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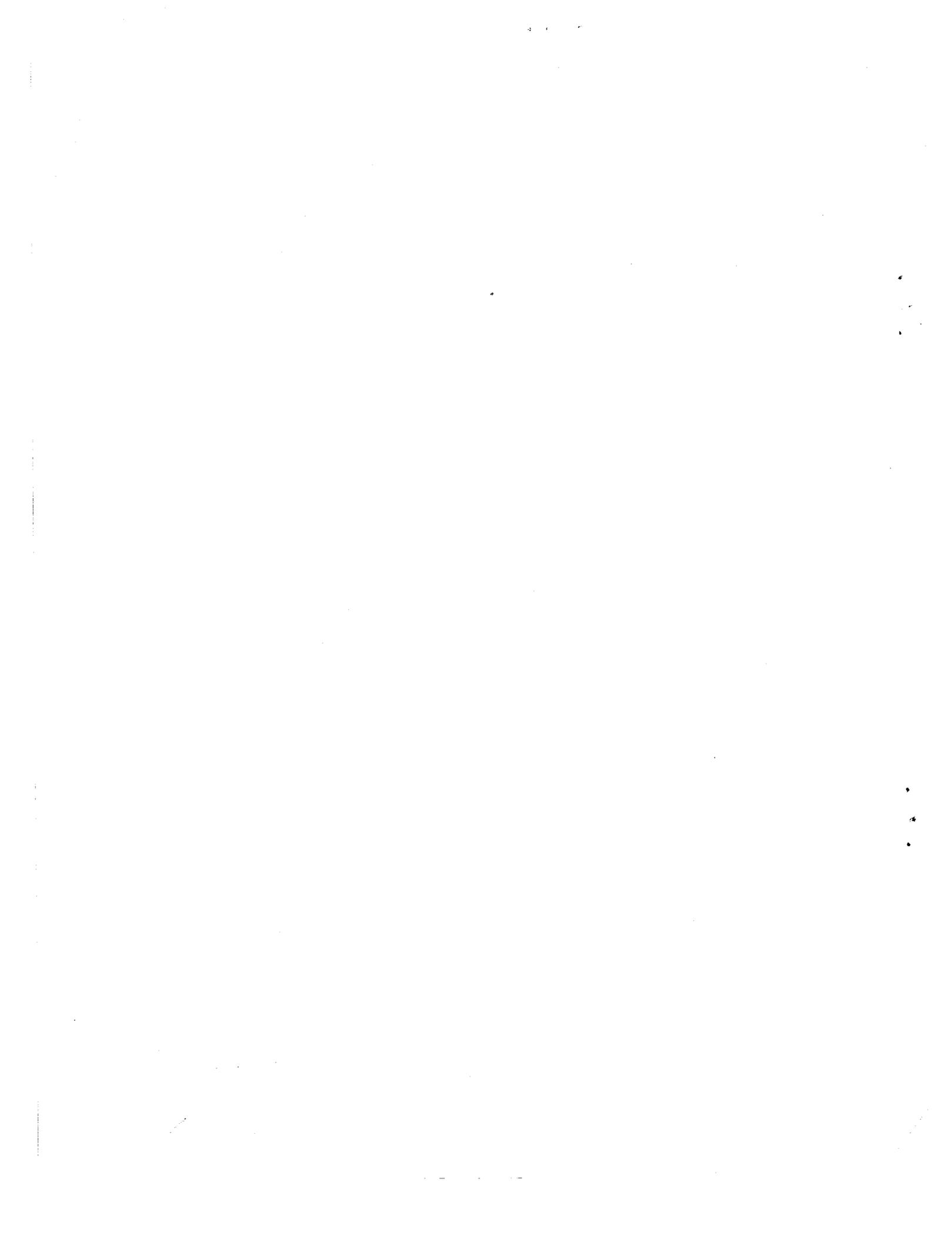
Coal Mine Health and Safety Program

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BUREAU OF MINES TECHNICAL PROGRESS REPORT

**USING HANDHELD INFRARED IMAGERS
TO LOCATE MINERS
IN SMOKE-FILLED MINE OPENINGS**

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USING HANDHELD INFRARED IMAGERS TO LOCATE
MINERS IN SMOKE-FILLED MINE OPENINGS

by

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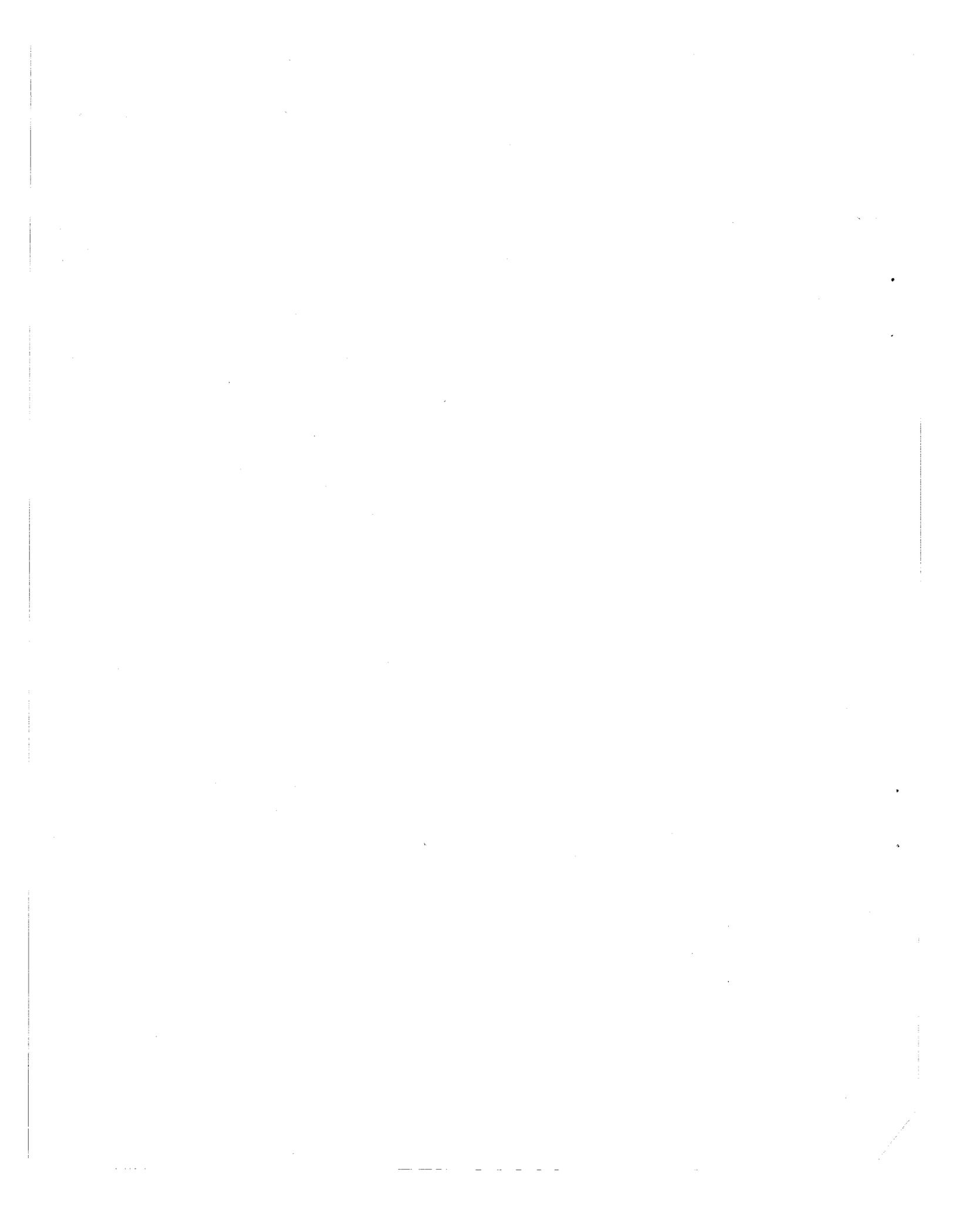
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by

Raymond M. Stateham¹ and Merle L. Bowser²

ABSTRACT

Two infrared imagers, both with a 3- to 5- μ m spectral range, were tested in a smoke-filled opening to determine their capability to "see through smoke." A mine opening 75 meters long was filled with coal smoke. A fire in a smoke generator and two men were used as targets. The men were detected and identified at 75 meters. Tests were discontinued on the fire because the instruments were saturated with the fire at 25 meters, indicating that fire could be detected at much greater distances. Because of their ability to "see through smoke," infrared imagers should be useful during rescue operations in smoke-filled mines.

INTRODUCTION

Infrared instruments have been evaluated as possible tools for postdisaster, mine rescue applications in coal mines. The tests were conducted in the Bureau of Mines Experimental Mine, Bruceton, Pa., as part of the Bureau's ongoing program of developing new techniques to improve safety in coal mines.

The feasibility of using portable infrared instruments to detect many mine-related hazards has been conclusively demonstrated in previous studies (1-6).³ These mine-related hazards include loose rock (1-2, 4), misfires (1, 6), fires in dumps (1, 3, 6), and potential combustion in underground mines (5). Although Merrill and Stateham suggested in 1972 (1) that infrared techniques might be used to detect lost or injured miners, this investigation was the first work done toward developing these techniques for use in smoke-filled openings.

GENERAL CONSIDERATIONS

Rescue teams that enter mines soon after fires and explosions often encounter dense smoke. The smoke reduces visibility to near zero, and the

¹Geophysicist.

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³Underlined numbers in parentheses refer to items in the list of references at the end of this report.

objects the rescue teams seek, whether men or even fire itself, may be hidden by the smoke. Some instrument or technique is needed whereby better visibility through smoke can be obtained. Efforts to achieve this increased visibility by means of more powerful lights have generally failed because the light must travel through the smoke to the target. Difficulties in transmission that are associated with scattering (and perhaps absorption) of the light by particulate matter in the smoke prohibit visual observation of the desired targets.

Infrared imagers were evaluated for use in a smoke-filled environment because they are passive instruments. Their utilization does not require the use of a lamp to illuminate the target. Rather they receive only the infrared energy (radiant energy) emitted by the target in the spectral range of the imager. By eliminating the use of a lamp, the travel path of radiant energy between the observer and the target becomes one-way, and the effect of transmission problems is reduced. Potential gains in transmission efficiency due to the longer infrared wavelength (Rayleigh scattering) were not theoretically evaluated because of the limited time span of study, and the scope of the investigation was limited to the use of infrared instruments in smoke-filled environments.

INSTRUMENTATION

Two different instruments were used during this investigation. Both instruments detect temperature differences within their field of view; from the electrical analogs of these differences they develop real-time images of the targets observed.

Handheld Infrared Scanner

The first of these instruments (fig. 1) is a third-generation model of a military instrument originally designed for use as a night vision device. This instrument is permissible for use in coal mines (Approval No. 2G-2614).

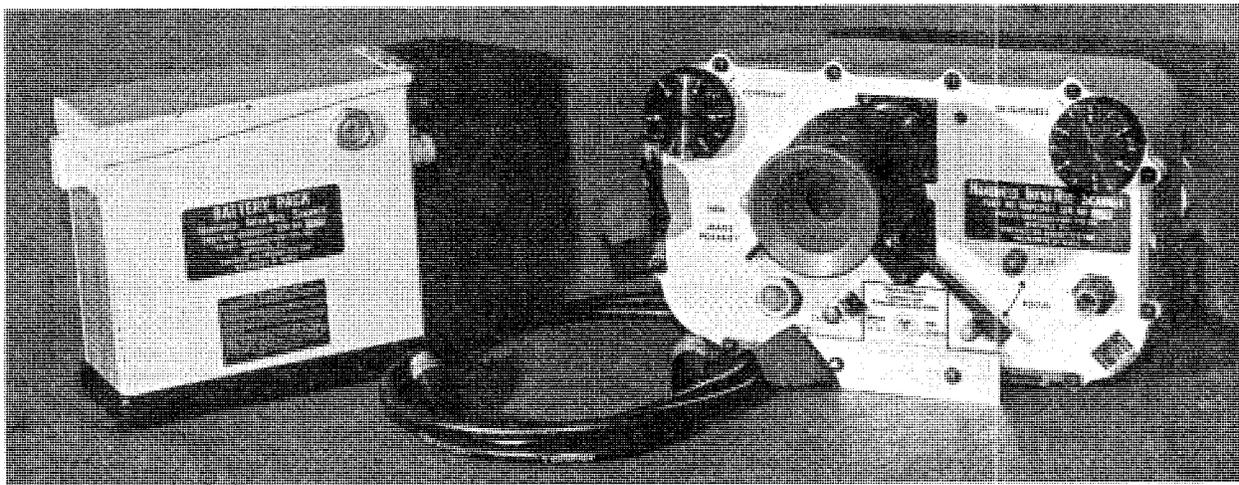


FIGURE 1. - Bureau of Mines handheld infrared scanner with battery.

It was manufactured to Bureau specifications by Philips Broadcast Equipment Corp.⁴ through a contract with the U.S. Army's Night Vision Laboratory, Ft. Belvoir, Va. This unit was named the handheld infrared scanner (HIS) by the contractor; it is small, lightweight, and battery powered. Consequently, it is extremely portable and can be used in any location accessible to man.

Thermoelectrically cooled lead selenide detectors provide an overall sensitivity of less than 0.2° C. A one-to-one relationship between the 48 detectors and 48 light-emitting diodes (LED's) permits development of a real-time image without the use of a multiplexor for signal synchronization.

Some of the technical characteristics of the instrument follow:

System:

Field of view.....6° vertical by 12° horizontal
Resolution.....2 mr by 2.08 mr (milliradians)
Frame rate.....20 frames per second

Optics:

Objective lens focusing range.....0.5 m (meter) to infinity
Eyepiece.....±4 diopters
Spectral region.....3 to 5 μm (micrometers)

Detector:

Type.....Pb-Se (linear array)
Number of elements.....48

Electronics and display:

Channels.....48
Display.....48 LED's (linear array)

Battery:

Number of batteries.....2
Type.....Silver zinc
Output voltage.....6 volts

Scanner dimensions.....3.5 by 5.5 by 10 inches

Weight:

Scanner.....6 pounds
Battery.....5 pounds

Design specifications require that the instrument detect a man at 50 meters with sufficient resolution that the target, when viewed on the display, can be identified as a man. In actual usage, the instrument exceeds this requirement.

⁴Reference to specific makes or models of equipment is made to facilitate understanding and does not imply endorsement by the Bureau of Mines.

Probeye

The second instrument (fig. 2) used in this investigation, the Hughes Probeye, has excellent portability. The Probeye uses 6 photovoltaic indium antimonide (PV - InSb) detectors with a 10-sided rotating mirror to produce a real-time image on light-emitting diodes (LED's) by means of a 10 to 1 interlace. Argon gas is used to cool the detectors.

Some of the technical characteristics of this instrument follow:

System:

Field of view.....7.5° vertical by 18° horizontal
 Resolution.....2.2 mr by 2.2 mr (milliradians)
 Frame rate.....15 frames per second
 Interlace factor.....10

Optics:

Focusing range.....2 m (meters) to infinity
 Spectral region.....3 to 5 μ m (micrometers)

Detector:

Type.....PV - InSb
 Number of elements.....6

Electronics and display:

Channels.....6
 Display.....LED's

Scanner dimensions.....4 by 9 by 8 inches

Weight of scanner (including argon
 bottle and batteries).....7.5 pounds

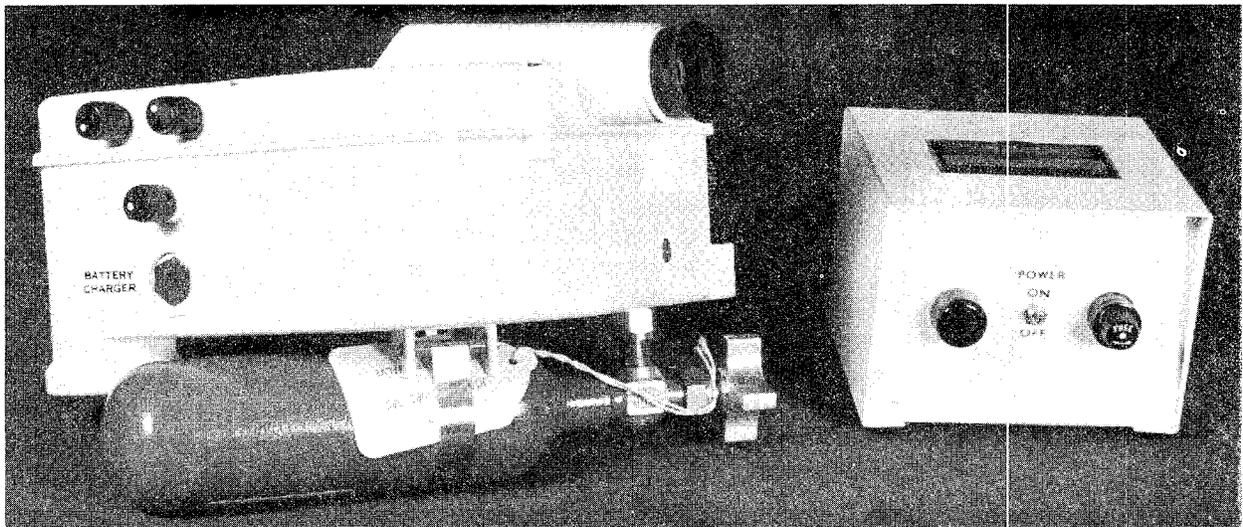


FIGURE 2. - Probeye with battery charger.

The nickel-cadmium batteries used by this instrument are contained inside the instrument housing, thereby eliminating a belt pack with associated cables.

TEST SITE

The Bureau of Mines Experimental Mine (underground laboratory) is located near Bruceton, Pa., and is within the Pittsburgh coal seam. The portion of the mine that is normally used in explosive testing was selected for these tests because of extra support and coating of the underground surfaces to exclude dust explosions. The portal of the opening was faced and lined with formed concrete that was sprayed or blown onto the surface. A lattice of steel had been incorporated into the roof lining to provide support. An additional reason for choosing this location was the fact that large volumes of fresh air could be made to flow through the test area and out the portal, thereby preventing contamination of the rest of the mine with smoke.

Figure 3 is a sketch of the test site, showing dimensions, direction of the airflow, and the source location from which the smoke was generated.

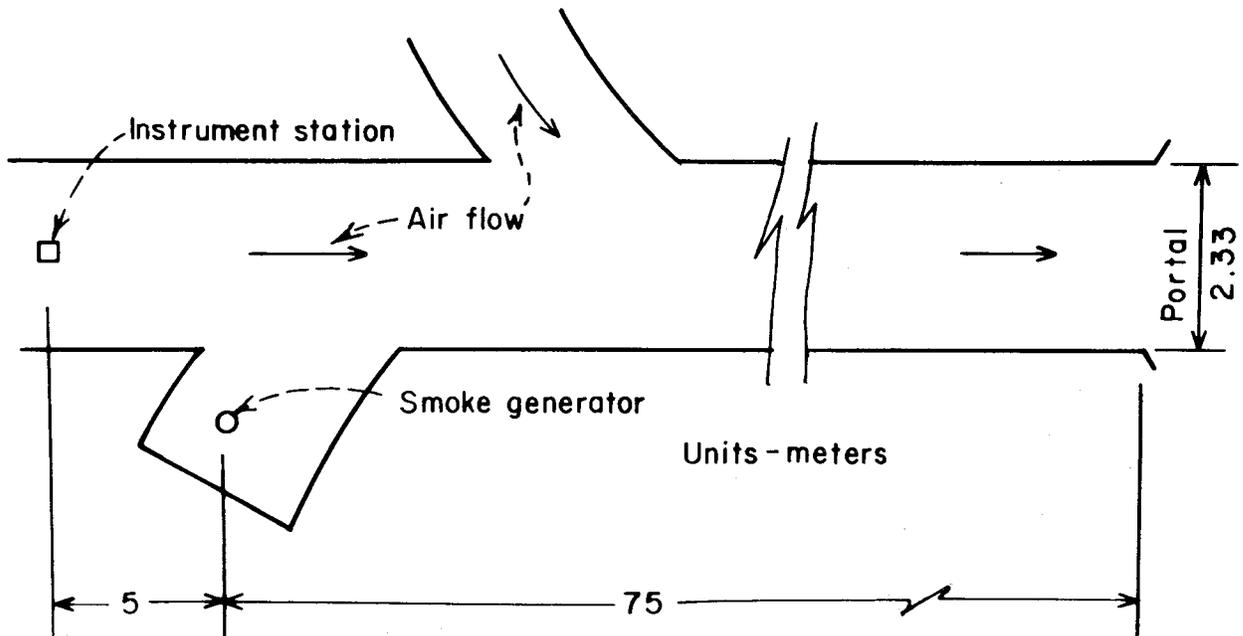


FIGURE 3. - Test site.

PROCEDURES AND RESULTS

All the procedures used in the study, whether designed to test the capability to detect men or to detect fire, required that the mine opening be filled with smoke. For this reason, a smoke generator was improvised by covering the bottom half of an oil drum with brick and burning coal (from other sections of the mine) in the drum. This burner provided ample quantities of dense smoke.

To test the capability of the instruments to detect fire through the smoke, the generator was placed on a flat car and pulled into the mine by a locomotive (fig. 4). For this test, the observers remained outside the portal

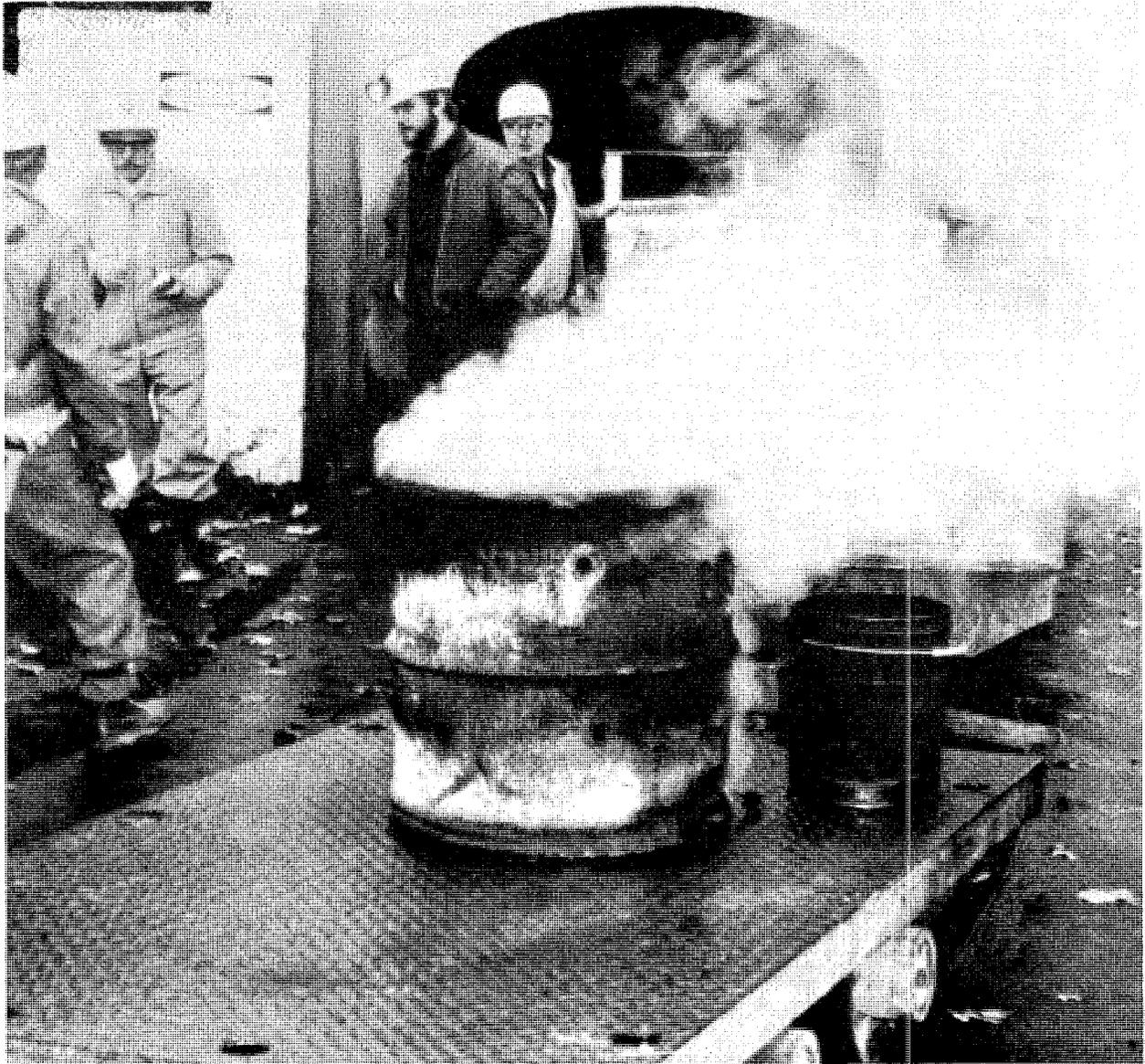


FIGURE 4. - Smoke generator on the flat car.



FIGURE 5. - Man wearing breathing apparatus used in the test.

the portal. The instrument station or location from which the infrared imagers were used was about 5 meters beyond the smoke generator in the main

and looked into the opening. Visual observation of the fire from the generator was impossible beyond 5 to 6 meters through the smoke. When the generator had penetrated to about 25 meters in the opening, the locomotive was stopped. At this distance the radiant energy was so great that the signal strength in the 3- to 5- μm range tended to overdrive or saturate the instruments even at the least sensitive settings. It was obvious that the fire was going to be detected by the instruments at relatively great distances (greater than could be used in this test). Two men wearing Bureau-approved breathing devices (fig. 5) entered the opening and walked to the generator. When the men were between the imagers and the fire, they could be seen on the instrument display because the men were colder than the fire (in the smoke generator). When the men were beside the fire, they were in the same field of view as the fire and generally could not be observed because the instruments were saturated by the heat of the fire.

In the tests that followed, the smoke generator was placed in an offset from the main opening (fig. 3), and an instrument station was established farther into the opening from the generator. As shown in figure 3, the generator was about 75 meters into the opening from

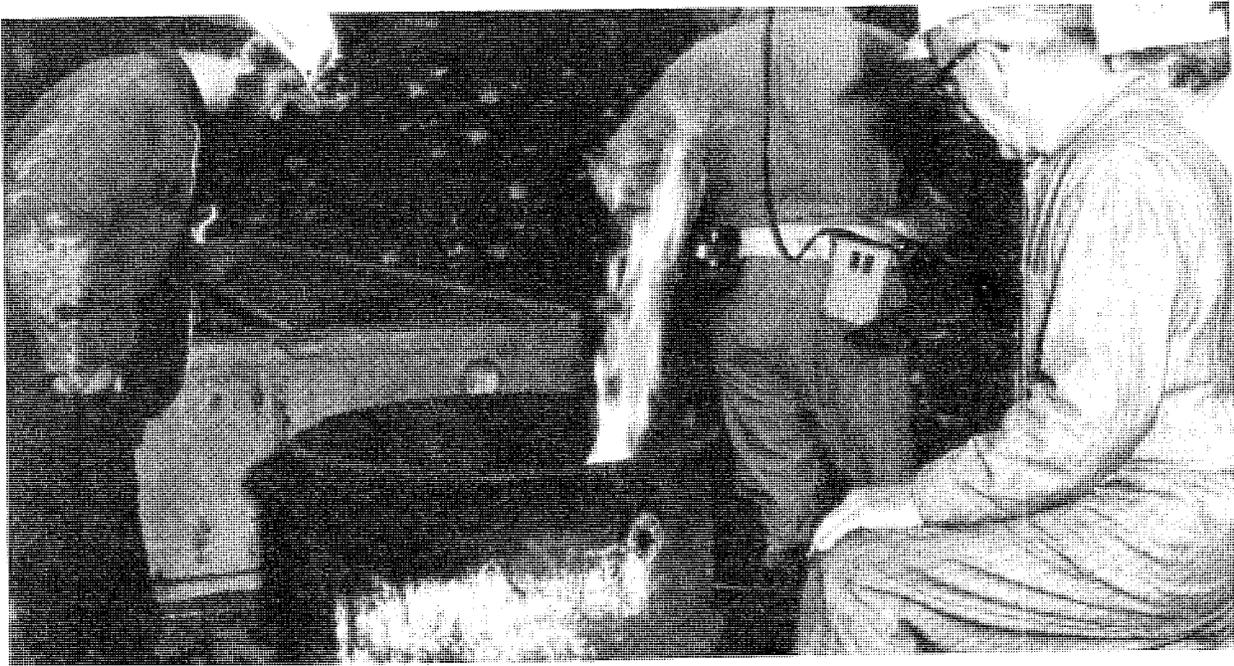


FIGURE 6. - Smoke generator being ignited.



FIGURE 7. - Smoke beginning to fill the opening.

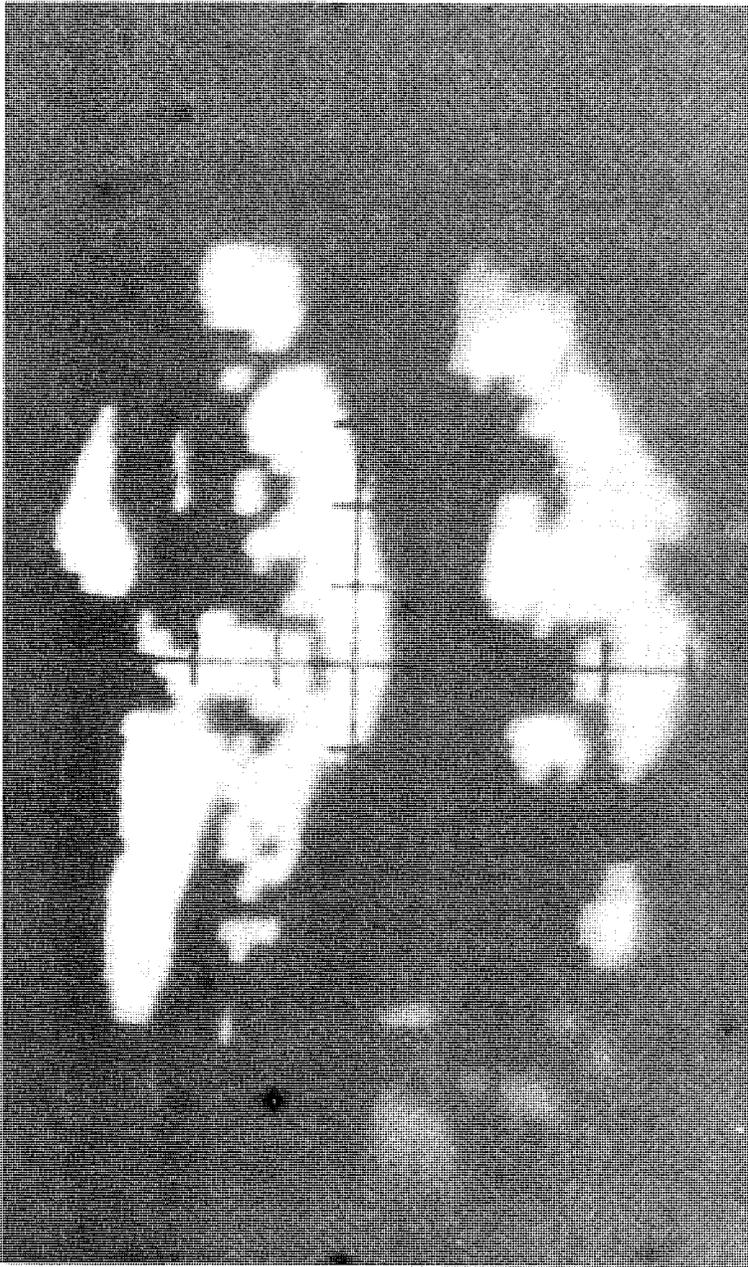


FIGURE 8. - Infrared image of two men 20 meters into the smoke.

infrared image of the two men as seen by the permissible scanner (HIS) when the men were 20 meters into the smoke. One of the men had his back to the instrument; the other presents a side view to the instrument and is partially shielded by the breathing device he wears.

opening. Figure 6 shows the smoke generator being ignited, and figure 7 shows the smoke beginning to fill the mine opening. When the opening had been filled with smoke, two men wearing breathing apparatus were again used as targets for the imagers; they moved from the instrument location, through the smoke, to the portal and returned through the smoke to the instrument location.

Although the airflow was moving the smoke out of the opening, the smoke concentration was dense, and the men could not be visually detected after they had gone about 4 to 5 meters into the smoke. With the imagers, it was possible to detect men at the portal (through about 75 meters of dense smoke). The image on the Probeye could be identified as two men at a distance of 30 to 35 meters. Beyond that distance, the image was two strong infrared targets that were unidentifiable. By using the Bureau-developed imager (HIS), it was possible to identify the targets as men at the full 75 meters through the smoke, though the targets were poorly defined. At 50 meters, definition of the images was good. Figure 8 shows an

CONCLUSIONS

The following conclusions can be drawn from the results of the investigation.

First, infrared imagers with a spectral range of 3 to 5 μm can detect men at distances of about 75 meters through very dense coal smoke.

Second, heat from the source of the smoke can also be detected through the smoke at distances of at least 25 meters. Because the fire creating the smoke is a much greater heat source than a man, it can be assumed that the fire could be detected at much greater distances than the 75 meters over which the two men were observed.

Judging by these findings and considering their portability and their ability to "see through smoke," the imagers should be useful tools in rescue and recovery operations following mine fires or explosions.

RECOMMENDATIONS

Infrared imagers show significant potential for use in postdisaster, mine rescue applications. They could be carried in mine rescue vehicles if such vehicles were available, but more importantly they can be worn or carried by a member of the mine rescue team. It is recommended that further studies be made to determine the optimum features of instruments intended solely for mine rescue application; for example, a binocular or open display might be preferable to the presently used monocular eyepiece and might be more easily used by operators wearing breathing apparatus. It is further recommended that instruments with the optimum features be stored and kept ready for use at suitable locations in case of disaster.

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