



Compliance with Proposed Regulatory Requirements on Damage Mechanisms

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Abstract

As part of the proposed improvements to the California Process Safety Management (8 CCR, Division 1, Chapter 4, 5189.1) and Accidental Release Prevention Program (19 CCR Division 21, Chapter 4.5), California petroleum refineries will be required to conduct a Damage Mechanism Review (DMR) of all covered processes. The DMR requirement of the regulations includes a strict review as well as documentation of the damage mechanisms that may affect the covered processes.

The proposed DMR requirements can be summarized as identification of potential damage mechanisms, determination of existing safeguards, determination of vulnerabilities and recommendation of measures to reduce the risk associated with the mechanism. To comply with the specifics of the regulations, an approach is discussed in this article. The intent of the approach is to generate a documented analysis that provides the required information for the specific damage mechanisms in a process.

In the first step, existing engineering and metallurgy documents are collected and catalogued. In the next step, the Process Hazard Analysis of the covered process and any other similar risk analyses are reviewed. In that process, the specifics of the damage mechanism and existing mitigative measures (i.e., inspection program) are identified and recorded. Doing so will establish potential vulnerabilities and identify whether recommended improvements are warranted. In the last step, a separate report is generated based on the analysis completed in the second step to document the identified vulnerabilities, existing mitigative measures, and recommendations. The report is organized such that the basis of the vulnerabilities and recommendations are clearly identified. The report will provide operations and other affected personnel with a single living document summarizing the damage mechanism related concerns associated with the process that can be updated on a periodic basis.

1. Introduction

Stemming from several catastrophic releases of hazardous chemicals [References 1 and 2], federal and California regulatory agencies have begun to consider improvements to update the Process Safety Management and Risk Management Plan regulations. Specifically, the California Governor's Office of Emergency Services (CalOES) and California's Occupational Health and Safety Administration (CalOSHA) have already issued several revisions of proposed modifications to the California Accidental Release Prevention Program (CalARP) and PSM regulations [see References 3 and 4 for current version] respectively.

A critical element of the proposed regulation is to establish a requirement for petroleum refiners in California to conduct a Damage Mechanism Review (DMR) of equipment in a covered system and revalidation of the DMR on a five year cycle. As DMRs are to be conducted to ensure the ongoing integrity of the covered system and associated equipment, this requirement of the regulations is defined under the Mechanical Integrity section of both regulations.

The list of DMR requirements in the proposed regulations effectively covers all the issues that one could raise related to the impact of damage mechanisms on process piping and equipment. This article provides guidance and an approach for addressing the damage mechanism review clause of the proposed regulation for California refineries, which can also be applied to non-regulated systems.

2. Regulatory Requirements and Suggested Compliance

The proposed requirements of the California Accidental Release Prevention (CalARP) Program and California Process Safety Management (PSM) regulations related to Damage Mechanism Review are provided in Appendix A. The latest revisions of both the CalARP and PSM regulations contain nearly identical requirements for Damage Mechanism Review as shown in the side-by-side comparison in Appendix A.

Note, the regulations have not been finalized and published for implementation. Therefore, changes to these regulatory requirements may occur. The intent of this article is to provide some guidance on initiating the process for achieving compliance with the regulations. Although the regulations have not been finalized, implementation of all elements of the proposed regulations may prove beneficial in improving process safety, as well as providing useful and structured knowledge in maintaining the ongoing integrity of process equipment. Additionally, the occurrence of damage mechanisms in the process industry, petrochemical and other, will continue to manifest itself. As such, it may be in the best interest of chemical processing and storage facilities to ensure the ongoing mechanical integrity of their system by implementing aspects of the propose requirements.

Each element of the proposed regulations will be discussed further below.

California Accidental Release Prevention Program (CalARP)	Process Safety Management
(f) Damage Mechanism Review	(k) Damage Mechanism Review
<p><i>(1) The owner or operator shall complete a Damage Mechanism Review (DMR) for each process for which a damage mechanism exists. Where no DMR is performed, the owner or operator shall document the rationale for the determination that no damage mechanism exists. The owner or operator shall determine and document the priority order for conducting the DMR based on process operating history, PHA schedule and inspection records. No less than 50 percent of the initial DMRs shall be completed within three (3) years of the effective date of this Article, and the remainder within five (5) years of the effective date of this Article. If the employer has conducted and documented a DMR for a process unit within five (5) years prior to the effective date of this Section, and that DMR includes the elements identified in paragraph (f)(6), that DMR may be used to satisfy the employer's obligation to complete an initial DMR under this paragraph.</i></p>	<p><i>(1) The employer shall complete a Damage Mechanism Review (DMR) for each process for which a damage mechanism exists. Where no DMR is performed, the employer shall document the rationale for the determination that no damage mechanisms exist. The employer shall determine and document the priority order for conducting DMRs based on the process operating history, the PHA schedule and inspection records.</i></p> <p><i>(2) The employer shall complete no less than fifty (50) percent of initial DMRs within 3 years and all remaining DMRs within five (5) years of the effective date of this Section. If the employer has conducted and documented a DMR for a process unit up to five (5) years prior to the effective date of this Section, and that DMR includes the elements identified in (k)(8), that DMR may be used to satisfy the employer's obligation to complete an initial DMR under this subsection.</i></p>

The regulation requires that a Damage Mechanism Review (DMR) be conducted for each process that is governed under the California PSM and CalARP regulations. Similar to the practice that many facilities with multiple covered processes utilize for conducting Process Hazard Analyses, DMRs may be distributed within a five year interval. For example, imagine a facility operates 30 individual processes. The DMRs can be spaced such that six (6) DMRs are conducted every year, satisfying the initial regulatory requirement for “50 percent of the initial DMRs shall be completed within three (3) years” and setting the cycle of DMR revalidations on a five (5) year cycle. It is typical for facilities with multiple covered processes to establish such a schedule to distribute workload and personnel demand among the five year interval.

Furthermore, depending on the corrosion/damage mechanism related analyses and documentation that a facility has already completed, many elements of the regulations may have already been satisfied or require a minimal amount of effort to ensure compliance. For example, facilities that maintain a Risk Based Inspection (RBI) Program [Reference 5], which establishes inspection intervals based on risk prioritization, may have satisfied several elements of the regulations. Since the RBI process requires identifying damage mechanisms and failure modes, assessing probability and consequence of failure, and risk management with inspection activities and process control, and identifying safe operating limits such as Integrity Operating Windows [Reference 6], required elements described in the proposed regulations may have already been addressed. Moreover, facilities may have developed corrosion diagrams or other similar documents identifying the major damage mechanisms of concern within a process unit. In some cases, facilities may have conducted thorough reviews of damage mechanisms in their Process Hazards Analyses. Reference 7 provides a paper discussing the process for addressing damage mechanism hazards as

part of Process Hazard Analyses. Based on the extent in which a facility has addressed damage mechanisms, the effort to ensure compliance with the proposed regulations may not be substantial.

California Accidental Release Prevention Program (CalARP)	Process Safety Management
<i>(2) A DMR shall be revalidated at least once every five (5) years.</i>	<i>(3) A DMR shall be revalidated at least once every five years following its initiation.</i>

Similar to the requirements for Process Hazard Analyses, Damage Mechanism Reviews must also be revalidated on a five year cycle. The intent of this requirement is to ensure that DMRs are maintained accurate and reflect any system modifications as well as industry and site learnings. Moreover, both the revised PSM and CalARP regulations require that a PHA address “all applicable Damage Mechanism Review Reports” [References 3 and 4]. Therefore, the authors of this article recommend that the DMR of a process to be completed or revalidated prior to its PHA revalidation. Maintaining the DMR and PHA cycles for a process unit or system within a year of each other will ensure that there is an accurate and up-to-date DMR prior to the PHA session. This will allow for the PHA team to further review and validate the hazards and risks associated with identified damage mechanisms.

California Accidental Release Prevention Program (CalARP)	Process Safety Management
<i>(3) A DMR shall also be conducted where a damage mechanism exists on new processes or a major change, prior to initial approval of the change.</i>	<i>(4) Where a damage mechanism exists, a DMR shall also be conducted on new processes and as part of a major change, prior to approval of the change.</i>

To comply with this requirement, the facility’s Management of Change (MOC) process can be updated to include a review of the change for potential introduction of new damage mechanisms or the potential to exacerbate the effects or likelihood of an existing damage mechanism. It is common for the MOC process to include a PHA or risk review of the change. The MOC should require that a DMR be performed of the change prior to or in conjunction with the MOC PHA.

Companies required to implement PSM and RMP regulations have typically implemented an MOC procedure and associated form(s). Typically these forms are checklist types to ensure that each element of the regulation as well as each foreseeable effect from the change (e.g., environmental effect) are reviewed and analyzed. The form should include checklist questions addressing potential damage mechanisms and the requirement to perform a DMR review for the change if necessary. Lastly, if a DMR is not required the form should include a section to provide the basis for this conclusion.

California Accidental Release Prevention Program (CalARP)	Process Safety Management
<i>(4) As part of an incident investigation pursuant to Section 2762.9, where a damage mechanism is identified as a contributing factor, the owner or operator shall review the most recent DMR(s) that are relevant to the investigation. If a DMR has not been performed on the processes that are relevant to the investigation, a DMR shall be completed prior to completing the incident investigation.</i>	<i>(5) Where a damage mechanism is identified as a contributing factor in an incident investigation, pursuant to subsection (o), the employer shall review the most recent DMRs that are relevant to the investigation. If a DMR has not been performed on the processes that are relevant to the investigation, a DMR shall be completed as part of the incident investigation.</i>

Common to incident investigations by outside investigators (see References 1 and 2 as examples of investigation reports by the CSB), investigators will request the PHA for the system with which the incident occurred. The purpose of this request is to determine whether the PHA team adequately addressed the specific incident. From the Process Hazard Analysis standpoint, the investigator is trying to determine whether the PHA was complete and whether appropriate controls were identified and if so, did any control fail? The Damage Mechanism Reviews will be used to similar effect, which will ensure that proper controls (e.g., inspection frequencies and types) are identified to reduce the potential for a catastrophic event.

California Accidental Release Prevention Program (CalARP)	Process Safety Management
<i>(5) The DMR for a process unit shall be available to the team performing a PHA for that process unit.</i>	<i>(6) The DMR for a process unit shall be available to the team performing a PHA for that process unit.</i>

The PHA facilitator should review the DMR and ensure the identified damage mechanisms and associated controls (e.g., inspection type and frequency) are addressed as part of the PHA. Specifically, the PHA team should conduct a Damage Mechanism Hazard Review during the PHA, which follows the system owner's PHA protocol for consequence development, identification of controls (safeguards), and risk ranking for each damage scenario. Reference 7 provides a method for integrating and addressing damage mechanisms as part of the PHA process. It is important to note that damage mechanism related discussions during PHA sessions must include a corrosion and materials expert to ensure accuracy of the discussion.

Since the DMR must be available to the PHA Team, it may be convenient that DMR and PHA revalidations are conducted within a similar timeline of each other. One suggestion would be to conduct the DMR revalidation within one year prior to the PHA revalidation. In doing so, this will ensure that the DMR is up-to-date prior to PHA revalidation and maintain the DMR and PHA cycles within similar timeframes.

California Accidental Release Prevention Program (CalARP)	Process Safety Management
<i>(6) The DMR shall be performed by a team with expertise in engineering, operation of the processes under review, equipment and pipe</i>	<i>(7) The DMR shall be performed by a team with expertise in engineering, equipment and pipe inspection, damage and failure mechanisms, and</i>

California Accidental Release Prevention Program (CalARP)	Process Safety Management
<i>inspection, and damage and failure mechanisms. The team shall also include one member knowledgeable in the specific DMR method being used. The owner or operator shall provide for employee participation in this process, pursuant to Section 2762.10.</i>	<i>the operation of the process or processes under review. The team shall include one member knowledgeable in the specific DMR methodology being used. The employer shall provide for employee participation in this process, pursuant to subsection (q).</i>

DMR Facilitator's Role - The DMR Facilitator's role is to guide the discussion using a standard and consistent methodology and ensure that there is detailed documentation of the discussion. Additionally, the DMR Facilitator is responsible for ensuring that all aspects of the regulations are satisfactorily completed.

Similar to PHA process, DMR is expected to be conducted in a group brain-storming session. Such sessions require a facilitator. Ideally, the facilitator should be well versed in the science of damage mechanisms, which effectively requires metallurgical knowledge. However, since facilitating a discussion session is not commonly done by such experts, the authors recommend that PHA facilitator to lead DMR discussions because they are trained on leading brain-storming sessions.

Materials and Corrosion Expert's and Inspectors Role - The Materials and Corrosion Expert provide the knowledge needed in identifying the damage mechanisms that may affect the system. They provide the materials, corrosion and inspection experience and the knowledge to accomplish the tasks provided in the technical requirements of the regulations (see below for the technical requirements)

Engineering and Operation Personnel - The Engineer and Operator provide the documents and knowledge that define the engineering and operational aspects of the process. The Engineer's and Operator's role is to provide information regarding normal operating process parameters (i.e., temperature, flow, pressure, composition), high/low operating limits, potential upset conditions (can be obtained in the PHA), and system conditions during alternative modes of operation to the materials and corrosion expert.

Additionally, the *Engineer and Operator* should note any unique or abnormal corrosion issues that have been observed. The DMR brain-storming session allows for members of engineering and operations to voice any observed concerns and receive an appropriate response for those identified issues. This may include any observed external corrosion on equipment, potential process deadlegs and mixpoints (injection points), cavitation heard in the system, abnormal levels of fouling in the system and upset conditions that may result in potential damage mechanisms.

California Accidental Release Prevention Program (CalARP)	Process Safety Management
<i>(7) The DMR for each process shall include: (A) Assessment of Process Flow Diagrams (PFDs);</i>	<i>(8) The DMR for each process shall include: (A) Assessment of Process Flow Diagrams (PFDs);</i>

California Accidental Release Prevention Program (CalARP)	Process Safety Management
<p>(B) Identification of all potential damage mechanisms;</p> <p>(C) Determination that the materials of construction are appropriate for their application and are resistant to potential damage mechanisms;</p> <p>(D) Qualitative assessment of the rate at which damage is likely to occur;</p> <p>(E) Methods to prevent or mitigate damage;</p> <p>(F) Review of operating parameters to identify operating conditions that could accelerate damage or that could minimize or eliminate damage;</p>	<p>(B) Identification of all potential damage mechanisms, pursuant to (k)(9);</p> <p>(C) Determination that the materials of construction are appropriate for their application and are resistant to potential damage mechanisms;</p> <p>(D) Methods to prevent or mitigate damage; and,</p> <p>(E) Review of operating parameters to identify operating conditions that could accelerate or otherwise worsen damage, or that could minimize or eliminate damage.</p>

The above section of the regulation establishes the technical requirements of the DMR. As stated previously, if the facility has already implemented an RBI or conducted a similar analysis to identify damage mechanisms (i.e., utilize the PHA process to identify damage mechanisms or develop other corrosion control documents), at least of portion of the requirements may have been met.

Indicated in the team requirement section of the proposed regulations, the DMR team must be composed of “*engineering, operation of the processes under review, equipment and pipe inspection, and damage and failure mechanisms*”. Resultantly, a team will be required to complete the tasks identified in this section of the regulations. The required tasks are discussed further below:

(A) Assessment of Process Flow Diagrams (PFDs)

Many facilities may already have addressed the requirement for assessing the covered system PFDs by establishing some form of metallurgy and corrosion diagrams utilizing the PFDs. The following items are typically included on these diagrams:

1. Process material in the piping and equipment (e.g., crude, diesel, stove oil, etc.),
2. Normal operating parameters (flow, pressure, and temperature),
3. Metallurgy of equipment (piping and all major equipment, including identification of cladding/overlay in vessels or piping),
4. Damage mechanisms applicable to each segment of piping or equipment, and
5. Predicted corrosion rates (if applicable)

If not already developed, the DMR team should assess the PFDs and P&IDs and consider identifying the above listed items on the PFD. If similar materials and corrosion PFDs have already been developed, then the full DMR team should review these existing PFDs for accuracy.

(B) Identification of all potential damage mechanisms;

The materials and corrosion expert and the inspector are the responsible party for identifying damage mechanisms. Typical damage mechanisms in refining and hydrocarbon processing can be found in API 571 [Reference 8]. Many, if not all, of these damage mechanisms can also be found in other industries. The materials and corrosion engineer’s primary role is to review the Piping & Instrumentation Diagrams (P&IDs), PFDs, and other system related Process Safety

Information (PSI) to identify all applicable damage mechanisms. The process engineer and member of operations will provide information regarding the process and normal operating parameters, such as flow, pressure, temperature, composition, which will assist the materials and corrosion engineer in establishing these damage mechanisms. Applicable damage mechanism should be identified on the system PFD as described in item (A) above.

(C) Determination that the materials of construction are appropriate for their application and are resistant to potential damage mechanisms;

The DMR team must be provided with the P&IDs and metallurgy related PSI in order to appropriately address potential damage mechanisms. While assessing the P&IDs and other PSI, metallurgical information should be notated on PFDs (PFD item 3 above). Industry standards and practices should be followed when determining whether the materials of construction are appropriate. During the review, the team will review piping and equipment, identify process material, and establish high/low operating parameters. At this point, it will be based on the materials and corrosion engineer and inspector or outside expert knowledge to determine whether certain materials must be upgraded. If it was deemed that materials upgrade is required, a recommendation must be generated and provided to management. In addition to the DMR, the PHA may also be a source to review damage mechanisms and proper metallurgy. Since PHAs have been an established requirement since the initial implementation of the RMP and PSM regulations in the 1990s, issuance of this type of recommendations during that analysis may be appropriate.

(D) Qualitative assessment of the rate at which damage is likely to occur; (Note, this is not identified in the PSM Regulation)

The DMR team may assess the corrosion rate in a variety of ways from purely qualitative to quantitative means. Facility management, in consultation with the regulatory authority must establish how these rates will be defined. Additionally, the materials and corrosion engineer will be the primary person responsible for establishing these rates. If possible, it may be beneficial to establish quantitative values using corrosion predictive software and models to postulate the rate of corrosion (i.e., establish rates in milli-inch per year).

(E) Methods to prevent or mitigate damage;

The methods to prevent or mitigate damage can be obtained from the system's mechanical program (e.g., inspection types/frequencies provided in an RBI, Mechanical Integrity (MI) program established based on industry or manufacture recommended practices, etc). Note, during the damage mechanism hazard review segment of the PHA, or even during scheduled system inspection, the effectiveness of the maintenance protocols should be considered and reviewed to ensure that the maintenance protocol is satisfactorily maintaining the integrity of the system component. That is, the corrosion rate is as expected.

(F) Review of operating parameters to identify operating conditions that could accelerate damage or that could minimize or eliminate damage;

During this stage of the DMR, the DMR team should review any alternative modes of operation (e.g., startup, shutdown, catalyst regeneration, complete unit recirculation) to determine whether any of these operating modes can result in additional damage mechanisms that may occur. One

such example is exceeding Minimum Pressurization-Temperature (MPT) curve of a vessel during startup or shutdown, which may result in brittle fracture concerns.

One source of potential initiating events that can assist in establishing these conditions is the PHA for the unit. As currently required by the CalARP, RMP and PSM regulations, PHAs must address “all modes of operation” [see Reference 4 for an example]. Therefore, the PHA can be a good source to obtain information regarding these different modes of operation.

Additionally, the PHA will have examined upset conditions that may exacerbate the rate of or result in new damage mechanisms that may not have manifested during normal operating condition. This issue stresses the importance of ensuring that PHAs and DMRs act as complements of each other. The PHA will systematically examine single point failures (e.g. operator closes a valve, pump fails, etc.) and determine the consequences of the failure. A suggestion when conducting a PHA is to encourage a damage mechanism/corrosion hazard review during the analysis to examine potential damage mechanisms that may arise due to upset conditions. Additionally, damage mechanisms that result from issues such as deadlegs may not be easily assessed using the PFDs and must be identified during field walks or by the operations and engineering representatives. Because of this issue, the PHA and DMR teams must identify noted deadlegs.

California Accidental Release Prevention Program (CalARP)	Process Safety Management
<p><i>(8) For purposes of this section, damage mechanisms include, but are not limited to:</i></p> <p><i>(A) Mechanical loading failures, such as ductile fracture, brittle fracture, mechanical fatigue, and buckling;</i></p> <p><i>(B) Erosion, such as abrasive wear, adhesive wear, and fretting;</i></p> <p><i>(C) Corrosion, such as uniform corrosion, localized corrosion, and pitting;</i></p> <p><i>(D) Thermal-related failures, such as creep, metallurgical transformation, and thermal fatigue;</i></p> <p><i>(E) Cracking, such as stress-corrosion cracking; and</i></p> <p><i>(F) Embrittlement, such as high-temperature hydrogen attack.</i></p>	<p><i>(9) For purposes of this subsection, damage mechanisms include, but are not limited to:</i></p> <p><i>(A) Mechanical loading failures, such as ductile fracture, brittle fracture, mechanical fatigue and buckling;</i></p> <p><i>(B) Erosion, such as abrasive wear, adhesive wear and fretting;</i></p> <p><i>(C) Corrosion, such as uniform corrosion, localized corrosion and pitting;</i></p> <p><i>(D) Thermal-related failures, such as creep, metallurgical transformation and thermal fatigue;</i></p> <p><i>(E) Cracking, such as stress-corrosion cracking; and,</i></p> <p><i>(F) Embrittlement, such as high-temperature hydrogen attack.</i></p>

A materials and corrosion expert is required during the entire DMR process to identify all possible damage mechanisms that may occur. An assessment of the PFD, which should include metallurgy and process information can be used as a starting point for identifying the possible damage mechanisms within a process unit. As a resource, many damage mechanisms in the refining and hydrocarbon processing can be found in API 571 [Reference 8]. API 571 addresses more than 70 damage mechanisms and can be used as a starting point to gain an understanding of damage mechanisms that may occur.

Also, it must be noted that API 571 is not comprehensive of all damage mechanisms. The damage mechanisms identified in API 571 are not unique to refining or hydrocarbon processing and all of them can be found in other process industries. It is the discretion of the materials and corrosion expert to determine which damage mechanisms are applicable and to use the appropriate publications and reference books.

California Accidental Release Prevention Program (CalARP)	Process Safety Management
<i>(9) DMRs shall include an assessment of previous experience with the process including the inspection history and all damage mechanism data; a review of industry-wide experience with the process; and applicable standards, codes and practices.</i>	<i>(10) DMRs shall include an assessment of previous experience with the process, including the inspection history and all damage mechanism data; a review of industry-wide experience with the process; and all applicable standards, codes and practices.</i>

The DMR team should take into consideration past experience, inspection results, industry knowledge, practices, standard, and codes when completing the technical requirements of the regulation. A review of past turnaround inspection results and past corrosion control plans may be beneficial to the DMR team.

California Accidental Release Prevention Program (CalARP)	Process Safety Management
<i>(10) At the conclusion of the analysis, the team shall prepare a written DMR report that includes:</i> <i>(A) The process unit(s) reviewed;</i> <i>(B) Damage mechanisms analyzed;</i> <i>(C) Results of the analyses conducted according to subsection (f)(7) above;</i> <i>(D) Recommendations for temporary mitigation;</i> <i>(E) Recommendations for prevention.</i>	<i>(11) At the conclusion of the analysis, the team shall prepare a written DMR report, which shall include the following:</i> <i>(A) The process unit and damage mechanisms analyzed;</i> <i>(B) Results of all analyses conducted, pursuant to (k)(8);</i> <i>(C) Recommendations for temporarily mitigating damage; and,</i> <i>(D) Recommendations for preventing damage.</i>

As stated in the regulation, a report shall be developed. Along with the following items identified by the regulations, the report should also include the following:

1. Purpose of the analysis
2. Scope of the analysis
3. Overview of the process
4. DMR methodology and approach applied
5. DMR team members and associated expertise
6. DMR meeting dates

Developing a detailed and well documented report will allow readers (e.g., auditors, operators, etc.) to easily understand the thought process behind the DMR. Additionally, a detailed report will provide the basis for recommendations issued during the DMR process, which will assist management addressing the issues posed.

California Accidental Release Prevention Program (CalARP)	Process Safety Management
<i>(11) The report shall be provided to and, upon request, reviewed with all operating, maintenance, and other personnel, whose work assignments are within the process unit covered in the DMR.</i>	<i>(12) The report shall be provided to and, upon request, reviewed with employees whose work assignments are within the process unit described in the DMR.</i>

Employees in the process unit addressed by the DMR should be informed that a DMR has been completed and the location of the latest DMR report. This can be accomplished through several means.

One of the required participants of the DMR is a member of operations. During the preparation phase of the DMR, request that the unit superintendent or manager inform all operators of the plans to complete or revalidate a DMR. Allow operators to voice any potential mechanical integrity issues that they may have noted or may be concerned about so that the DMR team can review and respond to the concerns (e.g., provide an operator questionnaire to be completed by select representatives of operations). Consider making the questionnaire anonymous if deemed necessary.

Following completion of the DMR, consider providing a summary presentation and/or report to members of operations, maintenance, and any other personnel that may be affected by the DMR. During the presentation or report, identify the location(s) where the DMR can be found and the person(s) that can be contacted for further information regarding the DMR.

California Accidental Release Prevention Program (CalARP)	Process Safety Management
<i>(12) The owner or operator shall follow the corrective action work process documented in subsections 2762.16(d) and (e) when resolving the DMR team's findings and recommendations, determining corrective action for implementation, tracking to completion, and documentation of closeout.</i>	<i>(13) The employer shall implement all recommendations in accordance with subsection (x).</i>

Similar to the requirements to track PHA, compliance audit, incident investigation, and other recommendations generated as part of PSM and RMP Program implementation, DMRs recommendations must also be tracked. DMRs recommendations should be tracked in a similar fashion as those recommendations, be it through a database, or other consolidated location.

Following the DMR session, recommendations owners should be established to ensure recommendations are completed within the required timeframe.

California Accidental Release Prevention Program (CalARP)	Process Safety Management
<i>(13) DMR reports shall be retained for the life of the process unit.</i>	<i>(14) DMR reports shall be retained for the life of the process unit.</i>

Pursuant to the requirement identified in the regulations, DMRs must be kept for the life of the system. Both a hard copy and an electronic copy should be maintained. The electronic copy should be kept in the facility's electronic database as part of PSI or mechanical integrity related documents. At least one copy of the DMR should be kept by the facility's Process Safety/Risk Management Department for ease of access in the event the DMR is required for auditing or review purposes.

3. Documentation

For each DMR consider developing a binder containing the final DMR report, recommendations from the review, and any supporting documents used in preparation of the DMR. The supporting documents should include the PFDs that were accessed, which should depict metallurgy and damage mechanisms on appropriate sections of the system.

Along with the DMR documentation, ensure that damage mechanism related documentation such as RBI reports, information regarding materials of construction, specification breaks, corrosion control plans, integrity operating windows (IOWs) or other set upper/lower operating limits and other technical information related to damage mechanisms are maintained as Process Safety Information for the system. As such, these documents must undergo the same rigors and practices that are applied to PSI established as part of the PSM and RMP regulations (e.g., P&IDs).

4. Limitations and Benefits

The process delineated in this paper provides guidance based on the author's interpretation of the proposed regulation and our history of implementing PSM and RMP programs for a multitude of industries and facilities. The author's understanding of the requirements, which is based on their experience with the PSM and RMP regulations, as well as their experience with the various local and other regulatory agencies, have been used to develop this article.

Additionally, based on the jurisdiction that governs a specific facility, the facility will still have to adhere to the specific requests and requirements of those governing offices. The purpose of this article is to begin providing some guidance to ensure that facilities that will fall under the jurisdiction of the regulation, begin the process of generating DMRs if not already done so.

5. Conclusion

With the continuing evolution of the regulatory environment to pursue modernization of the PSM and RMP regulations, the stress of further process safety improvements have occurred at not only California refineries, but other hazardous material handling industries within the state and beyond. Executive Order 13650 [Reference 9] was issued in response to recent catastrophic incidents at chemical handling facilities in the United States. The Chemical Safety Board on December 1, 2014 announced “to Modernize U.S. Process Safety Management Regulations is the Board’s newest Most Wanted Safety Improvement” [Reference 10]. Within the same statement, the CSB states “that PSM and RMP, although written as performance-based regulations, appear to function primarily as reactive and activity based regulatory frameworks”. It should be a primary focus of hazardous material handlers to ensure proactive process safety actions are taken. One crucial example is to ensure that the covered system maintains its mechanical integrity by conducting reviews such as DMRs to validate the continued integrity of the system.

Although a new requirement by a regulatory authority may seem as a daunting task, facilities within California have typically implemented some form of corrosion program to monitor, manage, mitigate, the effects of damage mechanism on process equipment. With that being said, at least parts of the requirements presented in the proposed regulations have already been addressed by current established practices.

No process system is immune to the effects of damage mechanisms. Although the proposed regulation is specific to petroleum refiners in the California, it may be beneficial for other hazardous materials handling facilities to consider implementing parts of the proposed regulations as part of their process safety practices. Initial steps such as requiring PHAs to specifically address damage mechanism related hazards, identifying the damage mechanisms applicable to the system and appropriate mechanisms in place to reduce the potential effects, ensuring safe high/low operating limits are established and operators are aware of these value may prove to be beneficial in protecting employees and the surrounding environment from releases of hazardous materials.

6. References

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- [2] *Final Investigation Report – Chevron Richmond Refinery – Pipe Rupture and Fire - Chevron Richmond Refinery #4 Crude Unit – Richmond, California, August 6, 2012.* U.S. Chemical Safety and Hazard Investigation Board, Report 2012-03-I-CA, January 2015.
- [3] *Proposed General Industry Safety Order (GISO) §5189.1 - Process Safety Management for Petroleum Refineries, Version 5.0 - September 14, 2015.* State of California, Department of Industrial Relations, Division of Occupational Safety and Health

- [4] *California Accidental Release Prevention (CalARP) Program*. Draft CalARP Program Regulations, September 24, 2015, California Governor’s Office of Emergency Services
- [5] *Risk-Based Inspection*. API Recommended Practice 580, 2nd Edition, November 2009.
- [6] *Integrity Operating Windows*. API Recommended Practice 584, May 2014
- [7] M. Tia, J. Waytashek, and M. Kazarians, *Integration of Damage Mechanism Review with Process Hazard Analyses*, presented at the 2015 Mary Kay O’Connor Process Safety Symposium, October 2015.
- [8] *Damage Mechanisms Affecting Fixed Equipment in the Refining Industry*. American Petroleum Institute, API Recommended Practice 571, Second Edition, April 2011
- [9] *Improving Chemical Facility Safety and Security*. Executive Order 13650, August 1, 2013
- [10] *CSB Board Members Identify Modernization of Process Safety Management Regulations as the Agency’s Second “Most Wanted Safety Improvement*. December 1, 2014, Available at <http://www.csb.gov>

Appendix A - Proposed DMR Regulations

California Accidental Release Prevention Program (CalARP)	Process Safety Management
CCR Title 19, Division 2, Chapter 4.5, 2762.5 (Mechanical Integrity), September 14, 2015 [Reference 3]	GISO §5189.1, Process Safety Management for Petroleum Refineries, Version 5. - September 14, 2015 [Reference 4]
(f) Damage Mechanism Review	(k) Damage Mechanism Review
<i>(1) The owner or operator shall complete a Damage Mechanism Review (DMR) for each process for which a damage mechanism exists. Where no DMR is performed, the owner or operator shall document the rationale for the determination that no damage mechanism exists. The owner or operator shall determine and document the priority order for conducting the DMR based on process operating history, PHA schedule and inspection records. No less than 50 percent of the initial DMRs shall be completed within three (3) years of the effective date of this Article, and the remainder within five (5) years of the effective date of this Article. If the employer has conducted and documented a DMR for a process unit within five (5) years prior to the effective date of this Section, and that DMR includes the elements identified in paragraph (f)(6), that DMR may be used to satisfy the employer's obligation to complete an initial DMR under this paragraph.</i>	<i>(1) The employer shall complete a Damage Mechanism Review (DMR) for each process for which a damage mechanism exists. Where no DMR is performed, the employer shall document the rationale for the determination that no damage mechanisms exist. The employer shall determine and document the priority order for conducting DMRs based on the process operating history, the PHA schedule and inspection records.</i>
<i>(2) A DMR shall be revalidated at least once every five (5) years.</i>	<i>(2) The employer shall complete no less than fifty (50) percent of initial DMRs within 3 years and all remaining DMRs within five (5) years of the effective date of this Section. If the employer has conducted and documented a DMR for a process unit up to five (5) years prior to the effective date of this Section, and that DMR includes the elements identified in (k)(8), that DMR may be used to satisfy the employer's obligation to complete an initial DMR under this subsection.</i>
<i>(3) A DMR shall also be conducted where a damage mechanism exists on new processes or a major change, prior to initial approval of the change.</i>	<i>(3) A DMR shall be revalidated at least once every five years following its initiation.</i>
<i>(4) As part of an incident investigation pursuant to Section 2762.9, where a damage mechanism is identified as a contributing factor, the owner or operator shall review the most recent DMR(s) that are relevant to the investigation. If a DMR has not been performed on the processes that are relevant to the investigation, a DMR shall be completed prior to completing the incident investigation.</i>	<i>(4) Where a damage mechanism exists, a DMR shall also be conducted on new processes and as part of a major change, prior to approval of the change.</i>
<i>(5) The DMR for a process unit shall be available to the team performing a PHA for that process unit.</i>	<i>(5) Where a damage mechanism is identified as a contributing factor in an incident investigation, pursuant to subsection (o), the employer shall review the most recent DMRs that are relevant to the investigation. If a DMR has not been performed on the processes that are relevant to the investigation, a DMR shall be completed as part of the incident investigation.</i>
	<i>(6) The DMR for a process unit shall be available to the team performing a PHA for that process unit.</i>

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<i>(6) The DMR shall be performed by a team with expertise in engineering, operation of the processes under review, equipment and pipe inspection, and damage and failure mechanisms. The team shall also include one member knowledgeable in the specific DMR method being used. The owner or operator shall provide for employee participation in this process, pursuant to Section 2762.10.</i>	<i>(7) The DMR shall be performed by a team with expertise in engineering, equipment and pipe inspection, damage and failure mechanisms, and the operation of the process or processes under review. The team shall include one member knowledgeable in the specific DMR methodology being used. The employer shall provide for employee participation in this process, pursuant to subsection (q).</i>
<i>(7) The DMR for each process shall include: (A) Assessment of Process Flow Diagrams (PFDs); (B) Identification of all potential damage mechanisms; (C) Determination that the materials of construction are appropriate for their application and are resistant to potential damage mechanisms; (D) Qualitative assessment of the rate at which damage is likely to occur; (E) Methods to prevent or mitigate damage; (F) Review of operating parameters to identify operating conditions that could accelerate damage or that could minimize or eliminate damage;</i>	<i>(8) The DMR for each process shall include: (A) Assessment of Process Flow Diagrams (PFDs); (B) Identification of all potential damage mechanisms, pursuant to (k)(9); (C) Determination that the materials of construction are appropriate for their application and are resistant to potential damage mechanisms; (D) Methods to prevent or mitigate damage; and, (E) Review of operating parameters to identify operating conditions that could accelerate or otherwise worsen damage, or that could minimize or eliminate damage.</i>
<i>(8) For purposes of this section, damage mechanisms include, but are not limited to: (A) Mechanical loading failures, such as ductile fracture, brittle fracture, mechanical fatigue, and buckling; (B) Erosion, such as abrasive wear, adhesive wear, and fretting; (C) Corrosion, such as uniform corrosion, localized corrosion, and pitting; (D) Thermal-related failures, such as creep, metallurgical transformation, and thermal fatigue; (E) Cracking, such as stress-corrosion cracking; and (F) Embrittlement, such as high-temperature hydrogen attack.</i>	<i>(9) For purposes of this subsection, damage mechanisms include, but are not limited to: (A) Mechanical loading failures, such as ductile fracture, brittle fracture, mechanical fatigue and buckling; (B) Erosion, such as abrasive wear, adhesive wear and fretting; (C) Corrosion, such as uniform corrosion, localized corrosion and pitting; (D) Thermal-related failures, such as creep, metallurgical transformation and thermal fatigue; (E) Cracking, such as stress-corrosion cracking; and, (F) Embrittlement, such as high-temperature hydrogen attack.</i>
<i>(9) DMRs shall include an assessment of previous experience with the process including the inspection history and all damage mechanism data; a review of industry-wide experience with the process; and applicable standards, codes and practices.</i>	<i>(10) DMRs shall include an assessment of previous experience with the process, including the inspection history and all damage mechanism data; a review of industry-wide experience with the process; and all applicable standards, codes and practices.</i>

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<p>(10) At the conclusion of the analysis, the team shall prepare a written DMR report that includes:</p> <p>(A) The process unit(s) reviewed;</p> <p>(B) Damage mechanisms analyzed;</p> <p>(C) Results of the analyses conducted according to subsection (f)(7) above;</p> <p>(D) Recommendations for temporary mitigation;</p> <p>(E) Recommendations for prevention.</p>	<p>(11) At the conclusion of the analysis, the team shall prepare a written DMR report, which shall include the following:</p> <p>(A) The process unit and damage mechanisms analyzed;</p> <p>(B) Results of all analyses conducted, pursuant to (k)(8);</p> <p>(C) Recommendations for temporarily mitigating damage; and,</p> <p>(D) Recommendations for preventing damage.</p>
<p>(11) The report shall be provided to and, upon request, reviewed with all operating, maintenance, and other personnel, whose work assignments are within the process unit covered in the DMR.</p>	<p>(12) The report shall be provided to and, upon request, reviewed with employees whose work assignments are within the process unit described in the DMR.</p>
<p>(12) The owner or operator shall follow the corrective action work process documented in subsections 2762.16(d) and (e) when resolving the DMR team's findings and recommendations, determining corrective action for implementation, tracking to completion, and documentation of closeout.</p>	<p>(13) The employer shall implement all recommendations in accordance with subsection (x).</p>
<p>(13) DMR reports shall be retained for the life of the process unit.</p>	<p>(14) DMR reports shall be retained for the life of the process unit.</p>