel pipe which had thinned due to sulfidation corrosion, ruptured and released hydrocarbons that ignited resulting in massive fire, smoke over residential areas, and over 15,000 local residents seeking medical help.. The pipe had thinned to the point of failure — however the true status was not reflected in the MI program data. Inspection for carbon steel components containing low silicon concentrations is challenging. Each pipe component, from one weld to the next, must be individually inspected. Chevron's inspection program examined only a few locations, all of which turned out to be high-silicone. Based on this incomplete inspection data, Chevron rejected recommendations to replace the carbon steel pipe with higher chromium steel pipe, less susceptible to sulfidation corrosion.

- **Tesoro Anacortes Refinery Explosion (2010)**: A heat exchanger ruptured due to High Temperature Hydrogen Attack (HTHA) — a degradation mechanism well-known to engineers but the site inspection strategy was based on design rather than actual

temperature proved unreliable so the inspections missed the degradation. Seven workers were killed.

The fact sheet provides the following table of MI related incidents:

Year	CSB Investigation/Deployment
2015	ExxonMobil Refinery (Torrance, CA)
2012	Chevron Refinery (Richmond, CA)
2011	Carbide Industries (Louisville, KY)
2011	Hoeganaes Corporation (Gallatin, TN)
2010	NDK Crystal Inc. (Belvidere, IL)
2010	Tesoro Refinery (Anacortes, WA)
2009	Silver Eagle Refinery (Salt Lake City, UT)
2008	Allied Terminals (Chesapeake, VA)
2008	DuPont (Belle, WV)
2007	Valero Refinery (Sunray, TX)
2005	BP America Refinery (Texas City, TX)
2003	Technic Inc. (Cranston, RI)
2002	DPC Enterprises (Festus, MO)
2001	Marcus Oil and Chemical (Houston, TX)
2001	Motiva Enterprises (Delaware City, DE)
1999	Tosco Avon Refinery (Martinez, CA)
Source: CSB Fact Sheet: Drivers of Critical Chemical Safety Change	

Other well known incidents include:

- BP Texas City (2005): Leaking valves, failed level indicators, and neglected blowdown drums all played roles. The Mechanical Integrity of these basic components was compromised — yet action was not taken in time to prevent the incident.
- Bhopal, India included MI causes including
  • Inoperable Safety Systems: The gas scrubber and flare tower were either undersized, turned off, or malfunctioning during the emergency.
  • Deferred Maintenance: Lapsed equipment maintenance and unreliable gauges blinded operators to early warning signs.

A review of the recent CSB Incident reports show that 70 to 90% of the incidents reviewed had a cause or underling cause related to MI. thus linking failed MI as a leading concern to monitor and address.

- Burner issues in PHA – ask Rene' for details

Key Findings by the CSB

- **Run-to-Failure Approach:** Facilities often address equipment issues only after a breakdown instead of implementing proactive, routine testing and inspection protocols.
- **Aging Infrastructure:** Long-term degradation, corrosion, and wall thinning in piping and pressure vessels frequently lead to major containment losses.
- **Deferred Maintenance:** Postponing equipment replacements, upgrades, or safety-critical repairs compromises the protective barriers assumed in Process Hazard Analyses (PHAs).
- **Quality Assurance Failures:** Inadequate inspection or testing of newly installed or modified equipment (such as manways and pumps) routinely introduces fatal vulnerabilities.

CSB Recommendations for Industry

In the absence of adequate industry guidance that incorporated findings from the Tesoro Anacortes failure, the CSB issued a Safety Alert to provide the following additional direction for industry.

1. Identify all carbon steel equipment in hydrogen service that has the potential to harm workers or communities due to catastrophic failure;

2. Verify actual operating conditions (hydrogen partial pressure and temperature) for the identified carbon steel equipment;

3. Replace carbon steel process equipment that operates above 400°F and greater than 50 psia hydrogen partial pressure; and

4. Use inherently safer materials, such as steels with higher chromium and molybdenum content.

Additionally, CSB recommends:

- **Thorough Inspection Programs:** Develop strict testing and protocol measures to catch equipment wear before failure occurs.
- **Clear Corrective Actions:** Ensure safety-critical deficiencies are actively communicated to all stakeholders and resolved promptly without deferral.
- **Management of Change:** Implement robust systems so that safety responsibilities and mechanical baselines are never lost during personnel or organizational updates.

CCPS Core Program Elements

The Center for Chemical Process Safety (CCPS) recommends establishing a risk-based Mechanical Integrity (MI)—or Asset Integrity Management (AIM)—program that ensures critical process equipment remains fit for service throughout its lifecycle. MI is one of the core elements of risk based process safety.

CCPS guidelines outline several key components required to build and sustain an effective mechanical integrity system:

- **Management Responsibility:** Define clear roles, accountability, and resource allocation for personnel managing and executing MI tasks.
- **Equipment Selection & Criticality:** Identify which process equipment, instrumentation, and safety systems require rigorous tracking based on risk and potential consequences of failure.
- **Inspection, Testing, and Preventive Maintenance (ITPM):** Develop routine schedules and procedures aligned with recognized and generally accepted good engineering practices (RAGAGEPs) like API and ASME standards.
- **Quality Assurance (QA):** Verify that newly installed or replacement parts, materials of construction, and fabrication methods match design specifications and are suitable for their intended use.
- **Procedures and Training:** Maintain up-to-date written work instructions and ensure maintenance, contractor, and operations personnel receive adequate training.
- **Equipment Deficiency Management:** Establish a systematic process to document, risk-evaluate, and correct equipment flaws or deviations discovered during routine inspections before returning items to service.

What Should Management Be Looking At?

Senior leaders do not need to review every inspection record or maintenance work order.

They do, however, need meaningful indicators that show whether mechanical integrity is protecting—or eroding—the facility's major accident risk controls.

Useful management-level questions include:

1. Which overdue inspections or repairs involve safety-critical equipment?

Not all backlog items deserve equal management attention. Critical equipment should be identified and prioritized based on its potential contribution to a major accident. This is why sites develop critical equipment lisrs based on PHAs.

2. Are inspection intervals being extended—and why?

Extensions may sometimes be technically justified. The concern is whether extensions are based on documented engineering evaluation and credible damage mechanisms, or simply operational convenience.

3. How much temporary equipment or temporary repair is in service?

Temporary solutions can be appropriate. The risk emerges when "temporary" becomes indefinite and the organization loses track of the original basis for accepting the condition.

4. Are we seeing recurring failures or repeat deficiencies?

Repeated equipment problems can indicate a systemic issue rather than isolated maintenance events.

5. Where are we operating with uncertainty?

Perhaps the most important question is:

> ***What critical equipment do we know the least about?"***

Uncertainty about equipment condition can itself be a risk factor.

Moving from backlog management to risk management

The objective should not be to eliminate every backlog item. That is neither realistic nor necessarily necessary. The objective is to ensure that backlog decisions are risk-informed and that critical barriers receive the attention they require.

Organizations can strengthen this approach by:

- identifying safety-critical equipment and mechanical integrity barriers; HOW? Talk about procedures and PHA approaches
- ranking overdue inspections and repairs according to major accident consequences;
- establishing clear criteria for accepting inspection or maintenance deferrals;
- requiring documented engineering justification for significant extensions;
- tracking temporary repairs and compensating measures;
- monitoring recurring equipment degradation;
- integrating mechanical integrity information into PSM risk assessments; and
- giving leadership visibility into trends affecting critical safeguards.

This changes the conversation from:

> ***"How quickly are we reducing the backlog?"***

to:

"Are we maintaining the barriers that prevent major accidents?"

That is a much more meaningful measure of process safety performance.

The Management Takeaway

Mechanical integrity failures are often treated as equipment problems. In a high-hazard facility, they can become major accident problems.

The greatest concern is not necessarily an individual overdue inspection or deferred repair. It is the gradual erosion of confidence that critical equipment will perform when it is needed. That erosion can be difficult to see because production can continue normally.

The facility may look healthy. The equipment may continue operating. The safety statistics may remain favorable.

Meanwhile, the margin of safety may be getting smaller.

Management's role is not to eliminate every maintenance deferral. It is to make sure that decisions affecting critical process safety barriers are visible, understood, technically justified, and actively managed.

Because when mechanical integrity begins to deteriorate, the risk doesn't always increase dramatically overnight.

It can increase quietly—one deferral at a time.

References

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