

Integrity Operating Windows

API RECOMMENDED PRACTICE 584
SECOND EDITION, DECEMBER 2021



American
Petroleum
Institute

Special Notes

API publications necessarily address problems of a general nature. With respect to particular circumstances, local, state, and federal laws and regulations should be reviewed. The use of API publications is voluntary. In some cases, third parties or authorities having jurisdiction may choose to incorporate API standards by reference and may mandate compliance.

Neither API nor any of API's employees, subcontractors, consultants, committees, or other assignees make any warranty or representation, either express or implied, with respect to the accuracy, completeness, or usefulness of the information contained herein, or assume any liability or responsibility for any use, or the results of such use, of any information or process disclosed in this publication. Neither API nor any of API's employees, subcontractors, consultants, or other assignees represent that use of this publication would not infringe upon privately owned rights.

API publications may be used by anyone desiring to do so. Every effort has been made by the Institute to ensure the accuracy and reliability of the data contained in them; however, the Institute makes no representation, warranty, or guarantee in connection with this publication and hereby expressly disclaims any liability or responsibility for loss or damage resulting from its use or for the violation of any authorities having jurisdiction with which this publication may conflict.

API publications are published to facilitate the broad availability of proven, sound engineering and operating practices. These publications are not intended to obviate the need for applying sound engineering judgment regarding when and where these publications should be used. The formulation and publication of API publications is not intended in any way to inhibit anyone from using any other practices.

Any manufacturer marking equipment or materials in conformance with the marking requirements of an API standard is solely responsible for complying with all the applicable requirements of that standard. API does not represent, warrant, or guarantee that such products do in fact conform to the applicable API standard.

All rights reserved. No part of this work may be reproduced, translated, stored in a retrieval system, or transmitted by any means, electronic, mechanical, photocopying, recording, or otherwise, without prior written permission from the publisher. Contact the Publisher, API Publishing Services, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001-5571.

Foreword

Nothing contained in any API publication is to be construed as granting any right, by implication or otherwise, for the manufacture, sale, or use of any method, apparatus, or product covered by letters patent. Neither should anything contained in the publication be construed as insuring anyone against liability for infringement of letters patent.

The verbal forms used to express the provisions in this document are as follows.

Shall: As used in a standard, “shall” denotes a minimum requirement to conform to the standard.

Should: As used in a standard, “should” denotes a recommendation or that which is advised but not required to conform to the standard.

May: As used in a standard, “may” denotes a course of action permissible within the limits of a standard.

Can: As used in a standard, “can” denotes a statement of possibility or capability.

This document was produced under API standardization procedures that ensure appropriate notification and participation in the developmental process and is designated as an API standard. Questions concerning the interpretation of the content of this publication or comments and questions concerning the procedures under which this publication was developed should be directed in writing to the Director of Standards, American Petroleum Institute, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001. Requests for permission to reproduce or translate all or any part of the material published herein should also be addressed to the director.

Generally, API standards are reviewed and revised, reaffirmed, or withdrawn at least every five years. A one-time extension of up to two years may be added to this review cycle. Status of the publication can be ascertained from the API Standards Department, telephone (202) 682-8000. A catalog of API publications and materials is published annually by API, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001.

Suggested revisions are invited and should be submitted to the Standards Department, API, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001, standards@api.org.

Contents

	Page
1 Purpose and Scope	1
2 Normative References	2
3 Terms and Definitions	2
4 Parameters that May Require Different Types and Levels of IOWs	5
5 IOW Work Process	7
6 IOW Risk Ranking	11
7 Examples of IOWs	13
8 IOW Development	17
9 General Considerations for Establishing IOWs and Their Limits	20
10 Documenting, Implementing, and Training on Established IOWs	22
11 Monitoring and Measuring IOW Parameters	24
12 Updating IOWs	25
13 Roles, Responsibilities, and Accountabilities for IOWs	25
14 Integrating IOWs with Other Related Work Processes	26
Annex A (informative) Examples of Potential Process Parameters for IOWs for Generic Process Units	27
Annex B (informative) Sample Format for Recording IOWs	53
Annex C (informative) Example of an IOW Development for a Heat Exchanger	54
Annex D (informative) Barriers to Successful IOW Implementation	56
Bibliography	58

Figures

1 Zones of Operation Including Target Ranges with Standard and Critical Limits	7
2 Example IOW Development Work Process	8
3 Generic Risk Matrix for Assessing IOW Levels	12
4 Example Risk Chart for IOW Types/Actions/Guidance	13
5 Example of IOW Limits for HTHA in a Hydroprocessing Unit	13
6 Examples of Different Levels of IOWs	14

Contents

Page

Tables

1	Examples of Accelerated Corrosion Rates That Can Occur Under Some Circumstances	21
A.1	Example IOWs for Crude Distillation Unit (Atmospheric and Vacuum Distillation)	28
A.2	Example IOWs for Catalytic Reformer Unit	32
A.3	Example IOWs for Hydroprocessing Unit	33
A.4	Example IOWs for FCC Unit and Gas Plant	36
A.5	Example IOWs for HF Acid Alkylation Unit	39
A.6	Example IOWs for Sulfuric Acid Alkylation Unit	39
A.7	Example IOWs for Delayed Coker Unit	41
A.8	Example IOWs for Steam Methane Reformer (Hydrogen Manufacturing) Unit	44
A.9	Example IOWs for Amine Unit	45
A.10	Example IOWs for Sour Water Stripper Unit.....	46
A.11	Example IOWs for Sulfur Recovery Unit.....	47
A.12	Example IOWs for Ethane Cracking Units.....	48
A.13	Example IOWs for Boiler Water Treatment and Return Condensate Quality	50
A.14	Example IOWs for Fired Heaters	51
B.1	Sample Format for Recording IOWs.....	53

Introduction

In today's operating environment, it is not enough to base future inspection plans only on prior recorded/known history of equipment condition. A fundamental understanding of the process/operating conditions and resulting damage mechanisms are required to establish and maintain an inspection program that yields the highest probability of detecting damage. Inspection plans should be dynamic and account for changing process conditions and current equipment condition. A fundamental step is to frequently rationalize and align the developed degradation knowledge base of the materials of construction with the operation of the equipment, its inspection history, measured corrosion rates and known industry problems. Whether utilizing time-based or risk-based methodology for determining inspection intervals, Integrity Operating Windows (IOWs) are useful to identify and track process information that either validates or might cause changes to existing inspection plans.

In order to maintain the integrity and reliability of pressure equipment in industry, multiple process safety management (PSM) systems may be necessary. Many of those management systems are oriented toward having a rigorous inspection program, as well as the supportive engineering activities. This may include the implementation of IOWs which can supplement process safety and inspection programs by identifying key process parameters potentially affecting mechanical integrity.

In addition to the application of industry codes, standards, and recommended practices, several other PSM systems are vital to support a rigorous inspection and mechanical integrity program to predict/avoid/prevent pressure equipment damage/corrosion; leaks and failures; and improve reliability. Three key elements of those supporting PSM programs include:

- the establishment, implementation, and maintenance of IOWs. See 3.6;
- an effective transfer of knowledge about unit specific IOWs to all affected personnel; and
- an effective MOC program to identify any changes to the process or the physical hardware that might affect the integrity of pressure equipment.

To operate any process unit, a set of operating ranges and limits should be established for key process variables, to achieve the desired results (i.e. product within specification, safe operation, reliability, etc.). These limits are generally called operating limits or operating envelopes. IOWs are a specific subset of these key operating limits that focus only on maintaining the integrity or reliability of process equipment. Typically, IOWs address issues that involve process variables that, when not adequately monitored or controlled, can impact the likelihood and rates of damage mechanisms, which may result in a loss of containment.

For purposes of this document, maintaining the integrity of the process unit means avoiding breaches of containment, and reliability means avoiding malfunctions of the pressure equipment that might impact the performance of the process unit (meeting its intended function for a specified time frame). In that sense, integrity is a part of the larger issue of pressure equipment reliability, since most breaches of containment will impact reliability. IOWs are those preset limits on process variables that need to be established and implemented to prevent potential breaches of containment that might occur as a result of not controlling the process sufficiently to avoid unexpected or unplanned deterioration or damage to pressure equipment. Operation within the preset limits should result in predictable and reasonably low rates of degradation. Operation outside the IOW limits could result in unanticipated damage, accelerated damage and potential equipment failure from one or more damage mechanisms.

Pressure equipment is generally fabricated from the most economical materials of construction to meet specific design criteria based on the intended operation and process conditions. The operating process conditions should then be controlled within preset limits (IOWs) to avoid unacceptable material degradation and achieve the desired economic design life of the assets.

Inspection plans are typically based on historic damage mechanisms and trends and are not generally designed to look for unanticipated damage resulting from process variability and upsets. Inspection plans generally assume that

the next inspection interval (calculated based on prior damage rates from past operating experience) are scheduled based on what is already known and predictable about equipment degradation from previous inspections. Without a set of effective and complete IOWs and feedback loop into the inspection planning process, inspections might need to be scheduled on a more frequent interval just to look for anything that might potentially occur from process variability. The owner-operator should implement and maintain an effective program for creating, establishing, and monitoring integrity operating windows. IOWs are implemented to avoid process parameter exceedances that may have an unanticipated impact on pressure equipment integrity.

Integrity Operating Windows

1 Purpose and Scope

1.1 The purpose of this recommended practice (RP) is to explain the importance of IOWs for process safety management and to guide users in how to establish and implement an IOW program for process facilities. Its express purpose is to minimize unexpected equipment degradation that could lead to loss of containment. It is not the intent of this document to provide a complete list of specific IOWs or operating variables that might need IOWs for the numerous types of process units in the industry (though some examples are provided in the text and a list of process variables for some example process units is included in Annex A); but rather to provide the user with information and guidance on the work process for development and implementation of IOWs to help strengthen the Mechanical Integrity (MI) program for each process unit.

The key goals of an IOW program are:

- 1) Defining IOW limits which will result in predictable and acceptable levels of equipment degradation to meet reliability expectations.
- 2) Enabling effective communication of equipment limits and exceedances between key Process, Operations, Maintenance, and other MI stakeholders to facilitate safe and reliable process operation and management.
- 3) Facilitating the reliable operation of equipment without loss of containment or the need for unplanned maintenance activities between scheduled outage or shutdowns.

1.2 The scope of this standard includes:

- definitions of IOWs and related terminology;
- creating and establishing IOWs;
- data and information typically needed to establish IOWs;
- descriptions of the various types and levels of IOWs needed for process parameters;
- risk ranking IOWs;
- documenting and implementing IOWs;
- monitoring and measuring process variables within established IOWs;
- communication of IOW exceedances;
- reviewing, changing, and updating IOWs;
- integrating IOWs with other risk management practices;
- roles and responsibilities in the IOW work process; and
- knowledge transfer to affected personnel.

1.3 This RP outlines the key elements in defining, monitoring, and maintaining IOWs as a vital component of integrity management (materials degradation control) and assisting in the inspection planning process, including Risk-Based Inspection (RBI). Other Process Safety systems may be affected by or involved with the IOW program, including management of change (MOC), process safety information (PSI), and training. For purposes of this RP, these systems are only addressed to the extent of mentioning the integration aspects that are needed with the IOW program.

1.4 This RP does not cover operating windows established for normal process control, such as for the purpose of maintaining product quality. It also does not cover operating windows for other PSM issues, including avoidance of operating error, that do not relate to control for the purpose of maintaining equipment integrity and reliability. However, IOWs should be integrated into a common system for managing all operating variables and limits.

Examples of equipment types, damage mechanisms and operating conditions that are typically not addressed by IOWs:

- Design limits for vessels and piping (i.e. design pressure and temperature limits).
- Rotating equipment, instrumentation, and electrical hardware. IOWs established within the scope of this RP typically cover only fixed equipment but can be extended to other types of equipment at the option of the site. Product quality or product specification limits.
- Some damage mechanisms that can occur or are strongly influenced by unanticipated short-duration upsets are not typically controlled by IOW limits. They are controlled by proper materials selection, design, by operations or maintenance procedures, or both. Examples include:
 - Brittle fractures that may occur during hydrotest,
 - Stress corrosion cracking (SCC) of sensitized stainless steels at downtimes controlled by soda ash treatment,
 - Chloride SCC at low point drains in stainless steel equipment during unit start-ups controlled by pre-start-up draining and drying of stainless systems.

2 Normative References

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any addenda) applies.

API Recommended Practice 571, *Damage Mechanisms Affecting Fixed Equipment in the Refining Industry*

API Recommended Practice 581, *Risk Based Inspection (Third Edition, Second Addendum Part 2, Annex B—Determination of Corrosion Rates, 10/2020)*

API Recommended Practice 970, *Corrosion Control Documents*

API 579-1/ASME FFS-1, *Fitness-for-Service (Annex 2B)*

3 Terms and Definitions

For the purposes of this document, the following terms and definitions apply.

3.1 alarms

An audible sound (e.g. horn, buzzer, beep, etc.) along with a visual signal (e.g. flashing light), in the control room that alerts operators to a deviation in a process condition that may require immediate attention.

3.2 alerts

A secondary level of communication to key stakeholders (i.e. operations, technical SMEs) that signifies a condition that will need resolution to avoid a potential operating condition that could lead to process safety or reliability impacts.

NOTE 1 Generally, alerts can be addressed over a longer time than alarms. Alerts may include visual signals or audible sounds or other real-time process tracking charts/graphs with limits identified, e-mail notifications, or a combination thereof.

NOTE 2 For this RP, alerts are related primarily to Standard IOW limit exceedances but may also be implemented for Informational IOWs.

3.3

corrosion control document (CCD)

A document or other repository or system that contains the necessary information to understand materials damage susceptibility issues in a specific type of operating process unit at a plant site.

NOTE 1 Generic CCDs can also be developed that provide generic guidance upon which to build a unit-specific CCD, but generic CCDs are not as useful as unit-specific CCDs that are based on actual hardware configurations, actual process conditions and actual materials of construction.

NOTE 2 See API RP 970, *Corrosion Control Documents*, which outlines a work process for development and maintenance of CCDs.

3.4

corrosion materials diagram (CMD)

A modified process flow diagram (PFD) or database list containing relevant equipment and piping damage mechanisms, operating conditions, materials of construction, systems/circuits, and other information that is determined to be useful for each portion of a process unit.

3.5

corrosion specialist

A person acceptable to the owner-operator who is knowledgeable and experienced in the specific process chemistries, degradation mechanisms, materials selection, corrosion mitigation methods, corrosion monitoring techniques and their impact on equipment.

3.6

integrity operating window (IOW)

Established limits for process variables (parameters) that can affect the integrity of the equipment if the process operation deviates from the established limits for a predetermined length of time (includes Critical, Standard and Informational IOWs).

3.7

IOW critical limit

An established IOW level that if exceeded could result in rapid deterioration such that the operator is required to take immediate predetermined actions to return the process variable back within the IOW to prevent significant defined risks of potential equipment damage or hazardous fluid release.

NOTE Other terminology has been used in place of critical limit, such as safe operating limit or safety critical limit.

3.8

IOW standard limit

An established IOW level defined as one that if exceeded over a specified period of time could cause increased degradation rates or introduce new damage mechanisms beyond those anticipated.

NOTE Other terminology for standard limits has been used such as key operating limit or reliability operating limit. Since the timing of the impact from an exceedance of an IOW Standard Limit can vary significantly, the notification and response to an exceedance can also vary. For higher risk exceedances, alarms or alerts are potentially needed and the operator may have some predetermined actions to take. For lower risk exceedances, alerts may only be needed for eventual interaction with operating supervisors or appropriate technical personnel and subject matter experts (SMEs).

3.9

IOW informational limit

An IOW Informational limit is a parameter that may be used to predict a change in corrosion potential. It may simply be trended rather than having a specified limit or range. Informational IOWs are used for parameters that cannot be controlled by operators.

NOTE Other terminology can be used in place of an IOW Informational Limit, such as corrosion control limit or reliability limit.

3.10

management of change (MOC)

A documented management system for review and approval of changes in process, equipment, or piping systems prior to implementation of the change.

NOTE For purposes of this RP, MOC may apply to making changes to or creating IOWs.

3.11

mechanical integrity (MI)

The management systems, work practices, methods, and procedures established to protect and preserve the integrity of operating equipment i.e. avoid loss of containment because of equipment damage mechanisms. MI is typically one part of a process safety program.

3.12

notifications

A message to an operator or SME, or both, that an IOW exceedance has occurred which may not necessarily have an alarm associated with it but may require a specific required action and response from an operator or SME.

3.13

operating limits/envelopes (OEs)

A set of operating ranges and limits established for key process variables to achieve the desired results (i.e. product within specification, safe operation, reliability, etc.).

NOTE IOWs are a specific subset of these key operating limits that focus only on maintaining the integrity or reliability of process equipment affected by damage mechanisms that may occur in the process unit.

3.14

process flow diagram (PFD)

A simplified diagram of a process unit showing the main pieces of equipment and piping, with limited details of process design parameters.

3.15

process hazards analysis (PHA)

A work process to assess and document the hazards and risks associated with operating a process unit, and to make recommendations on what actions may be necessary to mitigate unacceptable risks.

3.16

process variables

Parameters of the process fluids (chemical and physical) and equipment operational parameters (e.g. metal temperature) that need to be controlled.

3.17

process safety management (PSM)

The implementation of all the work practices, procedures, management systems, training, and process safety information that are necessary to prevent the release of hazardous substances from process equipment.

3.18

pressure equipment

Stationary, static, or fixed equipment for containing process fluids under pressure, which for the purpose of this document does not include rotating equipment.

EXAMPLE Pressure equipment includes, but is not limited to such items as piping, vessels, heat exchangers, reactors, tanks (static head pressure), pressure relief devices, columns, towers, heater tubes, and filters.

3.19

rationalization (alarm rationalization)

Rationalization is the process of ensuring an alarm meets the requirements set forth in the alarm philosophy, including the tasks of prioritization, classification, settings determination, and documentation.

NOTE One goal of Alarm Rationalization is to determine the most efficient number of alarms to ensure that the process system is safe and remains within the normal operating range yet does not overload the operators in the control room handling an operating emergency.

3.20

risk-based inspection (RBI)

A risk assessment and management process that is focused on inspection planning for loss of containment of pressurized equipment in processing facilities, due to material deterioration. These risks are managed through inspection and IOW monitoring to influence the probability of failure.

3.21

subject matter expert (SME)

One who has in-depth knowledge and experience on a specific subject as it relates to IOWs and is considered acceptable to the owner-operator.

NOTE Various SMEs are necessary to establish IOWs for each process unit, e.g. corrosion/materials SME, process SME, operations SME, equipment type SME, inspection SME, etc.

3.22

stakeholder

An individual, group, or organization that may affect, be affected by, or perceive itself to be affected by, the IOW issue.

3.23

total acid number (TAN)

A measure of various acids, including organic acids, in hydrocarbon streams. This is typically determined via an ASTM procedure involving titration of a hydrocarbon sample.

3.24

work process

A series of activities or steps aimed at achieving a set objective, with inputs and outputs. e.g. the IOW work process to establish IOW limits on operating parameters.

4 Parameters that May Require Different Types and Levels of IOWs

Parameters that may influence the mechanical integrity or reliability of the equipment fall into two types: chemical and physical. IOWs should also be classified in different levels, based on risk, to prioritize notifications (including alarms, alerts, and other notifications) and timing of actions needed when IOWs are exceeded. In this RP, three primary levels of IOWs: “critical”, “standard”, and “informational”, are described based on the predicted change in damage rate to equipment during an exceedance and the ability of the operator to take corrective action.

4.1 Chemical and physical parameters noted below are not all inclusive but provide examples of the process parameters that may need IOWs established.

4.1.1 Chemical parameters are those that relate to the chemistry and fluid content of the process. Examples include pH, water content, acid gas loading, sulfur content, salt content, NH_4HS content, NH_3 content, TAN, acid strength, amine strength, inhibitor concentration, chloride contamination levels, oxygen content, etc.

4.1.2 Physical (mechanical, operational) parameters are those that are not chemical in nature but include all other aspects of a process design that are vital to maintaining control within established design parameters. Examples include design and operating pressure and temperature, partial pressures, dew points, dry points, heating and cooling rates, delta pressure, flow rates, injection rates, inhibitor dosage, amperage levels, slurry contents, hydrogen flux, vibration limits, corrosion probe measurements, etc.

4.2 IOWs should be classified into three levels, “critical”, “standard”, and “informational”, as follows:

4.2.1 A Critical IOW level requires the operator to take immediate predetermined actions to return the process variable back within the IOW limits to prevent significant defined risks of potential equipment damage or hazardous fluid release or result in an emergency or rapid non-orderly shutdown.

Typically, Critical IOW limits will have control room alarms, alerts, or other immediate notifications to the operator that a limit has been exceeded.

4.2.2 A Standard IOW level requires predetermined operator intervention or corrective action by a SME if the duration of the exceedance is more than a specified time (typically the duration that could cause increased degradation rate or that could introduce new damage mechanisms beyond those anticipated) to avoid one or more of the following:

- an eventual loss of containment,
- a release of hydrocarbons or hazardous fluids,
- an unscheduled or non-orderly shutdown,
- a negative impact to the long-term unit performance and its ability to meet outage or shutdown run length.

4.2.3 Informational IOW limits, often less restrictive limits for Critical and Standard IOW limits, are for trending by the SME and may not be controllable by operations. An effective IOW program should include Informational IOW limits. Informational limits may be an indicator that damage will occur. Deviations from Informational IOWs could lead to accelerated corrosion or other damage over a longer period. Informational IOW parameters may provide secondary or circumstantial indication of active corrosion/ erosion. For example, in an atmospheric tower overhead, the primary process control parameter for corrosion in the reflux may be the pH of the condensate, and a secondary informational parameter may be iron content measured periodically by laboratory sampling. When Informational IOW limit exceedances occur, the appropriate SMEs may specify that engineering, process, or inspection activities be planned or adjusted to control the rate of deterioration and prevent unacceptable equipment deterioration over the longer term. Informational IOWs typically do not have alarms or alerts associated with exceedances. In most cases, the limits for informational parameters initiate a notification to the appropriate SME. Informational IOWs are typically associated with the following situations:

- would not be directly related to a potential loss of containment within the near term,
- provides for a secondary indication of operational performance or corrosion control issue,
- used to track parameters that are not necessarily controllable by operators.

4.3 The primary difference between a critical and a standard limit is in the reaction time allowed (and necessary) to return the process to within the IOW limits. For critical limits, there will typically be visual and audible alarms for the operators and typically all Critical Limits would require specific predetermined actions to be taken by the operator to urgently return the process to within the IOW limits. In some cases, there may also be instrumented shutdown systems that automate a sequence of steps to regain control of the process. For some standard limits, there may also be visual or audible alarms, or both, depending upon the level of risk and required response time.

associated with the IOW. A risk assessment process such as that outlined in 5.8 and Section 6 can be used to determine the need for what alerts and alarms are appropriate for each IOW. Standard limits can in many cases be more conservative limits for operating parameters than critical limits to provide the operator with more time and options to bring the process back within the IOW limit before the more urgent measures for exceeding a critical limit are required.

4.4 In addition to the predetermined operator intervention required for critical limits and potentially some standard limits that are exceeded, notification to designated SMEs should be designed into the IOW work process so that technical investigations and corrective actions can be implemented to prevent further exceedances. Notifications should include designated inspectors, corrosion/materials specialists, process engineers and other appropriate personnel in case inspection plans, corrosion management strategies or process conditions need to be adjusted.

4.5 Figure 1 illustrates how various types of operating limits might create boundaries for any specific operating window. The middle zone between the standard limits (high and low) is the zone designated for achieving operational targets. Outside of those limits, operator intervention is generally required to return the process into this zone. Some limit ranges may not have an upper or lower boundary, depending on the variable. For example, heater tube-skin temperatures generally have upper limits, but most times has no lower limit.

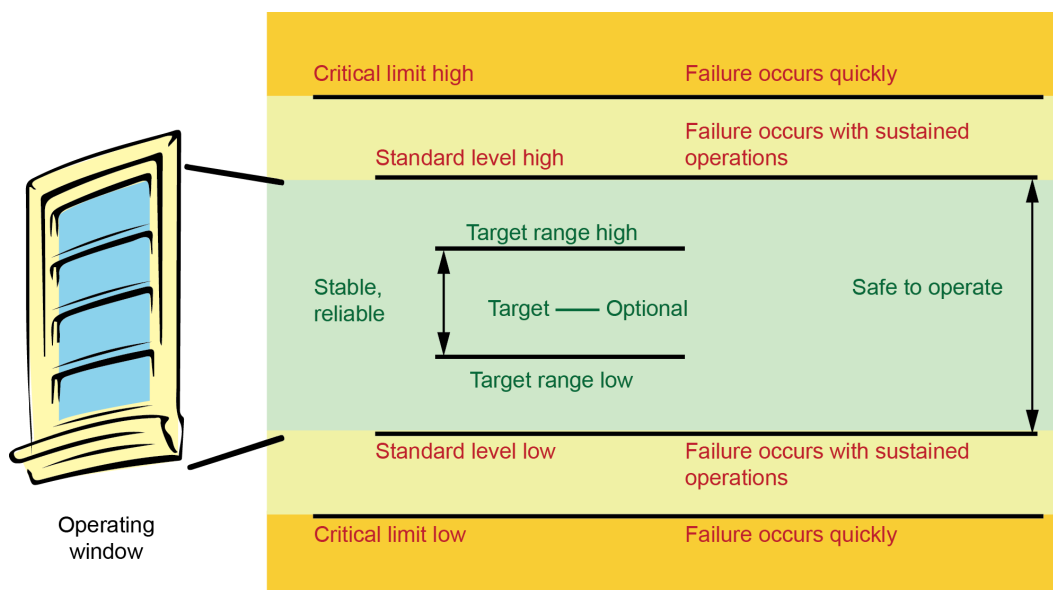


Figure 1—Zones of Operation Including Target Ranges with Standard and Critical Limits

5 IOW Work Process

5.1 In this section, a general work process is outlined for identifying IOWs, setting appropriate limits relative to a defined premise, and integrating IOWs into the site's mechanical integrity program. Additional details on the type and levels of IOWs are outlined in Section 4 and Section 6. For a specific example that closely follows the flow outlined in this section for one specific piece of equipment, see Annex C. General guidance and considerations for identifying and setting appropriately conservative limits is outlined in Section 9. Note that this work process may be applied to a single equipment item, multiple equipment items in a group (corrosion circuit) or more generally to the overall process unit. As an example, a chart reflecting a work process for setting IOWs is provided in Figure 2. Note that the owner-operator should develop and document their specific work process which may differ from Figure 2.

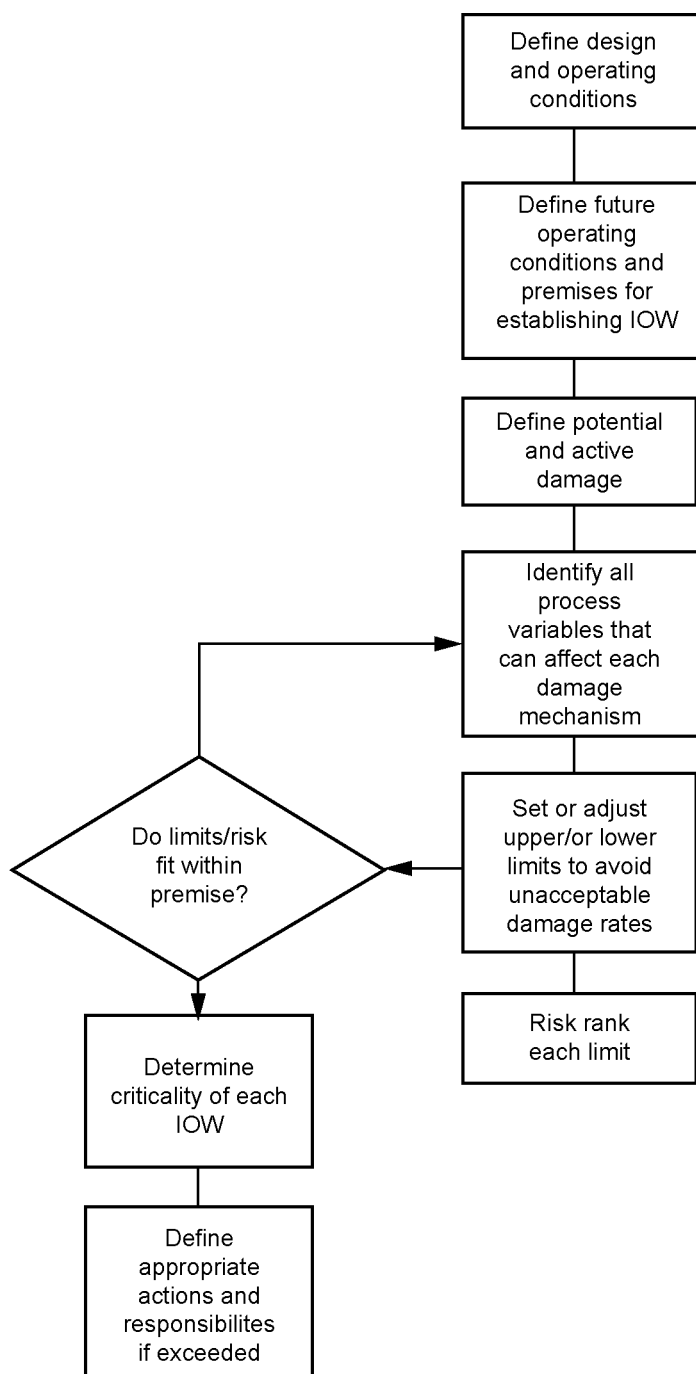


Figure 2—Example IOW Development Work Process

5.2 Step 1 in the process is to review the existing mechanical design conditions and prior operating conditions. Other operating conditions such as upset, start-up, shutdown, catalyst regeneration, decoking, hydrogen stripping, etc. and service type such as continuous, intermittent, or irregular should also be considered. The identification of the credible damage mechanisms in 5.5 requires a fundamental understanding of the mechanical design, the process operating conditions (temperatures, pressures, service, inhibitors, etc.) and the materials of construction including the alloy and material grade, method of fabrication, prior thermal and mechanical treatments, etc. Consideration should be given to both the normal operation and any abnormal operation that could produce unanticipated damage mechanisms or accelerated damage rates, or both.

5.3 Step 2 is to define a “premise” or basis for establishing IOW limits. Typically, the premise is established on a unit specific basis, however, in some cases a premise may be needed for an individual piece of equipment that

may experience significant operational changes. The premise should define and document the following type of information:

- Planned outage or shut-down cycle or desired run length;
- Anticipated future unit/equipment operating conditions;
- Approach for determining operation limits (historical vs limiting component);
- Method for determining damage rates (estimated, measured or industry based calculated rates);
- Maximum targeted wall loss rates based on equipment types.

Each premise is unique to the site or situation being considered and may include other types of information for definition, such as targeted risk levels, etc. A key consideration for establishing a premise is the time frame for which it will apply. In some cases, the established time frame may be very short (for example, for a specific operation to take advantage of an opportunity feed stock) but, in general, the time frame should be based on an acceptable run duration or life for the equipment. When establishing standard or reliability-based IOWs, one or two outage or shutdown periods are typically selected for the duration. After the premise has been established and accepted, changes to the operation should be considered through an MOC process. For small or incremental operational changes, the effected equipment or circuits should be reviewed for accelerated damage due to the change (e.g. slightly higher sulfur in the feed stock to a refinery). Significant changes or exceedances in the IOWs during operation may need revalidation of the premise document and IOW limits. It is important that the consequences of the premises be vetted and agreed upon by the IOW team.

5.4 Step 3 is to identify the credible damage mechanisms that could occur in each piece of process equipment. Historical damage rate and future rate considering any planned changes in operation should be estimated. API RP 970 covering corrosion control documents (CCD) presents a work process for assessing damage mechanisms. Integrating the CCD work process with the IOW work process may provide a more efficient manner in completing these tasks. Section 7 and Annex A contains examples of damage mechanisms and potential operating variables within process units that may need IOWs established. There are several sources of industry data that identify typical damage mechanisms for various operating units, including:

- API RP 571 Damage Mechanisms Affecting Fixed Equipment in the Refining Industry
- API RP 581, *Risk-Based Inspection Technology* (Third Edition, Second Addendum Part 2 Annex B—Determination of Corrosion Rates, 10/2020)
- API 579-1/ASME FFS-1, *Fitness-for-Service* (Annex 2B)
- ASME PCC-3, *Inspection Planning Using Risk-Based Methods* (Chapter 6—**Damage Mechanisms and Failure Modes**)

Operating site programs that have been used to identify/establish equipment specific damage mechanisms or risk, or both, that should be considered during this process may include the following:

- Risk-based inspection studies;
- Corrosion reviews or similar programs, such as those establishing CCDs;
- Damage mechanism review studies;
- Equipment risk assessments;
- Process hazards analysis (PHA) or hazards analysis and operability (HAZOP) studies.

5.5 Step 4 identifies key process variables related to activation or rate of progression of the damage mechanisms. The goal of the IOW program is to identify the key parameters to monitor and to set limits on controllable parameters that can be adjusted by operations to achieve the desired level of equipment integrity and reliability.

These variables may be leading or lagging indicators. Leading indicators are predictive while lagging indicators are reactive. Multiple variables may be leading indicators of the activation or rate of a damage mechanism. Desalter efficiency, pH, chloride content, conductivity, salt point, and dew point are examples of leading indicators of corrosion potential in a crude unit atmospheric tower overhead system. Iron content and corrosion probe response are examples of lagging indicators of corrosion potential in a crude unit atmospheric tower overhead system. The leading indicator parameter(s) most controllable and most effective at reducing the damage potential should be the primary variable(s) for monitoring and applying limits. In general, lagging indicators not directly controllable by the operator are considered as Informational IOWs.

5.6 Step 5 is to set upper or lower limits, or both, to identify when new damage mechanisms are triggered or when degradation rates change significantly in relation to the inspection planning strategy. Operation of a heater above the design tube metal temperature limit with the plan to retube this heater at the next planned outage is an example of a limit to indicate increased damage rate. Setting a maximum temperature limit to prevent high-temperature hydrogen attack (HTHA) is an example of a limit above which a new damage mechanism is activated. Existing limits should be reviewed against the defined premise (see 5.3) to ensure they will achieve the desired reliability and mechanical integrity. Multiple aspects of each variable need to be examined when establishing operating limits. The following paragraphs of this section provide the most common aspects to consider during the analysis.

5.6.1 The accuracy, relevance and location of the measurement need to be considered (e.g. the measurement location may not be optimal for the damage location and the measurement accuracy may require a conservative limit to provide adequate response time.)

5.6.2 The limit needs to be set considering the rate of further damage progression expected. Note that the time needed to adjust the operation and the potential effect on inspection planning strategy needs to be considered.

5.6.3 The limits need to be set considering the level of risk for exceeding the limits. A process limit will be set with the level of notification needed (alarm, alert, e-mail, or other notification) and by establishing the predetermined response actions when that limit is exceeded.

5.6.4 Consideration should be given to setting multiple limits on some IOWs to provide more time and less urgent responses to bring the operation back within normal operation before reaching a Critical IOW limit. Some process variables could have an IOW Informational limit that would provide time for an SME to consider an appropriate response, a Standard IOW limit at a next level which may have a designated operator response, and a Critical IOW limit which would require an urgent operator or automated response. Limits should be rationalized and prioritized based on the site's standard (see comments in 6.1).

5.6.5 Some limits in reality involve multiple co-dependent variables not just a single target value for a single parameter. Many of the corrosion related damage mechanisms also have a significant time effect that needs to be considered. For example, the rate of high-temperature sulfidation corrosion is dependent on; temperature, alloy type and amount of reactive sulfur present in the process stream influence. If a limit were to be set on temperature alone an exceedance may occur without any measurable damage to the equipment if there was insufficient time for measurable damage to occur.

5.7 Step 6—To determine the level of the IOW (Critical, Standard, or Informational), a risk assessment may be used. In some cases, the relative risk may be determined subjectively, and in more complicated cases, the risk analysis may need to be more rigorous. Many operating companies have developed risk matrices and risk analysis procedures to provide guidance for consistent management decisions which may also be used to determine the risk of exceeding the established IOW limit. An example risk matrix and analysis process are provided in Section 6. Determining the IOW level or risk, or both, for a given parameter is important to help distinguish which parameters and limits:

- will need alarms versus alerts;
- will need predetermined actions to be taken to speed recovery times;
- will need formalized follow-up and investigation after exceedances occur;
- if changed or adjusted, may need to be managed through a MOC process, etc.; and
- will need a review of the inspection strategy by the inspector or SME.

5.8 Step 7—Once the limits and relative risk ranking has been developed, the proposed limits should be reviewed and validated by the owner-operator and compared with the IOW premise developed in 5.3. The risk level for each parameter is often dependent (or co-dependent) on multiple factors and may need to be developed through an iterative process. In some cases, the existing sample points, instrument ranges, frequency of data acquisition, etc. may not be optimal, in which case the assumed risk based on that measurement limit may be higher than is desirable.

The intended business objectives for the run period should also be considered. For example, the consideration of achieving product yields or production rates may require a compromise between competing IOW limits, provided the risks associated with such compromises are acceptable to stakeholders. This may be accomplished intuitively during the risk ranking process by continually testing a proposed limit level against the risk assumed at that level.

5.9 Step 8—After establishing the limits and risk, the levels of the IOWs (Critical, Standard, or Informational) can be established. As noted in 5.8, the selected level of IOW is used to distinguish which parameters and limits will need alarms, alerts, or other type of notifications, as well as the required response actions and timing, per 5.10. The level is also linked to the need to determine the amount of documentation required, ownership of the IOW and necessary follow-up on exceedances that have been recorded.

5.10 Step 9—Determine the actions needed, with response time, for an IOW exceedance. Critical IOW limit exceedances will normally require an urgent specific response by the operator to avoid more rapid equipment degradation problems. Response time for Standard IOW exceedances will be less urgent than those associated with Critical IOW exceedances. Response times for both Critical and Standard IOWs should be defined and agreed upon by the IOW team. Some of those actions will likely be for operators, but other response actions may be for inspectors or designated SMEs, or both. Response actions and associated timing by operators for IOW Informational limits will be mostly related to which inspector or SME should be notified to determine what response action is needed. The notification of and follow up action by the inspector or SME is the essential step in linking applicable IOW exceedances to the MI program and inspection planning process. Automated communication of exceedances to the appropriate stakeholders is the most effective method.

6 IOW Risk Ranking

6.1 In this section, an example risk ranking process and risk matrix are provided to guide the user through an evaluation of the importance and priority of each parameter/limit combination under consideration. As noted in Section 5, IOWs may be risk ranked to help determine the appropriate priority of alarms, alerts, notifications, and response action. Risk assessment helps to determine what actions the operator needs to take and how fast the operator needs to act, i.e. the higher the risk, the sooner the operator may need to respond and the more definitive the response may need to be. Additionally, with higher risk, more levels of action might be designated for Standard IOWs to provide an increased chance of regaining control before a Critical IOW limit is reached. See Figure 6 showing an example where there might be more than one Standard limit for tube-skin temperature IOWs before reaching a Critical IOW limit. Note that Operating companies should also refer to their existing alarm management and rationalization strategies.

6.2 The risk for established IOW limits for a given operating parameter is a function of the event probability and consequence when the limit is exceeded. In each case or scenario, several sub-factors need to be considered when establishing the risk levels. An example approach to establishing three levels of IOWs (“Critical”, “Standard” and “Informational” limits) is outlined to separate IOWs for process parameters that have shorter term mechanical

integrity implications from those that have longer term process safety or reliability implications. After designating the highest risk IOWs (i.e. critical limits) additional prioritization can be achieved through risk ranking of the “Standard” and “Informational” limits to identify those limits that need quicker, more definitive action by the operator or designated SME.

6.3 Figure 3 and Figure 4 show examples of a risk matrix and an example chart of IOW potential actions for operating conditions that exceed the established limits. For the risk assessment process, start by assuming a limit to a given parameter that may meet the premise established for the intended operating period. For that limit, determine how likely and how quickly the component or equipment might fail if that limit is exceeded. Also determine the consequences if failure does occur at the imposed limit level, i.e. small leak; large leak; immediate emergency; safety issue and size; environmental issue and size; reliability issue and size; etc. The product of these probability of failure and consequence of failure is the risk of failure. In Figure 4, some example guidance, actions, involvement, and responses to different levels of risk are shown.

6.4 For this first example, time to failure is used to indicate probability of failure, where a probability of “5” = highly likely to fail within hours to days. For consequence of failure a combination of safety and business interruption will be used where the consequence of “D” = Significant exposure risk to personnel and potential loss of profit. This gives a “5D” category on the matrix in Figure 3 with a corresponding “high” risk. From Figure 4, Critical Limits are required to be established with appropriate alarms where operators are required to take urgent predetermined actions to return the process to normal operation. In addition, the appropriate SMEs are notified for this parameter exceedance along with the operations supervisor.

6.5 A second example involves an unexpected process change that results in a likely to fail within a few months corrosion situation, if something is not corrected. So, it is not urgent, but needs attention relatively soon. A probability of 4 is assigned. The consequence involves a big leak which would involve a possible environmental citation and business interruption, as well as undesirable media attention. A consequence of C is assigned, resulting in a 4C medium high risk on the matrix in Figure 3. From Figure 4, Critical or Standard IOWs would be established with predetermined actions for operations associated with the exceedance to be implemented within the predetermined time. Also, a notification to corrosion/materials specialist would likely be made to assess the situation and recommend further actions.

6.6 A third example involves a small increase in the pH of the feed stream, increasing the corrosion rates above those on which the inspection plan was established. The probability of 2 is assigned. The consequence involves a small leak above reportable quantity, so a consequence of B is assigned. From Figure 4 an IOW Informational limit is recommended. Action required by operations is to notify the unit inspector or designated SME, or both, for review and potential modification of the inspection plans.

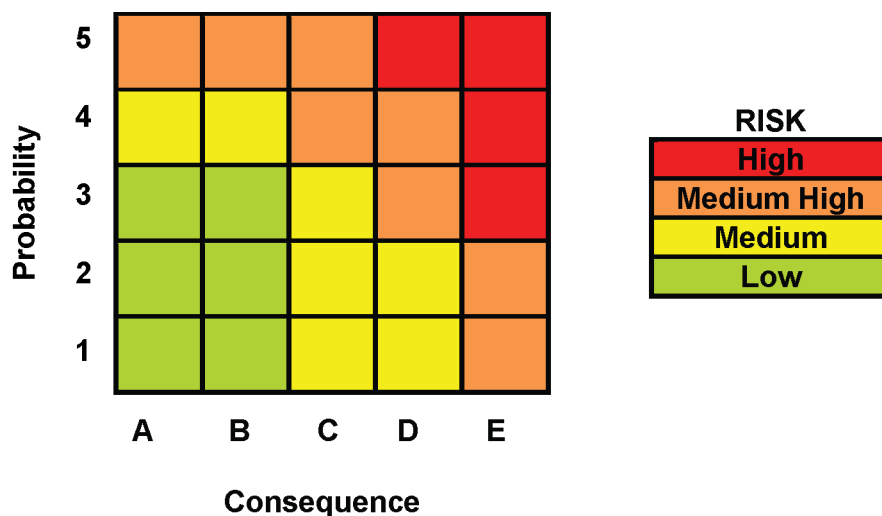


Figure 3—Generic Risk Matrix for Assessing IOW Levels

Risk	Type of IOW	IOW Guidance/Action
High	Critical	IOWs Required—Limits and durations established on all IOW process parameters for monitoring; IOWs are alarmed/alerted, and SMEs are notified of exceedances; Operations take urgent predetermined action to return process to normal operation.
Medium High	Critical or Standard	IOWs Required—Limits and durations established on all IOW process parameters for monitoring; IOWs are alarmed/alerted, and SMEs are notified of exceedances; Operations take predetermined action to return process to normal operation.
Medium	Standard or Informational	IOW Informational limits Identified—IOWs identified suggested limits specified for each IOW; Operations and SMEs are alerted/notified of exceedances; Troubleshooting initiated with planned adjustments to operations, inspection/maintenance developed.
Low	Informational	IOW Informational limits suggested—Normal operating parameters identified for analysis; Parameters tracked and trended by SME to determine long-term effects on equipment reliability.

Figure 4—Example Risk Chart for IOW Types/Actions/Guidance

7 Examples of IOWs

7.1 An example of an IOW set for high-temperature hydrogen attack (HTHA) is shown in Figure 5. Note that mechanical design limits from the construction code for the vessel are above the IOW limits for the process, which are typically set from the appropriate Nelson curve in API RP 941. Also, note that the start-of-run conditions (SOR) are within the IOW, but the end-of-run conditions (EOR) may be outside the IOW depending upon hydrogen partial pressure and the duration of the EOR conditions. In this case, some owner-operator may decide that short-term operation at EOR conditions above the Nelson curve is acceptable based on the amount of time it takes for incipient HTHA to occur, i.e. no significant HTHA damage will occur. Other owner-operators may decide that the IOW should never be exceeded, even with short-term EOR conditions. Such decisions and determination of the required risk controls (e.g. the required frequency and extent of HTHA inspections) can be made using appropriate risk analysis and the input of knowledgeable corrosion/materials SMEs who are aware of the damage accumulation and incipient attack issues with HTHA.

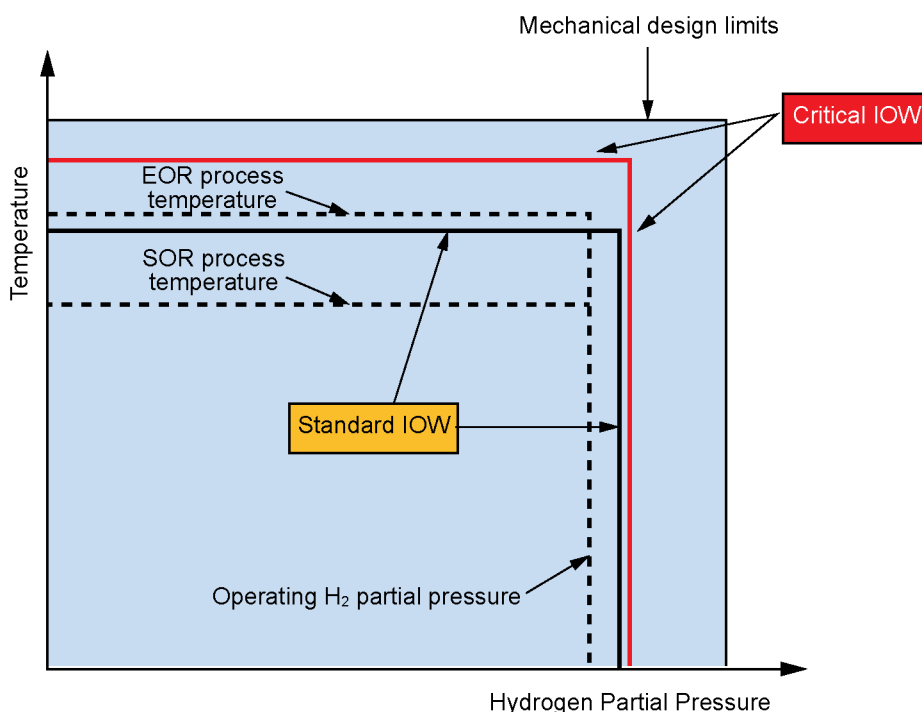


Figure 5—Example of IOW Limits for HTHA in a Hydroprocessing Unit