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Establishing a Process for the Setting of Real-Time Detection System Alarms

White Paper

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TABLE OF CONTENTS

Table of Tables

Table of Figures

Table of Appendices

Disclaimer

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Executive Summary

With the advancement of new detection technologies and miniaturization of components, opportunities for real-time detection of hazards of interest in occupational and environmental health and safety have expanded. Those same technological advancements now allow linking sensing and detection system data to automatically mitigate the conditions (ventilation dampers activated when smoke detectors go off) or alert people to immediate action (fire alarm strobes, audible alarms, and personal safety instruments). Initial action is most frequently taken on the basis of instantaneous readings rather than on the basis of statutory time history exposure limit calculations (e.g., STEL and TWA). Real-time instruments generally include STEL and TWA alarm calculations, but in most cases, the initial alarm is triggered by exceeding a real-time concentration limit. Unfortunately, there remains a lack of guidance for establishing a "fit for purpose" process for establishing and setting real-time alarms when the OEL does not provide direct guidance.

This AIHA white paper proposes to fill that void and promote a discussion directed at individuals responsible for maintaining a "standard of care" by selecting a sensor system that is fit for purpose, configured properly for detecting a condition, and announces that condition through signals that are most commonly considered and called alarms. The standard of care establishes five steps:

- Step 1 – Statement of Purpose *(in target of condition to detect)*
- Step 2 – Selection of Objectives *(parameters around the condition to detect)*
- Step 3 – Selection of the device(s) and determination that it is fit for purpose
- Step 4 – Establishment of an Alarm Set Point(s) and Response Process
- Step 5 – Stakeholder Communication *(of the results and determination)*

This white paper is intended to frame a common process that reasonably covers configuring appropriate alarms on various types of RTDS. In doing so, the process should sequentially assist with selecting the sensor and configuring the RTDS, including, but not limited to, its datalogging function and alarm setpoint(s). The entire process, when correctly applied, will ensure the user correctly interprets the condition(s) induced when an alarm is triggered and takes an associated action.

The authors look forward to dialogue with those in the real-time detection systems community of practice as we harness the power of sensor technology and the opportunity to engage with the hierarchy of controls that are available.

Abbreviations and Acronyms

ACC	Approval and Certification Center
ACGIH	American Conference of Governmental Industrial Hygienists
AIHA	American Industrial Hygiene Association
ASTM	ASTM International
BCS	Building Control System
BEEEAM	Building Energy Efficiency, Ergonomics and Management
BMS	Building Management System
BoK	Body of Knowledge
BSI	British Standards Institute
BT	Bluetooth
CDC	Centers for Disease Control
CFR	Code Of Federal Regulations
ClO_2	Chlorine Dioxide
CO_2	Carbon Dioxide
CS	Case Study
CSA	Canadian Standards Association
DHS	Department of Homeland Security
DRI(s)	Direct Reading Instrument(s)
DRI TF	Direct Reading Instruments Technical Framework [AIHA 2020b]
DOE	Department Of Energy
DOL	Department Of Labor
FMDT	Fatigue Monitoring and Detection Technologies
FEMA	Federal Emergency Management Agency
H&S	Health and Safety
HazMat	Hazardous Materials
HEPA	High Efficiency Particulate Air
HF	Human Factors
HFACS	Human Factors Analysis and Classification System
HMI	Human Machine Interface

HSE	see (UK) HSE
HSRC	Health & Safety Reclamation Code (British Columbia Canada)
IAQ	Indoor Air Quality
IDLH	Immediately Dangerous to Life and Health
IEC	International Electrotechnical Commission
IEQ	Indoor Environmental Quality
IEQM	Indoor Environmental Quality Monitor
IH	Industrial Hygiene
IRSST	Institut de recherche Robert-Sauvé en santé et en sécurité du travail
ISA	International Society of Automation
ISO	International Organization for Standardization
KSA	Knowledge, Skills and Abilities
LOD	Limit of Detection
LOQ	Limit of Quantitation
MOC	Management of Change
MSHA	Mine Safety and Health Administration
NFPA	National Fire Protection Association
NIOSH	National Institutes of Occupational Safety and Health
NIU	Northern Illinois University
NO_2	Nitrogen Dioxide
NRTL	Nationally Recognized Testing Laboratories
NYCAFC	New York City Association of Fire Chiefs
OA	Outside Air
OEHS	Occupational and Environmental Health and Safety
OEL	Occupational Exposure Limits
OELV	Occupational Exposure Limit Values
OH	Occupational Hygiene
OSHA	Occupational Safety and Health Administration
PEL	Permissible Exposure Limit
PC	Particle Count/ Particle Concentration
PID	Photoionization Detector (Detection)

PM	Particulate Matter
$PM_{2.5}$	Particulate Matter <2.5 um
PN(C)	Particle Number (concentration)
ppb(v)	parts per billion (volume)
PPE	Personal Protective Equipment
ppm(v)	parts per million (volume)
REL	Recommended Exposure Limit
RH	Relative Humidity
RP	Respirable Particulate
RPi	Raspberry Pi
RTDS	Real-time Detection System(s)
RTDSC	Real-time Detection Systems Committee
SCAQMD	South Coast Air Quality Management District
SDT	Signal Detection Theory
SESS	Standardized Equipment Specification Sheets
SME	Subject Matter Expert
STEL	Short-Term Exposure Limit
T	Temperature
TBD	To be determined
TF	Technical Framework
TLV	Threshold Limit Value™
TPM	Total particulate matter
TWA	Time-Weighted Average
(UK)HSE	(United Kingdom) Health & Safety Executive
(US)EPA	(United States) Environmental Protection Agency
WEL	Workplace Exposure Limit
WP	White Paper
WIPP	Waste Isolation Pilot Plant

1.0 PREAMBLE

The American Industrial Hygiene Association (AIHA)[AIHA 2021a] provides information and guidance to the industrial hygiene community (also referred to as Occupational and Environmental Health and Safety (OEHS)), a group commonly employing real-time detection systems (RTDSs). This white paper ("White Paper") proposes a comprehensive and defensible process for alarm setting for any RTDS that is applicable far beyond those for conventional OEHS direct-reading instruments. The general term alarm setting is being used to refer to the overall process of many possible setpoints and is simply a general/generic term that has applicability to an instrument or system that provides an alert to take action, or directs an action by other systems.

Systems is the broad term that encompasses sensors, arrays of sensors into a singular field instrument such as a multiple sensors-equipped monitor, and arrays of sensors into networks such as a building air-quality monitoring system [AIHA 2015a; AIHA 2020a; Agarwal 2021]. This white paper will most often cite "instrument" or RTDS as a link to the AIHA Real-Time Detection Systems (RTDS) Committee "Technical Framework: Guidance on Use of Direct Reading Instruments" document [AIHA 2020b], referred to as the Direct Reading Instruments (DRI)Technical Framework TF in this document.

For purposes of this document the following terms are defined as follows:

"**Fit for purpose** is used informally to describe a process, configuration item, IT service, etc., that is capable of meeting its objectives or service levels. Being fit for purpose requires suitable design, implementation, control, and maintenance."[2022]

"**White Papers** are persuasive, in-depth reports or essays that include executive summaries, are supported by scientific research, and are written to educate the target audience on an issue or explain and promote a particular methodology. White papers are meant to help readers understand an issue, solve a problem, or make a decision."[AIHA 2022]

"**Alarm setpoint**" [Automation 2018] is a user configurable threshold value that triggers an annunciation (audible, visual or both for remote devices; or report to a central station where an audible or visual or both call attention to the station attendant for action) for one or more signals (e.g., Low/High; warning/danger; above Time-Weighted Average (TWA) Threshold Limit Value(TLV), above Short-Term Exposure Limit (STEL) TLV. The authors consider the terms "limits", "levels", or "criteria threshold" to all be synonymous to "setpoint" in this paper.

In all cases, the device or system is reporting information for action, whether automated (computer logic drives devices to turn on or off a system, visible and/or audible facility alarm requiring donning of respiratory protection and/or egress from the area) or human intervention (confined space attendant directs entrants to leave the space). The report of the device for action may be immediate (concentrations of a gas in a breathing zone – Low/High, warning/danger), or may be deferred (trend data for an exposure assessment judgment – TWA or STEL alarm).

The DRI TF establishes “tiers” of users. When developing the DRI TF, the author group utilized a “bucket” analogy for describing the four (4) user tiers:

- Tier 1 – Basic User takes DRIs from the bucket to use on their person or for their team.
- Tier 2 – Intermediate User places DRIs into the bucket, making sure they are correctly tested and functional.
- Tier 3 – Specialist User selects the correct instrument to be prepared for the bucket, considering fitness for purpose.
- Tier 4 – Advanced User qualifies instrumentation for potential selection for the bucket, including handling novel situations.

The topic under consideration in this White Paper is directed to those persons with responsibility for a “standard of care” in the selection of a system that is fit for purpose, configured properly for detection of a condition, and which announces that condition through visual, audible and other (e.g., tactile) signals (most commonly considered and called alarms). Such persons (users) are considered Tier 3 (oversee system implementation and performance) and Tier 4 (specify instrument selection, performance, user proficiency and data evaluation).

The intention behind this analogy is to describe the obligations of escalating competency in the user tiers. That framework describes the escalating degree of trust (self/others/program/method) as it relates to specific competencies required for the described role.

When adopting the new process presented in this White Paper, consideration should be given to the documentation of alarm setting decisions. This information may be important to stakeholders who will implement the program, use the system(s), manage the data, or rely upon system outputs for conformance, compliance or risk assessment.

Finally, this White Paper supports the transition to the International Organization for Standardization (ISO) standard ISO17025 [ISO/IEC 2017] model of deterministic risk analysis from prior prescriptive risk assignment. This has bearing upon the occupational hygienist responsible for arriving at a determination that the instrument is fit for purpose.

2.0 BACKGROUND

There has been an exponential increase of technological advances in sensors, components, and data capture and decision-making elements of RTDS in recent years [CCPS and AIHA 2009]. Instruments are increasingly able to wirelessly communicate with remote data collection centers, reporting on personal health conditions (even epileptic seizures) [HSE 2013], personnel locations in construction zones [Soltanmohammadlou, Sadeghi et al. 2019] and hazardous gases in construction projects [Cheung, Lin et al. 2018]. RTDS are installed in facilities, used for public health in hazard monitoring, used in hazard detection for personnel health & safety (H&S), adopted for total workers exposure, included in holistic risk communication approaches, and in many other applications. This White Paper will hopefully catalyze discussions and dialogue on the manner of sensor deployment that was first addressed by AIHA with the Center for Chemical Process Safety in the joint publication Continuous Monitoring for Hazardous Material Releases [CCPS and AIHA 2009] and subsequently explored by the British HSE in RR973 Research Report titled Review of Alarm Setting for Toxic Gas and Oxygen Detectors [HSE 2013].

The treatment of "alarm philosophy" was tackled by the International Society of Automation (ISA) in the process industries in the early 2000s. Development of ANSI/ISA-18.2 Management of Alarm Systems for the Process Industries [ANSI/ISA 2009] was motivated by the connection between poor alarm management and the resultant process safety accidents that resulted (e.g., Bhopal in 1984, Milford Haven in 1983, Buncefield in 2005 (both oil storage facility fires with injuries) and Texas City BP in 2005). ISA developed a lifecycle model (approach) to work towards successful design, implementation, operation and management of alarm systems addressing the Bransby and Jenkinson observation that "poor performance costs money in lost production and plant damage and weakens a very important line of defense against hazards to people" [Bransby and Jenkinson 1998]. Figure 1 provides an overview of ISA 18.2, initiated in 2009 and revised in 2016 [2010; (ANSI) 2016]

A quote from Exida® (www.exida.com) summary [Exida 2020] of ISA 18.2 provides a useful summary:

> "The alarm management standard provides a framework for the successful design, implementation, operation and management of alarm systems in a process plant. It provides guidance to solve or prevent the most common alarm management problems and sustain the performance of the alarm system over time. It is organized around the alarm management lifecycle. The key activities of alarm management are executed in the different stages of the lifecycle. The products of each stage are the inputs for the activities of the next stage. The alarm lifecycle has three starting points: philosophy, monitoring & assessment, and audit. Site needs and system status dictate which is the appropriate starting point. Philosophy is the typical starting point for a new system, while monitoring & assessment or audit may be the starting point for an existing system."

As the seven steps (shown as B through H of Figure 1) of the lifecycle process proceed, the output of one step leads as inputs to the next. One of the limitations of the standards is the lack of guidelines on how to arrive to the determination of the alarm setpoint.

One important feature of H&S RTDS is the capacity to react promptly once a certain condition is reached. The reaction can be associated with the triggering of an alarm or (more generically considered) a signal. In all cases of detection, there must be a purpose behind the need for signal generation. In each and every case, that signal serves to alert a recipient (a person, a system) to take an action. The action can be to change a ventilation flow rate, to abandon a confined space, or to change a saw blade, and it can be generally considered a significant action(s). For this reason, the process of setting the logical rules that can trigger an alarm is extremely important and it should be carefully considered by health-safety professionals. The process also needs to be examined by all stakeholders impacted by the alarm and the action [HSE 2000; Wilkinson and Lucas 2002]. A prescient statement is provided by Connelly [Connelly 1997].

"Lack of planning in alarm system configuration is, in essence, planning to fail."

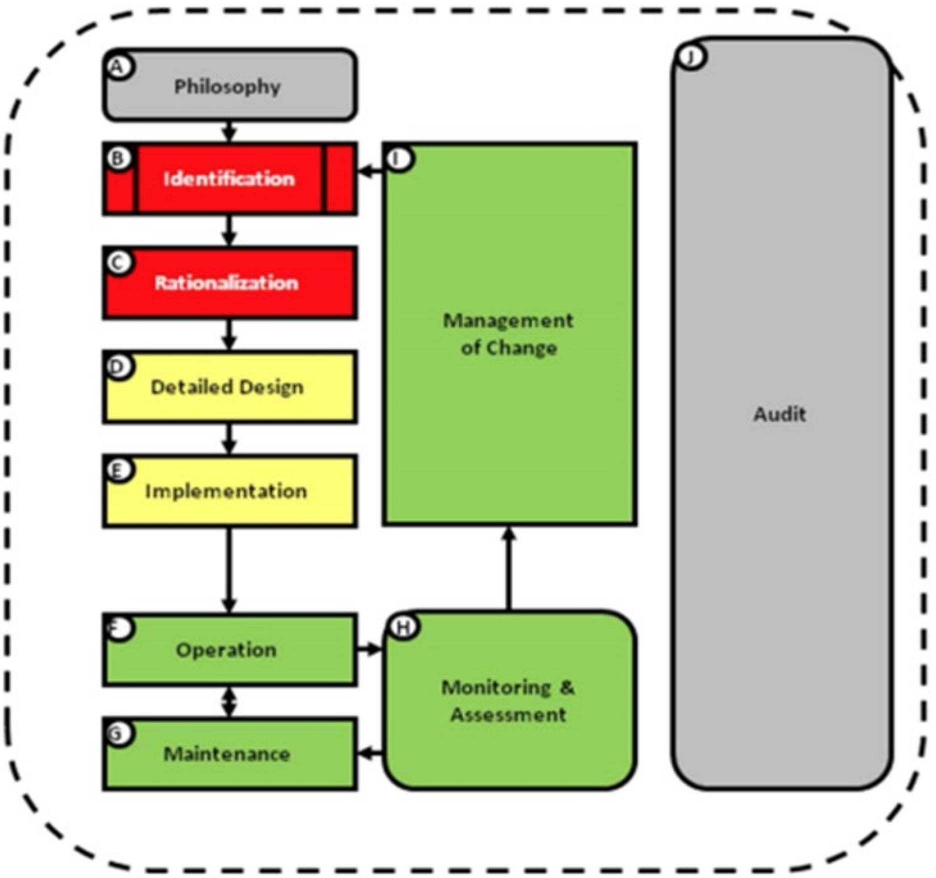

Figure 1: Overview of ISA 18.2 Summarized by Exida [Exida 2020]

The intent of this White Paper is to frame a common process that reasonably covers configuring appropriate alarms on various types of RTDS. In doing so, the process should sequentially assist with the sensor selection, configuration of the RTDS including, but not limited to, its datalogging function and alarm setpoint(s): the entire process, when correctly applied, will assure the user to correctly interpret the condition(s) induced by an alarm when triggered and to take an associated action. The description of the process is followed by a case study that should help the user in appreciating the application of a comprehensive and serviceable approach for different needs [AIHA 2020b].

3.0 PROPOSING AN ALARM SETTING PROCESS

The ISA 18.2 philosophy has been carefully explored by the authors and we find that the process is easily followed from start to finish for new design and installations of alarms for process monitoring. It also acknowledges that it can start with embracing adoption of a management of change program, or an auditing function (self- assessment of an organization's alarm philosophy status). Note that the specification of an alarm setpoint (ISA 18.2.2 Technical Report section 6.5.7 [Automation 2018]) does not provide a logic for the determination of an alarm setpoint, leading one to the anticipated utility of this White Paper.

We propose that an alarm setting process should function for any RTDS, array of sensors in an instrument, array of instruments in a network (portable or installed, commonly termed 'fixed'), and for both conventional industrial hygiene use or as "emerging" technologies. It is critically important that the purpose and objectives for using RTDS or instruments be fully defined before making decisions regarding which instrument to use. The authors recognize that there are many existing alarm systems deployed worldwide, and believe that anyone with accountabilities for designing, installing, or managing them would benefit from an audit or validation that the considerations found in this paper have been documented.

The proposed process consists of five (5) steps summarized in Table I.

TABLE I: Proposed Steps for Alarm Setting Process

STEP NO.	SHORT DESCRIPTION
Step 1	Statement of Purpose ("what are you trying to do")
Step 2	Selection of Objective(s) ("how do you plan to achieve the purpose?")
Step 3	Selection of Device(s) and Determination of Fitness for Purpose ("in order to succeed at the how")
Step 4	Establishing Alarm Setpoint and Response Process ("conclusion")
Step 5	Summarizing the Analysis for Effective Stakeholder Communication ("risk communication")

Table II contains a modified list of alarm setting factors considered for gas detection systems that the Health and Safety Executive (HSE) in Great Britain has developed [HSE 2013]. These same factors can apply to many types of RTDS for physical and health hazards and other types of uses.

TABLE II: Alarm Setting Factor Considerations for Installing Any Type of Gas Detector (Adapted from HSE 2013)

NUMBER	DESCRIPTION
1	Whether detectors should be fixed and/or whether personnel should be issued with portable, which includes personal, detectors
2	The location of the fixed detector and whether the work area is occupied or unoccupied
3	Whether the fixed detector is a point or open-path (also known as beam or line of sight detectors) detector
4	Whether egress is difficult and/or time-consuming or there is an emergency
5	Whether WELs, other Exposure Limit values or other health-based levels (e.g., IDLH) exist
6	Instantaneous or TWA alarm
7	Background variations and events from the process, which may trigger “spurious” alarms
8	False alarms caused by instrumental effects and interferent gases, which may also be classified as spurious
9	The characteristics of the source(s) and the potential rate of gas build up
10	Time to alarm of the detection system
11	Number of alarm levels (e.g., high and low levels)
12	Mixture of gases/vapors
13	Whether the fixed detector is a diffusion type or a pumped type (also known as sample draw) detector
14	Whether the monitoring area is in a hazardous or permit required location (which may introduce additional alarm setting constraints)
15	Whether the RTDS is able to communicate real-time alarms to other individuals (e.g., wireless communication between confined space entrants and attendants)
16	Whether RTDS results will be used to coordinate off-site response or third-party rescue;
17	Whether RTDS results will be used for instantaneous (Peak or Ceiling) or time history (STEL or TWA) alarms
18	Whether background variations and events from the process can trigger “spurious” alarms;
19	Environmental conditions that may exceed the design or certification limits of the RTDS (e.g., temperature (T), pressure and humidity)

TABLE II: Alarm Setting Factor Considerations for Installing Any Type of Gas Detector (Adapted from HSE 2013) (continued)

NUMBER	DESCRIPTION
20	Background conditions that can affect the proper performance of the sensors, (e.g., lack of oxygen due to natural or deliberate inerting of confined spaces)
21	Environmental conditions that can affect the user from knowing when an alarm occurs (e.g., high noise)
22	Activities that introduce additional hazards, (e.g., hot work)
23	Other external or internal factors that may affect or prevent the RTDS from activating the appropriate alarms

Application Background: Pulp Mill Chlorine Dioxide Monitoring

To provide context to the issues being discussed in this White Paper, a sample application is provided that illustrates and support issues discussed in the multistep process. The following is background information for the application provided after each step discussion.

Within the kraft pulping and paper process chlorine dioxide (ClO_2) is regularly used in the bleaching process. ClO_2 must be produced at the mill site at the point of application and stored in water solution (10-12g/L) for use in multistage bleaching towers. ClO_2 generation usually occurs in an isolated process area or separate building and piped to storage tanks for use in multistage bleaching, involving towers and washers in other mill areas. Vapors and other off gassing are collected and vented to atmosphere through a gas or wet scrubber. The bleaching sequence generally involves two phases: 1) a delignification segment, whose function is to remove the lignin; and 2) a brightening segment, whose function is to increase the brightness of the pulp. Gas detection (both fixed and portable monitoring) is used in both phases where ClO_2 is used.

3.1 *STEP 1 - Statement of Purpose*

Any deployment or implementation of a RTDS should begin with a clear, systematic analysis and statement of the purpose(s) [2021h] for which the monitoring is being performed, including any data collection. It is recommended that the purpose be at a high level; examples might include:

- Control worker entry to hazardous atmospheres
- Intervene in episodes of excessive drivers fatigue
- Alert workers to rising chlorine dioxide levels
- Manage ventilation efficiency through aerosol monitoring (particle counting) and carbon dioxide (CO_2) concentration

The thinking process behind developing a high-level purpose description can be quite valuable as part of the overall iterative process of alarm setting.

Application: Pulp Mill Chlorine Dioxide Monitoring

Step 1 Statement of Purpose ("what are you trying to do?")

1) Detect fugitive ClO_2 emissions in those generally occupied ClO_2 generation areas and warn of unsafe conditions allowing for safe egress
2) Provide workers with exposure monitoring information for specific tasks working in generation and bleaching areas (tower and washer area, and scrubber) where routine exposures are anticipated.

3.2 *STEP 2 - Selection of Objective(s)*

RTDS are often deployed with multiple objectives in order to satisfy the monitoring purpose. The study of RTDS for gas and vapor detection, and failures to appropriately set or to respond to alarms, prompted the discussion and development of this White Paper. While the example below is focused on gases and vapors, the need for the selection of objective(s) applies to any use of the process to a RTDS. The objective logically leads to examination of all the factors found in Table II to assure thorough review.

A simple construct for gas and vapor detection is offered in the International Electrotechnical Commission (IEC) standard 62990-1:2019 [IEC 2019]:

Safety Monitoring (SM): General gas detection applications where the performance requirements are focused on alarm signaling (e.g., safety warning, leak detection). General gas detection includes the following measurement tasks:

- Providing visual and audible alarms to warn workers of potentially harmful toxic gas concentrations.
- Measurements to monitor the effectiveness of protection systems (e.g., general ventilation and/or extraction).
- Leak detection in industrial and commercial environments.
- Providing alarm output signals to initiate operation of ventilation, shutdown of processes, safe evacuation, etc.
- Area monitoring to provide continuous information on the concentration of toxic gas over a site.
- Spot-reading measurements (e.g., to obtain a gas-free work permit prior to hot work).

For this objective, gas detection usually has at least two or three instantaneous alarms that are operated as a pre-alarm (low level, pre-warning, A1, etc.), sometimes a mid-level alarm, and a main alarm (high level, danger, A2, etc.). These alarms activate when the measured value exceeds the setpoint. Although work tasks like confined space entry involving portable equipment typically utilize only one of these alarms to initiate a response (low or pre-warning), some gas detection equipment may activate a visual alarm (light) first at a low-level condition, then trigger activation of ventilation system upon pre-warning alarm or mid-level alarm to limit an increase in concentration by diluting with air, and finally trigger the main alarm mandating further response such as evacuation.

Health Monitoring (HM): Health monitoring is done to identify conditions leading to longer term or chronic health conditions. This is done through occupational exposure measurement, where the performance requirements are focused on uncertainty of measurement of gas concentrations in the region of occupational exposure limit values (OELV). Such occupational exposure monitoring equipment is used in service for occupational exposure assessment where the performance requirements are focused on the uncertainty of measurement of gas and vapor concentrations for comparison to Occupational Exposure Limit Values (OELVs or OELs).

Most commonly alarms that are relied upon for 'health monitoring' typically employ time-weighted average (TWA or STEL) functions that activate when the average concentration over the measurement period exceeds a threshold (most commonly the contaminant TWA or STEL OEL or better, marginally lower than that limit).

Instruments can possess both SM and HM capabilities, but separating the functionality ***greatly simplifies*** risk communication to stakeholders.

A further utility of instruments is to meet objectives of process safety, confirming the functionality of process system controls.

Fixed gas detection normally speaks to 'Safety Monitoring' functionality (detecting combustible atmosphere conditions that could lead to an acute consequence), while the portable gas detection speaks to 'Safety Monitoring' and/or 'Health Monitoring' (exposure assessment for the similar exposure group (SEG) to check and verify worker task control measures (e.g., respiratory protection) and manage chronic consequences for members of the SEG to which the worker belongs. Also fixed detector instantaneous alarms are most predominantly used for 'safety monitoring' "as they do not measure workers' exposure in the breathing zone. There is typically only a weak correlation or even none at all between the gas concentration as measured by a fixed detector and that by a personal/portable monitor worn by personnel in the general area covered by the fixed monitor [HSE 2013]. This concept is of particular importance when determining the objective of alarm setpoints for portable monitors incorporated into base units located around a work site for temporary area monitoring during work activities.

As a conceptual example, consider the need to monitor for benzene in a waste processing facility where the facility must remove a benzene fraction as part of the separation and recovery process.

- The separation phase occurs in a robust and unmanned operation; the benzene feeds to an external receipt tank of 300,000 gallons. The tank is inerted with nitrogen in a positive pressure mode.
- Gas/vapor detection is established at all times as a sentinel measure to meet several purposes:
  - To demonstrate compliance to air emissions under a local and national air permit obligation.

- To allow worker access to the tank top, where operators perform rounds to verify that all equipment is in working order. This includes safety monitoring (flammable atmospheres) and health monitoring (gas concentrations to compare to Occupational Exposure Limits and understand exposure profiles).
- The functional fixed combustible gas/vapor detectors operate with readings each 10 minutes and report the results to a Central Control Room (CCR). These detectors serve to detect flammable hazards (combustible atmosphere not benzene exposure).
- Portable benzene specific detection (using a Photoionization Detector (PID)) at line breaks into the process system serve to confirm absence of hazard, or if hazard detection occurs, to confirm appropriate respiratory protection.
- Personal exposure monitoring with worn dosimeters is supplemented by conventional air sampling on activated carbon tubes for compliance monitoring purposes. These samples serve to demonstrate correlation of exposure variability over time to the workers who may access the tank top for intrusive maintenance tasks

The fixed gas detection in this example speaks to 'Safety Monitoring' functionality (detecting combustible atmosphere conditions that could lead to an acute consequence (also known as (AKA) explosion), while the portable benzene specific detection speaks to 'Health Monitoring' (exposure assessment for the similar exposure group (SEG) to check and verify worker task control measures (e.g., respiratory protection) and manage chronic consequences for members of the SEG to which the worker belongs).

It must be recognized that other types of RTDS that are neither Health or Safety Monitoring exist and should also be addressed during the Selection of Objectives step. This is the case, for example, of some process monitoring where product quality is the prime objective. For ease of conceptualization, this White Paper proposes that monitoring activities can be divided into four different activity designations (Table III).

TABLE III: Division of Monitoring Activities

Designation	Description
A	Safety Monitoring (e.g., explosive hazard or running machinery)
B	Health Monitoring (e.g., exposure levels , benzene, CO)
C	Combination of Safety and Health Monitoring (e.g., explosive hazard and benzene exposure)
D	Other (e.g., process monitoring, research activities)

RTDS can be used for collecting data for exposure assessment and their configuration must consider regulatory requirements and health impacts to the worker (Activity B). In the frame of this objective there can be three monitoring goals [AIHA 2015b]:

- determination of a baseline with the identification of similar exposure group exposure profiles;
- assessment of compliance with an occupational exposure limit; and
- analysis of exposure sources and contribution to exposure profile.

In the case of the determination of the baseline, an instantaneous alarm should be set as protective of the health consequence of the agent under study; in the case of assessment of compliance, the alarm can be set at the OEL if technically valid and feasible in the functions of the sensor, the context of use, and the recording of supporting data. Finally, if hazard identification and its contribution to understand exposure variability is the goal, the alarm should be set as high as possible while protecting the workers and workplace.

RTDS can be used as a component for researching an aspect of workplace health and safety. Information generated by RTDS can be part of a health and safety management system. For example, RTDS measurements can be used as a proxy (surrogate) for condition of concern: this is the case of using real-time respirable dust monitoring when the concern is the exposure to crystalline silica or quartz (Activity B). Or the condition of interest is so complex, like fatigue, that RTDS can only provide an indication on a specific aspect. When facing the task of configuring an alarm for RTDS used for these objectives, the user will need to adopt a more holistic approach. The holistic approach might include communication with the workers who might be affected by the alarm, analysis of historic data relative to the condition, and preliminary assessment using other non-RTDS techniques. If the process is not followed closely, alarms can induce confusion and frustration.

Surveillance of implemented control practices is a common objective for RTDS: this might include ventilation of confined space or enclosed equipment cabs, or any environment and situation where a site-specific plan has been negotiated between a regulator and company (Activity D). To accomplish this task RTDSs are integrated into control systems to report performance status. The RTDS might be installed to monitor that established control practice and alarm events might need to be recorded and cataloged to assess the performance of the control practice: values in an acceptable range won't produce any alarm or signal while alarms or signals of different natures (tone, frequency, color) are produced when there is infringement or out of tolerance range. For this objective, both the control of a process or the direct exposure monitoring can be pursued: with these options in mind, it is clear to image how the alarm setting might not be driven by a formal regulatory limit but as "process safety" monitoring.

RTDS can be commonly used for the purpose of demonstrating regulatory compliance to a certain criteria or limit (Activity D). In this case, options are available for alarm configuration. The user might want to set the alarm lower than the authoritative criteria to be proactive in terms of response actions and to avoid repercussions of reporting. The user could also set the alarm exactly at the published criteria while incorporating or not the instrument error. Each of these options should be considered, and the most appropriate one documented and shared with (approved by) the community of stakeholders who may be affected by the emission.

The selection of objective must also clearly identify ***appropriate*** uses and disclaim or limit ***inappropriate*** uses for any data stream. As many RTDS have configurable parameters (e.g., low, high, STEL and TWA alarms; TWA averaging period, logging interval), each parameter must be individually addressed. Failure to complete systematic analysis may result in data that does not fulfill the objective(s) of instrument use or introduces uncertainty by requiring substantial inference to interpret the data.

For Table III the 4 divisions can generally fit into one of four common categories: to demonstrate regulatory compliance; to inform exposure assessment judgments; to provide surveillance information to ensure control (control charting of information); or finally to collect information for research and diagnose a condition.

Application: Pulp Mill Chlorine Dioxide Monitoring

Step 2 Selection of Objective(s) ("how do you plan to achieve the purpose?")

There are two differing mechanisms of monitoring involved:

1) Safety Monitoring – Use of fixed gas detection for safety monitoring and alerting in ClO_2 generation and use areas
2) Health Monitoring – The use of portable gas detection for worker exposure monitoring.

3.3 STEP 3 - Selection of Device(s) and Determination of Fitness for Purpose

Considerations for the selection of the RTDS should include targeting the parameters necessary for the hazard to be recognized and the objective to be accomplished, operability, the environmental conditions challenging the device and user, and the human factors (HF) affecting the user responding to the alarm [Nimmo 2002].

Performance characteristics can vary widely between and within instrument classes, makes and models, and sensors. These characteristics must be considered in relation to critical factors such as types of agents detected, limit of quantification for a specific agent, and accuracy of detection. ***Collectively, an instrument must be fit for purpose for the identified context and objective.*** It is possible to select an instrument which detects a specific agent but is still not fit for purpose for other reasons. The concept of "fit for intended use" (or "fitness for purpose") is discussed in numerous documents [ISO 2008; Wenclawiak and Hadjicostas 2010; Eurachem 2014; ISO/IEC 2017] and is an important part of the validation of any analytical method, including sensors used in RTDS.

Evaluating instruments and systems is a complex task and should be approached carefully, especially for unusual agents or conditions. The AIHA Real-Time Detection Systems Committee (RTDSC) has developed a Standardized Equipment Specification Sheet (SESS) as part of the publication Reporting Specifications for Electronic Real Time Gas and Vapor Detection Equipment [AIHA 2021b]. The SESS can assist in identifying important performance characteristics when qualifying instruments as proper for their intended purpose. Another AIHA document of note is the Competency Framework: A Prime Resource for Using DRI's in Gas Monitoring and Detection [AIHA 2020a].

Just because an instrument has a claim of functionality does not mean it is fit for the identified purpose. Different stakeholders (workers wearing a device) may believe that the device will provide specific information that does not match functions established by the Tier 4 user who defines the configuration of the instrument. It is important to note that the instrument logic in calculating data from the sensors may not align to multiple authoritative limits applicable to a sensed chemical agent or condition. Examples might include buffered data in a log that does not match what was displayed at the time of alarm. A number of examples are listed in Table IV below.

TABLE IV: Some Examples of Systematic Failures Due to Insufficient Analysis

DESCRIPTION
False positive during monitoring due to cross-sensitivity to non-target analyte.
False negative during monitoring due to unidentified limit of quantification (LOQ) greater than an exposure limit.
Failure to report detection due to interrupted radio communications.
Interferences from adjacent RF signals to unshielded system components.
Alarm event visual and audible signals presented to the portable gas monitor wearer not matched with logged data showing the threshold exceedance condition.
Failure to report meaningful data due to confusing or difficult functional test process.
Overwriting of data due to inadequate internal memory.
Failure to record data due to absence of clear indication of recording mode.

Users should also preemptively consider other potential alternative frames of reference for the same data. Data used to validate engineering controls applied inappropriately for worker compliance to OELs would be a common example of data examined after the monitoring event by a regulator who must depend on field notes in the monitoring report for sufficient context. Such inappropriate uses should be called out expressly to support defense of the application of the instrument and its intended use (recall the need to state and document the Statement of Purpose and Selection of Objectives). This may be an important consideration for chemicals having a very low exposure limit compared to the sensor's ability to accurately detect the chemical (e.g., chlorine dioxide). The use of fixed gas detection in a work area to signal and alarm in the presence of the substance may not necessarily mean an applied time-weighted average OEL has been exceeded.

From another perspective, when considering using an instrument that generates an alarm, the alarm must be considered one of the selection parameters described below. For this reason, an analysis should be conducted and documented of the purpose behind determination that an alarm would be prudent for deployment and the consequences of doing so. This analysis can lead to a more knowledgeable selection and use of the device and depended upon when configuring alarm setpoint(s). Consider the following examples:

- During unloading of bunker fuel oil from ships, hydrogen sulfide is continuously venting on deck. Selection of the NIOSH Ceiling Recommended Exposure Limit (REL) of 10 ppm results in near continuous alarms on deck as each worker wearing one experiences intermittent triggering of alarms at an unnecessary frequency. If reducing the incidence of alarm could be pursued, a better selection might be the OSHA Ceiling Limit of 20 ppm.
- Acceptable mining equipment operator enclosure CO_2 levels are established in ISO 23785 Standard for the Design of Enclosed Cabs [ISO 2021]. The first visual alarm to be triggered is to be amber when the monitoring device detects concentrations within 10.0% of the alarm value. Having a standard defined

alarm setpoint of 1000 ppm the amber alarm would be set at 900 ppm ("within 10% of the alarm value"). When compared against the standard's performance requirement of "a maximum sustained CO_2 at the ambient level of CO_2+ 400 ppm" (approximately 820 ppm considering worldwide measurement of CO_2), it is conceivable that the visual amber alarm condition could repeatedly or continually exist. The standard also provides for a second alarm (in this instance audible and visually red) and for it to recur every 10 min, but then allows it to be silenced by the user. If the alarm is set at the standard required 2500 ppm and can be silenced, it begs the question "what is the value in configuring alarms at these values?" Establishing an alarm to resultant CO_2 field conditions but offering the equipment operator no manner of modifying the contributing causes of the condition render the alarm virtually useless.

3.3.1 Consideration #1: Target of monitoring / sensor parameters

The first task in the selection of a device is to identify all sensors, instruments or arrays that can first recognize, and as necessary quantify a condition (gas concentration, humidity level, particles count, blink frequency); however, when establishing a monitoring objective, one may be constrained by the available technology. As a result, consideration of alternate paths to recognize, then characterize the parameter may be necessary: oxygen concentrations may be the required measurement to assess biological activity in a tank or release of nitrogen; an electrochemical sensor may be selected based on cross sensitivities when no dedicated sensor can be used for direct measurement, or physiological conditions (i.e., blinking of the eye) may be associated with fatigue. Such monitoring may be referred to as proxy measurements or surrogates.

In other cases, the monitoring may be established for multiple purposes (respirable dust/silica; particle sizing/ metals analysis). In these occasions sensors or detection technologies housed in separate instruments may be combined to meet the stated objective. As one parameter range could be exceeded while the other may not, selection of appropriate alarm setpoints must incorporate consideration of all conditions (parameter 1 or 2 out of range, both out of range). In all cases the target of monitoring must be thoughtfully considered and formally declared so everyone observing the monitoring and its results are aligned on interpretation of the system behavior.

A second focus is the hazard range itself. Currently, there is a focus on silica measurements through correlation to respirable dusts established by optical particle counting. Historically, a bulk sample or XRD was needed to discriminate the crystalline silica source. One may build a correlation over repeated sampling events; the risk of this approach is the consistency of the silica content (hazard range) in establishing the correlation.

With respect to hazardous materials detection, sensors are built for the "normal" occurrence of "in control" conditions, where one is attempting to detect parts per million contaminants. Such instruments are overwhelmed and of little utility for emergency response conditions. In emergencies, a full suite of detectors is optimal to dial in the specifics of contaminant levels from the clean (cold zone) to source (hot zone) of the emergency response (i.e., not fit for purpose in this application).

Monitors used to provide real-time alarms must provide sufficient accuracy and include the necessary alarms based on the correct method of calculation to meet the monitoring objectives. As an example, in one instance, an instrument that reads in 1.0% LEL with ± 20% accuracy is not usable for making decisions that require 0.1 ppm resolution. Or in a specific case, the TLV-TWA® for nitrogen dioxide (NO_2) is 0.2ppm, while the OSHA permissible exposure limit (PEL) is 5.0ppm (Ceiling) and NIOSH REL is 1ppm (STEL). A real-time instrument for NO_2 measurement with 0.1 ppm resolution may be fine for monitoring for compliance with the OSHA PEL or NIOSH REL, but it should be deemed insufficient for measurement against the TLV-TWA®.

Along with issues relating to accuracy, repeatability and resolution, the methods used by the instrument to calculate when an alarm condition occurs may be constrained by the software design. For instance, when calculating a TWA over an extended 12-hour work shift, does the monitor evaluate results from only the most recently completed 8-hour period, or can it optionally calculate or project the equivalent 8-hour exposure over the actual 12-hour period (i.e., able to be configured for 720-minute averages)? Similarly, is the real-time instrument limited to calculating STEL alarms on a 15-minute basis, or can it optionally calculate STEL on an alternate time interval a 5-minute or 3-minute basis?

Application: Pulp Mill Chlorine Dioxide Monitoring

Consideration #1 – Target of monitoring / sensor parameters

1) Use of fixed gas detection installed in selected mill areas providing only 2 or 3 instantaneous alerts.
2) Use of portable single gas (or multi-gas) monitors equipped with ClO_2 sensors

As reference the following are the concentrations of interest for such applications:

ACGIH TLV	0.1 ppm (Ceiling / 2018)
OSHA PEL/BC/QC	0.1 ppm (TWA); 0.3 ppm (STEL)
NIOSH IDLH	5 ppm

As it is common for pulp mills to have extended work shifts for some work groups, consideration must be made for adjustment of the reference TWA (depending on the regulatory requirements of the mill location); with shift length commonly being at 12 hours the TWAEL may be required to be reduced to 0.05 ppm.

ClO_2 is identified to have a 'greenish-yellow' color and an odor similar to chlorine with an odor threshold of 0.1 ppm.

There are several considerations to be given for the selection of an instrument (with electrochemical sensor) including:

- Fixed gas detection
  - Commercially available in 0 to 1.0 ppm range with some at 0 to 5 ppm.
  - May only be equipped with instantaneous alarms (although some available may also have a TWA alarm.
  - Having the ability to read sensor values at transmitter location due to either to low light conditions or because the transmitter is not equipped with a display

- Portable gas monitors
  - Presence of multiple instantaneous gas alarms (2 or 3), as well as TWA and STEL alarms.
  - Can be highly influenced by environmental conditions (e.g., T and RH).
  - Sensor resolution may only provide data to 0.1 ppm resolution.

The detection limit for using either ClO_2 or chlorine gas sensors is critical in that many manufacturers list a 0.02 to 0.05 ppm detection limit for these sensors (with one fixed sensor having a minimum indicated concentration of 0.16 ppm); and having a sensitivity of ±2 to 5% of measured value and a long-term drift of ±0.2 ppm/year. Most manufacturers indicate linearity over the concentrations of concern.

ClO_2 sensors can have a range of 0 to 1 ppm with a resolution of 0.01 ppm; however, some are limited to single decimal reading.

3.3.2 Consideration #2: Operability

Consideration of the operability of any instrument or sensors is extremely important in the implementation of the device. Each instrument condition must be matched to an action, and the human factors (HF) implications for the expectations of personnel response must be defined and communicated (addressed further in Consideration #4). Stakeholder personnel must then receive training and demonstrate proficiency in that response action. Some workplace scenarios involve established alarm setpoints where the instrument is frequently placed into alarm (such as H_2S on oil barges, or CO monitors in high volume traffic or combustion equipment locations). This results in the alarm being ignored or treated as a nuisance. If the alarm threshold is not reasonable (though required at an appropriate setpoint), then discussions should be undertaken with the stakeholder(s) to explain the technical realities of the instrument's capability.

Here are some additional examples of considerations to explore:

- The deployment of a sensor or instrument must consider all the environments where the system would be expected to be used (e.g., clean versus contaminated; fresh air versus monitored locations, electromagnetic interference (EMI) in certain areas).
- Cross sensitivities may yield false positive or false negative results for the sensor; will the operator be able to interpret those conditions and react properly?
- Is the sensor or instrument to be deployed for the protection of personnel, equipment, or a process as a safety system (warn of combustible atmosphere) or health monitoring system (warn of compliance against corporate or authoritative limits)? Or is it to be employed for tracking system performance to remain "in control" (surveillance of CO_2 in air intakes next to a parking garage)?

The function of the sensor or instrument and the competencies required for appropriate use of the system will dictate who will have accountability for its operation and management.

As a final point for Consideration #2, the selection process should include how the continued fitness for purpose of the instrument will be verified. In other words, the procedures used to regularly test, calibrate and verify proper performance.

Application: Pulp Mill Chlorine Dioxide Monitoring

Consideration #2 – Operability

There are several operability issues involved with ClO_2 gas detection, including calibration and bump checks, and potential sensor cross-sensitivity.

- ClO_2 can't be found naturally, and ClO_2 calibration gas cylinders aren't available; ClO_2 must be generated.
- A ClO_2 gas generator with a source chemical cell is used to generate calibration gas. These are available in adjustable ranges from 0.5 to 5 ppm ClO_2 with adjustable flow rates. The source cells are purchased in 10-, 50-, or 100-hour cells.
- It is also possible to use chlorine gas (e.g., 10, 5 or 2 ppm) as a surrogate due to the available cross-sensitivity (varies depending on sensor manufacturer and filter use); however, one manufacturer states that calibration with cross-sensitivity gas is not recommended. The cross-sensitivity may fluctuate between +/- 30% and may differ from batch to batch and within the sensor's lifetime. There are opportunities for using chlorine gas for functional checks.
- ClO_2 sensors exhibit negative response to hydrogen sulfide (a potential collocated hazard at pulp mills).

The requirement to use a ClO_2 gas generator rather than a 'typical' docking station for bump/calibration checks requires additional training and education for users. There is also an opportunity to use chlorine gas sensors and determine and apply a correction factor due to the cross-sensitivity for response.

3.3.3 Consideration #3: Environmental conditions

The monitoring (field) environment can have a profound effect on the operation of the instrument (part of knowing the 'context of use' of the instrument). Variables such as T, RH, exposure to water spray or rain, and the presence of corrosive or interfering chemicals must all be considered. The absence of oxygen or the presence of gases such as nitrogen or CO_2 can prevent some sensors from operating correctly, while the presence of sensor poisons can damage or inhibit other sensors. If monitoring results are remotely evaluated by means of wireless connection in real-time, the method of communication must be sufficiently robust to avoid lapses or gaps (e.g., distance between instrument and monitoring from another device such as for Bluetooth (BT)-connected systems). Figure 2 provides an example of BT range considerations.

The use of a RTDS must consider the reasonably expected range of field conditions that the instrument and sensors will endure. Table V contains a summary of environmental factors that, at a minimum, should be considered.

Table V: Environmental Condition Considerations for Determining Appropriateness of a Deployed Technology

Considerations	Description
1	A simple but often overlooked consideration is the noise environments a portable instrument is placed in, and the sound level of the alarm. A high noise condition by activities of demolition will overwhelm and make inaudible instrument alarm settings, which consider a "normal" noise environment of 85 or 90 dBA.
2	If monitoring is for personal exposure over time, a smaller instrument (for example, using passive diffusion) which can be worn in the respirable zone is desirable.
3	Other environmental conditions for consideration include: a. T at the point of use (proximity to an operating boiler would be much higher than the T of a boiler room), b. humidity (water-based paints application in confined spaces and impacts to oxygen sensors), and c. airborne contaminants (other volatile organics that might occur cyclically with a vent releasing, or particulates that would need to be filtered out before the sensors).
4	If remote sampling is required, it may be necessary to use an instrument with a pump or a design which allows sensors to be deployed on the end of extender cables. Consider also implications with tubing such as in response time (sample delivery to sensor) and tube material compatibility (adsorption).
5	If the area to be monitored is a hazardous location, the real time instrument must carry the appropriate certifications for use (see 3.3.5) .
6	If the real time instrument is battery powered, the power source must provide sufficient operation time to meet the sampling objectives.
7	If logged sampling data is intended to be downloaded for later evaluation, the datalogging memory and data storage characteristics must be sufficient for the intended purpose.
8	If data transfer must occur, consideration of impediments to wireless technologies must be made (see Figure 3). As a general practice, the authors recommend all instruments have a physical port for downloading data, rather than relying on wireless technologies as the only download option.

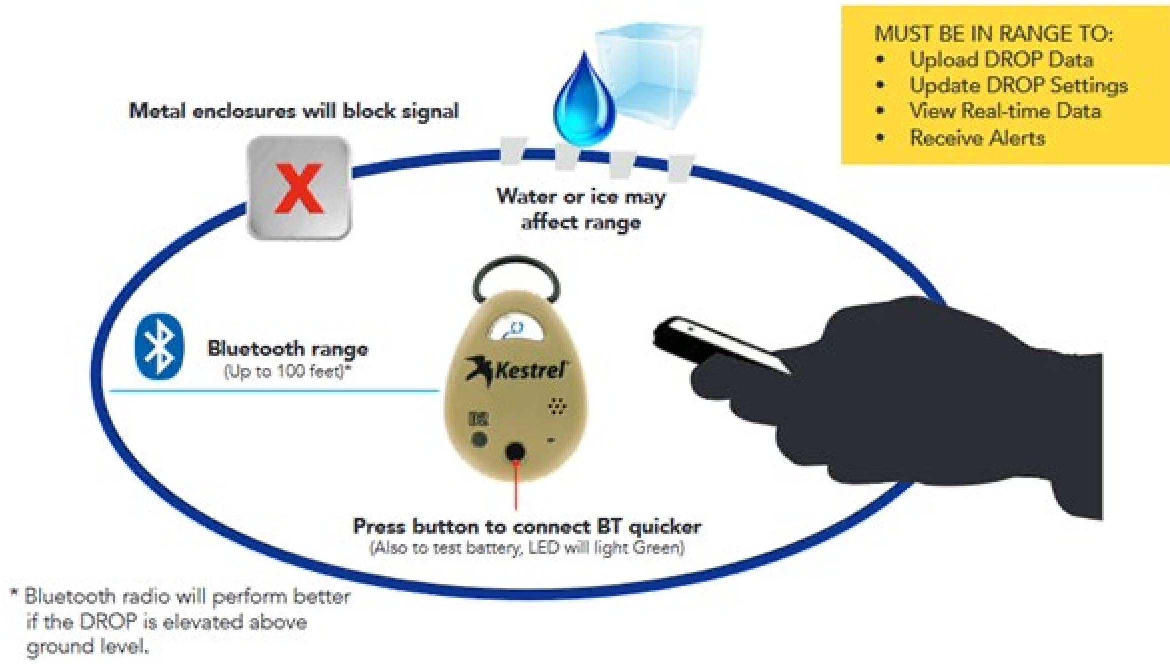

Figure 2: Example of Bluetooth range considerations[Kestrel 2021]
Visit www.kestrelinstrument.com/support/drop_support for more information

Application: Pulp Mill Chlorine Dioxide Monitoring

Consideration #3 – Environmental Conditions

ClO_2 sensors are identified by many manufacturers to be highly susceptible to moisture/humidity transients with some literature mentioning, "When the alarms for ClO_2 are set at 0.1 ppm it doesn't take much to generate a false positive alarm." Note that transients are positive for increasing moisture and negative for decreasing moisture.

"These sensors exhibit a positive moisture transient when exposed to a rapid increase in ambient moisture. Transient magnitudes ranged from 0.5 ppm to off-scale when sensors were suddenly exposed to moist air (23°C, 99% relative humidity (RH) after sitting in room air (23°C, 55 – 60%RH). The sensors took 2 to 3 minutes for the transient to fall below 0.1ppm while moist air exposure continued. The sensors underwent a negative transient of -0.3 to -0.5ppm when suddenly exposed to dry air (23°C, 0%RH) after sitting in room air (23°C, 55 – 60%RH). These transients took from 3 to 4 minutes to rise above -0.1ppm. Note that this negative transient could cause the transmitter to display "Sensor Fail". In addition to transients, moisture levels can cause a shift in the baseline level. Sensors zeroed after stabilizing under dried air displayed a 0.09 to 0.1ppm baseline when exposed to room ambient air (23°C, 55 – 60%RH). This shift was still apparent 24 to 72 hours later. The use of a sensor moisture barrier (*depending on the manufacturer*) can dampen these transients although they cannot be completely removed. Sensors used with these barriers exhibit a 0.3 to 0.4ppm transient when exposed to 99% RH moist air after stabilizing at room ambient."[Sensidyne undated].

Fixed gas units may be less influenced by humidity transients due to a stable environment but portable monitors in a pulp mill environment are routinely shown to be highly influenced. High T and moisture conditions may exist in the bleach washer area compared to a more controlled environment found in the ClO_2 generator area. A worker can travel to various mill locations, on the inside or mill exterior and passing through areas having high T with steam and high humidity conditions to cold dry exterior conditions.

The use of the ACGIH TLV 0.1 ppm as a 'Ceiling' (such as the 'Low' instantaneous alarm setpoint) presents difficulty for sensors that have the potential to be affected by humidity as outlined above.

3.3.4 Consideration #4: Human Factors Considerations in Device Selection and Alarm Parameters

Human Factors (HF) can be defined, for the purposes of this document, as the understanding of how humans interact with alarm systems for real-time detection systems or sensors. The interaction of humans is needed since an alarm can be defined as "a significant attractor of attention leading to interpretation and action" [1986], and in most instances the purpose of real-time instrument alarms is to elicit appropriate human response.

The key principles of alarm management that can be associated to the concept of HF are set out in Table VI.

TABLE VI: Human Factor Elements to Consider for Determining Device Selection and Alarm Parameters

ELEMENTS FOR CONSIDERATION NO.	DESCRIPTION
Step 3.4.1	Alert, inform, and direct the operator towards timely assessment or action.
Step 3.4.2	Be relevant and have a defined response.
Step 3.4.3	Allow for sufficient time to execute the defined response before a consequence occurs.
Step 3.4.4	Consider human capabilities and limitations associated with risk from the condition identified.

The brief treatment below is useful for the Tier 3 or Tier 4 reader to make instrument selection and alarm configuration decisions from the perspective of the stakeholder receiving and interpreting the alarm. Stanton has published a number of papers discussing HF and alarms that are a useful starting point for those interested in pursuing additional research on the topic [Stanton, N. 1991; Baber, Stanton et al. 1992; Stanton, N.A., Booth et al. 1992; Stanton, N.A. and Baber 1995; Stanton, N.A. and Baber 1997; Stanton, N. and Edworthy 1998; Stanton, N.A. and Baber 2008; Heikoop, de Winter et al. 2017; Hamim, Hoque et al. 2020; Stanton, N.A., Brown et al. 2022].

Considering the importance of humans to react to an alarm, the concept of "Swiss Cheese" in industrial incidences should be considered when analyzing the alarm setpoint [Reason, J. 2000; Stauffer, Sands et al. 2017; Roberts 2020; Wiegmann, L et al. 2021] [Reason, J. 2000; Reason, J.T., Carthey et al. 2001; Perneger 2005]. Imagine each layer of protection as a slice of Swiss Cheese, with the holes representing vulnerabilities to failure of that control. For an incident to occur, the holes in the slices of cheese must align. The size (area) of the holes in the cheese is proportional to the reliability of the layer of protection. A slice with a large hole area, comprised of many holes and/or big holes, has a higher vulnerability. To improve performance of the protection layer, there are several possible actions including reduce the area of the holes, ensure the holes in adjacent slices do not align, adding additional layers, or changing out layers of protection [Stauffer, Sands et al. 2017]. Figure 4 provides an example of the use of the Swiss Cheese Model resulting from the failure of a speed sensor on an Airbus A330 aircraft on Air France Flt 470 [Wannaz 2019a; Wannaz 2019b] In this case it was a combination of an airspeed sensor failure and the operator (pilot response) when it occurred. Another recent example where a combination of a sensor failure, alarms and inappropriate alarm response (due to HF) is the Boeing 727 Max [Demirci 2022]. It is important to note that this (the use of the Swiss Cheese Model) is really just a specific example of the risk assessment process carried out regularly in the OEHS profession [ANSI 2016; Lyon and Popov 2020].

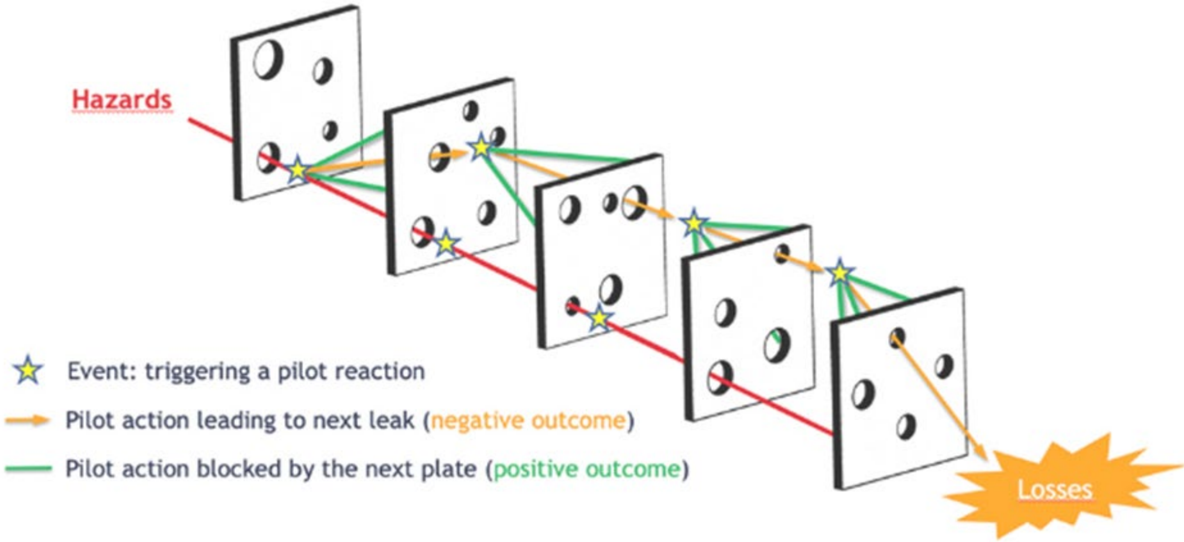

Figure 3: An example for the Swiss Cheese Model applied to the Air France Flight 470 A330 [Wannaz 2019a; Wannaz 2019b]

The type of alarm notification is commonly related to the associated risk and to the expected interaction of humans: notifications can be visible, audible, tactile, tiered, or a combination of these types (most commonly with high level risks to ensure acknowledgement by the user). On the other hand, the expected response of a human user to an alarm is a unique characteristic of this type of layer of protection. The human is, in many instances, a key component of an alarm setting process. As stated by Mica Endsley, a leading HF expert [Endsley, M. R. 2003; Endsley, M.R.J.D.G. 2004; Endsley, M. R. and Connors 2008; Endsley, Mica R. 2017], "a person's reluctance to respond immediately to a system that is known to have many false alarms is actually quite rational. Responding takes time and attention away from other ongoing tasks perceived as important" [Stauffer 2017].

Excellent references addressing HF approaches to alarm setting are the HSE Chemical Sheet No 6 Better Alarm Handing [HSE 2000; Wilkinson and Lucas 2002] which focuses on the realities of human behaviors in response to alarms as an important consideration in their application. Another useful document is Engineering Equipment and Materials Users Association Publication 191 Alarm Systems – A Guide to Design, Management and Procurement [Dadashi, Wilson et al. 2016]. Since it was first published in 1999, EEMUA 191 has become the globally accepted and leading guide to good practice for all aspects of alarm systems.

Lastly, these human factors considerations and resulting decisions must be communicated to the end user and those expected to respond to the alarm. Near misses have been documented [NYCAFC 2022] where alarms functioned properly but were not understood by those protected by them [WorkSafeBC 2018].

Application: Pulp Mill Chlorine Dioxide Monitoring

Consideration #4 – Human Factors Considerations

The presence of potential negative readings and/or false alarms requires that users are intimately knowledgeable about environmental issues and resulting difficulties arising in use with a particular manufacturer's ClO_2 sensor (also potentially creating alarm fatigue amongst users).

Fixed alarms, normally responded to by control room operators, would require a thorough understanding of how to interpret the readings that may be monitored by a Human Machine Interface (HMI).

3.3.5 Consideration #5: Determine Instrument Certification Requirements

Even after going through the 3.3.1 to 3.3.4 steps, there are additional fitness for purpose considerations that if missed, could result in the selection of inappropriate instrumentation. Specifically, a user needs to consider and verify the specific instrument certification requirements. Instruments are certified to specific standards. Examples of major standard setting bodies for DRI include (but are not limited to) the Canadian Standards Association (CSA), Underwriters Laboratories UL, Factory Mutual (FM), ISO, IEC and ISA. Testing to these standards is carried out by what are generally referred to as conformance assessment bodies (CAB) [ISO/CASCO 2022]. Other terms for CAB include Certification Bodies (e.g., ISO 17065), Nationally Recognized Testing Laboratories (NRTL as used by OSHA), Notified Bodies (IEC), Approval and Certification Center (ACC as used by the Mine Safety and Health Administration (MSHA)). As an example, instruments used at MSHA regulated sites must carry MSHA ACC certification(s).

3.4 *STEP 4 - Establishing Alarm Setpoint and Response Process*

Following the thoughtful considerations of a stated objective (STEP 2) to meet a declared purpose (STEP 1), the user has now determined the best system that is fit for purpose (STEP 3). With the device selected, one must now establish alarm set points. This White Paper is an attempt to emphasize this facet of implementing an alarm philosophy, plus provide a process to carry out the planning and implementation of deploying an alarm system (i.e., response process).

Occasions of instrument deployment almost always include a data criterion or limit to be applied for the intended purpose of using a real-time monitor. While initially applied to multiple sensor-equipped monitors, the alarm setting process established in this White Paper has been validated in the Case Studies section for the use of ventilation controls for Indoor Environmental Quality (IEQ) related to COVID aerosols management. The authors provide this sequence as useful in the determination of a limit assignment without regard to the detection technology, industry perspective or geographic authority, and reinforce appropriateness through application of the scenarios.

3.4.1 Ask first, "do we have a regulatory limit?"

If the purpose of the instrument use is a demonstration of compliance to a statute or regulation, then that limit is a first choice as a starting point for the criterion selection.

The limit assignment cannot be automatically selected from regulatory limits however as sensor response times for that hazardous contaminant may not provide sufficient time for warning of the condition (refer to the AIHA Standard Equipment Sensor Sheet T50 versus T90 response times [AIHA 2021b]). Instead, the alarm may need to be set to some fraction of the regulatory limit, such as for noise [OSHA ; OSHA 2008] and H_2S [OSHA 1993; OSHA undated]. Some advanced systems can also include measures of statistical certainty in this calculation to ease communication of details or compensate for uncertainty in performance characteristics.

Additionally, the assignment of an alarm term and value by the user or prescribed by the manufacturer (a manufacturer's default alarm setpoints) does not automatically impart to that value its utility as a demonstration of compliance. In multi-gas monitoring, high and low alarms are simple thresholds of a concentration (not determined with an algorithm calculating a time-weighted interval). The defense of the value ascribed to the alarms should be part of the summary technical basis.

3.4.2 Ask second, "do we have a limit assigned by contract, corporate policy, or other logical reason?"

If the purpose of the instrument is conformance to provisions of a contract, or to meet corporate expectations or some other documented, rational and communicated reason, that criterion may be used as the limit. This type of limit could also include those from other standards setting organizations such as ASTM, NIOSH (REL), ACGIH (TLV®), or AIHA (WEEL).

Further, ethical conduct [ICOH 2014] and a comprehensive approach to understanding exposures through the utility of real-time data would drive consideration of ACGIH Threshold Limit Values® as well as the suite of authoritative limits commonly known to the occupational hygiene community, see for example the GESTIS database of OELs [IFA 2022] over dated regulatory requirements (in the United States, OSHA PEL; in Canada, some provincial limit e.g., Health, Safety and Reclamation Code for Mines in British Columbia [MEMLCI 2021]).

The HSE 2013 guidance [HSE 2013] provides variable percentage citations depending on the industry and underlying toxicity established by those setting limits (internal corporate limits or the Authority Having Jurisdiction) and across many time intervals (instantaneous readings, TWAs or STELs, or IDLH values). Where coefficients to external limits are provided (often referred to as a "safety factor"), the reason for establishing such a modifier should be clearly identified and recorded as part of the technical basis, as such coefficients sometimes conflict with reasonability or capability of the system (e.g. ISO [ISO 2021] and Table B-I).

3.4.3 Ask third, "does the threshold need to be selected by the user based on field criteria?"

Such criteria may be subjective (such as ergonomic, fatigue, or odor parameters) or based on variable but objective criteria such as heat strain and multiple sources (infrared radiation plus ambient T plus encapsulating personal protection equipment or based on the type or phase of hazardous material present).

The process of limit assignment should be evaluated by the Tier 4 person deploying the technology, with validation provided by the Tier 1 or 2 user that they could make the needed determination and arrive at a correct limit determination.

3.4.4 Ask fourth, "how may we implement the Precautionary Principle when nothing else exists for guidance on establishing a criterion (or criteria) level?"

For instances where no authoritative criterion exists the authors' experiences are that a threshold percentage of a limit as determined by health and safety professionals or supporting technical opinions (legal department, toxicologists, product stewards) should be presented to stakeholders for consideration and adoption. This is an example of the Precautionary Principle [ICOH 2014].

3.4.5 Ask finally, "Is the selection of a limit a product of understanding the variability and historic data?"

There will be occasions where alarms can be anticipated from historical data, and adjustments may be made without incurring risks of adverse consequence to people or property.

Once the field conditions and hazard ranges have been established to drive instrument and sensor selections and configurations, these determinations should be shared with the stakeholders involved in the activity. No one is as familiar with ranges of conditions than the people who execute the work time and again. If that review finds the ranges reasonable, then a separate "what could go wrong?" review should occur by other stakeholders. Such "premortem" reviews can be facilitated by persons not directly familiar with the work, and their inquiry is often enlightening [Klein 2007].

3.4.6 Type of Alarms

In the case of multiple sensor-equipped monitors and electrochemical sensors where the authors first encountered the alarm setting dilemma, below is a more focused discussion of selection of alarm setpoints.

In the case of gas monitors, they generally include multiple alarms. Some may be set by users, while others are set by the manufacturer, or required by the certifications carried by the instrument. For instance, a percent LEL combustible gas detector typically has five or more alarms tied to the gas concentration.

In the case of chemical specific sensor applications, the user configurable gas alarms are broadly structured as instantaneous (peak or ceiling) low and high alarms, a STEL (15-minute interval) alarm, and a TWA (8 hour interval) alarm. Manufacturer-established alarms that cannot be "user modified" always include overlimit concentration and negative response alarms. Some manufacturers have also advanced to user configurable ranges for 3- or 5-minute averaging, as well as allowing variable resolution of the detection signal.

Some alarms have response parameters that can be configured by the user. For instance, many combustible gas detector users set the "Low" alarm at 10% LEL. The Low alarm is activated any time the reading even briefly exceeds 10%. The low alarm remains activated as long as the reading exceeds 10%. Once the reading drops below 10% LEL, the alarm is silenced. This type of alarm activation / deactivation is referred to as a self-resetting alarm.

The High 1 alarm is often set at 20%. Most chemical sensor designs allow the user to set the alarm to be self-resetting or configured as a latched alarm. Once activated, latched alarms continue to sound even after the alarm state has cleared. It is necessary for the user to acknowledge the alarm in order to silence the alarm. Users are usually able to turn off the High 1 alarm or set it at the same value as the Low alarm if a high alarm is not desired.

The requirements for certification for intrinsic safety may require that user settable LEL alarms cannot be set higher than 60% LEL. LEL alarms can be set lower, but never higher than 60%. The High 2 alarm cannot be turned off by the user and is usually a latched alarm.

The over-limit alarm is activated by conditions interpreted by the instrument as indicating the presence of 100% LEL conditions. Instrument manufacturers use sophisticated programming and signal analysis to make this decision. The NRTL that are responsible for certifications for intrinsic safety (for OSHA regulated locations in the US) verify that the over-limit alarm activates properly and accurately in the correct circumstances. The over-limit alarm is normally a latched type of alarm, and it is necessary to acknowledge the alarm, as well as verify that the instrument is in a fresh air location where there is adequate oxygen, before the instrument can be reset.

Besides the gas alarms there are numerous other LEL sensor alarms that are tied to other conditions and measurable parameters such as ambient T too low, ambient T too high, power too low for continued operation (low batt), electronically detectable sensor fault, or oxygen concentration too low for continued operation of LEL sensor. Depending on the design there may be other alarms as well, such as insufficient data logging memory, bump test due, calibration due or inspection due.

Tables VII and B-I below offers a summary of typical capabilities for alarm selection in gas monitoring devices.

Similarly, some alarms are based on context. Some manufacturers have implemented a “man down” alarm, which establishes a heuristic of combined gas detection and accelerometer measurements indicative of a fall or impact. Combined with remote monitoring, these alarms aim to eliminate delays in emergency response to unconscious employees by detecting multi-factor conditions consistent with loss of consciousness. Typically, a user can easily cancel a man down alarm with a touch. In the absence of an immediate cancel, a distress signal is transmitted. Signals sent in the absence of user interaction when prompted are colloquially known as a “dead man’s switch”.

While this discussion has offered examples for chemical specific and LEL sensors and the variety of alarms, readers should be aware of what certifications are required for their application (e.g. fitness for purpose) carefully explore alarms with instrument vendor literature (including exactly which standards the instruments are certified to), seek clarification with manufacturer technical experts where literature is inadequate, and document the results of systematic evaluation and the sources of any data used.

TABLE VII: Typical Configuration for Combustible Gases Alarm Selection in Gas Monitoring Devices

T gas alarms*				
	Method of calculation	**User set-table**	**Limitations**	**Typical Setting**
Low	Real time exceedance	Yes	User settable, range defined by manufacturer. Cannot be set higher than 60% LEL. Alarm self-resetting or latched.	10% LEL
High 1	Real time exceedance	Yes	User settable, range defined by manufacturer. Cannot be set higher than 60%. Alarm self-resetting or latched.	20% LEL
High 2	Real time exceedance	Yes	User settable, range defined by manufacturer. Cannot be set higher than 60% LEL. Alarm usually latched, requiring reset by user.	60% LEL
Over-Limit	Defined by NRTL	No	Generated by conditions which indicate presence of 100% LEL atmosphere. Latched alarm, instrument must be reset to clear alarm and restore normal function.	100% LEL
Negative reading	Defined by manufacturer	No	Alarm normally self-resetting.	–3% LEL

*Alarms and discussion intended as example only. Actual instruments may differ.

The main takeaways from this section include the following:

1. there is a potential for many different alarms, depending upon the parameters being monitored
2. the Tier 1 user would mainly only need to know how to differentiate between them and how to respond to them
3. Anyone setting an alarm level (e.g., Tier 3 or 4) needs to understand whether an alarm is user adjustable or is set by the manufacturer (i.e., only adjustable or set at the factory)

Application: Pulp Mill Chlorine Dioxide Monitoring

Step 4 Establishing Alarm Setpoint(s) and Response Process ("conclusion")

1. "Do we have a regulatory limit?"
2. "Do we have a limit assigned by contract, corporate policy, or other logical reason?"
3. "Does the threshold need to be selected by the user based on field criteria?"
4. "How may we implement the Precautionary Principle when nothing else exists for guidance on establishing a criterion (or criteria) level"
5. "Is the selection of a limit a product of understanding the variability and historic data?"

In this instance most regulatory jurisdictions have retained the historic TWAEL 0.1 ppm and STEL 0.3 ppm (rather than adopting the ACGIH 2018 TLV 0.1 ppm ceiling); however, the operability and environmental conditions challenge the ability of any particular ClO_2 sensor to maintain 'fit for purpose' under all situations, especially if the ACGIH ceiling is referenced. The alarm setpoints would also need to relate to any adjusted exposure limits for reduced shift lengths.

There is also an implied philosophy that alarms should alert the worker 'before' a maximum limit is reached (e.g., peak exposure or ceiling limit or TWA/STEL) so alarm setpoints should accommodate for this.

It is noted that in most kraft pulp environments workers would be required to have on their person minimal respiratory protection ('escape respirator') typically meant for H_2S (acid gas cartridges) that are also effective for ClO_2. Donning of this type of respirator in the event of alarm notification would be a typical response prior to exiting the work area (and consistent with the 'Swiss-Cheese' philosophy) to ensure worker exposures are minimized.

With the parameters defined that are necessary as a framework for the Alarm Setting Process, we now turn to the summary documentation necessary for communication of the results to stakeholders.

3.5 STEP 5 - Summarizing the Analysis for Effective Stakeholder Communication

If a sensor technology or instrument is to be deployed, someone (preferably a competent, confident party meeting Tier 4 user qualification) must be accountable to establish that instrument as 'fit for purpose'. Any process that does not establish fitness for purpose is, by default, trusting the manufacturer's marketing of the instrument to make that decision in the absence of all other evaluation. Once fit for purpose, a system must be configured to provide the right information meeting that purpose. Finally, the decisions made along the way need to be documented and shared with stakeholders affected by the decision (those purchasing or renting the device; maintaining and using the device; reporting data from the device; and interpreting that data).

The Alarm Setting Framework is complete when the determination that the instrument selection, its configuration of alarm set points and data logging, and the interpretation of the data is recorded and shared with stakeholders.

Appendix A contains a Documentation Template for the user to consider as a starting point. A mechanism of documentation and management approval is found in the EFCOG Practical Guide For Use Of Real Time Detection Systems For Worker Protection And Compliance With Occupational Exposure Limits [Siegel, Abrams et al. 2019].

An important point to make here is that the Alarm Setting Process needs to be reviewed on a predetermined basis for ongoing suitability (i.e., remaining "fit for purpose") or when a major change occurs (often referred to as Management of Change (MOC) in the HF field of study)[Phillips 1987; Manuelle 2012; McNay 2020].

An effective alarm system requires that the operator know the correct action to take in response to each alarm. Initial training should be conducted during the implementation stage with some levels of retraining on an appropriate frequency; continuing training is considered a recurring activity in the operations stage and should specifically require demonstrated proficiency in the application of knowledge, skills and abilities to properly respond to alarm conditions.

ISA 18.2 [ANSI-ISA 2009] notes that training on the alarm system functionality is sometimes overlooked in operator training programs and the alarm philosophy should be communicated during this training.

As a reminder, the five steps, discussed in this White Paper and summarized earlier in Table I are shown in Figure 4.

Application: Pulp Mill Chlorine Dioxide Monitoring

Step 5 Stakeholder Communication ("risk communication")

The preparation of stakeholder communication would need to describe:

- The fixed alarm set points, their basis within the selected technology and the need to egress a working area and other response actions (don respiratory protection)

Communication for portable monitors would require:

- Objective of portable monitoring and its' distinction from fixed detection monitoring
- Calibration requirements for fixed gas detection and any specific requirements for portable gas monitoring
- Having a thorough understanding of alarm set points and response to alarms (including any required investigation requirements)

Having concluded use of the White Paper 5 step process in the scenario of Chlorine Dioxide, it is important that one would summarize the process outcome for stakeholder communication and transparency.

Application Summary: Pulp Mill Chlorine Dioxide Monitoring

The initial statement of purpose was to have appropriate ClO_2 fixed and portable gas detection equipment with appropriate alarm setpoints that would be fit for purpose.

In this examination the low regulatory limits present difficulties in both equipment selection (limit of detection and measurement resolution) as well as alarm setpoint determination in light of sensor abilities and the need to avoid spurious alarms considering environmental conditions that may be present. Referencing and more specifically selecting the historic TWAEL and STEL for application is difficult but can accommodate the statement of purpose and objectives; whereas current technology would have great difficulty being 'fit for purpose' using the 2018 ACGIH 0.1 ppm ceiling limit.

For the occasion of ClO_2 use, greater consideration needs to be made for portable gas detection equipment than fixed gas detection equipment due to the variability in environmental conditions that can be found at the process facility and the use of instantaneous alarms on portable monitors.

The examination identifies that for fixed and portable ClO_2 monitor use with a general workforce that follows a 4 on – 4 off work 12-hour shift schedule:

FIXED MONITORS

- Equipment with local display having the ability to provide 0.01 or 0.02 ppm resolution within a range of 0 to 2 ppm would be preferred.
- Equipment with multiple instantaneous alarm setpoints has the ability to provide increasing alerting abilities to both control room operators and area notification (visual alerts/colored beacons, followed by colored or signaling beacons and audible alarms at selected concentrations).
- If possible, the instantaneous alarm setpoints for these units would be configured for:
  - Pre-alarm/low 0.3 ppm (set at the STEL) VISUAL NOTIFICATION
  - Main alarm/high 0.5 ppm AUDIBLE / VISUAL NOTIFICATION

Having a STEL of 0.3 ppm allows users to be warned of increased gas concentrations and have the ability to leave the area. As noted, it is common practice in pulp mill environments to don an escape respirator in the event of alarm conditions and notification at the STEL and egress, rather than allow unprotected workers 15 minutes of exposure.

- Fixed monitors can be regularly calibrated (e.g., monthly) with the use of a ClO_2 gas generator.

PORTABLE MONITORS

- Equipment with local display having the ability to provide 0.01 or 0.02 ppm resolution within a range of 0 to 2 ppm would be preferred (also acceptable would be monitors with a range of 0 to 1 ppm).
- Given the environmental conditions faced caution is warranted when setting the pre-alarm/low

instantaneous alarm to avoid spurious alarms because of humidity effects. If possible, the alarm set points for portable units would be configured for a maximum of 5 times the TWA which would include the adjusted TLV (for the purpose of this discussion considered to be 0.05 ppm for a 12-hour shift exposure):

- Pre-alarm/low 0.20 ppm (set below the adjusted TWA)
- Main alarm/high 0.25 ppm
- TWA alarm 0.05 to 0.20 ppm*
- STEL alarm 0.15 ppm

*The selection of a TWA is difficult as this is the limit of detection for many available monitors.

- Regular calibration of the portable monitors may be feasible using a ClO_2 gas generator however daily operational checks may best be carried out using chlorine gas through a docking station. The actual level would need to exceed the pre-alarm/low and main alarm/high value to ensure operation of the monitors visual/audible/vibration alarm (if equipped). This would require using an equivalent ClO_2 concentration employing a chlorine (Cl_2) calibration gas at a minimum concentration based on the manufacturer's cross-sensitivity data (e.g., 2 ppm Cl_2 calibration gas cylinder using a 60% sensitivity would be equivalent to a 1.2 ppm ClO_2 reading).

Key in the application of the identified instruments and the determined alarm set points is worker understanding of interferences and sensor operating issues:

- cross-sensitivities resulting in false or spurious alarms
- RH and T changes and implication to readings (both positive and negative effects in the sensor readings)

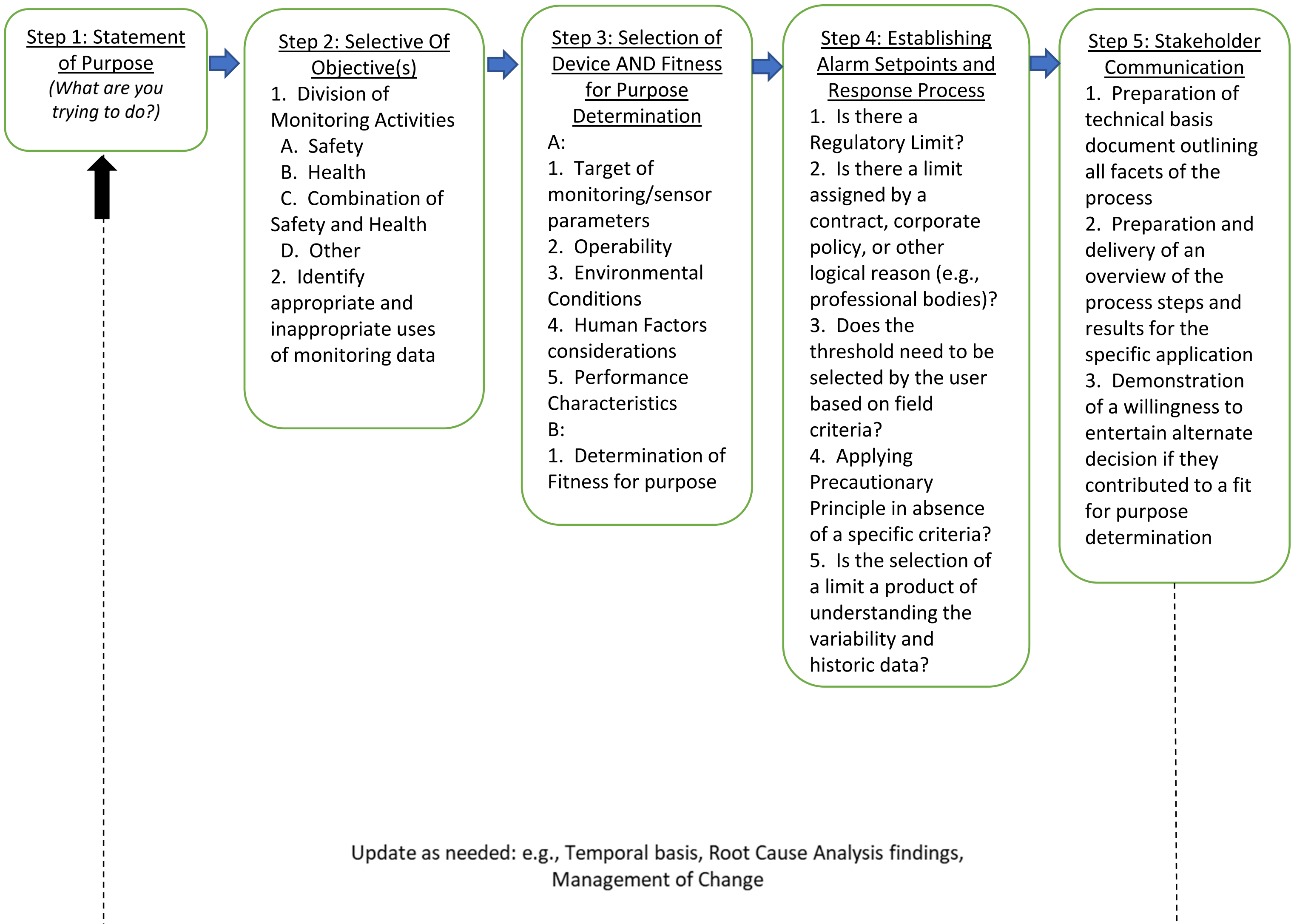

Figure 4: Summary of Steps in Proposed Alarm Settings Framework

4.0 CASE STUDY (CS): Testing of the Alarm Setting Framework- Low- Cost Sensor- Based Building Management System for Covid-19 Risk Mitigation Using Ventilation Control

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In this Case Study (CS) the robustness and technical applicability of the Alarm Setting Framework approach was tested by applying the 5 Step Process to develop the alarm settings for a pilot scale Building Management System (BMS) to provide risk mitigation for COVID-19 through ventilation control. It is important to note that the 5 Step Process was applied, without any reference to any of the examples used above. As such this is an example of applying the scientific method to the testing of the applicability of the Alarm Setting Process [Gauch Jr and Gauch 2003; 2021i; 2021c; Smith 2021]. It was found that the proposed Alarm Setting Framework worked well for this case study.

A Building Control System (BCS) (BCS-1) located in in the Building Ergonomics, Energy Efficiency, Ergonomics and Management (BEEEAM) Laboratory at Northern Illinois University (NIU) has been described previously [Martin and Mills 2017] (Figure 5). The BCS-1 was primarily focused on control logic; the system was not meant to be able to fully heat or cool the full BEEEAM laboratory space, but rather to control the components in response to the sensor inputs. While the BEEEAM BCS-1 is a general model for central heating, ventilation, and air conditioning (HVAC), the control system could be applied to other HVAC types (e.g., radiant heat and wall air conditioning) provided they also include a capability to bring in outside air at a variable rate. .In the period since the BCS-1 was first built there have been improvements in the performance of the RPi microcomputers (e.g., RPi 3 and 4 and 400) and increases in the number of sensors available, many of which have additional capabilities and/or lower costs.

A number of upgrades were made to BCS-1 to address COVID-19 mitigation with ventilation. The upgraded BCS-1 is referred to as the NIU BEEEAM Indoor Environmental Quality Monitor (IEQM) + Management System (MS) 2.0 or Building Management System (BMS-2.0) with the schematic shown in Figure 6. Both Rpi 3 and 4 models were tested with the various sensors; however, for standardization purposes all RPi units used for actual operations are RPi Model 4. The BMS-2 has additional management functionality for data logging and managing the cleaner and AC/heater operation compared to the BCS-1. The room monitor, with replacement sensors), formed the basis for the NIU BEEEAM Indoor Environmental Quality Monitor (IEQM), which has additional light and noise sensors [Bikun 2022] [2021a].

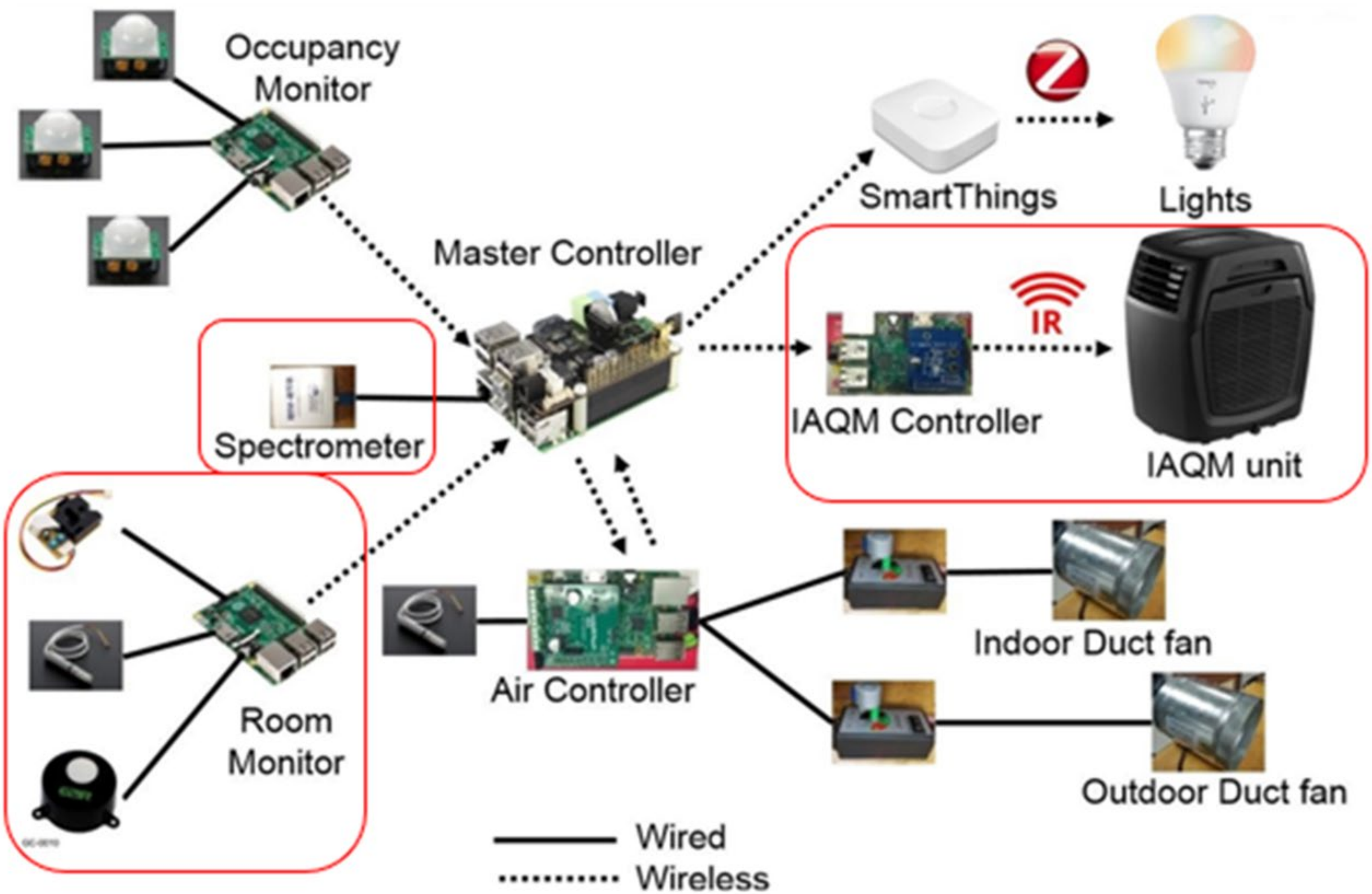


Figure 5: BCS-1 schematic [Martin & Mills, 2017]. Red outlined components were changed/upgraded in BMS-2

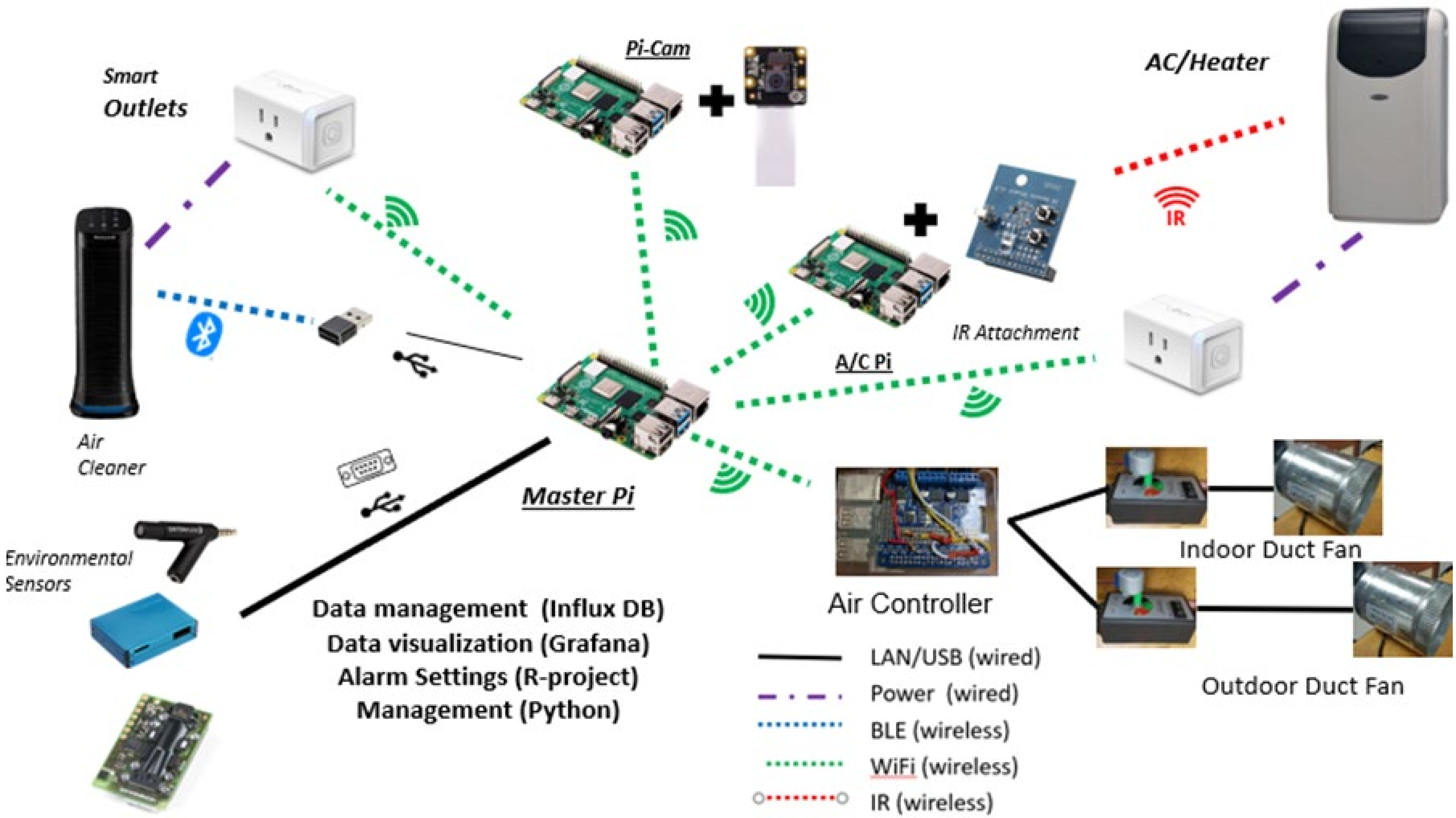


Figure 6: NIU BEEEAM BMS-2. This system, minus red elliptical (lab based) was implemented in a real-world space with notification

4.1 Applying the Alarm Setting Process

The Alarm Settings process outlined in Table I was applied to develop setpoints for control of operation of the HEPA and heating/cooling and notification of system operation to provide for "good "ventilation in a space for COVID-19 prevention. These activities collectively referred to here as "alarm settings".

4.1.1 Step 1: Statement of Purpose (of Monitoring)

The purpose (or aim) of the BMS monitoring systems were stated as:

The NIU BEEEAM BMS-2 will be used to:

1) monitor IEQM parameters, including certain indoor air quality (IAQ) parameters,
2) control HVAC components in response to these parameters, and
3) provide for optimization of energy use, without adversely impacting the IAQ.

4.1.2 Step 2: Selection of Objective(s)

As noted previously, objectives are related to but different from the purpose(s) of the monitoring. The objective(s) are useful to describe (or determine in part) how the purpose(s) in STEP 1 of the process will be achieved.

STEP 2.1: Referring to the 4 types of monitoring that are set out in Table III, for this CS, the type of monitoring can be considered "Other (Activity D)", as no specific parameters related to an OEL are being monitored. Instead, the control of the IAQ to provide "good ventilation" is subject to the framework objective; however, it recognized that there are clearly related health implications from the monitoring. In particular these are for aerosols (PM) regarding respiratory aerosols (for possible Covid-19 transmission) [de Mesquita, Delp et al. ; Stabile, Luca, Dell'Isola et al. 2016; Bazant and Bush 2021; Good, Fedak et al. 2021; Stabile, L., Pacitto et al. 2021; Wang, Prather et al. 2021] and CO_2 regarding cognitive and physiological impacts [Shendell, Prill et al. 2004; Fisk, W., Wargocki et al. 2019; Villanueva, Notario et al. 2021].

STEP 2.2: In this step we considered the major factors that determine whether there is "good" ventilation in a space from general dilution ventilation, which is what typical HVAC systems are concerned with. The ventilation in a space can be described by four general terms:

i) total air flow rate (which can be expressed in terms of a) air changes per hour (ACH) in a space [Qian and Zheng 2018] or b) air volume supplied per person per time, based on occupancy of a space) (e.g., total recirculated + outside air (OA)) [Dajose 2021],
ii) the amount of OA (which may not be directly related to the ACH),
iii) air flow patterns in the space [Liu, H., He et al. 2021] [Li, Qian et al. 2021; Liu, H., He et al. 2021], and
iv) thermal patterns in the space, including possible thermal lock-up[Qian and Zheng 2018; Villafruela, Olmedo et al. 2019; Liu, F., Qian et al. 2020].

STEP 2.3: An important part of the Step 2.3 is to determine what parameters to monitor in order to meet the purpose stated in STEP 1. Several IAQ parameters can provide an indication of ventilation related issues. Since COVID-19 is transmitted via respiratory aerosols, an obvious parameter to study is the buildup of aerosols in a space which could come from respiratory aerosols or other sources. Another parameter that is especially good for dilution ventilation assessment is CO_2, since CO_2 is produced from human respiration [Scheff, Paulius et al. 2000]. Temperature (T), which can come from body heat (or equipment operation) in poorly ventilated spaces is an IEQ parameter but is related to ventilation rate since inadequate ventilation can result in elevated T. RH, another IEQ parameter which can be related to occupancy in a space, can also affect the measurement of aerosols.

In the case of this CS the specific parameters that were identified to be monitored are:

i) aerosols (as PM concentration or Particle Counts (PC))

ii) CO_2

iii) Temperature (T)

iv) RH

STEP 2.4: *Alarm Setting Factor Considerations (Table II).* The factors set out in Table II were evaluated in Step 2.4

1. *Whether detectors should be fixed and/or whether personnel should be issued with portable, which includes personal, detectors:* The detectors used will be fixed initially.
2. *The location of the fixed detector and whether the work area is occupied or unoccupied:* The fixed detector will be in a single location (as near to the center of spaces as possible). The area will be occupied on an intermittent basis.
3. *Whether the fixed detector is a point or open-path (also known as beam or line of sight) detector:* The fixed detectors are all point detectors.
4. *Whether egress is difficult and/or time-consuming or there is an emergency:* The issue of egress was not considered an issue as all spaces were easily accessible.
5. *Whether WELs (HSE), other Exposure Limit values or other health-based levels (e.g. IDLH) exist:* Possible limits that might apply to the parameters PM, CO_2, T and RH include general IAQ-related recommendations for comfort [Idph 2021]. Both PM and CO_2 have available operational limits and OELs, but such values are much higher and inappropriate in demonstration of control for dilution ventilation in non-industrial environments.
6. *Instantaneous or TWA alarm:* The IDLH values for PM and CO_2 are several orders of magnitude above expected levels, so instantaneous alarms are not expected to be needed. Various averaging times will be investigated to determine an optimum alarm set point in terms of sensitivity and decision making.
7. *Background variations and events from the process, which may trigger "spurious" alarms:* Variation in the ventilation process is exactly what is being monitored and is the basis for control. The alarm set point is to trigger control AND to determine if control is working acceptably. The biggest source of background variations are expected to be caused by occupancy, or from cleaning operations. It was recognized that there may be an impact from local ambient air quality, and as a result, the indoor/outdoor ratios had to be considered.

8. *False alarms caused by instrumental effects and interferent gases, which may also be classified as spurious:* False alarms caused by instrumental effects and interferent gases are not expected to be an issue.
9. *Time to alarm of the detection system:* Time to alarm for the detection system is a function of averaging time and change in a parameter. Another issue that come into play on this item, is how long it takes for the space to respond to ventilation operational changes after control signals are sent from the BMS-2.
10. *Number of alarm levels (e.g., high and low levels):* There will be several alarm levels based on short and long term levels for the parameters, and how high they rise above setpoints.
11. *Mixture of gases/vapors:* There are no conditions expected to include a mixture of gases other than the major components of air (e.g., N_2, O_2, CO_2).
12. *Whether the fixed detector is a diffusion type or a pumped type (also known as sample draw) detector:* The aerosol sensors are fed by a small fan driving aerosol across a sensing cell, while the CO_2, T and RH are diffusion-based sensors.
13. *Whether the monitoring area is in a hazardous or permit required location (which may introduce additional alarm setting constraints):* The monitoring area is not hazardous.
14. *Whether the RTDS is able to communicate real-time alarms to other individuals (e.g., wireless communication between confined space entrants and attendants):* The RTDS will be able to communicate real-time alarms via wireless (Wi-Fi) and wired connection (ethernet).
15. *Whether RTDS results will be used to coordinate off-site response or third-party rescue:* This consideration is not applicable.
16. *Whether RTDS results will be used for instantaneous (Peak or Ceiling) or time history (STEL or TWA) alarms:* Both instantaneous and time averaged data were evaluated against IEQ limits.
17. *Whether background variations and events from the process can trigger "spurious" alarms:* This is not expected to be an issue.
18. *Environmental conditions that may exceed the design or certification limits of the RTDS (e.g., T, pressure and humidity):* This is not expected to be an issue since the environmental conditions are being controlled by the IEQM.
19. *Background conditions that can affect the proper performance of the sensors, (e.g., Lack of oxygen due to natural or deliberate vessel inertion procedures):* This is deemed not applicable.
20. *Environmental conditions that can affect the user from knowing when an alarm occurs (e.g., high noise):* Noise in the area was considered and concluded to be a possible issue, which will require more than just auditory notification.
21. *Activities that introduce additional hazards, (e.g., hot work):* None anticipated.
22. *Other external or internal factors that may affect or prevent the RTDS from activating the appropriate alarms:* The largest potential factor was loss of power to the BMS-2.

STEP 2.5: *Identify potential systematic failures.* A non-exhaustive list of potential system failures that were identified include:

- Power failure(s) for monitoring or control parts of BMS
- Failure of data logging for sensor after power failure
- Sensor failure to communicate
- Interferences with sensors (especially RH on aerosol sensor, persons breathing directly on CO_2 sensor)
- Communication failures between sensors and RPi
- Communication failures between monitoring and control RPis
- Communication failures between RPi and Engineering Controls (e.g., HEPA unit, AC/heater)
- Failure in alarm alerts
- Corruption in database(s)
- Failures in data analysis and alarm level calculations
- Inappropriate or non-representative fixed sensor location
- Control system activates, but engineering control does not respond in the expected manner or direction (e.g., heats up when the direction was to cool down)
- Loss of monitoring data

STEP 2.6: *Limitations on the use of the data.* The IEQ monitoring data is not for regulatory compliance purposes. The spatial representativeness of the monitoring data will be limited by only having one sensor per location. The use of open-source software (vs proprietary) for data management and control may be a limitation but could also be a benefit.

STEP 2.7: *What is an alarm and how it will be responded to.* The general levels of measurements for each of the parameters that were contemplated are listed below.

1. Background levels, defined by unoccupied spaces. No response required
2. Normal (occupied and ventilation sufficient). Review on ongoing basis, no immediate response required
3. Normal, elevated (occupied, ventilation insufficient.) Notification.
4. Elevated (ventilation inadequate). Notification, with higher level of warning
5. Unacceptable (ventilation failure condition). Notification, exit from space if necessary

In addition to a specific current level, the trend for a parameter will be analyzed in terms of direction and magnitude. The actual alarm levels and methods for notification will be discussed in STEP 4 below.

One advantage of the BMS-2 is that it has the ability (with proper programming) to learn from prior monitoring results and control responses.

4.1.3 Step 3 Selection of Devices

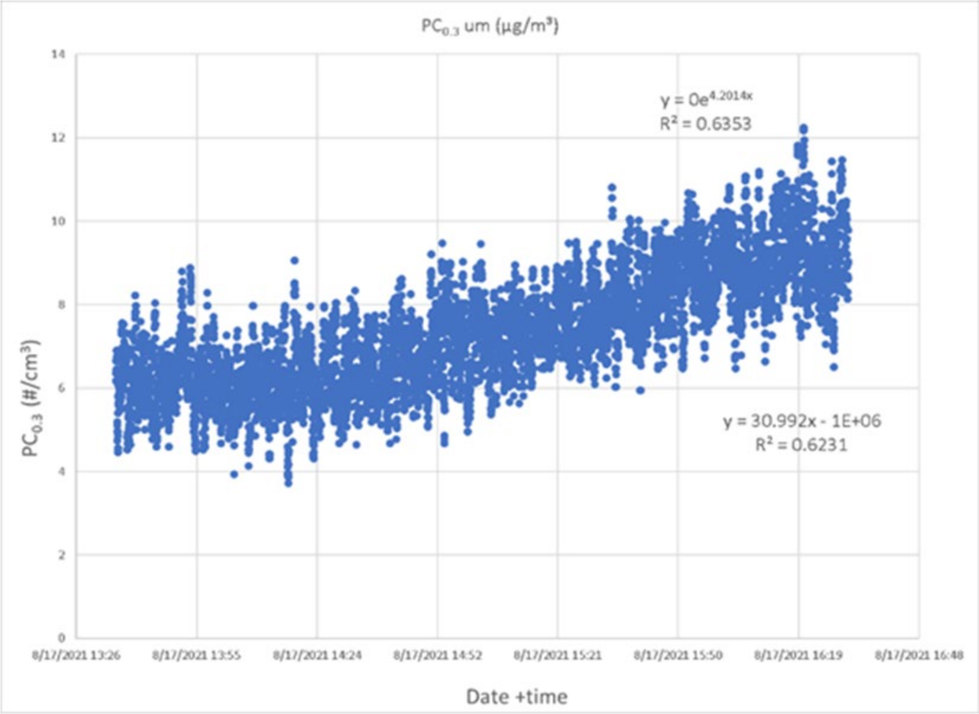
In the process Step 3, the system to be used is selected, this includes the selection of the devices (sensors) and an evaluation of their fitness for purpose. For the CS, this included an evaluation of the BCS-1 and replacement of certain components. This will be discussed in terms of the parameters for monitoring and alarms.

Aerosol sensor(s): As discussed above, Covid-19 is transmitted by respiratory aerosols. While the SARS-CoV-2 virus is approximately 0.14 um in diameter [Zhu, Zhang et al. 2020], it is rarely, if ever in aerosol form on its own, but rather it is associated with the respiratory aerosols with saliva, mucus and associated salts and proteins [Nazarenko 2020]. Aerosol concentrations can be expressed on two bases, particulate mass (PM) expressed as mass/volume and particle concentration (PC) (sometimes also referred to as particulate number (PN) expressed as particulate number/volume. On a mass basis, particulate mass for the 2.5 um ($PM_{2.5}$) fraction can dominate even if PC for lower fractions are higher, due to the mass vs. volume relationship. Research measurements have indicated that respiratory aerosols have a multimodal distribution, and that on PC (e.g. number) basis the majority of exhaled aerosols are <5.0 um and a large fraction are <1.0 um [Wang, Prather et al. 2021]. Work in the BEEEAM lab and many others has shown respiratory aerosols can be measured using real-time methods based on light scattering including photometric (nephelometry), optical particle counter (OPC) and condensation particle counter (CPC) based instruments.

Based on literature reviews [Alfano, Barretta et al. 2020] and our evaluation in the BEEEAM laboratory, sensors from Plantower (models 5003 and 7003) [Kelly, Whitaker et al. 2017; Kuula, Makela et al. 2020; Vogt, Schneider et al. 2021] and Sensirion (Model SPS30)[Vogt, Schneider et al. 2021] [Hong, Le et al. 2021] [Kuula, Makela et al. 2020; 2021e; 2021g; deSouza, Oriama et al. 2021; Vogt, Schneider et al. 2021] were identified to replace the Grove PM sensor in the BCS-1. These sensors have been found to behave very similarly to each other [SCAQMD 2022] and are used interchangeably in the BMS-2. The Plantower 7003 is used in the TSI Qtrak XP , the Plantower 5003 is used in Purple Air commercial sensors while the Sensirion SPS30 is used in the TSI AirAssure units. Both sensors are optical particle counter (OPC) technology, that provide PC (#/volume) for 6 size ranges (bins) and can estimate a PM concentration for each bin size based on a assumed PM density. The assumed density is the largest contributor to the overall uncertainty in PM concentration. Debia [Debia, Trachy-Bourget et al. 2017] have advocated for the use of Particle Number Concentration (PNC) as better parameter for indoor air studies RTDS than $PM_{2.5}$. Figure 7 compares PC0.3 vs $PM_{2.5}$ over the course of 2 hour+ meeting in a large lecture hall with reduced occupancy (<30 in a room rated for 100+) and all attendees were required to wear masks, but no HEPA filtration was being used. It can be seen that the PC0.3 data is less noisy and a provides clearer trend in the buildup of respiratory aerosols. .Based on the above, the Plantower and Sensirion aerosol sensors are considered to be "fit for purpose" for their intended use to monitor for respiratory aerosols.

CO_2, T and RH sensors: In the BCS-1, the initial CO_2 and T/RH sensors were separate, relatively large and expensive. Since then a single, smaller, less expensive and more accurate sensor, the Sensirion SCD30 has become available [Leo-Ramírez, Tabuenca et al. 2021]. In verification testing (not shown) In verification testing (not shown) good agreement of CO_2, T and RH with a TSI-Quest EVM-7 reference unit (unpublished data) was shown. Based on the literature testing and our own evaluation, this sensor was considered "fit for purpose" for use in the intended operations to monitor for CO_2, T and RH.

a)



b)

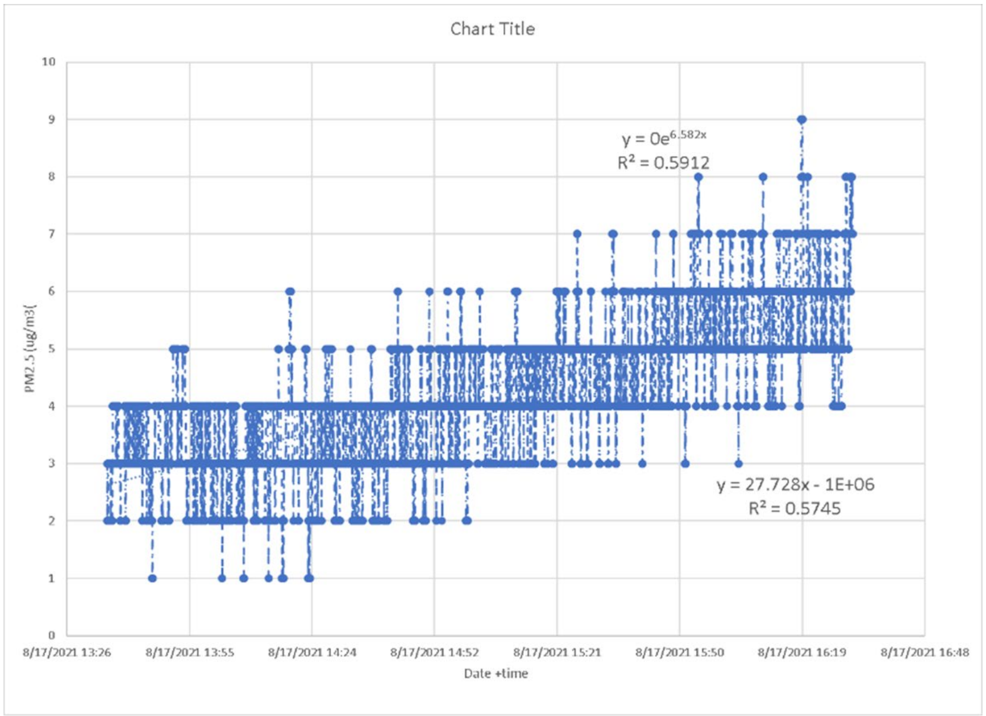


Figure 7: Plots of a) (Top) PC0.3 and b) bottom PM2.5 in a space at NIU during a 2+ hr. meeting with all attendees wearing masks, no HEPA filtration

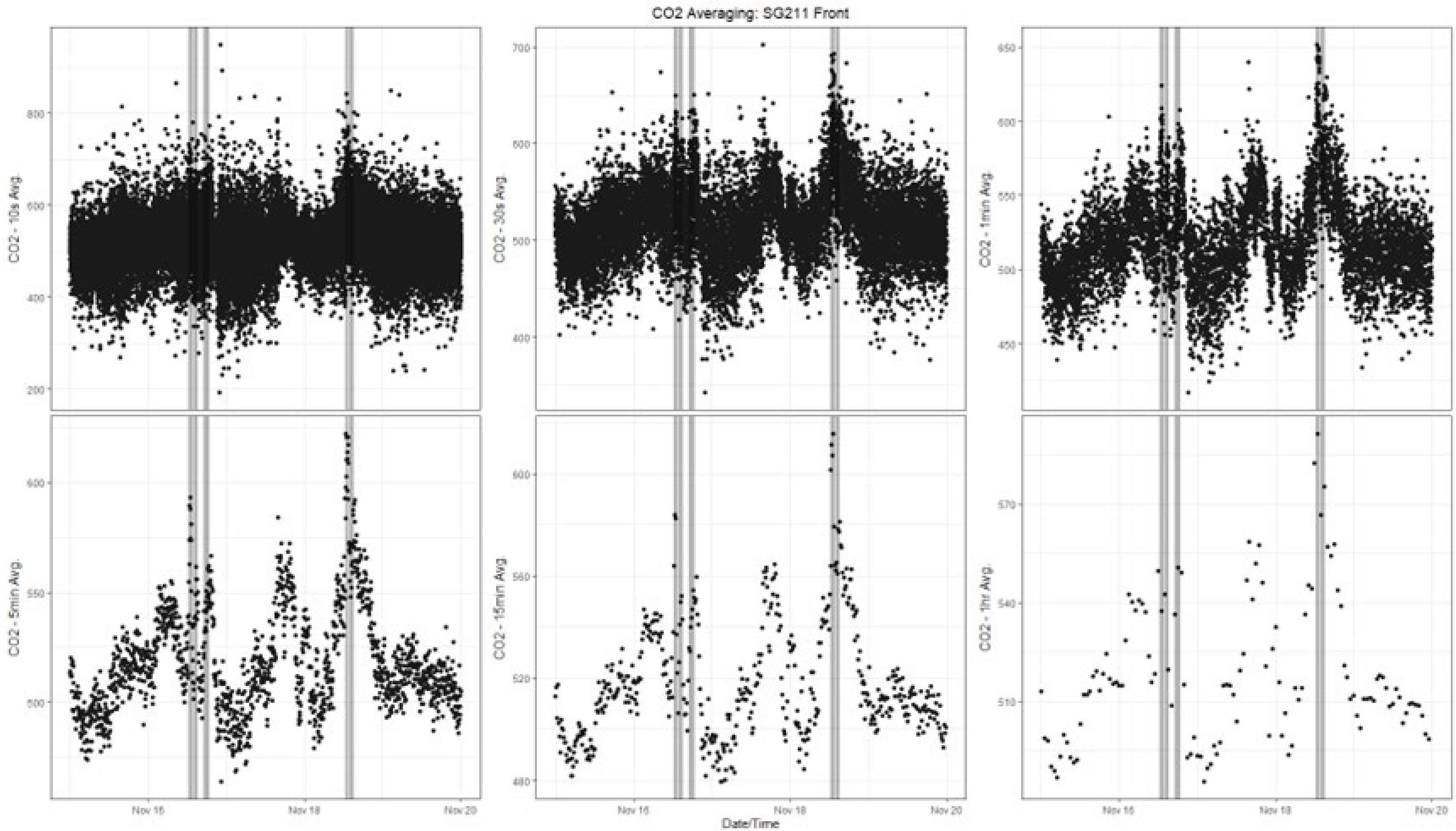


Figure 8: NIU IEQM CO_2 data with effect of averaging time (from upper left, clockwise-10 s, 30s, 1 mi, 5 min, 15 min, and 60 min)

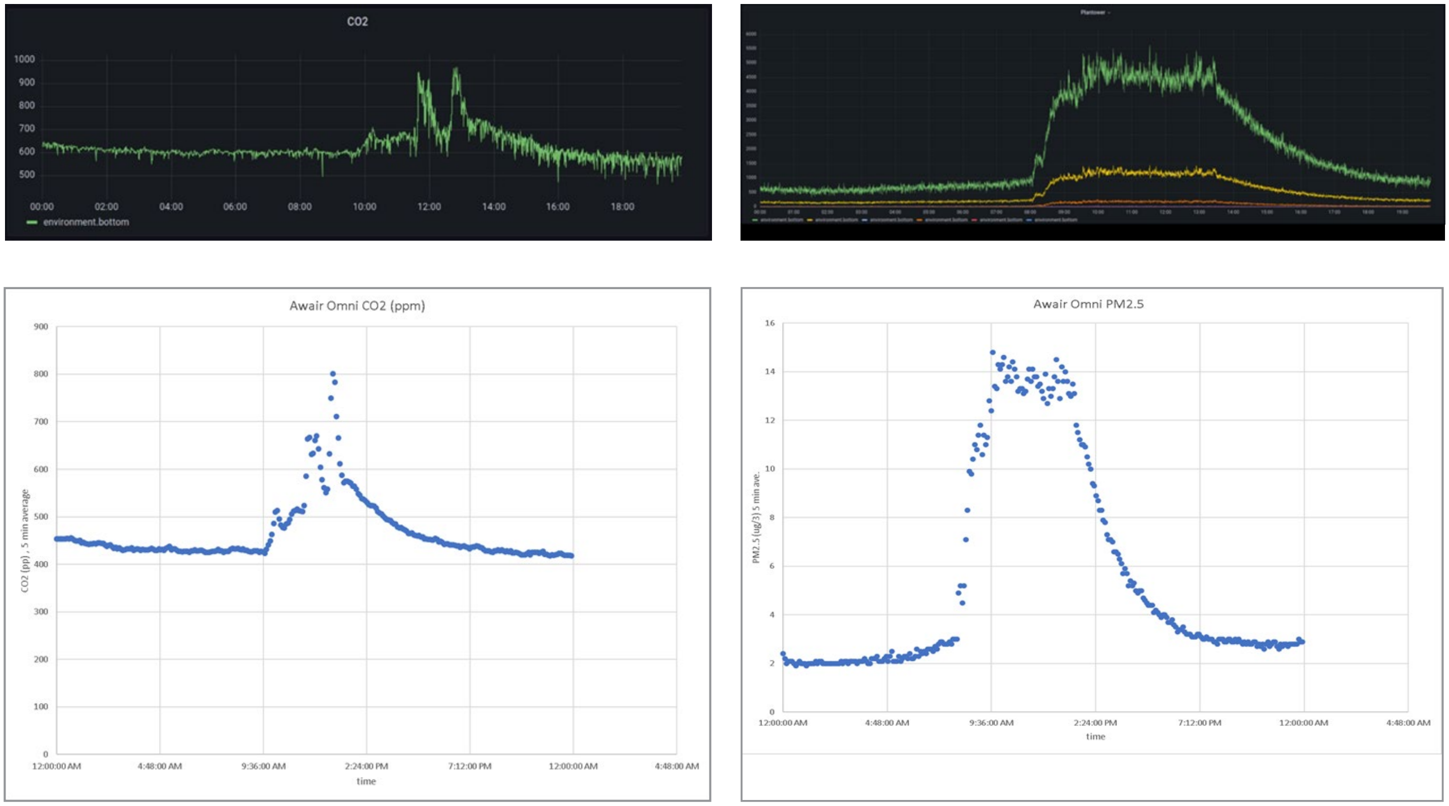


Figure 9: IEQM CO_2 and PC0.3 vs Awair Omni CO_2 and PM2.5 for in a space at NIU

The sensors are interfaced to an RPi where the data is logged into a InfluxDBtm a time series database[2021d], with Grafana dashboard [2021b] used for data display and plotting. In Figure 8 the effect of averaging time for the CO_2 data was evaluated for 10s up to 60 minutes. Based on this comparison 5 minute averaging times was determined to be optimum as it was less noisy than shorter averaging times, while still showing an acceptable response to changes in CO_2 concentrations.

Figure 9 contains the CO_2 and PC0.3 data from the IEQM and a commercially available system (Awair Omni) in the NIU BEEEAM laboratory during an open house event on February 26, 2022. This space was visited by several groups, but noticeable were two groups of 15-20 people each. There was no ventilation system running during this time but face masks were required. It can be seen in this Figure that the PC0.3 is more sensitive (than the $PM_{2.5}$).

Additional sensors, beyond those described here have been evaluated and utilized, including the IMM-6 microphone, nanolambda np-32V1 and XL-50 spectrometers, ams Osram TSL2951 light sensor and the NoIR camera, but are not discussed further.

4.1.4 Step 4 Establishing Alarm Setpoint and Response Process

In Section 3.1 a series of questions to be address were proposed. For this CS, this process is followed below.

Step 4.1 *Is there a regulatory limit?*: For CO_2, there is an OSHAPEL of 5000 ppm (8 h TWA) Both NIOSH and ACGIH have a STEL of 30000 ppm [OSHA 2019a]. For PM(total) there is a OSHA limit of 15 mg/m^3 (TWA) and for Respirable Particulate (RP) there is an OSHA limit of 5 mg/m^3 [OSHA 2019b]. There is no specific regulatory limit for T and RH, however the Illinois Department of Public Health (IDPH) does have IAQ Guidelines for CO_2, $PM_{2.5}$, T and RH [Idph 2021] .

Step 4.2 *Is there a limit a limit assigned by contract, corporate policy, or other logical reason?* No limits were identified from this question.

Step 4.3 *Does the threshold need to be selected by the user based on field criteria?* To some extent this can apply based on the field measurements, see question 5 below for further discussion.

Step 4.4 *How may we implement the Precautionary Principle* when nothing else exists for guidance on establishing a criterion level?* For these parameters the Precautionary Principle was not considered to apply.

Step 4.5 *Is the selection of a limit a product of understanding the variability and historic data?* This was considered to be the most relevant question for Alarm Setting for this CS. Further discussion of the Alarm settings for each of the parameters is provided below.

4.1.4.1 CO_2 Alarm Setpoints

There are several aspects to the Alarm Settings for CO_2 that need to be stated. CO_2 is produced from human activities, and will build up in a space, depending upon the ventilation rate, room volume, occupancy and activity type. For this CS there are three main CO_2 concentration regimes:i) CO_2 levels as an indicator of adequate dilution ventilation for risk reduction for spaces where no air cleaning is taking place, ii) CO_2 levels in spaces where there is additional air cleaning taking place, and iii) CO_2 levels for optimum human performance (academic or workplace). Based on the literature, levels of CO_2 that are above the 700-800 ppm range are indicative of inadequate dilution ventilation in general, where no air cleaners are being used[Cdc 2021a]. Even with air cleaners, levels above this are indicative of inadequate OA delivery into the space. The scientific literature indicates clear negative impacts of CO_2 on human performance and health at levels as low as 1000 ppm [Shendell, Prill et al. 2004; Satish, Usha, Mendell et al. 2012a; Fisk, W.J. 2017; Jacobson, Kler et al. 2019], much lower than the current OSHA OEL of 5000 ppm.

The levels for CO_2 Alarm Settings were organized into the following concentration related tiers:

1. Background levels (typically <450 ppm)
2. Normal-acceptable. (400-600 ppm)
3. Normal-elevated (600-750 ppm)
4. Alert (>800 ppm)
5. Caution (>1000 ppm)

6. Warning (>2000 ppm)
7. Exceedance (>5000 ppm, TWA)

The Alarm Settings for CO_2 are summarized in Table IX

4.1.4.2 PM Alarm Set Points

For PM, the primary parameter used for setpoint is $PM_{2.5}$. Similar to CO_2, PM2.5 has two uses; one is that it provides a general indication of the adequacy of dilution ventilation in a space and the second is that there are health effects related to increased $PM_{2.5}$, even if Covid-19 was not an issue. In addition to $PM_{2.5}$, the aerosol sensors being used provide size selective particle data in several size ranges or "bins". There are currently no regulatory limits for indoor air for the general public. The OSHA PEL for respirable particulates (5000 mg/m^3) does not represent the most current science. The US EPA has developed the Air Quality Index (AQI), based on health risks associated with $PM_{2.5}$ [Epa 2022]. Health Canada current guidance is that $PM_{2.5}$ levels indoors should be kept as low as possible and should not be higher than OA. Based on this, the 24-hour averaged $PM_{2.5}$, concentrations set out in the EPA AQI were adopted as alarm setpoints for the $PM_{2.5}$. The PC0.3 was used as an additional setpoint, using the buildup rate and actual number as compared to "background" (unoccupied) values the alarm setpoints for PM are summarized in Table X.

4.1.4.3 T Alarm Settings

The use of T as a mitigation strategy for Covid-19, is not feasible since T higher than 60 deg. C are needed inactivate SARS-CoV-2 in a timely manner [Wu, Zheng et al. 2020; Auerswald, Yann et al. 2021]. Thus, T is a comfort parameter for occupants of a space The T settings used for BMS-2 are shown in Table X.

4.1.4.4 RH Alarm Settings

While RH has impacts on the stability of Covid-19 and infectious disease aerosol transmission [Aboubakr, Sharafeldin et al. 2020; Biryukov, Boydston et al. 2020; Sarkodie and Owusu 2020; Božič and Kanduč 2021], it's control can be problematic. The Plantower and Sensirion PM sensors have been found to have a high bias for elevated RH, compared to a reference value. RH was not used as an alarm setting but rather was monitored so it could used to either correct for, or at least flag values where RH might be impacting the sensor performance.

4.1.5 Step 5 Declaration of Decision

The preparation of the documentation of the process steps 1-4 above is the final step in the process. In the case of the CS this was not the end of the process. An MS Thesis (Bikun, 2022) is being prepared and presentations of the Alarm Settings and the IEQM findings have been made to several meetings of faculty at NIU and scientific meetings. In practice, at an actual facility it would be expected that these Alarm Settings would be documented and discussed with a project team to make sure there is an understanding of what the set points are and how they will be implemented, including operating staff and in any BMS.

TABLE IX: CO_2 Alarm Settings For CS

CO_2 (ppm)	Alarm Level	Averaging time(s)	BMS (Alarm) Notification(s)	BMS Control Action(s)	References
<500	Outdoor background	5 min 8 h	1X daily, email to general contact list	None	
<600	Normal, acceptable	5 min 8 h	1x daily, email	HEPA running during occupied periods 0800-1800 hrs.	[Fisk, W.J. 2017]
>800	Alert	5 min 8 h	Email after 1st 10 min at > Alert level 2nd email after 30 minutes at alert concentration	HEPA running during occupied periods 0800-1800 hrs. Increase HEPA filtration rate. Increase OA to Level 2	[Cdc 2021b]
>1000	Caution	5 min 8 h	Email and text messaging to primary contact(s) after 10 min at >1000 ppm Email notification to building services contact	HEPA running during occupied periods 0800-1800 hrs. Increase HEPA filtration rate. Increase OA to Level 2	[Satish, U., Mendell et al. 2012b; Fisk, W.J. 2017; 2021j; Avella, Gupta et al. 2021; Idph 2021; Villanueva, Notario et al. 2021]
>2000	Warning	5 min 8 h	Email and text messaging to primary contact(s) after 10 min. Text Messaging added after 30 minutes, continuing until acknowledged Email notification to building services contact	Increase HEPA filtration rate Increase OA to Level 3 Notification of building services Consult with physical plant or HVAC expert	[Curtius, Granzin et al. 2020; 2021j]
5000	Exceedance	5 min 8 h	Email and text messaging to primary contact(s) after 10 min at Email notification to building services contact	No reoccupancy if >5000 ppm	[OSHA 2019b]

TABLE X: Alarm Settings For PM Sensor(s)

$PM_{2.5}$ (ug/m^3)* range	AQI Category	AQI	PM 0.3 (counts/ cm^3)	Alarm Level	Averaging time(s)	Notification(s)	Actions	References
0-12.0	Good	0-50	TBD Differs for each space and class	Unimpacted, background Normal low	5 min 24 h	none	none	[Epa 2022]
12.1-35.4	Moderate	51-100	TBD	Urban background Normal	5 min 24 h	none	HEPA on low	[Epa 2022]
35.5-55.4	Unhealthy for Sensitive	101-150	TBD	Elevated	5 min 24 h	Email @ 15-minute intervals	if >25 ug/m^3 in 5 min, turn on HEPA on medium	[Epa 2022]
55.5-150.4	Unhealthy	151-200	TBD	Alert Urban impacted	5 min 24 h	Email @5-minute intervals until <55	Keep HEPA on to High	[Epa 2022]
>150.5	Very Unhealthy	201-300	TBD	Warning Normal , elevated	5 min 24 h	Email and SMS text messages @5 min. intervals	Keep HEPA on high	[Epa 2022]

TBD: to be determined

*$PM_{2.5}$ based on 24 h average

TABLE XI : T Alarm Settings

Tmin (deg F)	Tmax (deg F)	Alarm Level	Averaging time(s)	Notification(s)	Actions	References
	<60	Too Low	5 min 24 h		Turn heat on Suspend operations or wear coats, until min 60 deg F reached	
60	68	Low	5 min 24 h		Turn Heat on	
69	75	Normal range, Winter	5 min 24 h		None for Heat	[Idph 2021]
7	79	Normal range Summer	5 min 24 h		None for AC	[Idph 2021]
80	<90	Warning	5 min 24 h		Increase AC if possible	
>90 deg. F		Too High, Exceedance	5 min, 8 h		Suspend operations until T <90 deg. F	

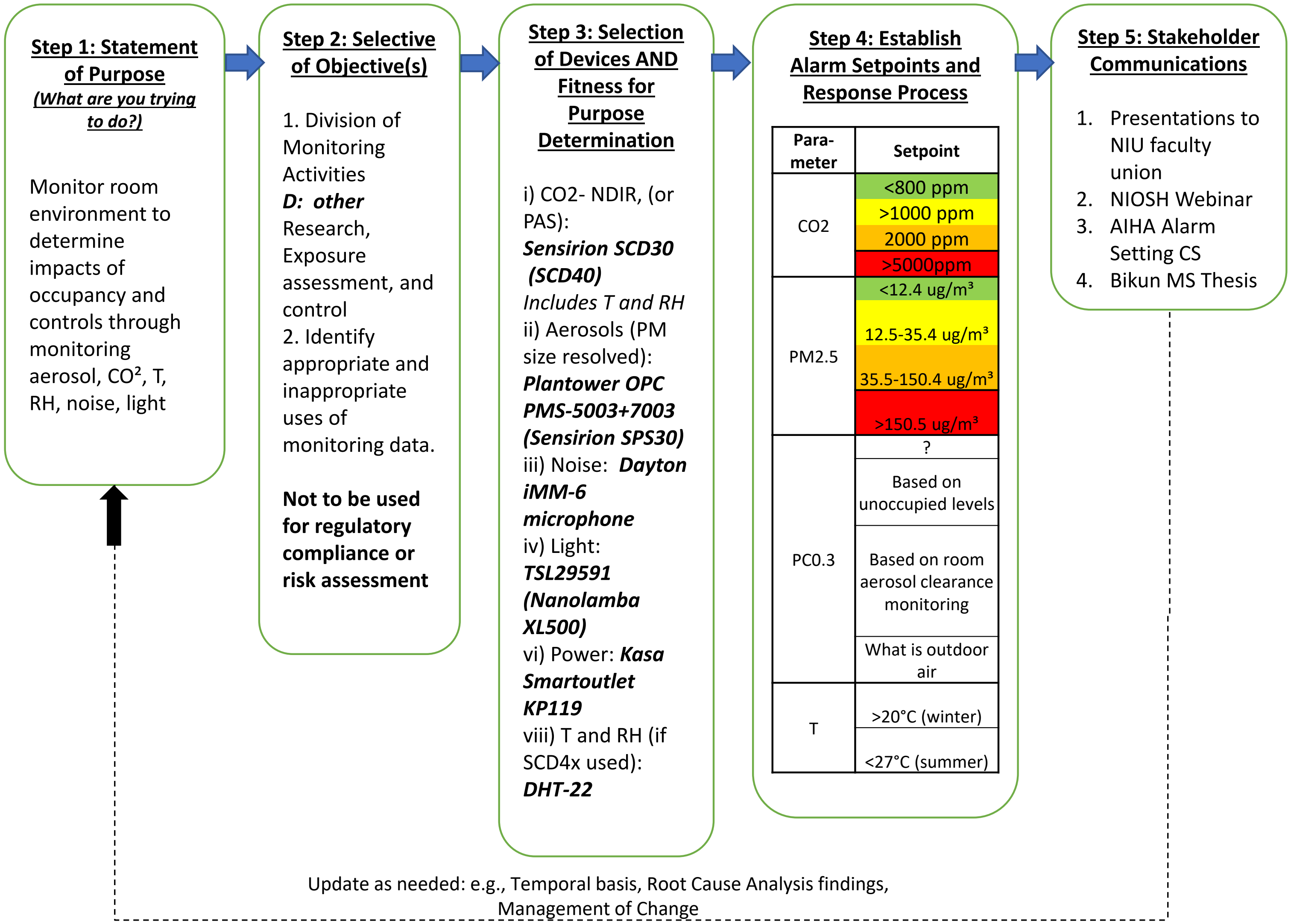


Figure 10: Completed Alarm Settings for CS

4.2 CS Conclusions

This case study discussed the application of the proposed process to alarm setting for ventilation control for COVID-19 risk mitigation using the BMS-2. Following the Alarm Setting Process steps discussed did identify some issues with the initially proposed process. For example, the Statement of Purpose needs to come before the Statement of Objectives and needs to be more general and higher level. The alarm settings step helped identify the need for visual and auditory alarms to go along with the email and text message notifications, which was not anticipated as a clear need before going through this step. Another issue that the alarm setting step helped identify is the probable need for looking at 15-minute averaging (e.g., 3 X5 min average times) for making HVAC decisions especially for higher air changes per hour (ACH) values.

The are some limitations to the BMS-2 in this CS. First off BMS-2 is meant to be a proof-of- concept system, focusing more on management and control logic based upon the selection of sensor technologies. For example, the BMS-2 does not address air flow patterns and thermal lockup. In a full-scale system these could easily be addressed by using multiple sensors and/or additional types of sensors in a space.

Finally, the application of process worked well and demonstrated robustness that should make it widely applicable in the OEHS field. The type of independent testing that was done for this CS, is recommended for other AIHA documents/frameworks/projects.

5.0 SUMMARY AND CONCLUSIONS

The AIHA Real-Time Detection Systems Committee believes that the manner of setting instrument or system alarms has not received sufficient attention from the community of stakeholders.

This White Paper represents a first attempt to formalize a process that provides a comprehensive treatment of the subject. Overall, it can be seen that the process has similarities to the Plan Do Check Act (PDCA) cycle (see Table XII) [Asq 2021].

Practitioners are invited to use the process steps in their preparation and documentation of a transparent technical basis, and to provide improvements and constructive criticisms in the peer-reviewed literature.

TABLE XII: Comparison of PDCA [2021F] and Proposed Process

Process Step	Description	Section(s) in WHITE PAPER	Title/comment in WHITE PAPER	Comparison to PDCA
1	Determining Purpose	3.1	STEP 1 – Statement of Purpose	P
2	Determining/Selecting Objectives	3.2	STEP 2 – Selection of Objectives	P/D
3	Selection of Device	3.3 3.3.1 3.3.2 3.3.3 3.3.4 3.3.5	STEP 3 – Selection of Device(s) and Determination of Fitness for Purpose Consideration #1: Target of monitoring / sensor parameters Consideration #2: Operability Consideration #3: Environmental conditions Consideration #4: Human Factors Considerations in Device Selection and Alarm Parameters Determine Instrument Certification Requirements	D
4	Establishing Alarm Setpoint	3.4 3.4.1 3.4.2 3.4.3 3.4.4 3.4.5 3.4.6	STEP 4 – Establishing Alarm Setpoint and Response Process Ask first, "do we have a regulatory limit? Ask second, "do we have a limit assigned by contract, corporate policy, or other logical reason? Ask third, "does the threshold need to be selected by the user based on field criteria?" Ask fourth, "how may we implement the Precautionary Principle when nothing else exists for guidance on establishing a criterion (or criteria) level Ask finally, "Is the selection of a limit a product of understanding the variability and historic data?" Types of Alarms	C
5	Declaration of Decision	3.6	STEP 5 – Summarizing the Analysis for Effective Stakeholder Communication	A

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APPENDIX A: Documentation Template

Step 1 Statement of Purpose (What are you accomplishing in monitoring)

Step 2 Statement of Objective(s) (How to achieve the purpose)

- Safety monitoring to protect from acute harm (IDLH)
- Health monitoring to protect from chronic harm (exposures resulting in cancer)
- Other process monitoring (fugitive or particulate emissions to meet regulations)

Step 3 Selection of Device(s)

- Targets of monitoring and important parameters
    - Contaminants of interest
    - Sensor ranges of functionality
    - Sensor Response times
    - Alarm Limits Criteria (applicable regulations)
    - Exposure Assessment Program monitoring objectives
    - Assurance of Exposure Controls and worker behaviors
- Operability
    - Contaminant Range appropriateness
    - Cross Sensitivities/+ or – bias
    - Alarm Response planning and execution (sufficient to escape the condition)
    - Procedures used to regularly test, calibrate and verify proper performance
- Environmental Conditions of use (Table V)
    - Audibility of alarms in conditions of use (noise environment)
    - Worker confinement/constraint or orientation (worker interface with activity)
    - Sensor loading (particulate on a gas sensor)
    - Sampling Train length/impact to response rise time
    - Flammable or explosive atmosphere (IEEE or UL Certified devices required)
    - Operational time of battery life versus field use duration
    - Datalogging capacity sufficient for data capture versus field use duration
    - Datalogging and migration to surveillance systems (man-down connections to satellite)

Step 3 Selection of Device(s) (continued)

Human Factors considerations (Table VI)

Appropriate to alert, inform and drive operator assessment and or action

Lead to a defined response

Allow for sufficient protective response prior to a consequence

Consider human capabilities and limitations (worker physical responses) appropriate for the condition identified

Step 4 Establishing Alarm Setpoints and Response Process

Setpoint for each configurable (High and Low) as well as automated criteria (TWA and STEL instrument calculations)

Simple and clear declaration of a basis for each setpoint

Simple and clear declaration of expected action in response

Step 5 Summarizing the Analysis for Effective Stakeholder Communication

Frame as a risk communication tool

Table of summary setpoints and basis from Step 4

APPENDIX B: Illustrative Example: Combustible and Chemical-Specific Sensor Gas Detection

TABLE B-I: Example Alarm Selections Basis in a Four Gas Monitoring Device

The following table presents the results of applying the 5-Step alarm setting process for a worksite work procedure requiring monitoring of the four gases: ammonia, carbon monoxide, hydrogen sulfide and nitrogen dioxide.

The selection process involved reference to a worksite specific alarm criteria strategy such as the high alarm set point criterion discussed in the table notes and the application of the structured IRSST permissible exposure value adjustment process. Each of the 16-alarm set points activate a defined and documented response process that was learned through formalized 'Stakeholder Communication'.

One important aspect to recognize in this example is the philosophy of setting alarms at a reduced. (see section above) value to important concentrations (i.e., 95% of maximum permissible exposures, TWAs, and STELS) allowing the user pre-warning of impending exposures limits.

Hazard	TWA	Basis	STEL	Basis	Low	Basis**	High	Basis *****
Ammonia	23.7	95% HSRC TWA IRSST based (No Adjustment)	33.3	95% HSRC STEL OEL	25	8-hour HSRC TWA IRSST based (No Adjustment)	95	95% implied effects (TLV reference 13) Criterion 4
Carbon Monoxide	15.9	95% IRSST based (adjustment factor 0.67)	71.3	95% HSRC STEL (default 3X TWA)	16.7	Adjusted 12-hour HSRC TWA (adjustment factor 0.67)	118.7	95% HSRC Ceiling (default 5X TWA) Criterion 3
Hydrogen Sulfide	9.5 ***	95% HSRC TWA IRSST based (No Adjustment)	14.3	95% HSRC STEL OEL	10.0	8-hour HSRC TWA IRSST based (No Adjustment)	47.5	95% Company Policy Ceiling (default 5X TWA) aligns to OSHA Z-2 Table Peak value And lower than 50% IDLH Criterion 2
Nitrogen Dioxide	0.6	95% IRSST based (adjustment factor 0.67)	2.8	95% HSRC STEL (default 3X TWA)	1.0	8-hour HSRC TWA IRSST based **(no adjustment because of sensor MDL limitation)**	6.5	50% IDLH**** Criterion 1

*Critical that the Tier 4 users understand instrument capability to match alarm settings to datalogging so the views match; many occasions they do not based on datalogging logic set up by the manufacturer that recognizes sensor fluctuations, responses to humidity and other .

** No safety factor applied to low alarm as discrete condition does not merit a lower administrative limit

*** Refer to Appendix B "In Defense of Discounting Application of TWAs and STELs"

**** "The IDLH value for nitrogen dioxide, 13 ppm (24 mg/m^3), is based on a lowest observed adverse effect level of 30 ppm for respiratory irritation and severe cough in volunteers following a 70-minute exposure."

***** Progression of HIGH Alarm selection criteria is Criterion 1: use of IDLH for acute health effect (OSHA/IRSST classes I-a through I-c); Criterion 2: 95% of Ceiling Value; Criterion 3: default 5 times the TWA value as Peak for longer term health effects. Where available, Criterion 4: specific references may inform selection of a "best value"