cap lamp. Class IIIa laser diode light sources were used separately to illuminate the tags and rail. All lasers were low power (< 5 mW output) and had the following peak wavelengths: green = 532 nanometers (nm), red = 650 nm, and blue = 405 nm.

Human subject testing was conducted at the NIOSH Mine Illumination Laboratory (MIL) in Pittsburgh. Because age is a factor in illumination research, the subjects were grouped into three age categories. The MIL contains a smoke chamber and the associated test apparatuses to conduct mine illumination research in a simulated, smoke-filled environment. The smoke chamber was sealed from the outside air to contain the simulated smoke. It was also constructed to isolate the human subjects, and the researchers conducting the testing, from the smoke during the testing; thus, the human subjects were in a fresh air environment with no direct contact of their eyes with the smoke which could have caused eye irritation. A transparent window located at one end of the chamber (right side of Figure 7) enabled the subject to see into the smoke-filled chamber. Test apparatus located inside of the smoke chamber included red, blue, and green ceiling tags on a continuous chain loop mounted to the ceiling and a moving section of track on the floor. The ceiling tags and track travel towards the human subjects in the smoke to mimic the person walking (0.91 m/sec (3 ft/sec)) through a mine. Theatrical smoke was used to simulate smoke from a mine fire. Smoke density was controlled via a closed-loop control system that used an optical density sensor.

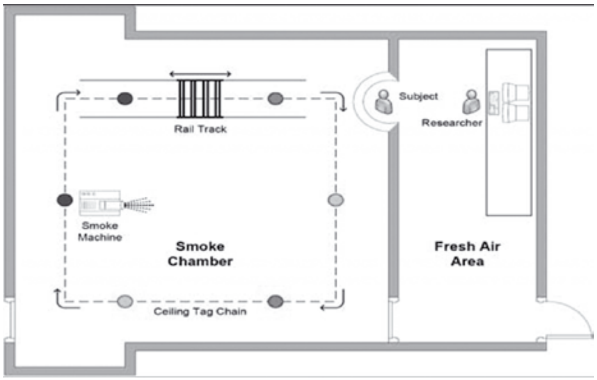

Fig. 7. Floor plan of the Mine Illumination Laboratory smoke chamber.

Subjects were instructed to stand at the clear window of the smoke chamber (Figure 7) and place their chin on a chin rest so as to enable a consistent field of view among the subjects. One subject at a time was tested. Each subject used a handheld, pushbutton device to start and stop the tests. The subjects depressed the pushbutton to start the test and released it when they detected a target (ceiling tag or rail track) approaching them in the smoke. The data acquisition system of the test apparatus then measured and recorded the detection distance between the subject and the detected object. This detection distance was used to determine visual performance where the greater distances indicated better visual performance.

Results of this study indicate rather complex relationships among the cap lamps and lasers used in smoke conditions, the type of target being detected, and the age group performing the tasks. However, while several interactions were present for many of the comparisons tested, a number of important findings can be gleaned from this study. Cap lamps were superior to lasers in all circumstances of ceiling tag detection with the exception of when using the green laser. The INC cap lamp worked best in the simulated smoke compared to the LED cap lamps for the youngest subjects when detecting the rail track; however, this benefit was not observed for the two older age groups. The INC cap lamp's color-corrected temperature is indicative of a warm-white light which will result in better color rendition that could have been apparent to only the youngest subjects. The green laser was the best color for detecting the ceiling tags and rail track compared to the red and blue lasers. The green ceiling tags were the easiest color to detect, followed by red then blue. On average, the track was easier for the subjects to detect than the ceiling tags, where the average detection distances were 2.50 m (98.48 in) and 1.88 m (73.90 in), respectively.

While several important findings emerged from this research, several limitations existed. The theatrical smoke used for the testing was a white-colored smoke which could differ from the smoke generated by some mine fires. Further, variations in the smoke due to density, particulate size, reflectivity, and color would differ from actual mine fires. Secondly, the three ceiling tag colors were selected because they are commonly used in mines. Twelve tag colors are available, so it is unknown if another color may prove to be better than green.

The potential impacts of this research could lead to new cap lamp designs and a standardization of ceiling tag colors that are the most visible in smoke. These impacts could improve miner safety and the knowledge gained could potentially cross over to benefit others such as firefighters. More research is needed given the importance and complex scientific nature of this research.

Refuge alternatives

All underground coal mines are required to provide refuge alternatives within a particular distance of the working face and at additional locations outby the faces. It is required by CFR Title 30 Part 75.1506, "Refuge Alternatives," that "At all times, the site and area around the refuge alternative shall be kept clear of machinery, materials, and obstructions that could interfere with the deployment or use of the refuge alternative [and that] The operator shall protect the refuge alternative and contents from damage during transportations, installation, and storage" (CFR, 2010). Therefore, the deployment, use, and maintenance of refuge alternatives must be addressed.

Visual inspection is used to detect and recognize hazards and conditions that could damage the refuge alternative. A miner's cap lamp is used for illumination during visual inspection; however, the cap lamp is ill-suited for the required visual tasks given the intense spot beam provided. Wide area lighting would better suit the visual inspection of the site and area around the refuge alternative. This inspection occurs on a regular basis as well as during placement. Thus NIOSH researchers are investigating auxiliary lighting that can illuminate large areas such as the mine roof. Figure 8 depicts the roof illumination for a 6.1-m-wide (20-ft-wide) entry as provided by a prototype LED area light. The prototype LED area light requires about 4 watts of power and occupies a space of 101.6 mm x 76.2 mm x 101.6 mm (4 in x 3 in x 4 in), thus enabling portability.

Gait study

Our prior research concerning balance was conducted because it factors into one's risks for falls (Sammarco et al., 2012). Balance was measured under static conditions with the test subjects standing still while looking down a narrow entry in the SRCM. The research results merited further investigation; therefore, we are conducting a gait study to explore the measures of a person's dynamic stability in an actual underground mine. Dynamic stability will be measured through kinematic variables including head angle and trunk acceleration during walking down a coal mine entry that is nominally 6.1 m (20 ft) wide. This width will enable us to overcome the limitations of having a narrow entry. We expect that the new dynamic stability data will enable greater insights into one's risks for falls, and this new gait study will overcome the narrow entry limitation of our prior research.