Effectively Addressing New PSM/RMP Damage Mechanism Review Requirements with an Integrated PHA (iPHA)

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Prepared for Presentation at
11th Global Congress on Process Safety
Austin, Texas
April 27-29, 2015

UNPUBLISHED

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Keywords: PHA, Mechanical Integrity, MI, Damage Mechanism Review, DMR, Integrated PHA. iPHA

Abstract
Since August 2012, significant changes have been proposed by a number of agencies to Safety Management Systems (SMS) Programs, e.g., Process Safety Management (PSM), Risk Management Programs (RMP), and related SMS Regulatory Requirements. Many of these are framed within OSHA's and EPA's PSM/RMP Modernization/Expansion Programs, and key technical and regulatory changes are being proposed by Federal OSHA, U.S. EPA, Chemical Safety Board (CSB), California Office of Emergency Services (OES), and other agencies. As part of these SMS Regulatory Program Modernization Initiatives, on October 31, 2014, Cal/OSHA issued the latest update to its proposed regulation for "Process Safety Management for Refineries" in response to a report from the California Interagency Refinery Task Force.

A number of these modernization initiatives have focused on perceived weaknesses in the application of the Process Hazard Analysis (PHA) and Mechanical Integrity (MI) elements of PSM/RMP. The main objective of this paper is to provide some tangible suggestions for effectively addressing proposed changes associated with Damage Mechanism Reviews (DMRs), with the intent of providing straightforward tips for owner/operator companies to address contemporary best practices and to minimize the effort associated with later upgrades to various PSM/RMP Program elements, once these proposed initiatives become regulatory requirements. The core of this paper will detail a Streamlined DMR approach to address near-term objectives and an Integrated PHA (iPHA) approach to address long-term objectives by harmonizing PHA and MI efforts. Key topics include:

- The Challenge – Identifying Potential Mechanical Integrity Hazards and Adhering to New Regulatory Program Requirements
- Addressing Damage Mechanism Review (DMR) Requirements
- DMR Preparation
- DMR Implementation Using the iPHA Approach
- DMR Documentation Documenting the DMR within the iPHA
1. The Challenge – Identifying Potential Mechanical Integrity Hazards and Adhering to New Regulatory Program Requirements

1.1 Pre-2012 PSM/RMP Universe

The December 2, 1984 Methyl Isocyanate (MIC) release from the Union Carbide Bhopal Facility is considered a pivotal event in catalyzing Safety Management System (SMS) approaches to control process safety. Referencing the analogies in Figure 1.1, the MIC release resulted from the concurrent alignment of several “holes,” and the magnitude of the tragedy (3,928 fatalities and over 100,000 permanent injuries are estimated)\(^1\), drew the attention of industry, the public, and the regulatory community to the potential consequences associated with process safety events (Figure 1.2). Industry was quick to realize the significance of the event, with respect to the need to create and implement SMS mechanisms at highly-hazardous facilities, and the importance of developing mechanisms to control process safety.

Industry’s response as swift and definitive. The American Institute of Chemical Engineers (AIChE) founded the Center for Chemical Process Safety (CCPS) in 1985, recognizing that the most effective mechanism for addressing process safety was not the application of additional prescriptive mechanisms, or by addressing any specific action, but by effecting changes in the way business is done (i.e., safety culture and management systems). CCPS Guidebooks are currently considered key references in conveying the technologies needed for process safety, and the very first guidebook (“Guidelines for Technical Management of Chemical Process Safety”\(^2\)) published in 1987 was designed to address this pressing need.

![FIGURE 1.1 – Swiss Cheese and Spinning Disk Models for Accident Causes](API RP 754)

![FIGURE 1.2 – Tragedies to Avoid](Endress Ammonia spill, Blair, NE, 1970)”
Shortly thereafter, the American Petroleum Institute (API) distilled its version of Safety Management Systems and issued Recommended Practice 750, “Management of Process Hazards” in 1990. The following characteristics have remained consistent from the onset:

- All segments of the process industries correctly identified SMS as the primary and most effective mechanism for addressing core issues associated with process safety incidents.
- Although some details differed between the above two documents, and also between the current requirements of OSHA’s Process Safety Management (PSM) Program, U.S. EPA’s Risk Management Program (RMP), Bureau of Safety and Environmental Enforcement’s (BSEE’s) Safety and Environmental Management Systems (SEMS) Program, the same key Safety Management System elements are at the core of PSM, RMP, and SEMS, spanning an entire spectrum of facility types and geographic application.

Figure 1.3 illustrates the parallel evolution of PSM, RMP, and SEMS Programs. It is interesting to note that although PSM and RMP were catalyzed by an onshore tragedy and focus on onshore facilities in the United States and SEMS was catalyzed by an offshore-US tragedy and focuses on offshore facilities in waters off the coast of the United States, the key prevention program elements are nearly identical (see the key elements of PSM in Figure 1.4). This parallel evolution and resultant overlap are important to note for several reasons:

- Understanding potential hazards (Process Hazard Analysis – PHA), and maintaining equipment functionality and the integrity of containment (Mechanical Integrity – MI), have always been key accident prevention elements (see Figure 1.4). The importance of quality PHA and MI application is reflected by over two decades of SMS application.
- Although these regulatory programs were developed independently, at different
times, and in different locations, industry and the regulatory community noted the importance of SMS application across all facility types.

- As performance-based regulatory requirements continue to evolve, best practices for both PHA and MI must continue to be applied.

The Richmond Refinery fire on August 6, 2012 and West (Texas) Ammonium Nitrate Explosion (April 17, 2013) triggered a fresh look at the different SMS programs, the application of hazards identification techniques (as applied to hazardous material containment integrity), and resulted in several proposals for the modernization of PSM and RMP, including the performance of a “Damage Mechanism Review.”

1.2 Overview of Key Safety Management Systems Program Modernization Initiatives

Since August 2012, significant changes have been proposed by a number of agencies to (SMS) Programs. After various high-profile incidents occurred, Executive Order 13650 was signed by President Obama on August 1, 2013 to emphasize the importance of various agencies working together towards the common goal of improving process safety, as well as modernizing the current standards[7]. In addition to Executive Order 13650 mandating increased coordination amongst federal agencies, the Chemical Safety Board (CSB) investigated the Richmond Refinery Fire, and identified improvement areas[8,9,10] for both PSM/RMP implementation at the facility, as well as agency oversight and cooperation (eventually forming the Interagency Refinery Task Force). Figure 1.5 illustrates the various agencies involved in SMS Program Modernization Initiatives, and Figure 1.6 depicts some of the key activities associated with these initiatives. As a result of these activities, there have been changes proposed for the following key programs: Federal OSHA PSM[11], U.S. EPA RMP[12], and Cal/OSHA PSM[13]. Reference 14 may be reviewed for details and current status of all of these regulatory initiatives; however, the key topic for this paper is the Damage Mechanism Review (DMR), which is driven by a CSB recommendation for application to California Petroleum Refineries and proposed updates to Cal/OSHA PSM.
2. Addressing Damage Mechanism Review (DMR) Requirements

2.1 DMR Requirements

Damage Mechanism Reviews (DMRs), as a required element for California Petroleum Refineries and correlated to the PHA, originated from CSB’s investigation of the August 2012 Richmond Refinery Fire. CSB Recommendation 2012-03-I-CA-9 involves California revising its PSM Standard to:

“...require improvements to mechanical integrity and process hazard analysis programs... engaging a diverse team of qualified personnel to perform a documented damage mechanism hazard review... The damage mechanism hazard review shall identify potential process damage mechanisms and consequences of failure, and shall ensure safeguards are in place to control hazards presented by those damage mechanisms.”[8]

In response to CSB Recommendation 2012-03-I-CA-9, in 2014, Cal/OSHA proposed an update (8 CCR §5189.1)[13] to its PSM requirements, which, among other changes, included this new element for DMRs. Cal/OSHA defined damage mechanisms as “mechanical, chemical, physical, or other process that results in equipment or material degradation”, and the DMR was intended to involve a broad team (including inspection and damage/failure mechanism experts) using process flow diagrams, materials of construction, process conditions, chemical substances, inspection history, and industry-wide experience with the process to determine potential damage/failures. While currently only being proposed for California Petroleum Refineries, refineries and other facilities nation-wide should evaluate whether beginning the implementation of DMR practices into their current PHAs would be considered by regulators to be a best practice.

Section k of 8 CCR §5189.1 defines damage mechanisms and stipulates the requirement for implementation of a DMR:

- Prior to any PHA and changes affecting chemistry, metallurgy, or operating limits prior to the change
- Initial DMR to take place at the earliest of the following:
  - No later than 3 years after effective date of 8 CCR §5189.1
  - Prior to next scheduled turnaround
  - Prior to next PHA revalidation

Section k of 8 CCR §5189.1 requires that, at a minimum, the following should be evaluated:

- **Mechanical Loading Failure** (ductile fracture, brittle fracture, buckling, mechanical fatigue)
- **Wear** (abrasive wear, fretting)
- **Corrosion** (Uniform corrosion, localized corrosion, pitting)
- **Thermal-Related Failure** (creep, thermal fatigue, transformation)
- **Cracking** (Stress corrosion cracking)
• **Embrittlement** (High Temperature Hydrogen Attack (HTHA))

A common reference when discussing damage mechanisms is API Recommended Practice 571: “Damage Mechanisms Affecting Fixed Equipment in the Refining Industry”, released in 2003\(^{[15]}\) then updated in 2011\(^{[16]}\). API RP 571 is intended to provide guidance for refineries and petrochemical facilities to perform fitness for service evaluations on equipment, as well as provide supplemental information to aid in existing Risk Based Inspection and Testing (RBIT) Programs as outlined in API RP 580 and 581.

### 2.2. What Should I Be Doing Now?

The Cal/OSHA update to its PSM requirements (8 CCR §5189.1\(^{[13]}\)) was proposed in 2014, is scheduled for implementation in 2015, but is not anticipated to be promulgated until First/Second Quarter of 2016. The key unknowns are, of course, the specific timing and the specific requirements. Even through improvements in Mechanical Integrity assessments in the form of a DMR have been identified by a number of different agencies, and regulatory requirements addressing DMR are inevitable, there is no specific regulatory requirement at this time (April 2015). Thus, a facility encompassed by PSM, RMP, or an analogous state program has three main options (See Figure 2.1):

- Implementing a Streamlined DMR
- Implementing a Full DMR
- Doing Nothing

In addition, with the Cal/OSHA PSM update that pertains to Petroleum Refineries anticipated for First/Second Quarter 2016, the facility also has an option regarding implementation timing. This should be tempered by recommendations from the regulatory community that, once promulgated, the “schedule will be tight,” limiting the potential availability of qualified resources who can provide balanced and high quality DMR support. Regulators may also give some credit to having performed suitable analyses on high value/priority portions of the covered process, allowing de-prioritization and additional time for full DMR implementation on those systems.

So, because DMR is not a formal regulatory requirements until Cal/OSHA promulgates its proposed updates to PSM, the owner/operator of the facility does have
the prerogative to not make any changes to its current implementation of PSM/RMP (and for the California petroleum refineries that may be subject to 8 CCR §5189.1, California Accidental Release Prevention Program (CalARP)). However, this may not be consistent with best practices and a general duty to address potential deficiencies that were identified by the CSB’s investigation of the August 2012 Richmond Refinery Fire.

The Owner/Operator also has the prerogative to address the full requirements specified in the proposed 8 CCR §5189.1; however, this might be inadvisable until the details of the regulation are finalized and promulgated, and any additional guidance documentation released.

Recognizing that the potential deficiencies identified by the CSB revolve around actions that are associated with the PSM/RMP elements of Mechanical Integrity (MI) and Process Hazard Analysis (PHA), one could conclude that:

- Any improvements would be linked to MI and PHA elements.
- Actions to address DMR could be addressed as an extension of existing MI and PHA activities.

There are numerous PHA tools applied, as appropriate, to petroleum refineries (see Figure 2.2), and the commonly-applied HAZOP Study (see Figure 2.3) provides a framework for the:

- identification of scenarios associated with a wide range of causal events (good quality HAZOP Studies already look at a variety of causes leading to loss-of-containment events)
- evaluation of ultimate consequences associated with loss-of-containment events
- gauging of the reliability of applicable safeguards
- use of risk-ranking or quantitative analysis to identify potential vulnerabilities

In addition, petroleum refineries already expend a lot of effort to assure the mechanical integrity of equipment, e.g.:

- Materials identification
- Corrosion Studies
- Field inspections
- Testing
- Maintenance
- Repair

FIGURE 2.2 – PHA & Hazard Evaluation Techniques
Thus, one could argue that DMR objectives can be achieved by identifying any potential gaps in existing PHA and MI Programs, and filling them. With PHA and MI already required by PSM/RMP, a framework for addressing DMR objectives exists, there is a “general duty” for adhering to best practices, and regulators are likely to recognize accomplishments made in addressing DMR. Thus, it makes sense to start infusing DMR into existing practices by identifying and filling any gaps in what this paper terms a Streamlined DMR (see Figure 2.1). A recommended approach for infusing DMR into existing practices includes:

- Maintaining SMS HAZOP/MI activities
- Initiating high-value DMR activities in the form of a Streamlined DMR
- Addressing high priority issues
- Initiating a transition of SMS HAZOP/MI Program to address DMR objectives
- Maintaining progress towards long-term DMR objectives

A Streamlined DMR approach that works well in the context of maintaining progress towards long-term DMR objectives involves infusing key DMR elements into the HAZOP Studies that are currently being performed and clearly documenting how high-value DMR elements are being addressed as part of the HAZOP Study. Although there are many different mechanisms that accomplish this, the following approach has been shown to be effective:

- For each High/Low Pressure & High/Low Temp Scenario, review specifications of associated piping & equipment.
- Each Node – Execute key MI issues “Mini-Checklist,” and apply corrosion screening software, as appropriate.
- Documenting as a Separate Node – Understand extent & status of MI Program & corrosion control evaluations, and identifying potential gaps.

The above Streamlined DMR approach is something that can be done now with minimal incremental effort to provide an effective framework for addressing best practices while making progress towards long-term DMR objectives. Implementing the full DMR objectives will require a scenario-based assessment that is systematic, methodical, and comprehensive, which would naturally work in tandem with the HAZOP Study process. Recognizing that the HAZOP Study is the industry workhorse for identifying and evaluating hazard, especially for the identification of
potential hazards in highly hazardous processes, the remainder of this paper (Sections 3-5) will focus on practical mechanisms for augmenting the HAZOP Study and key portions of the MI Program to accomplish the objectives of DMR in a manner that we will term an Integrated PHA (iPHA) (See Figure 2.4).

3. DMR Preparation

3.1 DM-Node Background

In development of the Integrated PHA (iPHA) process, the normalization of unit size between studies is key to maintaining applicability to both large and small processes. The highly hazardous chemicals processed in large and complex units often vary in composition, phase, and operating parameters. The metallurgy used in the equipment and piping for containment may also vary accordingly. In order to efficiently analyze a process, fragmenting the unit into manageable pieces is required. For current HAZOPs, this is done by separating the process into nodes. It is most often the responsibility of the HAZOP facilitator familiar with the methodology to determine the nodes and their boundaries within the unit to be studied.

When developing node boundaries, the primary intent is to create boundaries that a team familiar with the process can consistently envision and imagine throughout discussions of hypothetical scenarios. Smaller nodes are likely to increase repetition, which can often bog down the team and derail them from their primary objective, i.e., brainstorming potential hazards. Many facilitators will use general (flexible) guidelines, such as:

- maintaining a single process chemical, (for example, a major indication of a node boundary is when the service that is flowing through the piping undergoes a change that greatly affects the composition),
- maintaining a single phase, and
- utilizing the inlet/outlet of a major piece of equipment (pressure vessel, separator, heat exchanger, column, etc.) as a node boundary.

In preparation for a HAZOP, the facilitator would use a process description, material and energy balance information, Process Flow Diagram (PFD), and Piping & Instrumentation Diagrams
(P&IDs) to define node boundaries that can optimize the team’s ability to evaluate the process dynamics, balance operational issues, and effectively implement the HAZOP.

![Sample Noded PFD](image)

**FIGURE 3.1 – Sample Noded PFD**

To address DMR objectives, the proposed team-based methodology requires segmentation of the process analogous to HAZOP nodes, as well as an analogous preparation strategy. For the purpose of this paper, these are referred to as DM-Nodes. In many cases, DM-Nodes can be defined to align with the HAZOP nodes, with self-evident advantages; however, in some cases, it may be advantageous to define DM-Nodes and HAZOP nodes with different boundaries.

As previously discussed, the purpose of the DMR is to identify the potential damage mechanisms that affect the unit and ensure that adequate safeguards are in place to control those hazards. The damage mechanisms that affect the unit may vary throughout the process due to changing conditions (e.g., process chemical changes due to reactions or fractionation, operating parameters, metallurgy of piping and equipment, external environment, etc.). To ensure consistent focus of the team, the process is broken up into more manageable sections. These DM-Nodes would be dictated by the various process changes that determine the potential damage mechanisms. Since HAZOP node boundaries typically include major pieces of equipment, phase changes, and/or major parameter changes, DM-Node boundaries may align to some HAZOP node boundaries, but there may be differences.

### 3.2 Developing DM-Nodes

DM-Node boundary development should employ a focused team of personnel that will also be involved in the HAZOP and DMR sessions. Different from HAZOP Node development, the rules
for DM-Node development are less flexible. DM-Nodes will be based on operating parameter changes as well as material changes. As a rule of thumb, DM-Node development begins with dividing the PFD into where the different services (i.e., process chemicals and metallurgy) flow through. For example, a typical gas plant would include the following service divisions:

- Feed Gas at the inlet
- Ethane (from Deethanizer Overhead)
- C3+ (Deethanizer Bottoms)
- Propane (Depropanizer Overhead and Propane Refrigeration System)
- C4+ (Depropanizer Bottoms)
- Butane (Debutanizer Overhead)
- Natural Gas Liquids (Debutanizer Bottoms)
- Lean Glycol
- Rich Glycol
- Chemicals used for Injection (i.e. Methanol, H2S Scavenger, etc.)

The second division is performed by segmenting DM-Nodes at points where the operating parameters of the services undergo a major change. For example, when analyzing a flow path, an increase in pressure by means of compressor or pump would potentially change the damage mechanisms involved, or through a heat exchanger a temperature change may introduce/eliminate damage mechanisms that can be used as boundary points for the DM-Nodes. After the second division is made, the final step in determining the DM-Node boundaries involves not only the facilitator but the full preparation team which includes a process engineer familiar with the unit and a Mechanical Engineer/Metallurgist. The process engineer will provide confirmation on the operating parameters and service to ensure the DM-Node boundaries are appropriate as they were divided by the facilitator, and the Mechanical Engineer/Metallurgist will provide input on the relative amount of damage mechanisms per DM-Node. The input from the Mechanical Engineer/Metallurgist should be focused on confirming the types of damage mechanisms for each DM-Node.

The next step of DMR preparation involves an analysis of each DM-Node and cross-reference to established literature, including company-specific studies and API RP 571. Within API RP 571, damage mechanisms are organized to include relevant information that will be needed for the DMR. It is the responsibility of the preparation team to compile and ready the information for review during sessions. A full compilation of each damage mechanism associated with each DM-Node is an essential part of the preparation step to ensure the team’s time and focus is used efficiently. In addition, site specific information associated with preventative maintenance inspections, results from the inspections, and failure history should be available electronically for reference during the study. This site specific information not only is a relevant reference for the team but will provide a data point to ensure recommendations are developed with more focus. Finally, as best practice, compilation of industry incidents on analogous units associated with damage mechanisms should be included in the preparatory materials. Industry incidents are particularly important to the DMR to provide additional potential scenarios that might not have been imagined and a break from the hypothetical method.
For many facilities, corrosion studies are standard practice, and the majority of the work associated with preparation for a DMR is completed through these corrosion studies. The analogous DM-Nodes are determined by the Inspector/Mechanical Engineer, and they are commonly referred to as Corrosion Loops. The information presented in a corrosion study can be readily used in the DMR in the same fashion. Depending on the depth of the report, the details of each of the damage mechanisms studied may or may not be included. A cross reference with API RP 571 or similar literature may be required to provide the DMR team with the information necessary to perform an adequate study.

Preparation for the DMR is similar to the steps taken during HAZOP Preparation. They are completed with similar intents and are required to maximize efficiency and focus of the team. The following steps are involved in comprehensive preparation for a DMR:

1. Facilitator familiarizes self with process using select Process Safety Information (PSI)
2. Facilitator performs high level DM-Node division of process by different materials/services involved in the process
3. Secondary DM-Node division is completed by examining major operating parameter changes within the first division
4. Focused team of facilitator, Process Engineer, and Metallurgist review and confirm the DM-Nodes and determine if final divisions are necessary, keeping team efficiency in mind
5. Using industry literature and API RP 571, damage mechanisms applicable to each DM-Node are documented and details associated with each damage mechanism are readied for review
6. Compilation of industry incidents applicable to the unit studied are included in the appropriate DM-Node

4. DMR Implementation Using the iPHA Approach

The previous section identified preparation elements that would be necessary for any DMR approach. The objective of this section is to introduce the Integrated PHA (iPHA) approach that can combine and synchronize the HAZOP and DMR activities to realize significant improvements in quality and efficiency. This optimization of quality and efficiency is achieved because a DMR and HAZOP have more in-common than not.

The HAZOP Study involves a team of multiple disciplines systematically analyzing deviations from normal operation. The defining characteristics of the methodology are its comprehensive nature and team-based approach. The proposed method to address DMR requirements is developed specifically to seamlessly integrate into the PHA process, including its team-based characteristics and objective of developing understandable hazard scenarios. From an implementation perspective, HAZOP Studies rely on a systematic approach that includes the following steps:

1. Facilitator provides a training presentation explaining methodology
2. Facilitator guides the team through P&IDs highlighting the node boundaries for the specific node to be studied
3. Process Engineer provides a detailed description of equipment, process technology, and operating parameters involved in the node to be studied
4. Perform HAZOP on Node
5. Repeat Steps 2-5 for next Node

For facilities that perform Corrosion Studies on a routine basis, and have supporting records on file, like Corrosion Control Documents (CCD), the DMR augmentation of the HAZOP Study to achieve an Integrated PHA is straightforward and involves similar steps. The summary in the CCD, quantitative piping/equipment data (i.e., wall thickness), and projected Integrity Operating Windows (IOWs) all supplement the discussions associated with the damage mechanism scenarios and discussion. All of these elements drive the team in providing a much more robust determination of risk as well as distilling recommendations to specific actions, hence saving time and effort on post-study reviews and meetings.

4.1 DM-Node Introduction

During the HAZOP Study, a crucial step is the process briefing as the analysis for each node is begun. This briefing is important to ensure that key information is discussed at the outset before scenarios are imagined and accident sequences are detailed. The briefing can help minimize rework, synchronize the understanding of the process, and calibrate the team on the section to be studied.

The DMR portion of the iPHA involves an analogous briefing following the HAZOP analysis of the node. Since the nodes for the HAZOP were specifically bounded with the intention of maintaining the efficiency and focus of the team, the DMR follows the same principle. Following the HAZOP portion of the node, the facilitator will define the DM-Node(s), explain the boundaries, and guide the team through the P&IDs and other relevant design information. For the DMR briefing, the Mechanical Engineer/Metallurgist will explain the details of the piping and metallurgy specific to the DM-Node, recapping the operating parameters and IOWs as well. A strong supplement to the introduction as a whole is the trended parameter data for select sections. This information will provide the team with a more complete picture of actual operating conditions (e.g., pressure and temperature) that can be compared to details surrounding the damage mechanism as described by industry literature. The DMR will then progress led by the facilitator and the prepared details and damage mechanisms from API RP 571 with applicable industry literature.
4.2 Consequence Development

To support integration of the HAZOP and DMR, the proposed approach involves directly augmenting the worksheet used for the HAZOP Study. Although node boundary synchronization would be the appropriate objective, within each HAZOP node there may be more than one DM-Nodes. This condition can be addressed by clarifying the DM-Node in the iPHA Deviation column, possibly including descriptive information, as well as the applicable nominal operating parameter range. For each DM-Node, the process will progress with each of the applicable damage mechanisms in the cause column. The consequence column would be developed in the same manner as if it were in the HAZOP, employing the three HAZOP consequence defining qualities:

1. Full description of the ultimate potential consequence
2. Global analysis (any effects upstream and downstream will be covered)
3. No tempering of the consequences based on the existence of safeguards

The DMR portion of the iPHA will employ the same consequence development methodology of describing the ultimate potential consequence, taking into consideration both safety and environmental concerns. This is done by fully playing out the accident sequence, as appropriate, to personnel exposure and injury. As part of the iPHA’s mandate to review the ultimate consequences, the damage mechanism being evaluated will consider effects to all potentially-affected sections either upstream or downstream of the DM-Node. Not tempering the consequences based on the existence of safeguards is important for several reasons:

- Focusing on the ultimate potential consequences allows synchronization with the HAZOP for improved scenario understanding, risk-ranking accuracy, and decision-making
- Facilitating the ability of the team and worksheets to discuss, document, highlight, and challenge the effectiveness of the safeguards in place which mitigate or prevent the consequence from reaching its ultimate potential

As discussed in Section 4.3, a clear correlation of safeguard effectiveness with consequence mitigation provides added value for the iPHA by providing additional information to the maintenance department regarding safeguard criticality that can then become part of the basis for the preventive maintenance interval/task accordingly.

The description of the accident sequence has always been an important element of a HAZOP. For the DMR portion of the iPHA, it is even more critical for the consequence (and documentation) to focus on the accident progression, e.g., how a failure initiates, propagates, and reaches loss of containment using relevant information, the metallurgist’s expertise, and operational observations. All of this information should be used to develop a complete and detailed picture of the accident sequence for the entire iPHA, and especially the DMR portion.

In general, by integrating the DMR and HAZOP Study activities, uniformity and synchronization in consequence development, understanding, and ranking provides a significant quality and efficiency advantage.
4.3 Safeguard Development

Following consequence development, the team must determine the safeguards associated with the scenario. In order to maintain continuity and to assist in follow-up use of the iPHA Worksheets, the proposed methodology uses two different safeguard categories, inherent and non-inherent, to enhance the documentation of DMR-specific scenarios. The non-inherent category encompasses all safeguards that are classically included in PHAs, such as process controls, alarms, shutdowns, and references to specific operating procedures. Inherent safeguards detail the preventive measures inherent to the design of the system that minimize the effect of the damage mechanism or extend the lifecycle of the piping/equipment. The most common inherent safeguard is metallurgy. If a chemical is injected into the product or feed, this may also be included in the inherent safeguards category. Table 4.1 provides examples of inherent and non-inherent safeguards. The iPHA methodology provides the team with additional insights on scenarios, as the non-inherent safeguards will typically be part of the process which is prone to failure rather than an inherent part of the process that does not degrade.

Table 4.1: Example Inherent vs. Non-Inherent Safeguards

<table>
<thead>
<tr>
<th>Inherent Safeguards</th>
<th>Non-Inherent Safeguards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Piping Metallurgy</td>
<td>Controls</td>
</tr>
<tr>
<td>Substituted Material</td>
<td>Process Alarms</td>
</tr>
<tr>
<td>Injected Chemical</td>
<td>Shutdowns</td>
</tr>
</tbody>
</table>

Another layer of safeguards that should take on an increased level of scrutiny in the DMR portion of the iPHA that are not as closely examined in HAZOP are piping and equipment inspection tasks and frequencies. Classically, an in-depth assessment may not have been performed; however, for the iPHA methodology, observed states of the piping/equipment should be discussed and documented, not only to provide the extra information to more precisely apply a likelihood ranking, but also to assist the team in progressing toward a more specific and appropriate recommendation (if needed). Thus, the DMR portion of the iPHA improves on documentation of inherent safeguards such as metallurgy and service, and delves deeper into the preventive maintenance frequency and tasks associated with the inspection and maintenance of equipment/piping.

In general, by integrating the DMR and HAZOP Study activities, consistency in the application of safeguards provides a more comprehensive understanding of the required reliability and associated preventive maintenance practices and frequencies. Specific to Safety Instrumented Systems (SIS), a complete assessment in one location facilitates the ability to apply LOPA or other analytical mechanisms for the determination of meaningful Safety Integrity Levels to be applied to the SIS.

4.4 Risk-Ranking

After the safeguards have been adequately discussed and documented, the team has a full picture of all the elements (damage mechanism details, ultimate consequence, and inherent as well as non-inherent safeguards) involved in the scenario. Since the ultimate objective of the DMR is validating the adequacy of the existing design and operational/maintenance characteristics, as for the HAZOP, risk-ranking is useful in support of decision-making for the iPHA. In keeping the
spirit of synergy in the integrated PHA, the risk-ranking matrix that is used for the HAZOP should also be used for the DMR. The synchronization of the risk-ranking matrix for the iPHA approach provides two key benefits:

- Aligning the risk-ranking for the different methods utilized in the iPHA can support quality, consistency, and effectiveness; especially by synchronizing consequence ranking and minimizing re-assessment. For example, referencing an analogous scenario from a previous part of the iPHA can help calibrate the team and focus the discussion and decision-making. Some facilities supplement qualitative risk-ranking with selective quantitative application for high consequence scenarios, making synchronization even more beneficial.
- From a managerial perspective the synchronization of risk-ranking throughout the iPHA can facilitate the prioritization of actions resulting from the iPHA.

For DMR risk-ranking, the two-fold benefits of alignment with the HAZOP risk matrix provides benefits to team calibration and management priority determination.

4.5 Recommendations

As identified above, the objective of the HAZOP/DMR/iPHA is to identify the adequacy of the existing design, operation, and mechanical integrity implementation, or to identify recommended actions to address vulnerabilities. With DMR results falling closely in line with the Mechanical Integrity element, DMR recommendations are more likely to focus on:

- Equipment inspections – type/frequency
- Equipment materials of construction

However, recommendations may also be made for adding process controls (interlocks or alarms) to minimize the potential for reaching the damage mechanism consequence or a review/update of the maintenance procedures. As for the HAZOP, to maintain efficiency and team focus, designing solutions in the iPHA session should be avoided.

5. Documenting the DMR within the iPHA

Historically, for corrosion or damage mechanism scenarios documented in PHAs, the details in the associated documentation did not reflect any analysis depth. A key thrust of the DMR requirements in the proposed updates to Cal/OSHA PSM is more specific consideration of mechanical integrity issues. Documentation strategies must also echo these enhanced focus on scenarios related to mechanical integrity, while providing a workable approach to documenting the DMR details. This paper has found that the general tabular segregation of causes, consequences, safeguards, and risk-ranking used for the HAZOP can easily be expanded to address DMR details in the form of a useful Integrated PHA.
As discussed in Section 4, a HAZOP Study and DMR are analogous scenario-based analysis approaches that work harmoniously in the manifestation of an Integrated PHA. In the same manner, one would expect a high degree of consistency with the post-session documentation worksheets, software used to create them, and action item tracking. The columns presented in the DMR worksheet example (see Figure 5.1) depict a DMR scenario representation, analogous to HAZOP Study Worksheets, allowing ease of use and reference from all parties that are familiar with HAZOP Studies and the common method of worksheet documentation. As PHAs become a more integral reference tool for facilities, the output and functionality of software is of utmost importance. It is with this in mind, that DMR worksheets were purposely developed to match in style, function, and software. The synergy in using one software for both methods, resulting in analogous output and worksheets serves what many facilities would consider the main purpose of an iPHA, action item tracking. Maintaining one location with common action tracking provides a major time and effort savings for process safety managers and parties responsible for action item closure.

### FIGURE 5.1 – Sample DMR Worksheet Scenario Hydrogen Heater HTHA

<table>
<thead>
<tr>
<th>DMN-Node</th>
<th>Damage Mechanism</th>
<th>Consequences</th>
<th>Mitigation</th>
<th>Initial Risk</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1. Hydrogen Heater Outlet</td>
<td>High Temperature Hydrogen Attack</td>
<td>1.1.1. Potential for Hydrogen attack of the steel piping and equipment when partial pressure is &gt;400 psig and temperature &gt;400°F, resulting in cavities, microfissures, and fissures that may combine to form cracks, and potential catastrophic failure, with release, fire/explosion hazard, and personnel impact.</td>
<td>1.1.1.1. Inherent: All Hydrogen system metallurgy is 1.25 Cr - 0.5 Mo to mitigate against. 1.1.1.2. Non-Inherent: TAHH-351 on the outlet of the Hydrogen Heater (H-1) will shut down the heater via shutting the fuel gas valves (SDV-01 &amp; 02) if the outlet temperature reaches 400°F.</td>
<td>4</td>
<td>B</td>
</tr>
</tbody>
</table>

During the DMR, the team referenced the Nelson Curve to confirm the appropriate metallurgy was in place. Per the nominal operating parameters provided by operations (listed in the DMN-Node), the metallurgy meets the appropriate design requirements.

### 6. Discussion and Conclusion

For a HAZOP Study, the inherent parts of the design are not considered safeguards, and in fact they are used to eliminate the credibility of a scenario, essentially demoting a deviation from a hazardous situation to an operational issue with no environmental or safety consequences. This includes the likes of design characteristics, such as metallurgy, material qualities and equipment locations. It is for this reason that many HAZOP studies have not been able to adequately analyze corrosion scenarios. Many studies that adhere to the methodology of a HAZOP will (correctly) not
consider inherent parts of the design as safeguards. However, when analyzing consequences of a damage mechanism the inherent parts of the design are exactly the ones that potentially need to be examined by the reliability and maintenance department. This simple change in methodology when describing the consequence in a DMR versus a HAZOP will provide the major value of the review and the associated markers to indicate when a scenario is of potential high risk or not.

The proposed DMR methodology as part of the Integrated PHA will serve as a supplement to the current PHA practices for any facility processing hazardous materials. While increasing the scope of preparation for the iPHA facilitator, an analysis method similar to HAZOP with only minor alterations will ensure a relatively seamless integration. Full availability of industry literature combined with technical team expertise will allow a more complete consequence to be developed with regards to damage mechanism description. Safeguards scope will be extended to include metallurgy of equipment and piping as well as other inherent factors that are normally not considered safeguards by modern HAZOP standards. The consistency of the risk-ranking matrix will ensure alignment among the aspects of the iPHA, as well as easing risk tolerance determination by management post-session. Finally, the DMR post-session documentation highlights are to magnify the details of damage mechanisms that were not classically detailed in PHAs analyzing corrosion, and to align the output among all aspects of the iPHA to primarily synergize action item tracking and reference.

The intent of the iPHA is to consolidate required methods and ensure integration ease. With the addition of the DMR, the PHA and MI elements will be more closely tied creating even more value from the process as a whole. From a logistical perspective the iPHA:

- Provides a framework of familiarity that can facilitate implementation at plants,
- Requires no new software,
- Makes good use of team resources,
- Allows the facility to meet requirements associated with 5189.1(k)(3) as well rather than a separate PHA and DMR to address MOC, and
- Allows the creation of a single document to address regulatory requirements
- Adds value to the Mechanical Integrity element by consolidating damage mechanism results and studies and creates a secondary reference tool for the Reliability department

Finally, the synchronized iPHA approach is meant to meet long term goals while addressing current requirements, best practices, and potential upcoming requirements with high efficacy and flexibility.
7. References