

Emergency Management and Response: Characterizing and Assessing Critical Self-Escape Competencies



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NIOSH Mining Program

Part 1: Background

The National Academy of Sciences (NAS) has recommended a shift from time-based to competency-based self-escape training

“Regulations appear to emphasize training duration and frequency rather than training to mastery...

A train-to-mastery system with competency standards is needed, not time in class.”

-NAS, 2013



Time-based training might not adequately prepare mineworkers for successful self-escape

“In training, miners seldom have to demonstrate mastery of a skill, but only have to be in attendance”

-NAS, 2013

“tell me and
i’ll forget.
show me
and i may
remember.
involve me
and i learn.”

- Benjamin Franklin

What does a competency-based training system require?



- 1) A standardized definition of competence
- 2) Safety personnel to serve as competence assessors
- 3) Assessment tools and workplace observations
- 4) Performance monitoring and improvement

-Powell & Carraccio, 2018

Competency-based training and assessment has been shown to improve performance outcomes

“Results cited early and sustained improvement in resident technical ability...”

-Nguyen & Lovee

“After assessment and remediation practices, nearly all teams achieved mastery of the required skills”

-Scott et al.

“99.7% of healthcare providers improved their overall competency score...”

-Ameh et al.

“Residents’ skills rapidly improved and transferred from the classroom to the laboratory setting”

-Martin et al

Not new to the mining industry: Competency-based assessment is used at mine rescue team competitions



Miner performing CPR at a mine rescue team competition while a judge observes

First Aid: CPR

Skill		Competencies
Establishing unresponsiveness	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	A. Tap or gently shake shoulders B. Ask “Are you okay?” C. Determine unconsciousness D. Call for help E. Get AED
Monitoring patient for breathing	<input type="checkbox"/>	A. Look for absence of breathing or gasping breaths
Checking for carotid pulse	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	A. Correctly locate the carotid pulse B. Check for presence of carotid pulse C. Immediately start CPR if there is no pulse

*Adapted from the National Mine Rescue, First Aid, Bench, and Preshift Contest Section II First Aid Rules handbook

Recent NIOSH findings suggest that hours in training \neq competence

Survey results are included in the Jan-Feb 2018 Coal Age issue (pp. 30-31)

Among 696 hourly mineworkers surveyed:

Over 50% were less than fully confident in their ability to:

- Read mine map symbols
- Identify what alarms/alerts mean

SAFETY TRAINING

THE ABCs of KSAs

Assessing the self-escape knowledge, skills and abilities of coal miners

BY CARMINDA HODGINS, MICHAEL L. BRENCH AND MARGARET E. LYNN

What simple step can help to prevent a mine emergency from becoming a mine disaster? Preparation.

Mine emergencies can happen at any moment. Although all mines and mine emergencies are unique, being equipped with an easily adaptable set of knowledge, skills and abilities (KSA) can help underground coal miners prevent a dangerous situation from becoming a tragedy.

The Mine Improvement and New Emergency Response Act of 2006 (MINE-RE Act) strengthened existing safety and health training regulations and introduced new measures aimed at improving emergency preparedness and response in underground coal mines. Although the MINE-RE Act also required more specified assessment of self-escape KSAs for miners, there is no standard protocol describing how to know or evaluate these competencies.

Now more than 10 years later, the National Institute for Occupational Safety and Health (NIOSH) expanded its research to answer three important questions:

- What are the critical self-escape competencies that all miners need in order to be prepared to respond to an emergency?

Identifying Critical Self-escape KSAs

After NIOSH research, the National Research Council 2013 report, "Improving Self-Escape From Underground Coal Mines," and multiple industry reports have addressed the need for improved self-escape training and assessment that emphasize task mastery over the completion of time-based training requirements. To address this need, under a NIOSH contract, the Group for Organizational Effectiveness (GOE) and Applied Inc. partnered to conduct a formal task analysis to identify the tasks critical for successful self-escape. The primary goal of this work was to provide detailed descriptions of all tasks critical to successfully self-escape. The protocol was reviewed and approved by the NIOSH Institutional Review Board and found to be in compliance with the Paperwork Reduction Act by the Office of Management and Budget.

Assessing Gaps in Critical Self-escape KSAs in Miners

To identify gaps in the critical self-escape KSAs among mineworkers, NIOSH developed a survey using 28 of the critical self-escape tasks identified in the task analysis. Because standard self-escape competency and assessment protocols are yet to be developed and tested, it is difficult to assess mineworker confidence was used as a "proxy" to measure competence. Participating miners were asked, "On a scale of 0-100%, how confident are you that you could correctly demonstrate or explain the following (KSA) to a brand new miner?"

In late 2016, NIOSH researchers visited eight mines and collected surveys from 695 volunteer mineworkers. To the authors' knowledge, this is the first study to assess gaps in the critical self-escape KSAs from the perspective of the mineworkers themselves.

"MAKE SURE YOU HAVE A GOOD UP-TO-DATE MAP AND KNOW THE ESCAPEWAYS OUT OF THERE RIGHT OFF THE BAT. . . IF THE GUYS . . . THEY DIED IN THE FIRE KNEW THEIR ESCAPEWAYS . . . AND KNEW WHERE THEIR SELF-RESCUERS WERE, THEY WOULD HAVE MADE IT OUT."

— Jim Willberg, from the 2017 documentary, "Remember Willberg"

Remember Willberg is a documentary film produced under a grant from NIOSH, written and directed by Blake Galloway, and produced by the UTA Film School.

Key Results

Survey results suggest that, despite unmet efforts to improve health and safety training by researchers and industry alike, there are still many gaps in critical self-escape KSAs among mineworkers.

Figure 1 displays the 28 items included on the survey along with the percentage of hourly and salaried mineworkers who report they are not fully confident in each of the self-escape tasks. For example, as shown in Figure 1:

- 29% of the hourly workers surveyed reported less than full confidence in their ability to demonstrate or explain how to properly don a self-contained self-rescuer (SSR).
- 49% reported being less than fully confident about where to report in the event of an emergency.
- Less than half reported full confidence in their ability to explain the chain of command for responding to an emergency, or how to read mine map symbols.

When reviewing these results, it is especially important to note the wording of the question itself. The question introduced no complicating conditions (stress, smoke, real emergency, etc.), so the re-



One of 695 underground coal mineworkers who volunteered to participate in NIOSH's self-escape survey study.

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Among 696 hourly mineworkers surveyed:

Over 40% were less than fully confident in their ability to

- Identify what lifeline symbols mean
- Identify the location of SCSR caches, escapeways, tetherlines, or the refuge alternative (RA)

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- 29% of the hourly workers surveyed reported less than full confidence in their ability to demonstrate or explain how to properly don a self-contained self-rescuer (SCSR).
- 40% reported being less than fully confident about where to report in the event of an emergency.
- Less than half reported full confidence in their ability to explain the chain of command for reporting an emergency, or how to read mine map symbols.

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Among 696 hourly mineworkers surveyed:

Over 20% were less than fully confident in their ability to

- Don an SCSR
- Know when to don an SCSR

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Furthermore...

Miners who found their escape training realistic and hands-on were **4 times more likely** to report high self-escape confidence than those who did not.



Could competency-based training and assessment practices help improve miners' competence?



The NIOSH Core Competency Profiles

Competency Areas:

1. Everyday preparedness
2. Situational awareness: mine layout
3. Emergency diagnosis and response
4. Wayfinding
5. SCSRs: locating, donning/switching
6. SCSRs: when wearing
7. Communication
8. Refuge alternatives
9. Firefighting

For each:

- Core & supplemental knowledge, skills and abilities (KSAs)
- Training suggestions
- KSAs in action

Core Competencies – Situational Awareness: Mine Layout

Location of Mine Emergency Features and Resources	<ul style="list-style-type: none"><input type="checkbox"/> Recognizes personal position in the mine relative to the locations of all emergency features and apparatus, including:<ul style="list-style-type: none"><input type="checkbox"/> Mine phones and other communication technology<input type="checkbox"/> Meeting places<input type="checkbox"/> SCSR caches<input type="checkbox"/> Lifelines<input type="checkbox"/> Primary and secondary escapeways<input type="checkbox"/> Refuge alternatives<input type="checkbox"/> Tetherlines<input type="checkbox"/> Mine maps<input type="checkbox"/> Firefighting equipment<input type="checkbox"/> First aid equipment/medical supplies
Establishing and Maintaining Situational Awareness	<ul style="list-style-type: none"><input type="checkbox"/> Knows the general layout of the mine<input type="checkbox"/> Knows how entries and crosscuts are numbered<input type="checkbox"/> Establishes and maintains awareness of own location relative to the event<input type="checkbox"/> Establishes and maintains awareness of own position relative to fresh air and exits<input type="checkbox"/> Uses handheld multigas meters to assess air quality as location in mine changes<input type="checkbox"/> Notes whether transportation is staying or going

Training Suggestions – Situational Awareness: Mine Layout

Ask miners to consider these questions every time they go to a place to work:

- What am I going to do in an emergency?
- Which direction will I head in order to escape?
- Where is the closest escapeway?
- What is between the escapeway and me?



KSAs in Action – Situational Awareness: Mine Layout

Cases:

Aracoma Alma:

“... [they] did not escape via the alternate escapeway . . . [one] possibility is the two miners intended to remain in... the route with which they were most familiar”

Darby:

“... the lack of practice relating to the alternate escapeway, more likely than not, added to the delay in evacuation of the mine”

Wilberg:

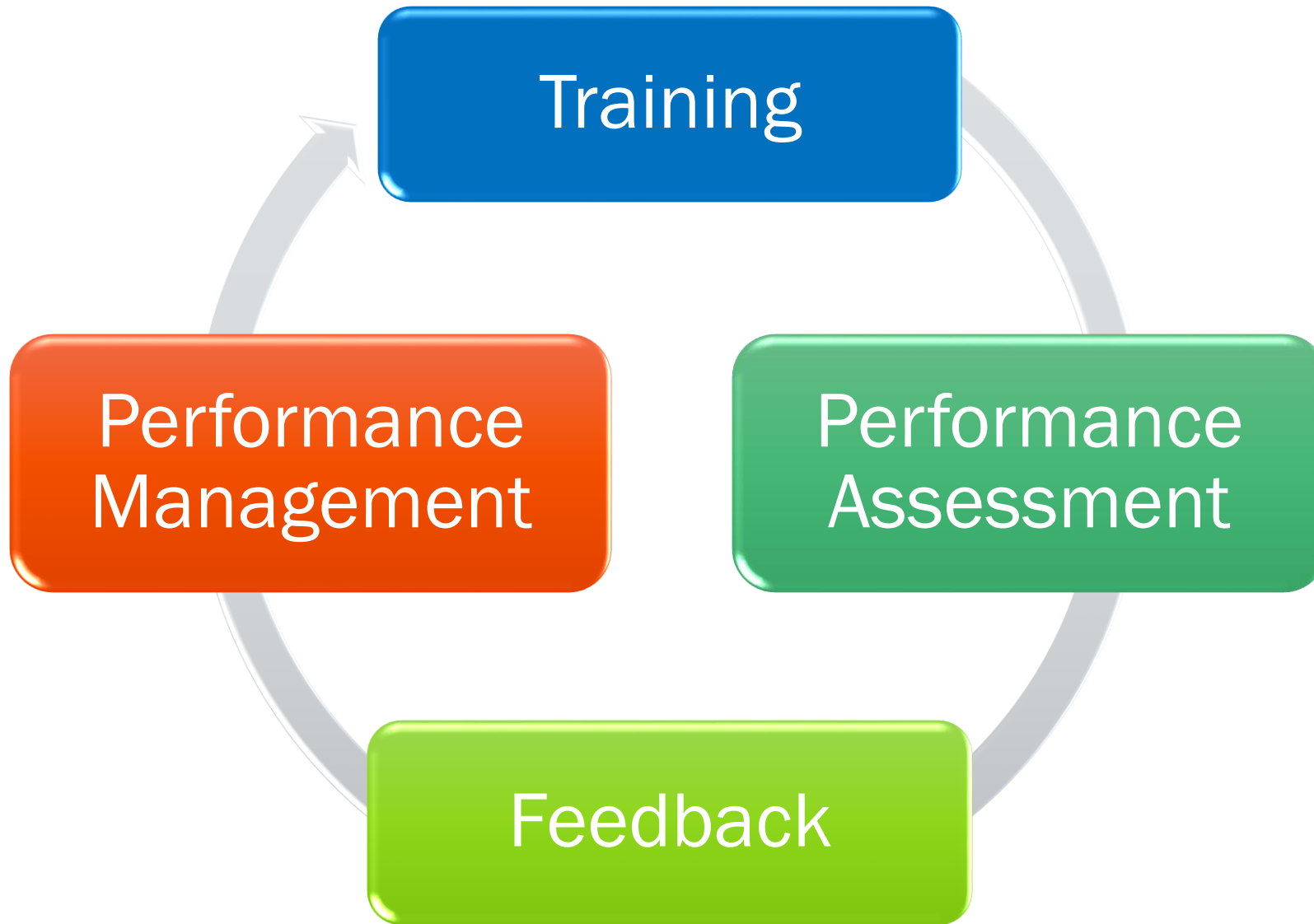
“... we always said if anything happened go to the new air shaft. He didn't do it. He went the wrong way”



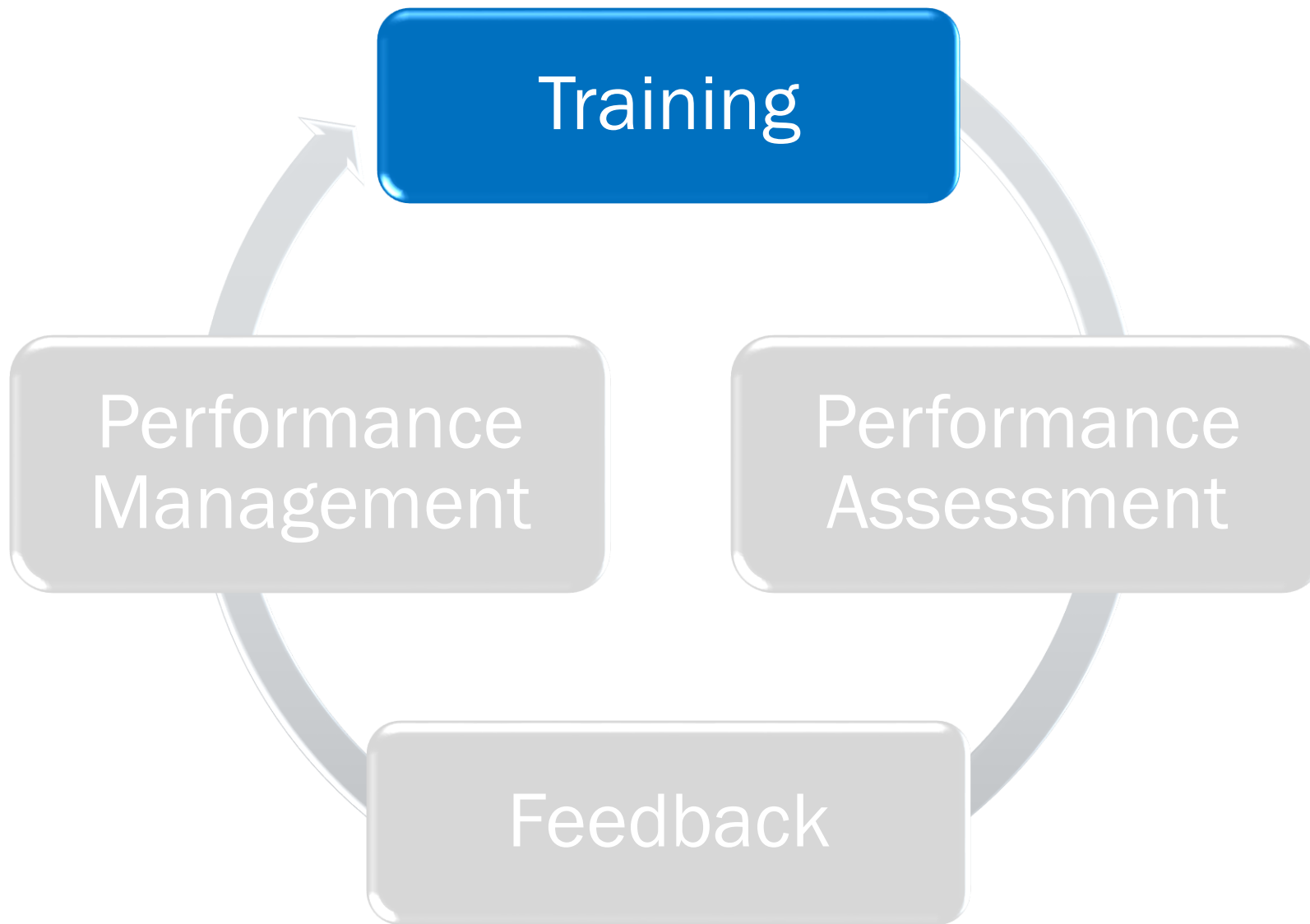
Relevant KSAs:

- ☐ Recognizes personal position in the mine relative to the locations of all emergency features and apparatus, including primary and secondary escapeways
- ☐ Establishes and maintains awareness of own location within the mine relative to the event
- ☐ Establishes and maintains awareness of own position within the mine relative to all exits and fresh air
- ☐ Knows general locations of man doors (e.g. every 5th crosscut, etc.)

Competency-based training and assessment in action

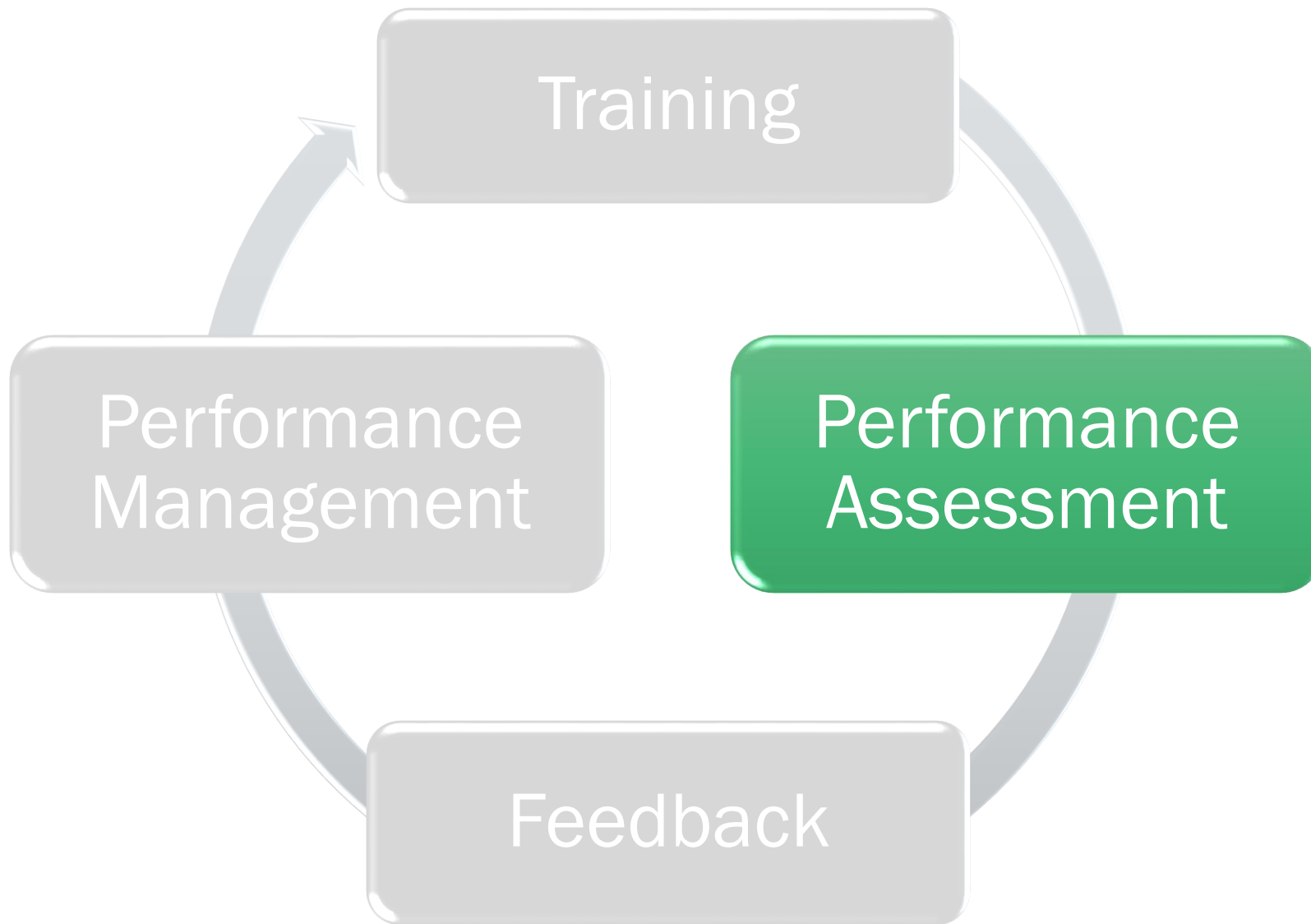


Competency-based training and assessment in action



- Emphasize students' abilities and needs in design and instruction (Martin et al.)
- Use trainee performance to assess/improve training curriculum and delivery (Holmboe et al.)

Competency-based training and assessment in action



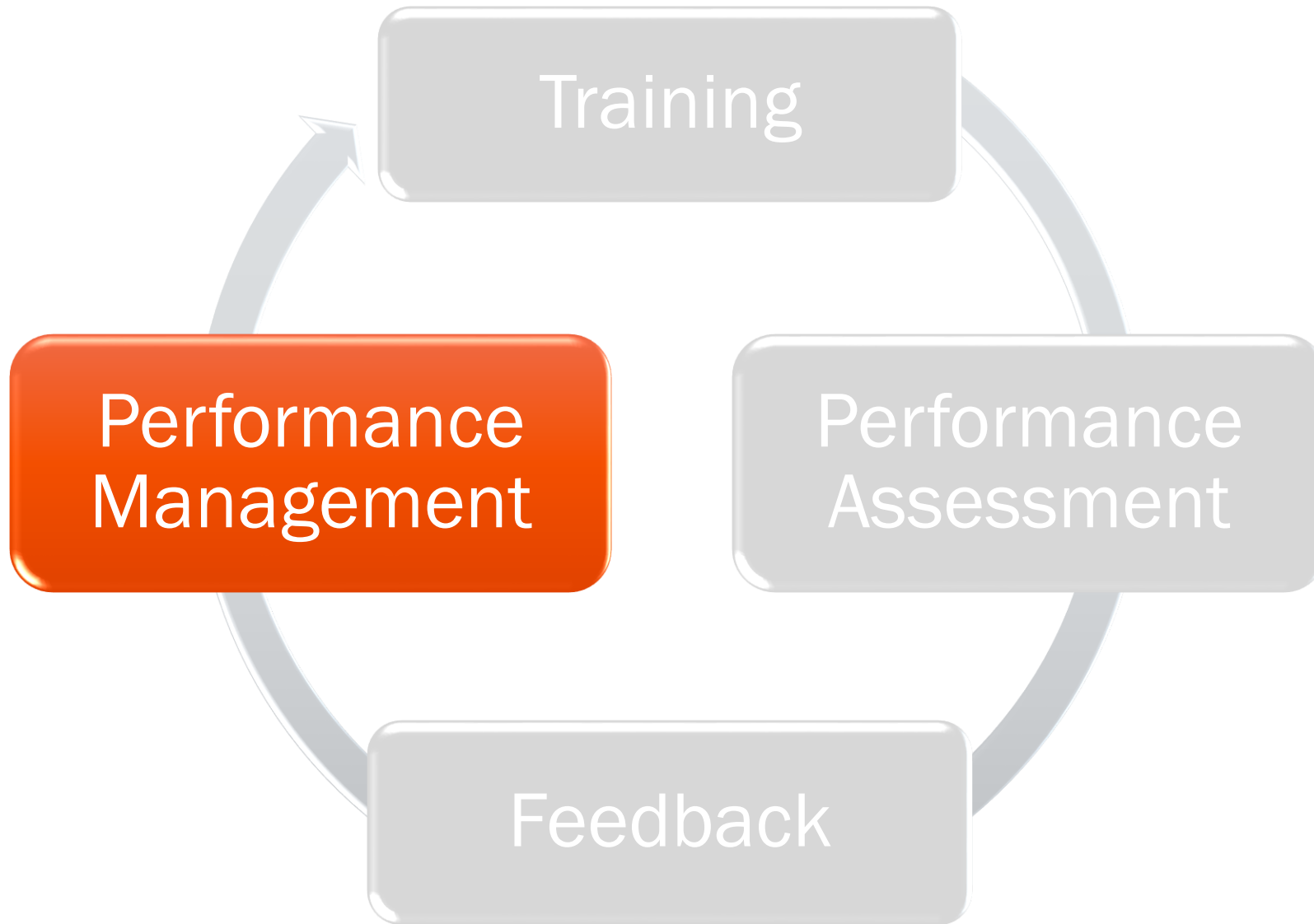
- Require the demonstration of essential skills (Martin et al.)
- Measure performance against objective criteria (Lockyer et al.)

Competency-based training and assessment in action



- Include timely and focused feedback on performance (Nguyen & Losee)
- Identify, address, and remediate areas of concern or deficiency (Nguyen & Losee)

Competency-based training and assessment in action



- Document and monitor trainee performance over time (Lockyer et al.)

Part 2: A Case Study

Case Study - NIOSH teamed with a mine company to implement competency-based training and assessment at its FY18 training events

A detailed description of the case study is included in Coal Age's 2018 October-November issue (pp. 29-31)

OPERATING IDEAS

USING PERFORMANCE MANAGEMENT STRATEGIES TO IMPROVE MINE EMERGENCY TRAINING AND PREPAREDNESS

BY MARGARET E. RYAN, JASON DIAMOND, MICHAEL J. HOSBEL

The MINER Act of 2006 called for significant improvements to emergency response training and preparedness at U.S. underground coal mines. Yet, results from a recent survey on self-escape competency by the National Institute for Occupational Safety and Health (NIOSH) suggest that underground coal miners may still be underprepared for self-escape. These findings can motivate safety trainers to identify strategies for improving the workforce's self-escape preparedness for every worker during every shift in the event of an underground mine emergency.

While the MINER Act requires assessment of self-escape competency, it provides no standardized definition of the specific self-escape competencies that all miners must have, no standardized competency-based training methods or tools, nor any guidelines on how to assess them. In the 2013 report, "Improving Self-Escape From Underground Coal Mines," the National Academy of Sciences urges the industry to adopt a "train-to-mastery" system with competency-based standards instead of focusing on fulfilling time-based training requirements. To that end, competency-based self-escape training and assessment focuses on outcomes, such as the mastery of critical self-escape knowledge, skills, and abilities (KSAs), thus placing the emphasis on task performance and individual proficiency instead of training duration. The National Academy of Sciences report noted that this shift toward a train-to-mastery system would help improve self-escape training and, in turn, improve self-escape preparedness.

In response to the report recommendations, NIOSH identified the critical self-escape competencies and administered the Self-Escape Competency Survey under a research protocol approved by the NIOSH Institutional Review Board (IRB) and Office of Management and Budget

OMB's self-escape critical competencies. To mine critical assessment, workers allow training to be on one mine after post-competency strategy mediator and through

Survey
In 2011, mines participate in the Self-Escape Competency Survey. The survey results showed that their miners were not as prepared for self-escape as they had believed. Unfortunately, many times the true self-escape preparedness of a mine's workforce is only determined after an actual mine emergency occurs, when it is too late to intervene. Regular competency-based assessment and remediation would help mines to make informed decisions about where to direct their resources and efforts to best maximize the benefit of the already-required self-escape trainings (e.g., the annual refresher training, annual smoke expectations training, quarterly response drills, etc.).

By employing simple, cost-effective assessment methods such as pen-and-paper quizzes (like the ones developed by Consol), mine companies can identify weaknesses in self-escape competency and tailor training content to "fill in the gaps." These methods allow for the assessment of a large number of miners at once, making it easier and more time-effective than trying to gauge competency through performance, also allowing safety trainers to identify miners who are struggling so that they may provide more individualized remediation where necessary.

gling on a training topic, demonstrating increased personal accountability for their self-escape preparedness.

Mine rescue team members, who assisted in carrying out the expectations and fire prevention training, similarly reported having seen marked improvement and increased engagement among the workforce, noting that miners seemed to be asking more questions and participating more enthusiastically compared to prior years.

To reinforce the year-round retention of self-escape KSAs and to continue to develop trainings that are tailored to specific competency gaps among the workforce, the training coordinator plans to incorporate additional assessment and remediation strategies into the mine sites' quarterly escapeway drills. This will enable consistent and targeted self-escape KSA monitoring and improvement.

Incorporating Competency-based Assessment Into Self-Escape Training
Mine safety professionals who participated in NIOSH's Self-Escape Competency Survey were surprised when results showed that their miners were not as prepared for self-escape as they had believed. Unfortunately, many times the true self-escape preparedness of a mine's workforce is only determined after an actual mine emergency occurs, when it is too late to intervene. Regular competency-based assessment and remediation would help mines to make informed decisions about where to direct their resources and efforts to best maximize the benefit of the already-required self-escape trainings (e.g., the annual refresher training, annual smoke expectations training, quarterly response drills, etc.).

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This enables mine companies and safety trainers to respond to KSA gaps at both the mine-wide and individual level.

Self-Escape Competency Survey results also indicated that miners were more confident in their self-escape KSAs when they felt that health and safety training was a priority at their mine and that their escape training was realistic and hands-on. Simply making the effort to assess and improve preparedness gaps and asking miners what they want or need is a great place to start. These efforts can demonstrate the mine company's commitment to the health and safety of its miners, creating more opportunity for open communication about areas where improvement is necessary and what efforts might help achieve that improvement.

Recent NIOSH self-escape research has produced materials that can aid mine companies in developing competency-based training and assessment practices to implement during already-required trainings. The aforementioned critical self-escape items included on the competency survey, detailed in the prior Coal Age article, "The ABCs of KSAs," can help mine companies to prioritize key competencies to focus on during training. Additionally, a detailed table listing training resources and assessment opportunities for each of the self-escape competencies listed on the Self-Escape Competency Survey was included in that article and is available by request from NIOSH.

Disclaimer
The findings and conclusions in this paper are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention. Mention of any company or product does not constitute endorsement by NIOSH.

Margaret E. Ryan is an associate service fellow with NIOSH. Jason Diamond is the training coordinator of Consol's Bailey, Harvey and Blount Fork mines. Michael J. Hosbel (retired) was a lead mining engineer with NIOSH for 30 years. Cassandra Hosbel is a research behavioral scientist with NIOSH. For more information, contact mining@cdc.gov.

Figure 2—Worker donning an SCSR unit to prepare for smoke training.

using fire hoses in the company's fire gallery. To improve miners' procedural knowledge and understanding of refuge alternative setup and operation, company trainers revised this training by grouping related activation and setup steps into logical step clusters. Trainers used specific feedback from the survey and from trainees' recommendations to develop this training, with the intent of making the process more intuitive.

Early Results: Increased Engagement and Personal Accountability
When NIOSH researchers spoke with the company's training coordinator about the results of these competency-based training, assessment, and remediation efforts, the coordinator mentioned that he had seen improvement in his workforce's self-escape KSAs as well as their attitude about health and safety training at the mine site. He reported that, in his opinion, the workforce was more engaged in their training, more willing to ask for specific training that they were interested in or felt was necessary (e.g., more realistic and hands-on escape training, including using live one-hour SCSR units as well as live 10-minute units, etc.). The trainer also reported that miners were more eager to ask questions when they needed more information or help on a subject and were open to admitting when they were struggling.

OPERATING IDEAS CONTINUED

NOVEMBER 2018

- Training activities built around identified competency gaps
- Assessment and feedback given at each training event
- Performance tracked throughout year

Case Study – Improving situational awareness: mine layout

Miners quizzed about where key self-escape resources are located

1st
Quarter

Miners travelled to meeting location, located equipment underground

2nd
Quarter

3rd
Quarter

4th
Quarter

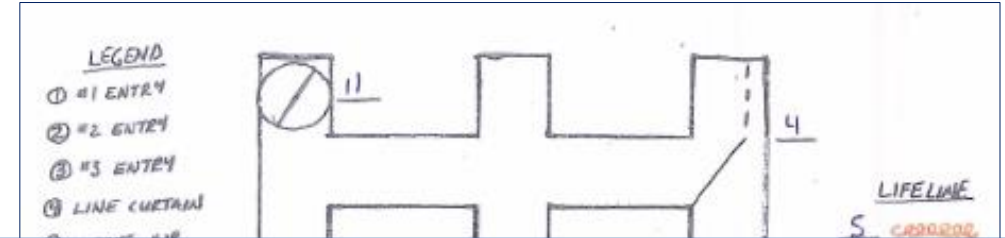
Miners filled in and used a map to locate resources during smoke escape exercise in simulated mine

Miners retook quiz from quarter 1 to assess competency improvement

1st Quarter: Competency-based assessment

EMERGENCY/SCSR QUESTIONNAIRE

NAME _____ MINING EXPERIENCE _____
LOCATION _____ OCCUPATION _____



Self-Escape KSA from NIOSH Survey

Mine's Assessment Item

Where SCSR caches are located



Name specific locations where SCSR caches are kept

Where escapeway maps are located



Name two locations where escapeway maps are kept

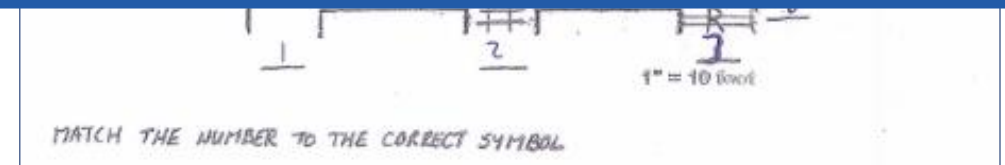
Where tetherlines are located



Name two locations where tetherlines are kept

5. What is the explosive range of Methane?

- | | |
|--------------|-------------|
| 1. 2% - 12% | 3. 5% - 15% |
| 2. 10% - 20% | 4. 7% - 20% |

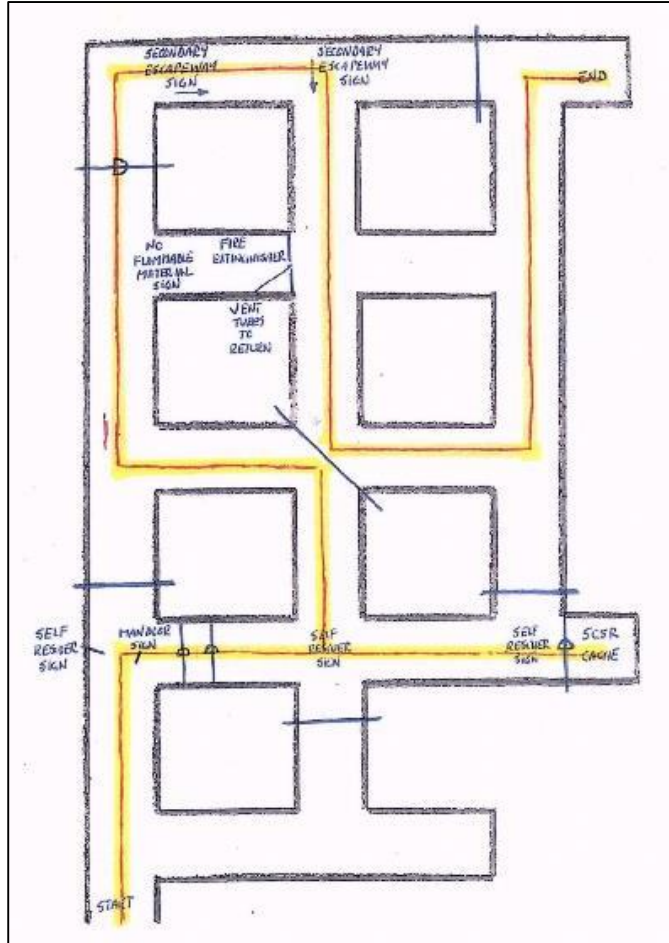


2nd Quarter: Competency-based training



Trainees
participated in an
escape exercise in
smoke

2nd Quarter: Competency-based training



More map
reading and
lifeline
symbols!



2nd Quarter: Competency assessment and feedback



3rd Quarter: Competency-based training, assessment, and feedback

Trainers conducted a surprise underground firefighting drill



4th Quarter: Competency assessment and feedback

- Training activities built around competency gaps
- Assessment and feedback at each training event
- Performance tracked throughout year
- Training tasks built around the workforces' identified competency gaps



Part 3: Practice

The NIOSH-developed competency profiles will set the foundation for competency-based training and assessment in underground mining

Requirements:

- 1) A standardized definition of competence ✓
- 2) Trainers/safety personnel willing to serve as competence assessors
- 3) Evidence-based assessment tools and workplace observations
- 4) Performance monitoring and remediation



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Company A:

- NIOSH-identified critical self-escape KSAs
- Training coordinator, corporate safety personnel, mine rescue team members
- Quizzes, mapping exercises, simulated and underground escape exercises
- Assessment, remediation, and monitoring

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- 2) Trainers/safety personnel willing to serve as competence assessors
- 3) Evidence-based assessment tools and workplace observations
- 4) Performance monitoring and remediation



**Is this feasible
for your mine
site?**

Barriers to implementing competency-based training and assessment

- Time
- Cost
- No standardized assessment protocol or tools available
- Large groups – hard to assess each trainee individually
- Certain tasks that are trained may not be practiced hands-on (e.g., firefighting, deploying refuge alternatives)



*Barriers come from the NIOSH publication “Enhancing mine workers’ self-escape by integrating competency assessment into training”

Barriers to implementing competency-based training and assessment

Company A:

- Time
 - Cost
 - No standardized assessment protocol or tools available
 - Large groups – hard to assess each trainee individually
 - Certain tasks that are trained may not be practiced hands-on (e.g., firefighting, deploying refuge alternatives)
- Incorporated into already-required training events cuts down time requirements
 - Costs (personnel time, assessment quiz prints, etc. minimal)
 - Assessment at the group level during observation, at the individual level with quizzes
 - Incorporated hands-on training with tasks during required training events

Barriers to implementing competency-based training and assessment

- Time
- Cost
- No standardized assessment protocol or tools available
- Large groups – hard to assess each trainee individually
- Certain tasks that are trained may not be practiced hands-on (e.g., firefighting, deploying refuge alternatives)



**How do these
barriers affect
you?**

Competency-based training exercises and assessment

Let's discuss:

- How to incorporate competency-based training exercises into required training events throughout the year
- How to assess miners' competencies

Core Competencies – SCSRs: Locating and Donning/Switching

Locating	<ul style="list-style-type: none"><input type="checkbox"/> Knows the locations of SCSR caches<input type="checkbox"/> Understands that SCSR caches are relocated during a section equipment or power move<input type="checkbox"/> Moves outby toward next accessible cache to switch SCSRs
Donning	<ul style="list-style-type: none"><input type="checkbox"/> Knows to don an SCSR:<ul style="list-style-type: none"><input type="checkbox"/> Upon evidence of a fire<input type="checkbox"/> At the first sign of smoke<input type="checkbox"/> When a multigas detector alarms<input type="checkbox"/> When instructed to do so<input type="checkbox"/> Understands how to perform steps for opening, preparing, and donning all SCSRs in use at mine:<ul style="list-style-type: none"><input type="checkbox"/> Isolates the lungs first and adjust straps to secure the unit close to the body second<input type="checkbox"/> Uses the manual start-up procedure if necessary and the correct procedure for model<input type="checkbox"/> Adjusts neck straps so there is no tension or kinking in the breathing tube<input type="checkbox"/> Knows how and when to help others don SCSR<input type="checkbox"/> Understands that sealed, mine-ready SCSRs are more difficult to open than training units
Switching	<ul style="list-style-type: none"><input type="checkbox"/> Knows when to switch between SCSRs<input type="checkbox"/> Masters the sequence of steps for switching between SCSRs<input type="checkbox"/> Knows how and when to help others switch between SCSRs
General Maintenance	<ul style="list-style-type: none"><input type="checkbox"/> Inspects SCSRs before each shift, checking case, seals, clips, oxygen gauge, and temperature indicator<input type="checkbox"/> Does not use an SCSR for anything unsuited to its design (e.g., as a blunt force tool)<input type="checkbox"/> Knows when an SCSR should be removed from service

Core Competencies – Wayfinding

General Principles	<ul style="list-style-type: none"><input type="checkbox"/> Trusts and relies on procedures taught in training and the resources available<input type="checkbox"/> Understands escape speed in emergency can be slower than normal walking speed<input type="checkbox"/> Knows how to use other tactile wayfinding techniques (rib line) lifeline not available<input type="checkbox"/> Returns doors to position found in when travelling through man doors or regulators<input type="checkbox"/> Crosses over or under belt at designated crossings<input type="checkbox"/> Uses handheld multigas gas meters to assess air quality as position changes<input type="checkbox"/> Recognizes the need for oneself or someone else to assume a leadership role<input type="checkbox"/> Knows to always ride out of the mine instead of exiting by foot if possible
Moving Effectively as a Group	<ul style="list-style-type: none"><input type="checkbox"/> Moves with the group, avoids splitting up the group, and gathers others as encountered<input type="checkbox"/> Places hand on shoulder or belt of the person directly ahead if a tagline is not available<input type="checkbox"/> Reminds others to use available tethers or taglines<input type="checkbox"/> Allows most experienced worker to lead tethered group, with slowest person in middle<input type="checkbox"/> Participates in the identification of all miners present underground<input type="checkbox"/> Ensures the safety of inexperienced miners, if assigned
Mine Emergency Features and Apparatus	<ul style="list-style-type: none"><input type="checkbox"/> Knows how to locate and use the following:<ul style="list-style-type: none"><input type="checkbox"/> SCSRs<input type="checkbox"/> Taglines (e.g., with everyone on same side, reattaches upon exiting transportation)<input type="checkbox"/> Lifelines (knows tactile symbols)<input type="checkbox"/> Escapeways (knows types of markers used and colors)<input type="checkbox"/> Escapeway maps<input type="checkbox"/> Firefighting equipment

A necessary next step is to study the implementation of competency-based systems at mines in the U.S.



NIOSH Mining Program
www.cdc.gov/niosh/mining

Disclaimer: The findings and conclusions in this report are those of the author(s) and do not necessarily represent the views of the National Institute for Occupational Safety and Health. Mention of any company or product does not constitute endorsement by NIOSH.

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Human Factors and Lighting for Underground Mining



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Human Factors Branch

Illumination Team

Why conduct lighting research?

It's fundamental for health & safety

80% of our perception is visual

Workers depend on lighting to see hazards and work safely

Underground mines are considered one of the most difficult places to light



Underground mines present unique challenges that need to be addressed

Low ceilings and very low reflectivity

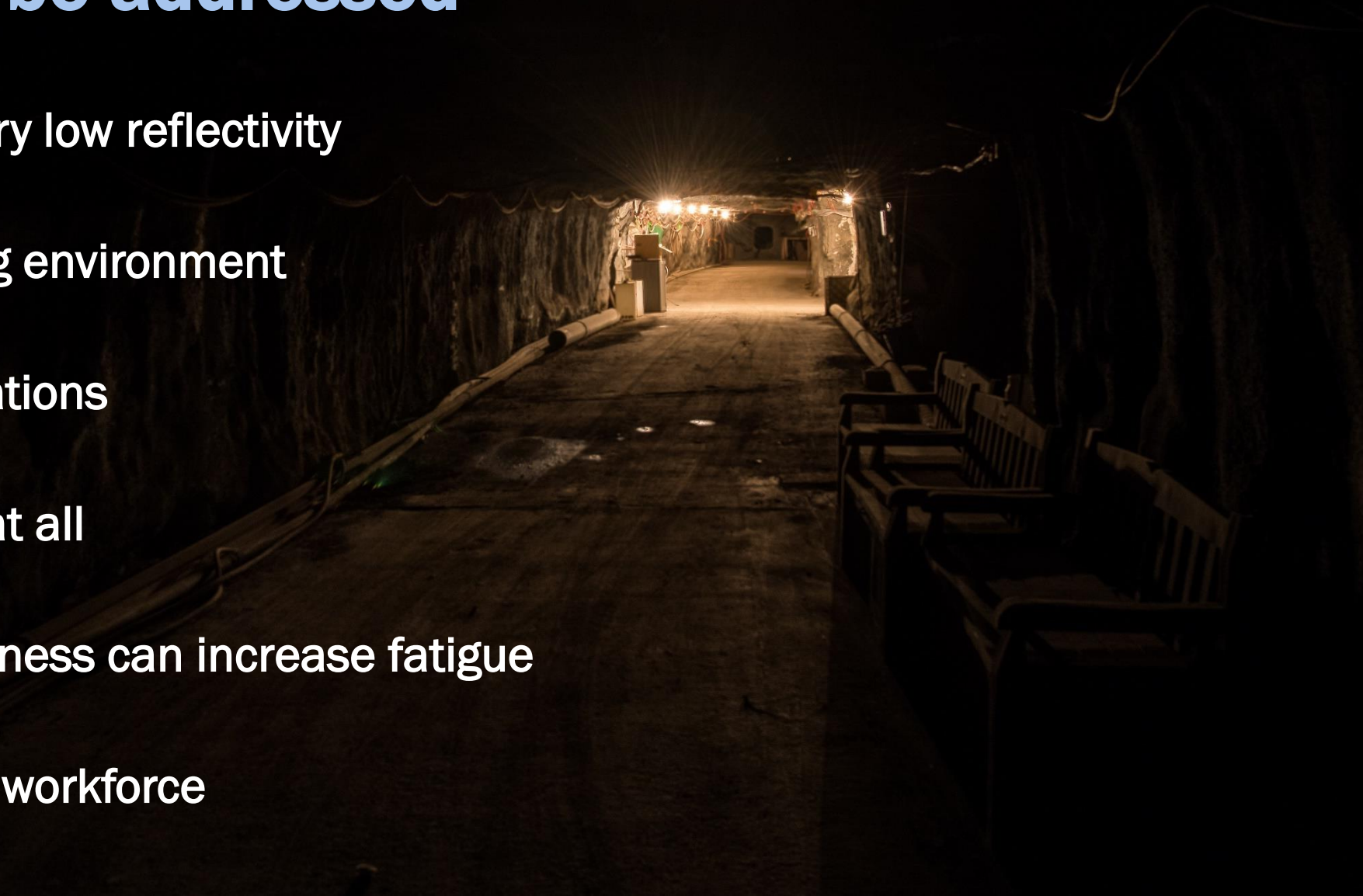
Constantly changing environment

Strict lighting regulations

Some areas not lit at all

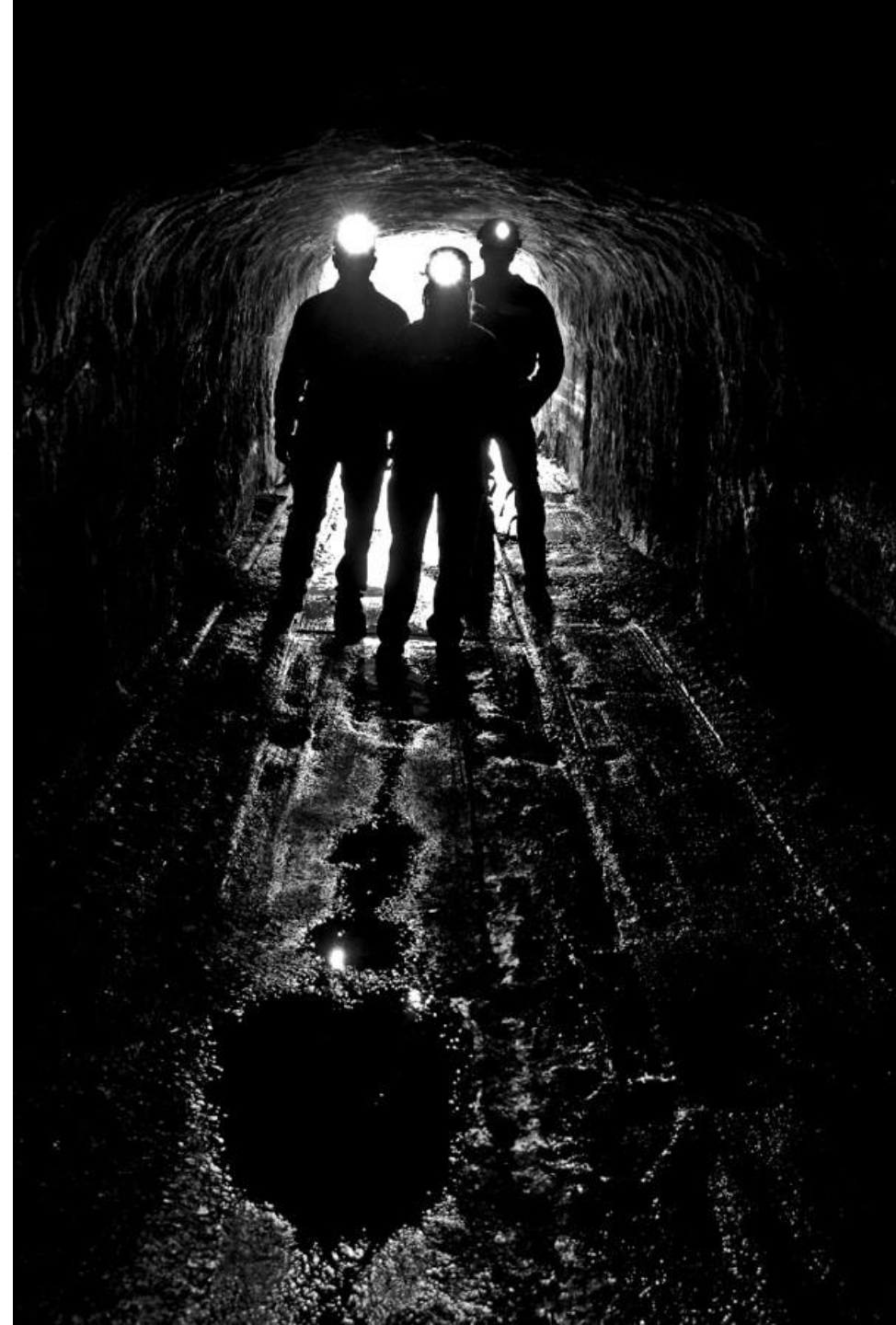
Shift work and darkness can increase fatigue

Aging of the mining workforce



Topics for discussion:

1. Visual cues for self-escape
 - a. Escapeway markers
 - b. Lighted Lifeline
2. Lighting interventions for visibility
 - a. Saturn light
 - b. NIOSH LED cap lamp
3. Light and fatigue



Improving self-escape

- Every second counts during an emergency escape
- Small improvements to visual cues can have life-saving effects
- Improving escapeway markers and lifelines



Escapeway markers: Passive beacons

- Federal law requires marking primary and secondary escapeways
- **Problems:**
 - No color code
 - Various colors, sizes, and shapes
 - Various retroreflective materials
- Tested red, green, and blue markers for detectability in smoke
- Tested FYG, white, yellow, and green markers for differentiation



Escapeway marker color is critical for visibility in smoke



Green Marker



Red Marker



Blue Marker

NIOSH researchers are testing markers to generate recommended escapeway colors

Experiment:

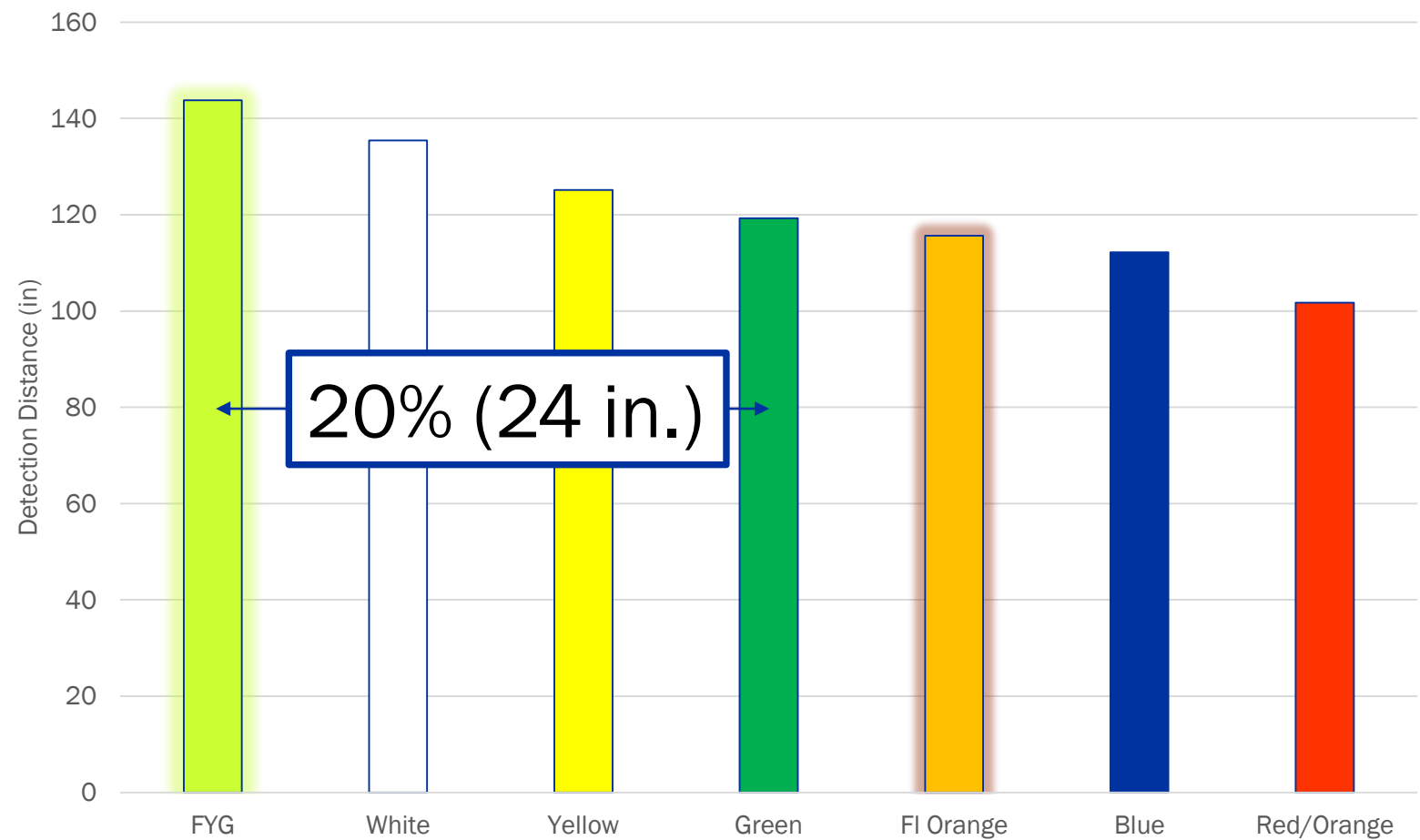
- Tests are performed in clear and smoke
- People are asked to identify colors
- Then they are asked to differentiate marker colors between primary and secondary escapeways

Results so far:

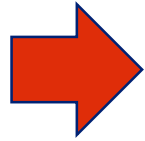
- White marker correctly has near-perfect identification
- Fluorescent yellow-green misidentified at a rate of 35%



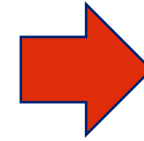
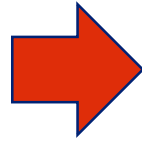
Escapeway marker detection improved 20% for FYG vs. Green



Form industry group to standardize marker colors



- Detectability
- Color recognition
- Differentiation



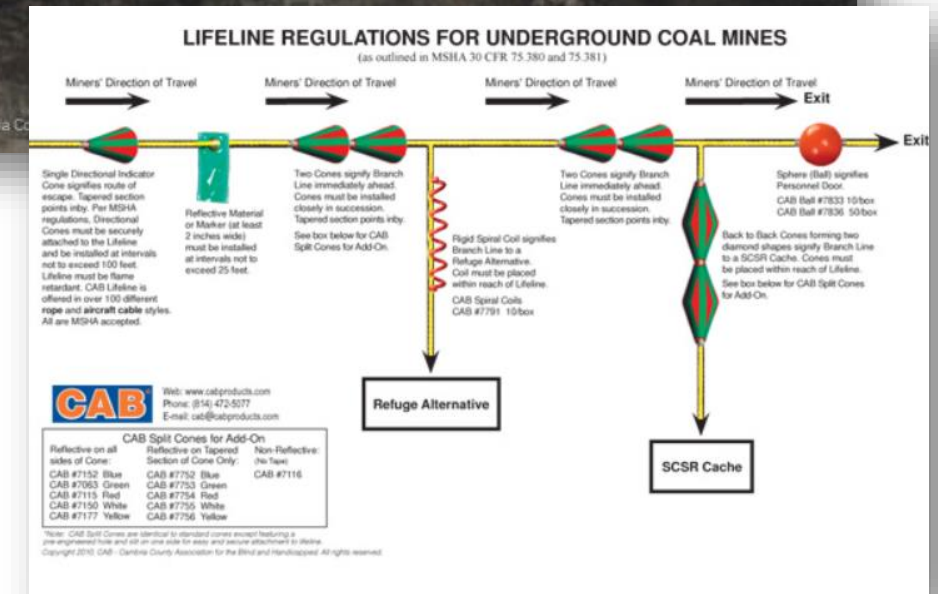
Marker
color code

Lifelines for emergency self-escape

- Required by law for underground coal mines
- Tactile objects indicate:
 - Escape direction
 - Locations of safety resources

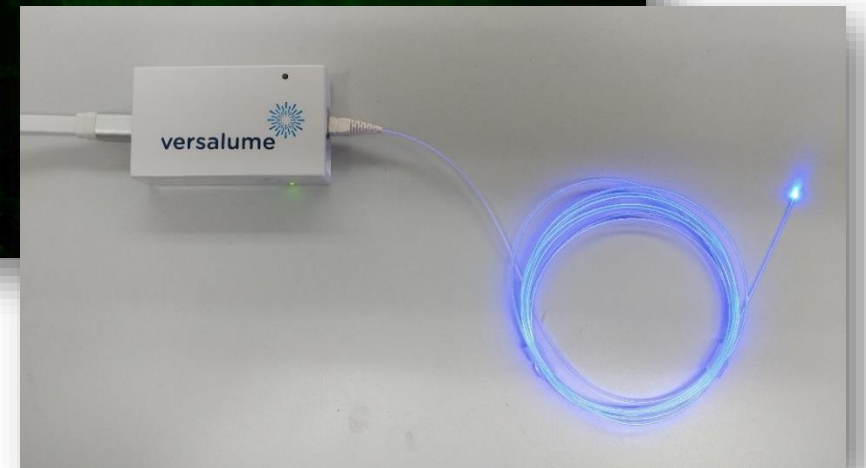


- Problem:
 - Mine disasters typically produce smoke
 - How can miners find the lifeline?

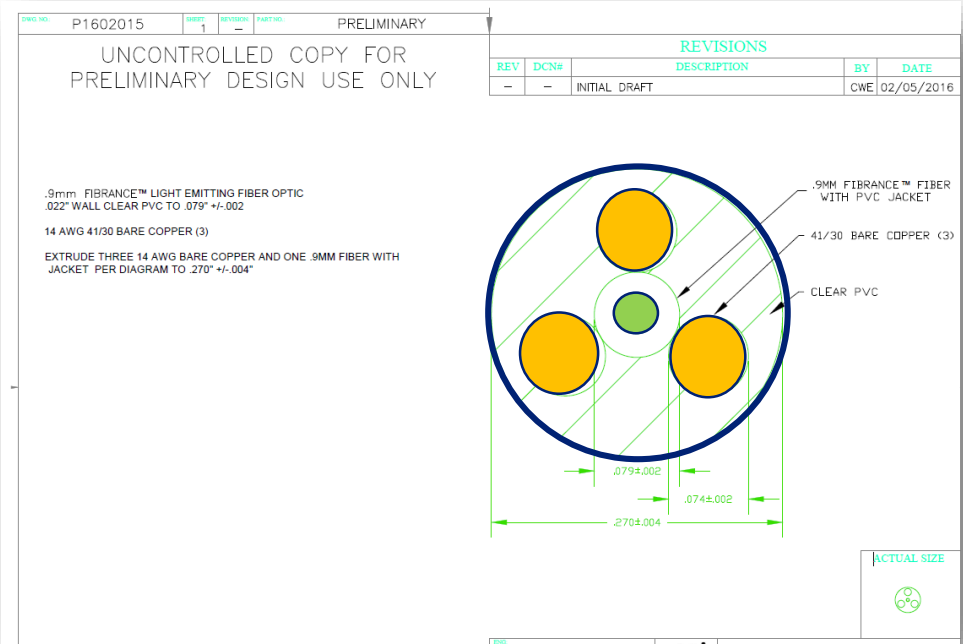
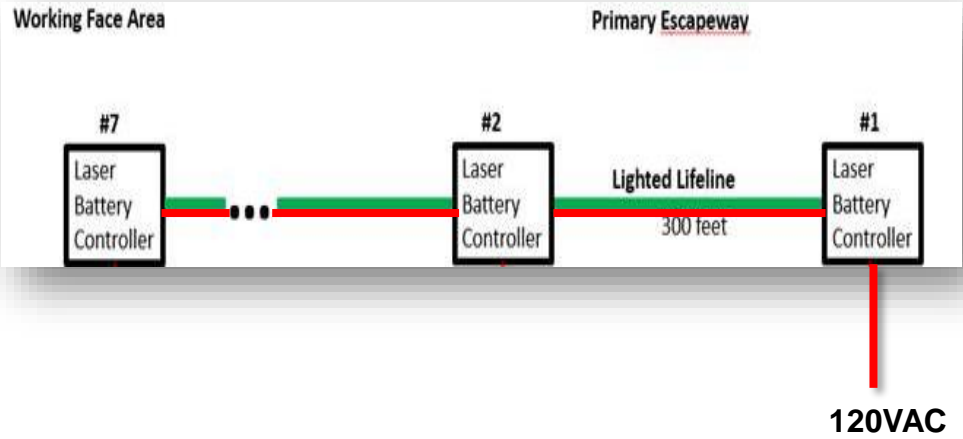


The Lighted Lifeline increases detectability in smoke for miner self-escape

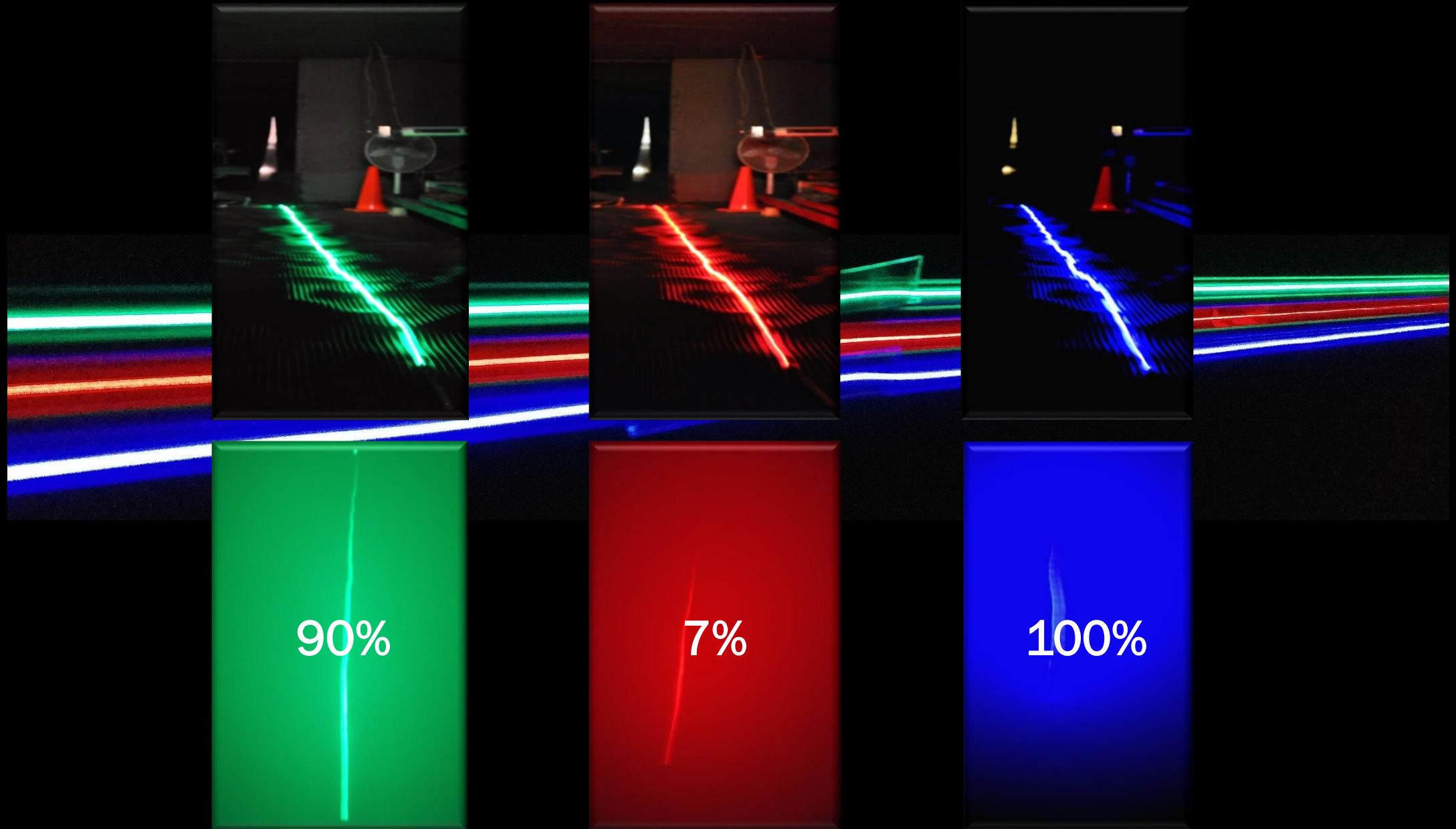
- Fiber optic cable illuminated by lasers
- Greatly increases lifeline visibility in smoke



Prototype Lighted Lifeline System Overview

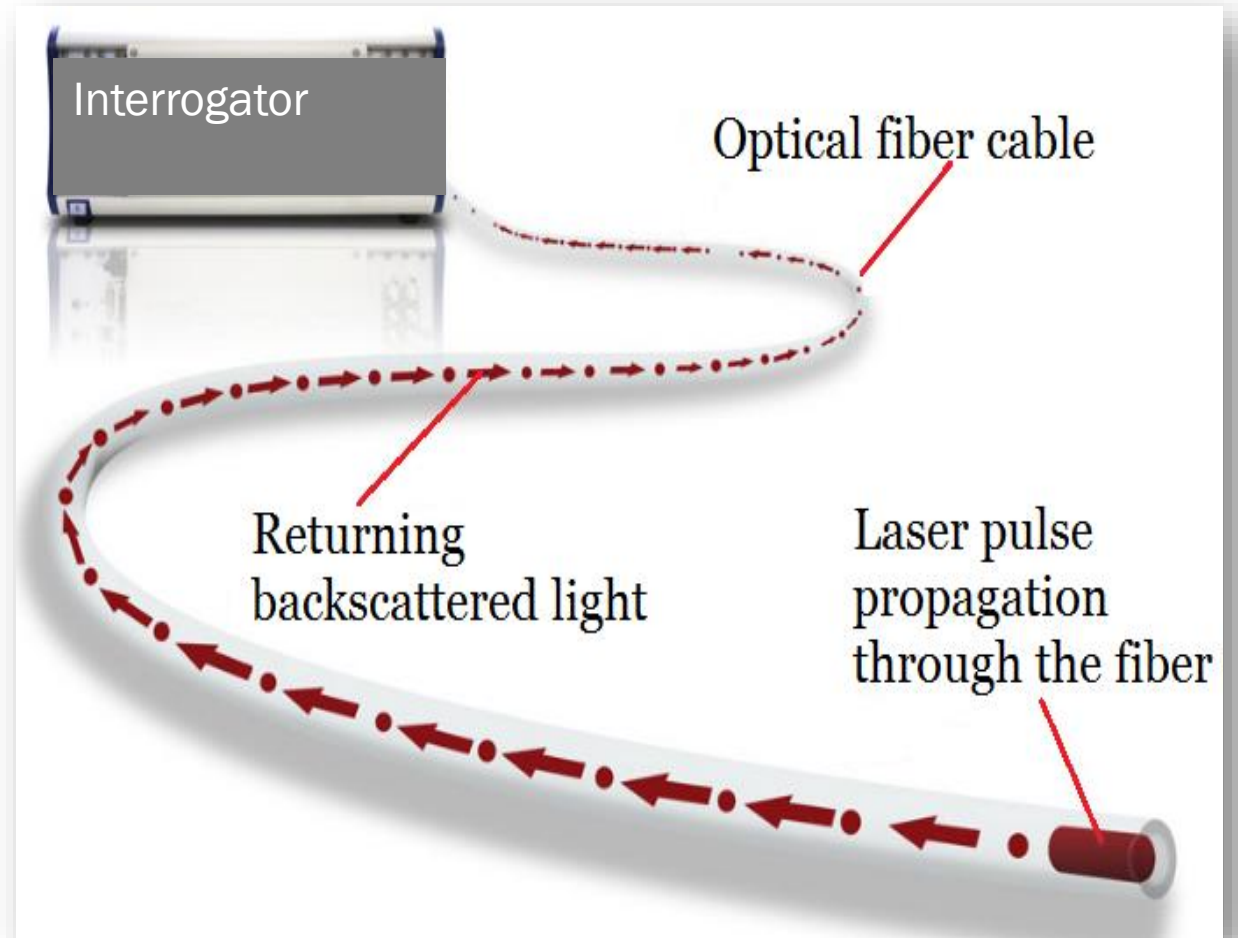


Detection of Lighted Lifeline colors for emergency self-escape in smoke



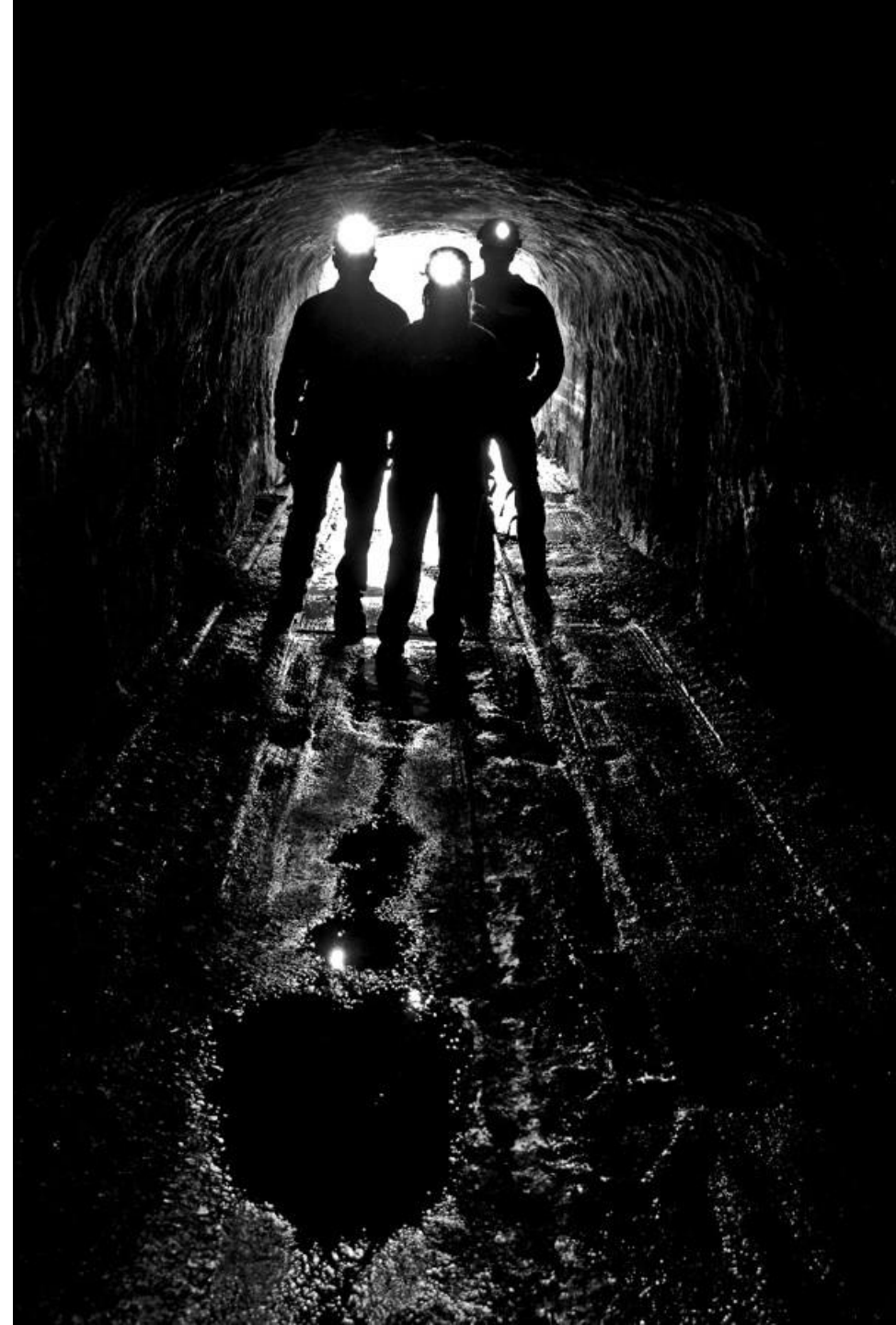
Lighted Lifeline added value: potential distributed sensing abilities

- Vibration:
 - Sensing tapping on lifeline
- Temperature:
 - Locate fires
 - Locate people
- Measure strain:
 - Locate roof falls
 - Locate people flexing the lifeline



Topics for discussion:

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Roof bolter illumination

- One of the most dangerous machines to operate
- Drills bolts to secure roof
- Federal requirements for lighting
- Problems:
 - Excessive glare
 - Poor lighting of interior workspaces
 - Confined spaces difficult to illuminate
 - Hazardous environment requires explosion-proof lights



Glare types and consequences

- Disability glare: impedes vision
 - Inability to see hazards
 - Eyestrain
- Discomfort glare: annoying or uncomfortable
 - Distraction
 - Reduced work efficiency
- How to develop a lighting intervention that:
 - Reduces glare
 - Improves hazard detection



Saturn LED Area Light

- Reduces glare and improves hazard detection
- Replaces two existing CFLs
- Improvements:
 - 37% less glare
 - 112% increased reaction time
 - 2303% more floor illumination
 - 875% less weight
 - 675% less electrical power
 - 598% less volume



Saturn area light increases illumination while decreasing glare



Trip object detection greatly improved

- Up to 53% faster trip hazard detection
- Trip hazard “miss” rate
 - <1% Saturn
 - 28% Existing lighting



Discomfort glare reduced by 3 levels

Discomfort Glare Reduced

The well-established De Boer 9-level rating scale used to determine discomfort glare

Existing Light

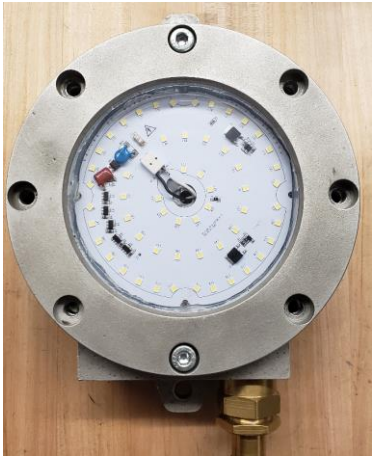


Saturn Light



1:	Unbearable
2:	—
3:	Disturbing
4:	—
5:	Just acceptable
6:	—
7:	Satisfactory
8:	—
9:	Just noticeable

Jupiter II Area Light



Specifications Summary	
Total output	1664 lumens (lm)
Efficacy	78.1 lm/watt
Maximum candela	983 candela
Voltage	120 volts AC
Current	0.1854 amps
Power	21.29 watts



<https://www.cdc.gov/niosh/mining/content/JupiterIIAreaLight.html>

Cap Lamps

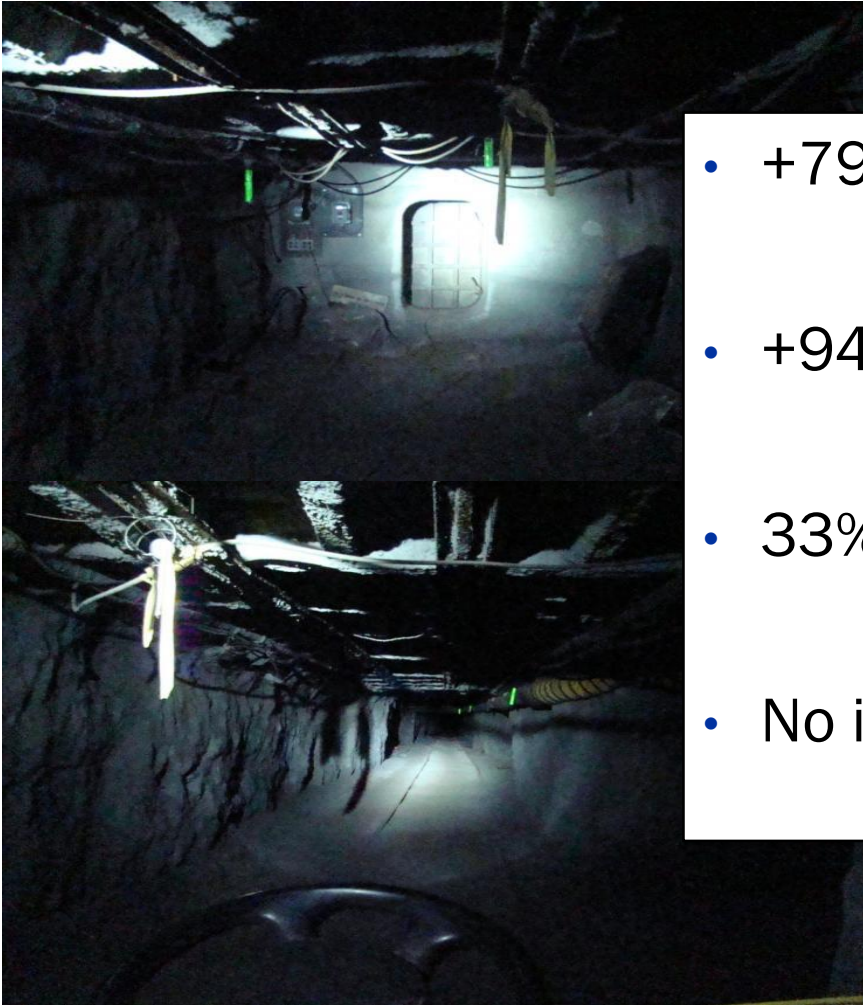
- Problem:
 - Current cap lamps provide poor visibility
 - No peripheral vision from tunnel vision effect
 - Causes glare from spot beam

NIOSH LED Cap Lamp

- 3 angled LEDs with optics
- Programmable intensity & light pattern
- Uses less power
- Reduces glare and tunnel vision effect



The NIOSH LED Cap Lamp improves visibility without causing glare

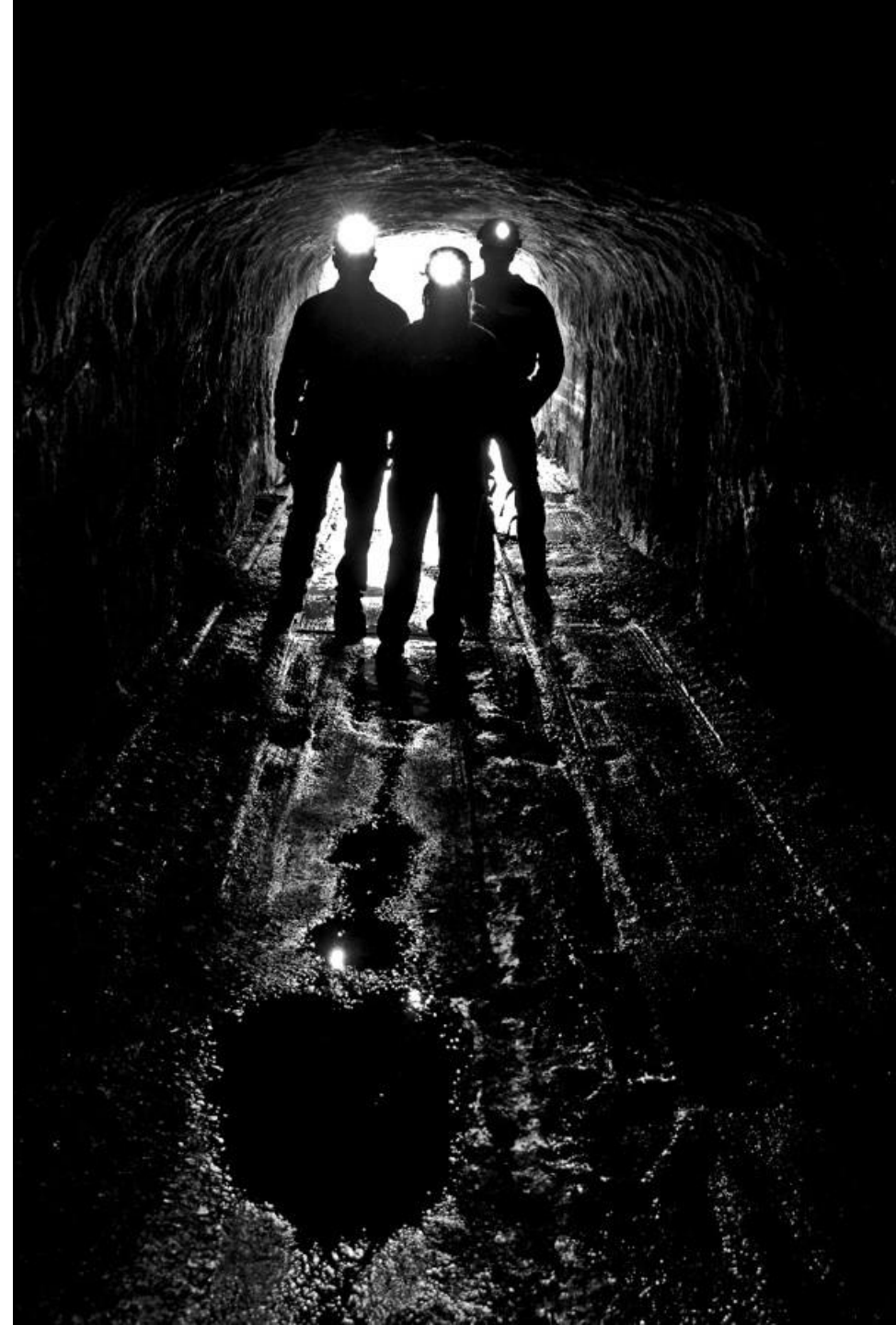


- +79% peripheral detection
- +94% floor hazard detection
- 33% to 50% less power
- No increase in glare



Topics for discussion:

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Insufficient light can disrupt circadian rhythms and lead to fatigue

- Highly dependent on the day/night cycle of light
- Underground miners work in darkness for large portions of the day making them especially vulnerable
- Majority of miners shiftwork
- Some areas and machines use “yellow” light



Insufficient light has numerous impacts on safety, including:

Decreased: {

- alertness
- productivity
- reaction time
- cognitive function

Increased: {

- accidents
- health impacts
- sensitivity to light
- fatigue



Circadian disruption can lead to severe consequences for health

Short-term: {

- Loss of sleep
- Weak immune system
- Depression

Long-term: {

- Obesity
- Diabetes
- Cancer

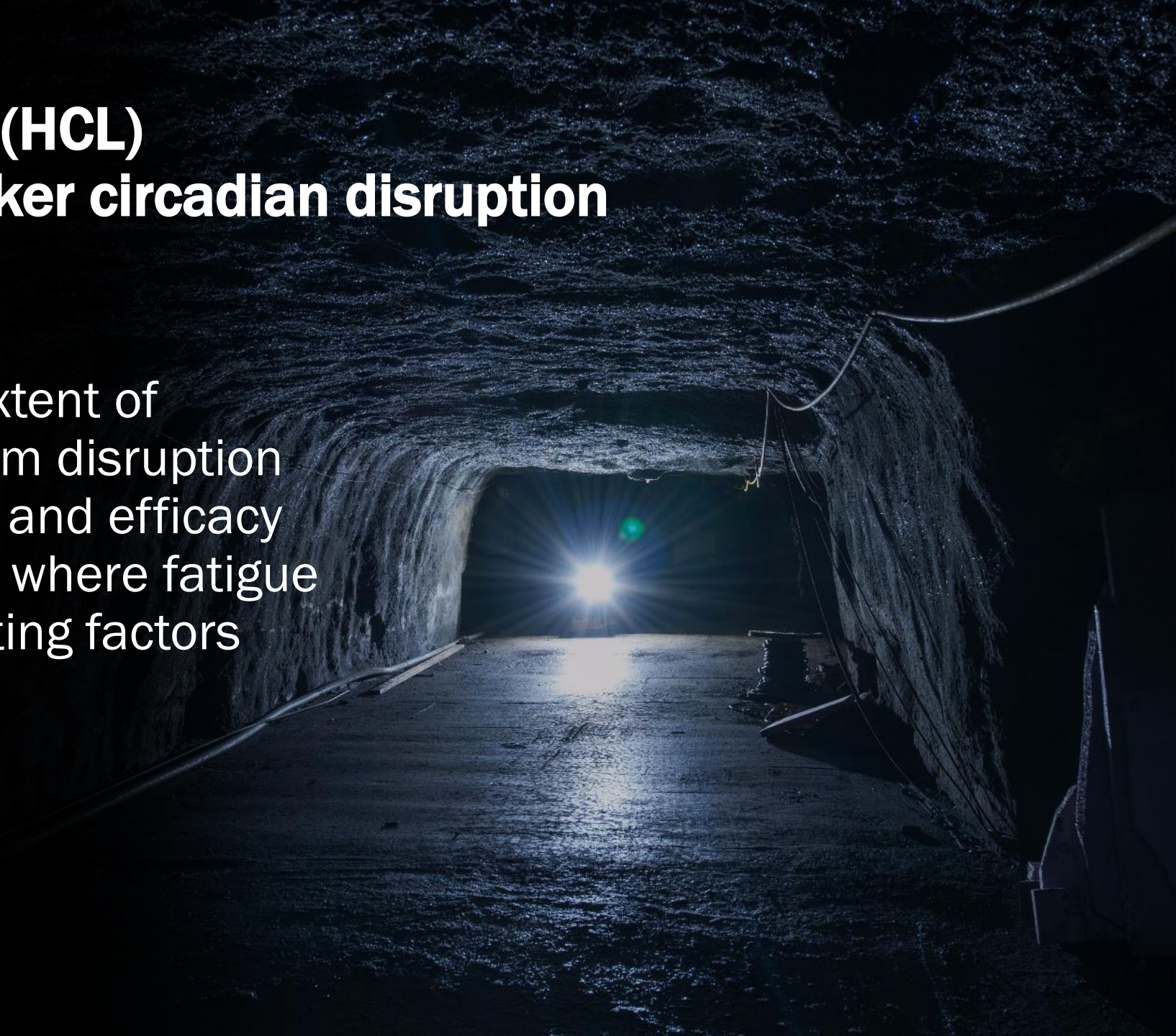


NIOSH project

Human-centric lighting (HCL)

for mitigating mineworker circadian disruption

Objective: Determine the extent of mineworker circadian rhythm disruption and evaluate the feasibility and efficacy of HCL to reduce accidents where fatigue and alertness are contributing factors



Project challenges for underground mines

- Considered one of the most challenging places to light
- Coal mines require “approved” lighting
 - Intrinsically safe, XP housings, etc.
- Unlikely actigraphy devices would be “approved”
- Difficult data collection
- Hardhat & safety glasses limit retinal illumination
- Aging of the mining workforce



Lighting is fundamental for the health & safety of underground miners

