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Inspection of Contaminated Hot Cell Ductwork

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OPERATED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

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Instrumentation and Controls Division

INSPECTION OF CONTAMINATED HOT CELL DUCTWORK

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ABSTRACT

Radiation Sterilization, Incorporated (RSI), of Dekalb County, Georgia, has used Cesium-137 radiation sources for sterilization of medical instruments and other commercial items. The cesium is contained in welded stainless steel capsules. One of these capsules has leaked, allowing the cesium to escape and to contaminate the internals of the sterilization cell including the cell ventilation ductwork penetrating the thick concrete cell roof.

This ductwork requires decontamination prior to release of the facility to resume sterilization activities. Due to the small size (20-in. × 24-in. cross section) and the long runs embedded in the cell roof, it was determined that remote visual inspection and preliminary radiation mapping of this ductwork was necessary. This report covers the inspection effort and evaluation of the results.

I. INTRODUCTION

Radiation Sterilization, Incorporated (RSI), of Dekalb County, Georgia, has used Cesium-137 radiation sources for sterilization of medical instruments and other commercial items. The cesium is in the form of a salt (CsCl) contained in welded Type 316 stainless steel capsules. One of these capsules has leaked, allowing the cesium to escape and to contaminate the internals of the sterilization cell including the cell ventilation ductwork penetrating the thick concrete cell roof.

The embedded cell ductwork requires decontamination prior to release of the facility to resume sterilization activities. Due to the small size (20-in. × 24-in. cross section) and the long runs embedded in the cell roof, it was determined that remote visual inspection and preliminary radiation mapping of this ductwork was necessary prior to determination of the method of decontamination to be employed. Important considerations were (1) was the ductwork 100% metal lined, (2) what was the condition of the metal lining that was present, and (3) what was the extent of the contamination problem. An activity was undertaken, led by Oak Ridge National Laboratory (ORNL) personnel, to identify a commercially available remote inspection vehicle and to equip it with the necessary attachments to perform the required inspection. This report covers these inspection efforts and evaluation of the results.

II. SUMMARY OF INSPECTION ACTIVITIES

A. CAMERA CRAWLER ASSEMBLY SELECTION AND PREPARATION

At the beginning of the inspection effort, little was known about the internals of the heating, ventilating, and air conditioning (HVAC) ductwork at the RSI facility. The original assumptions regarding the physical layout were taken from a 1983 drawing (Fig. 1), which shows the expected duct details. No as-built drawings of the facility were available to confirm this layout. In addition, the levels of contamination were unknown, and it was possible that personnel barriers were installed within the ductwork. Consequently, it was decided that the inspection should be performed by a remotely controlled vehicle with integral television camera and lighting.

After thoroughly surveying available equipment, a camera-crawler assembly (CCA) supplied by PLS International of Cleveland, Ohio, was selected for the inspection effort. This vehicle is shown in Fig. 2, along with the radiation detector provided by ORNL. As may be seen in the figure, four lights are built into the CCA around the camera lens to illuminate the area being viewed and videotaped.

Primary criteria for selection of the CCA were as follows:

- Small enough to negotiate the embedded ductwork with ease.
- Steerable to allow flexibility during the inspection.
- Onboard color TV camera with remotely controlled lens focus and mirror.

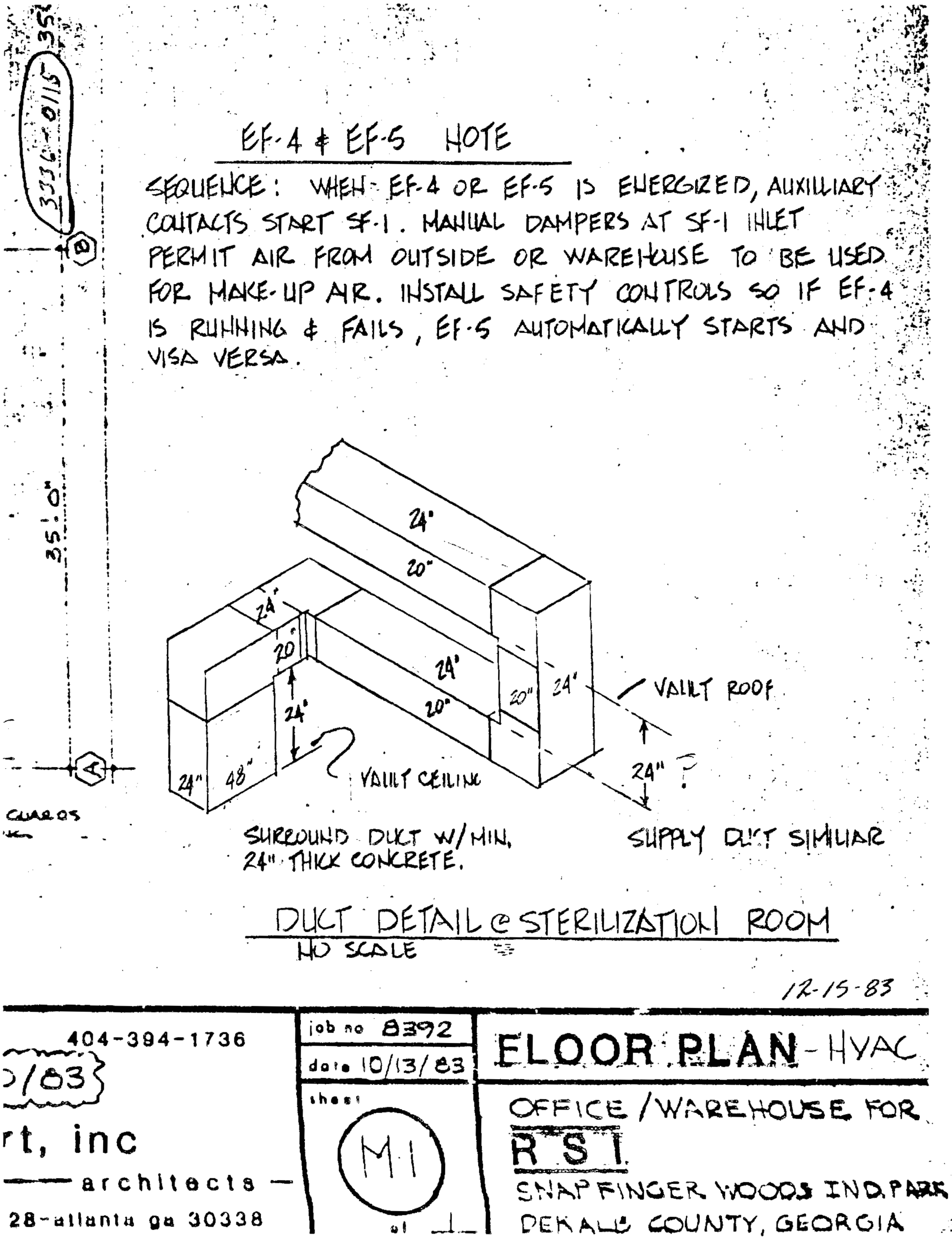

Fig. 1. Original 1983 drawing of duct.

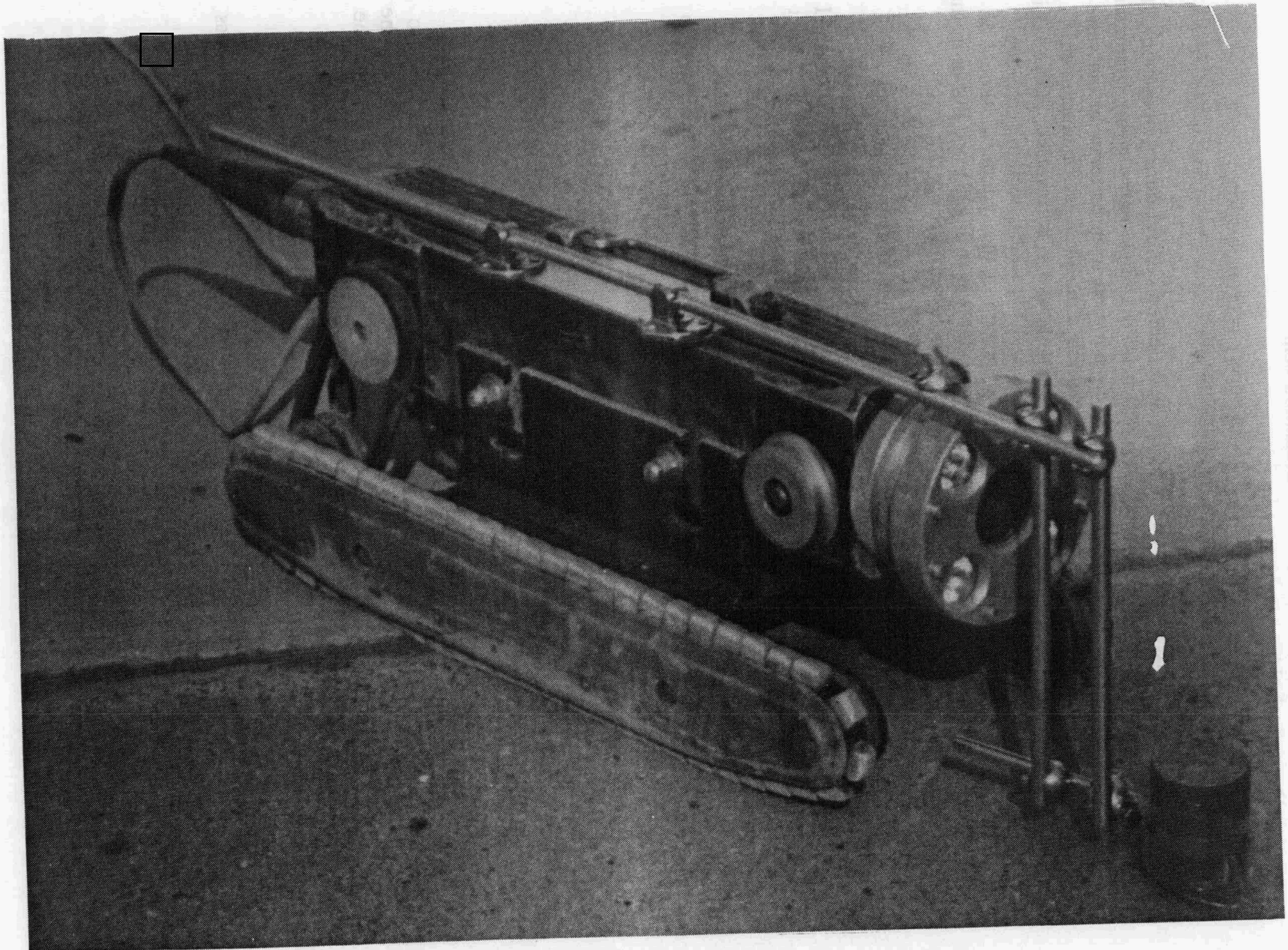

Fig. 2. Camera crawler assembly used for duct inspection.

- Controllable from outside the sterilization cell.
- Decontaminable.
- Capable of carrying significant loads of survey instrumentation.
- Available with an inspection service agreement.

This CCA system utilizes dual track drives for skid-steered control during operation. It is designed to inspect pipes and ducts up to 450 ft from a single entry, giving continuous distance measurements as it travels. It is remotely powered from batteries in the van that also houses the inspection personnel. A remotely controlled mirror attachment enables inspection of the entire inside of the duct or pipe as it is traversed. Figure 3 is a cutaway view of the actual duct, showing the CCA in the fourth section (counting from the bottom to the top). Figure 4 is a block diagram of the system. It should be noted that there is an additional section of ductwork (shown in Fig. 3) not shown in the original design depicted in Fig. 1. The difference is discussed in Sect. IV.

The first portion of the inspection was performed using the CCA fitted with a beta-gamma radiation detector supplied by ORNL. ORNL personnel installed the detector on the CCA and calibrated it using a Technetium 99 source supplied by CNSI (see Sect. IV). The floor of the duct was to be inspected first, so the detector was set to face downward, end-window style, about 0.5 in. from the floor. The detector was later repositioned to inspect the walls.

After installation of the detector, the vehicle and its cable were sheathed and taped so that decontamination could be accomplished without the loss of either one. Overall preparations and setup entailed more than one-half day of effort.

B. INSPECTION ACTIVITIES

1. Duct Contamination Measurement

Detector readings were taken from the floor and sides of the longest section of the duct, which was ~6 ft long. These readings ranged from ~20,000 counts/min (CPM) to ~80,000 CPM for different locations. As was expected, the higher readings were on the floor of the duct. Due to the detector calibration efficiency of 5.0% at 0.5 in. from the radiation source (see Sect. III), these readings correspond to ~400,000 disintegrations/min/in.^{2} (DPM/in.^{2}) to ~1,600,000 DPM/in.^{2} from the surface contamination in the ductwork for an area approximately the size of the detector (1.125 in. diam). These conversions use the known calibration source as the standard. Since at least 400,000 DPM/in.^{2} were uniformly present throughout the duct area, it was felt that there was no further need for radiation readings in the ductwork and that ductwork decontamination would be required. Details of the readings are given in Sect. III.

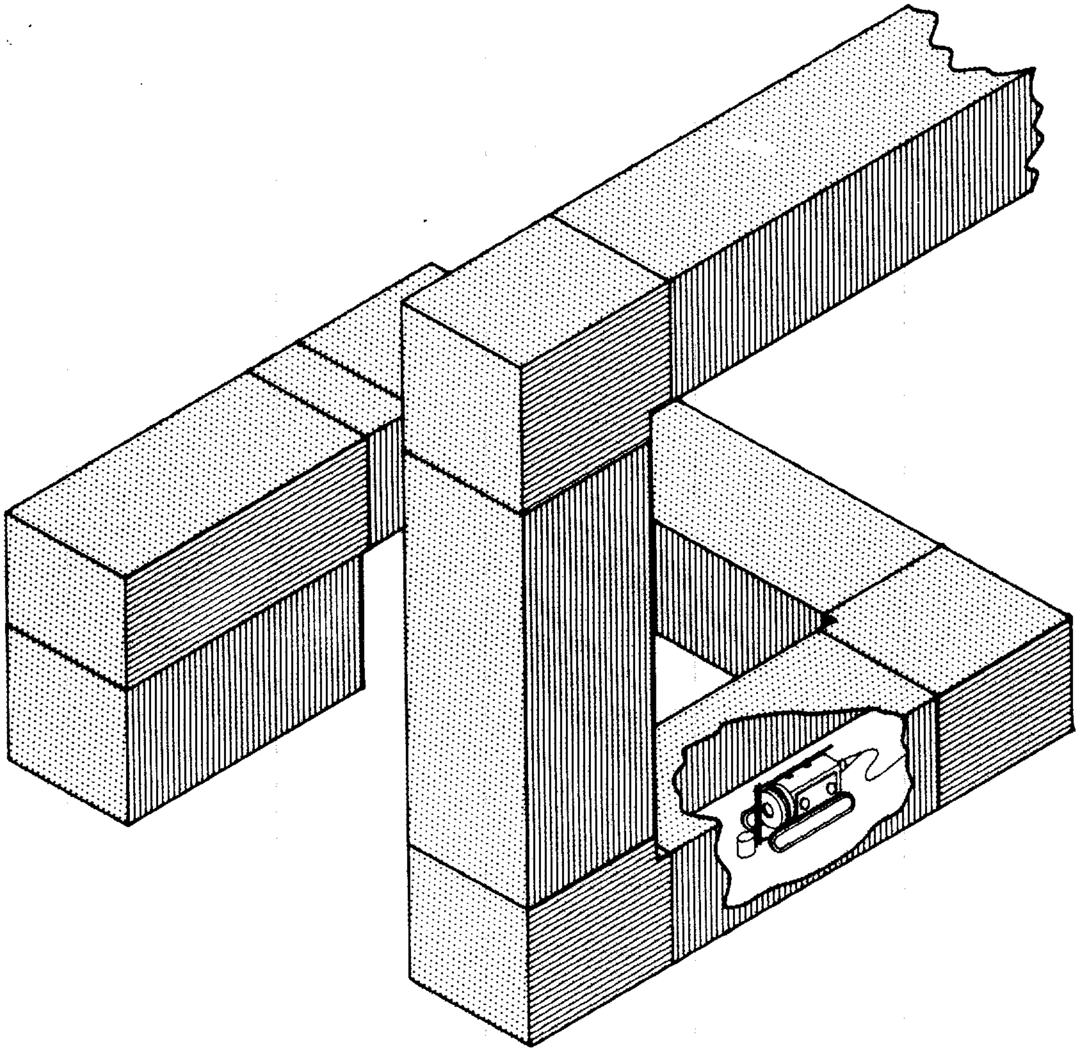

Fig. 3. Cutaway view of camera crawler assembly in duct.

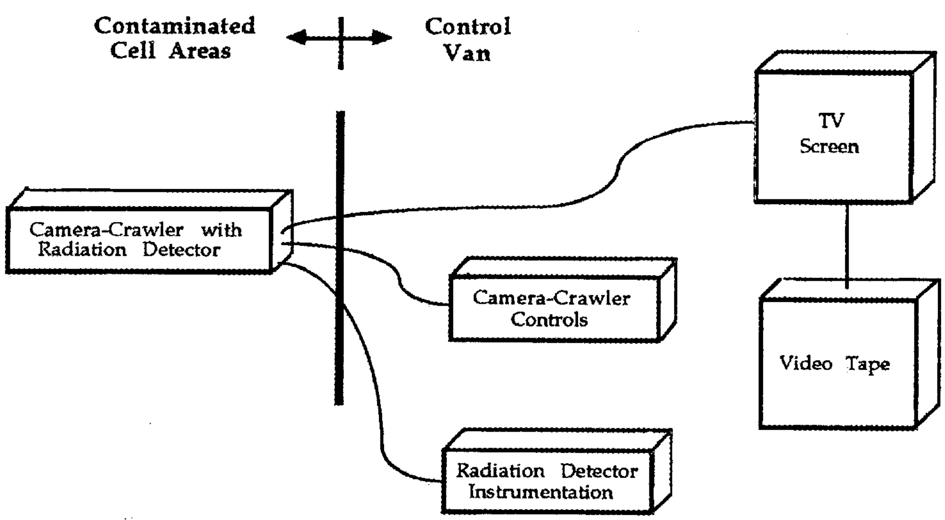

Fig. 4. Block diagram of inspection equipment.

2. Inspection for Surface Continuity and Metallic Nature

Several wooden 2x4s in the ductwork, probably installed for bracing during construction, had to be removed to allow the CCA to traverse the ductwork. One of these was removed from the end of the duct using a wrecking bar. However, one section of the ductwork not shown in the available prints was inaccessible from the duct entrance (see Sect. IV); two 2x4s in this section had to be removed. A CNSI worker was triple-suited with a respirator to allow him to crawl into the ductwork to remove them.

While inside the ductwork, the suited CNSI worker visually inspected the surfaces for cracks or other flaws in the metal lining of the duct. He also checked the surfaces to determine their ferromagnetism and, therefore, their metallic nature. He reported that the top, sides, and bottom of the ductwork were uniformly magnetic and that there were no cracks or breaks in the metal lining of the ductwork. He also reported that the section of ductwork not shown on the drawing (see Sect. IV) had the same dimensions as those of the section before it.

The CCA was equipped with a remote-controlled mirror attachment with the mirror mounted at a 45° angle to the direction of travel. This feature enabled the mirror to rotate so the camera could "see" in any direction perpendicular to the direction of motion so as to inspect the duct wall. It was found that the welded seams in the ductwork looked uniformly satisfactory (see Figs. 5-8). Some small surface rusting was seen where the welding had melted the zinc away from the weld junctions (see Fig. 8), but no other problems were seen. The mirror was also used to look upward in the vertical section of the duct (see Figs. 9a and 9b). A magnet was lowered on a string through that section of the duct to check its four sides for ferromagnetism (see Fig. 10). That duct also was found to be uniformly ferromagnetic.

A rod was fastened to the CCA with a magnet tied to it such that the magnet was visible to the video camera. The sides and bottom of the duct were inspected by watching the magnet stick to the ferromagnetic sides (see Figs. 11-14). The top of the ductwork was not directly inspected in this way but, as noted previously, the roof was partially inspected by the worker who crawled into the ductwork. Visual inspection established continuity of the ceiling with the sides (see Fig. 15), showing the uniform metallic nature of the ductwork.

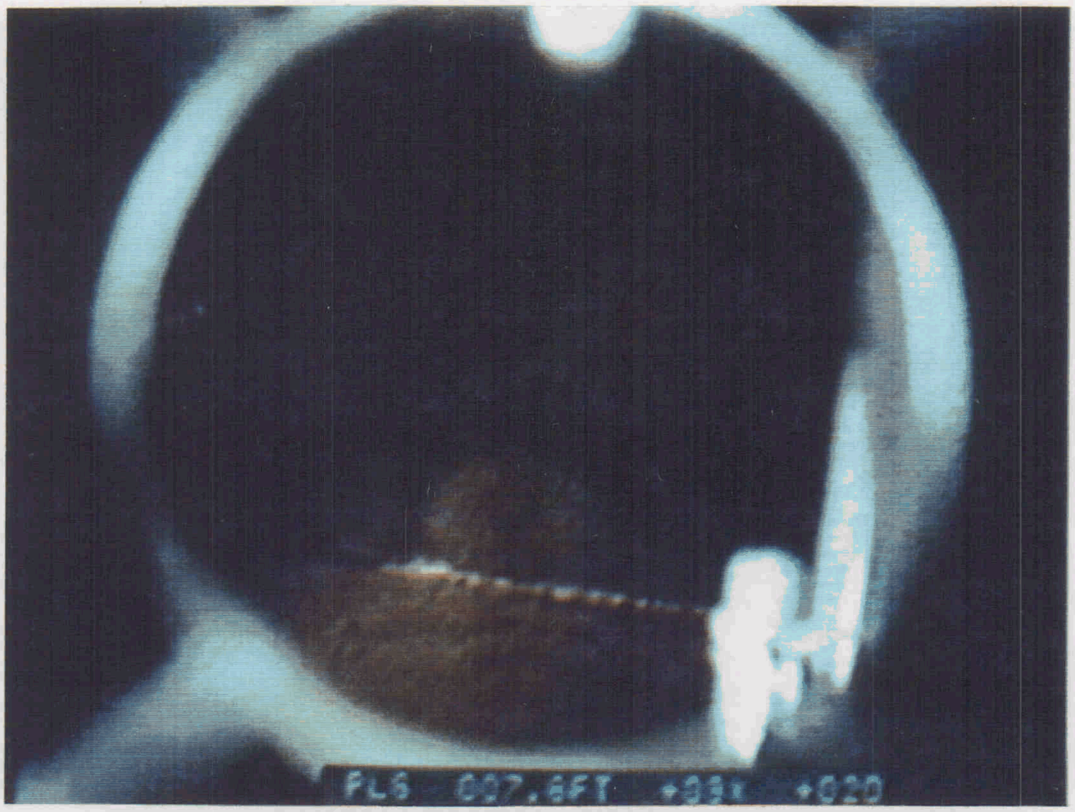

Fig. 5. Welded seam on duct corner in Sect. 3.

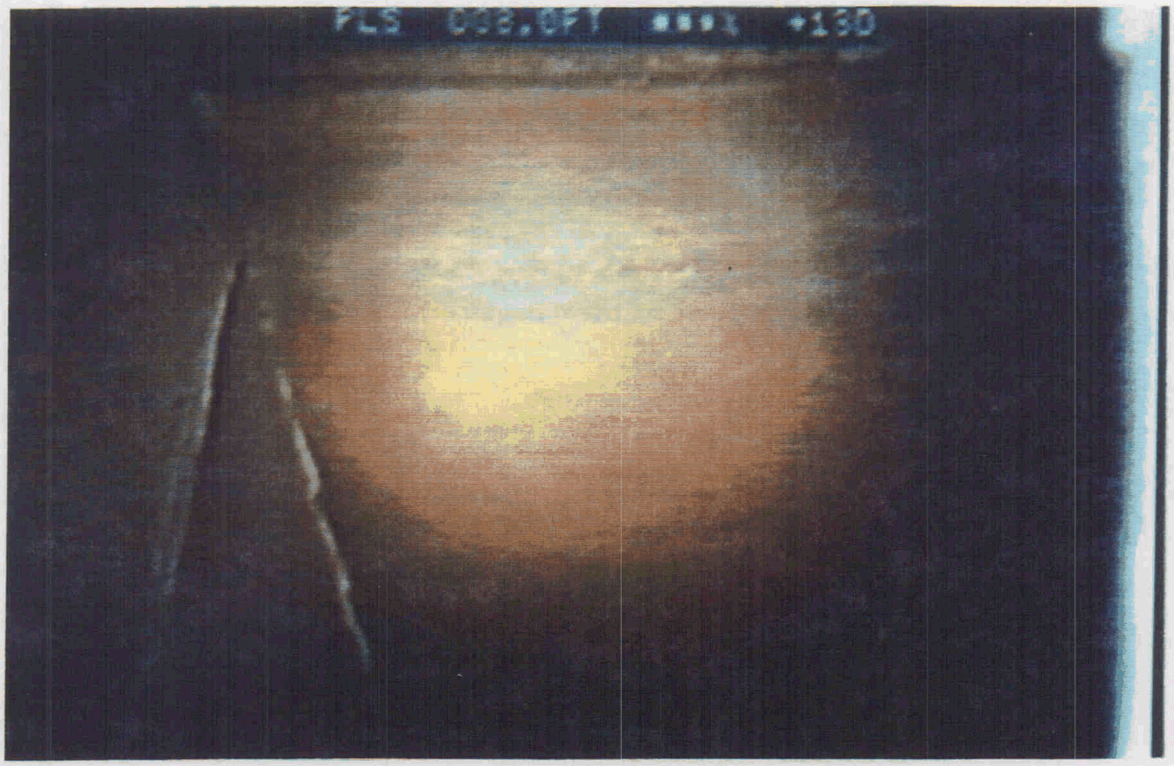

Fig. 6. Inside view of welded seams on Sect. 3 wall and roof.

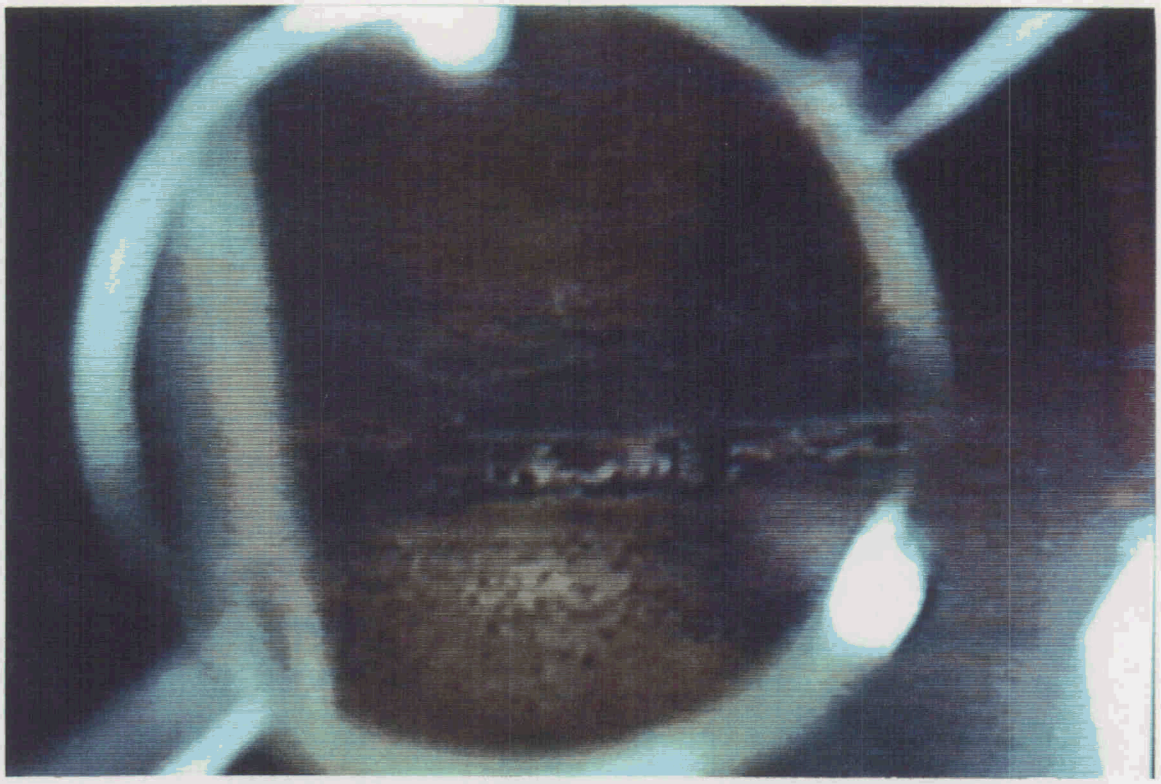

Fig. 7. Welded seam in roof corner of duct with caked dirt on wall.

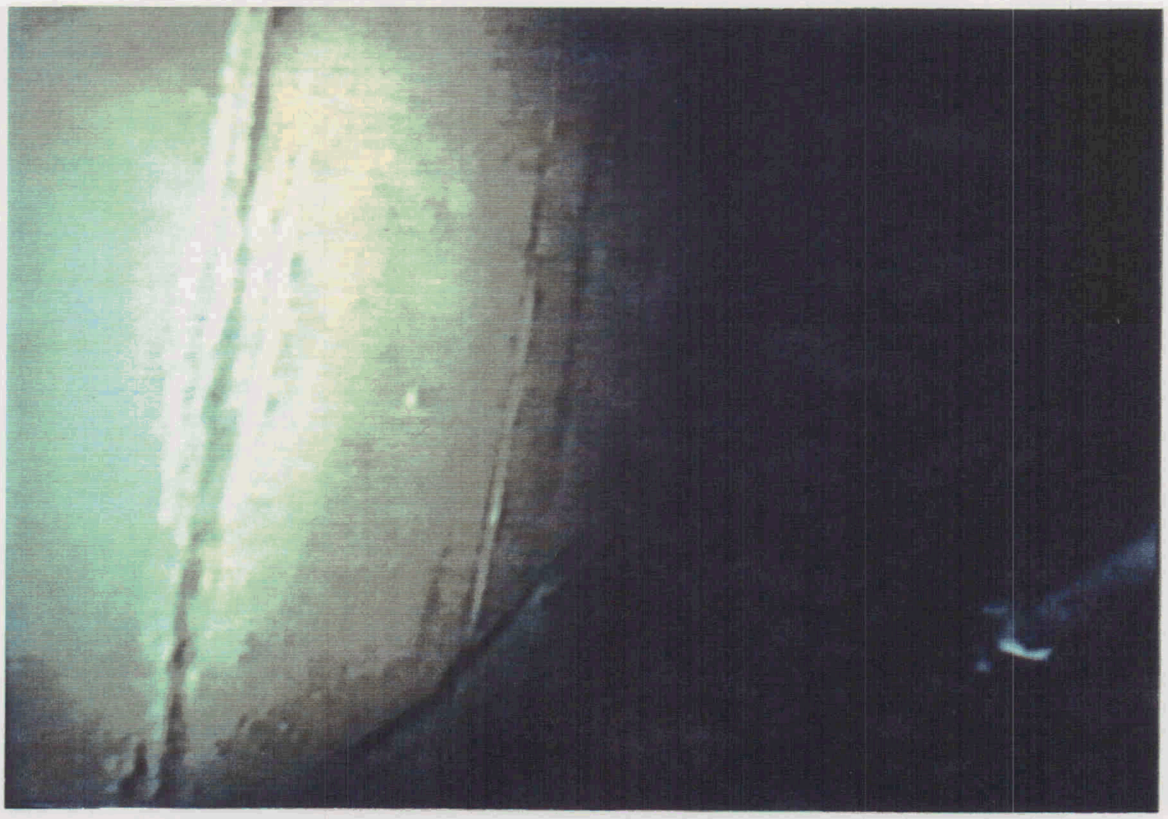

Fig. 8. Welded seam with zinc coating melted back from joint.

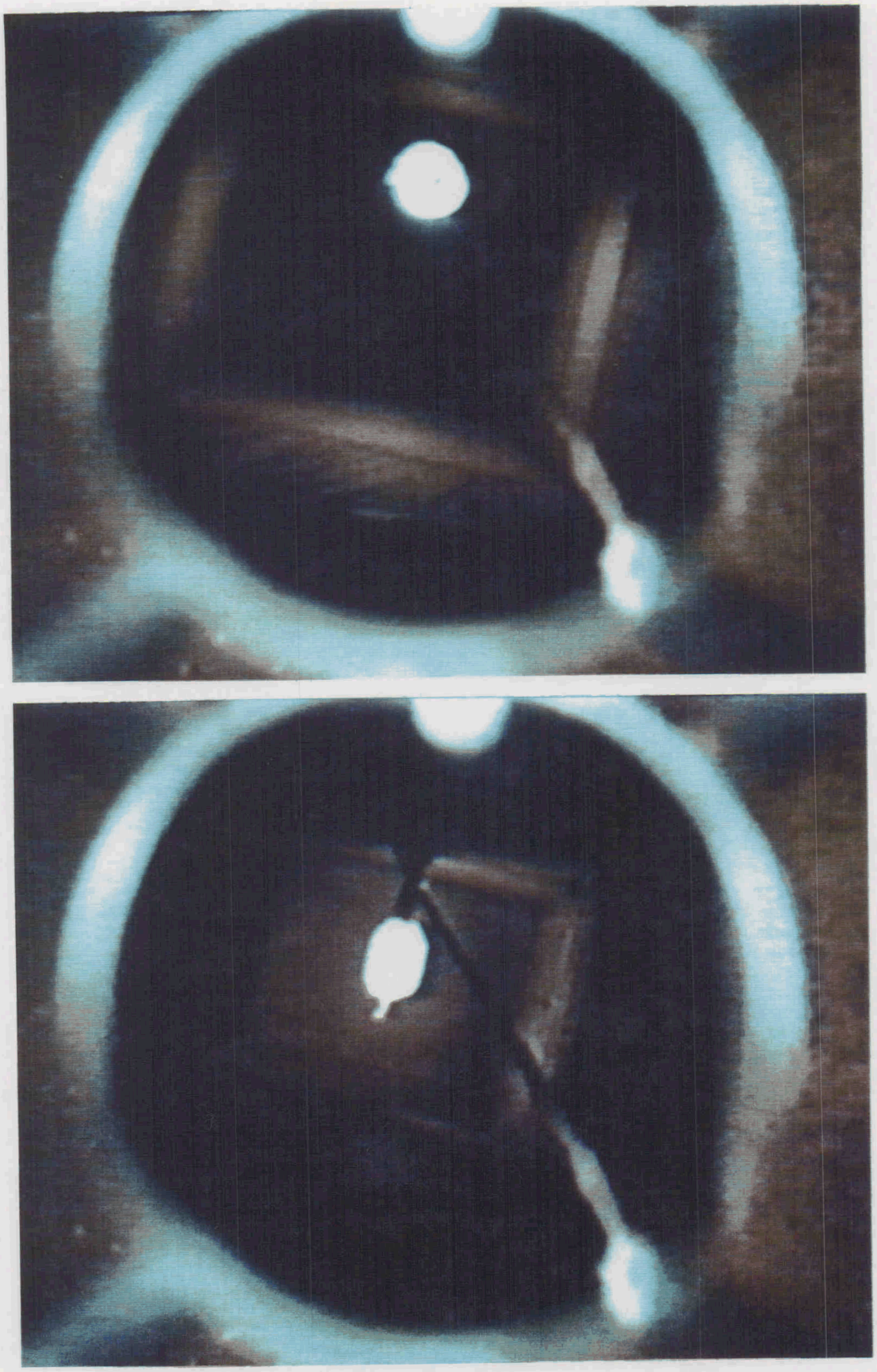

Fig. 9. Two views looking upward into Sect. 5.

Fig. 10. Magnet sticking to side of Sect. 5.

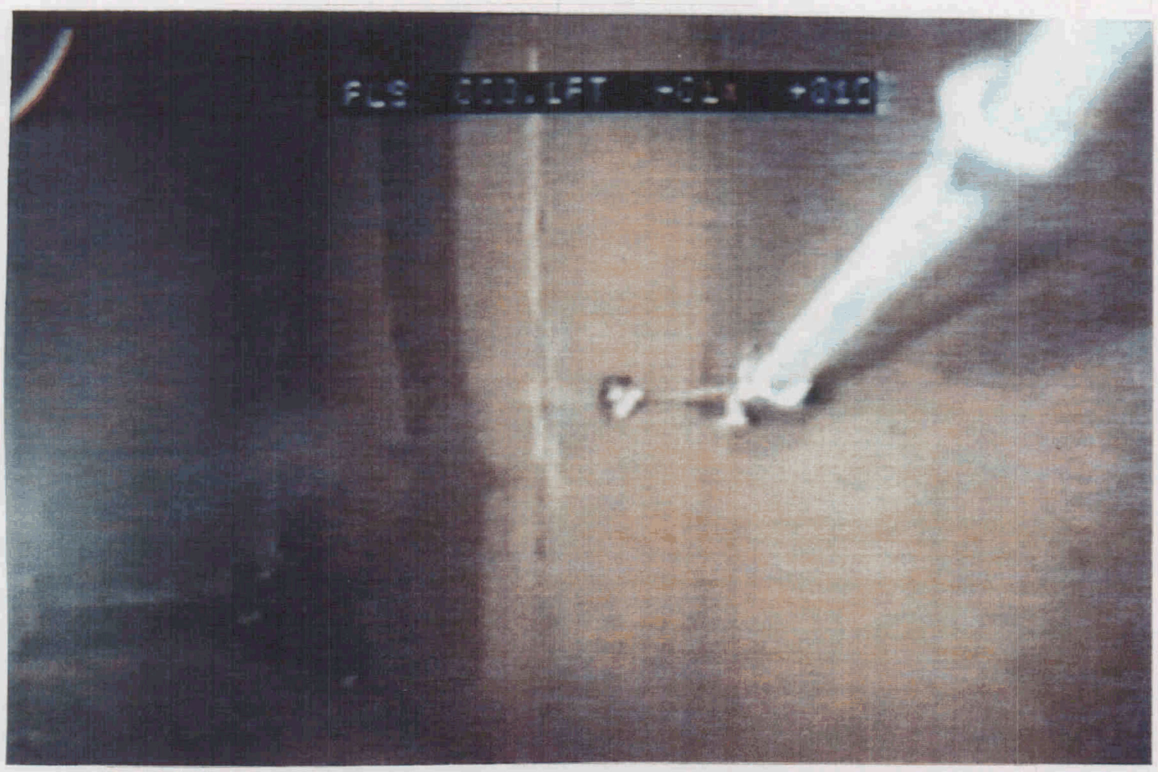

Fig. 11. Magnet being dragged along metallic wall of Sect. 4.

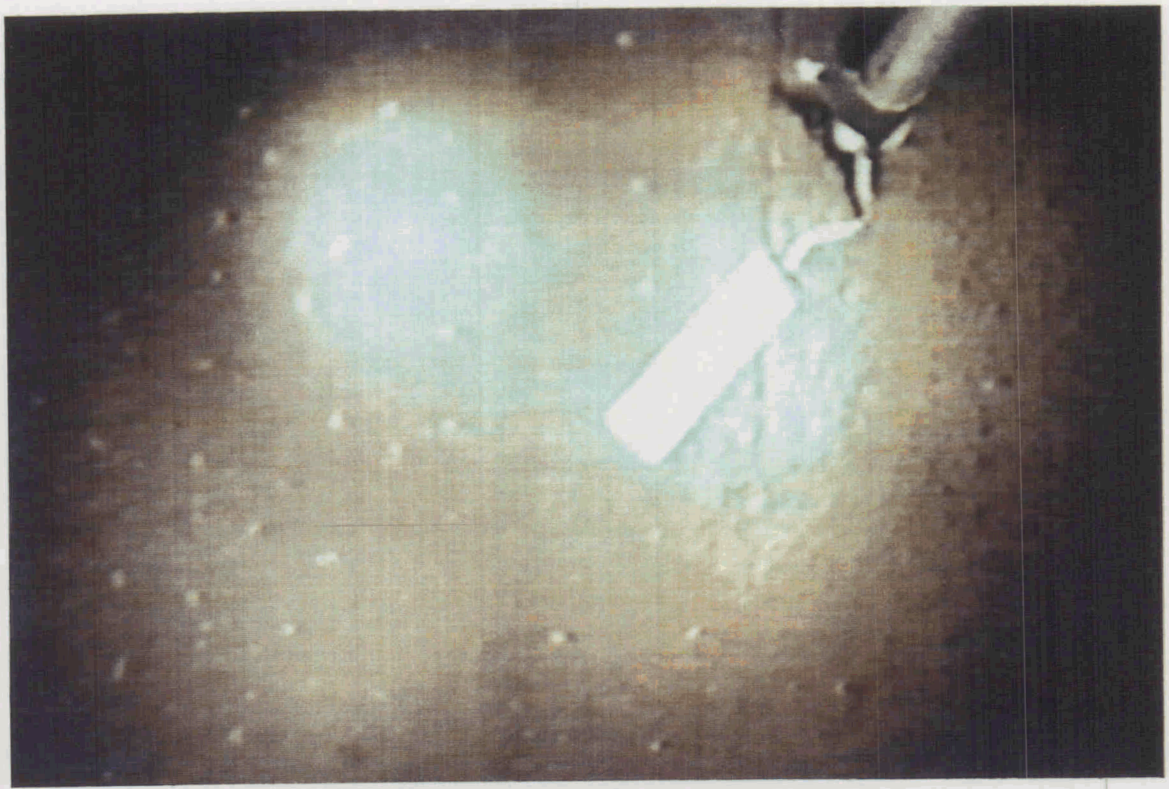

Fig. 12. Magnet sticking to wall at end of Sect. 3.

Fig. 13. Magnet sticking to beginning of Sect. 4.

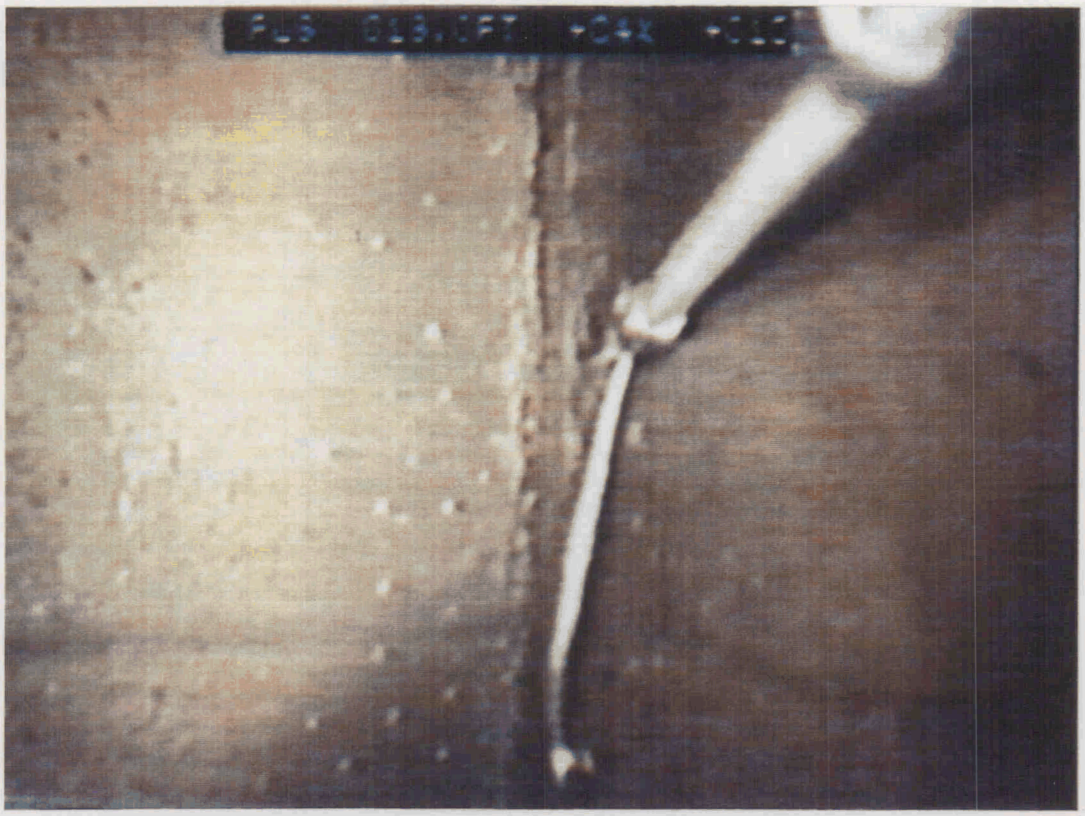

Fig. 14. Magnet sticking to end of Sect. 4.

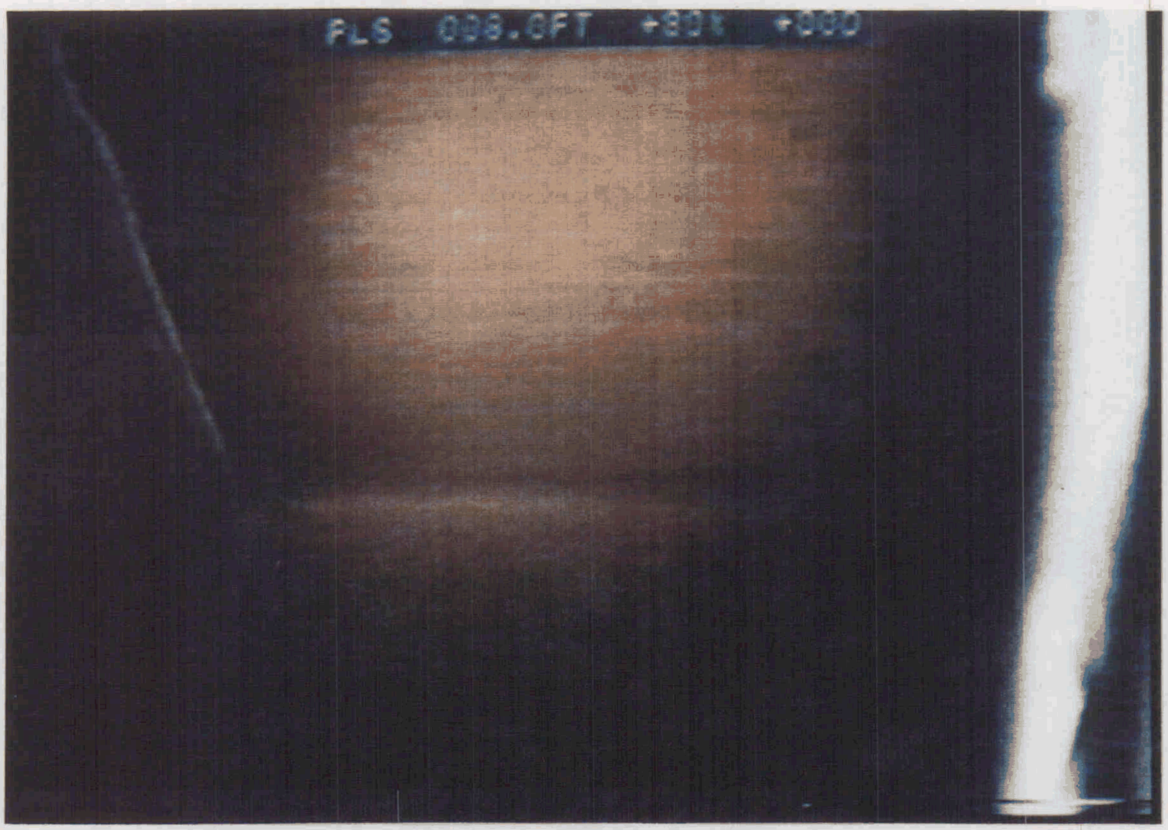

Fig. 15. View of Sect. 3 roof showing metal continuity.

III. RADIATION MEASUREMENTS

A. RADIATION DETECTOR CALIBRATION

The radiation detector was chosen for sensitivity to beta rays, which are energetic electrons, and gamma rays, which are energetic photons. The detector was calibrated by placing a known technetium source coaxially with the detector at two different distances from the open (unshielded) end of the detector and logging the resulting readings. The dimensions of the source were used to calculate a geometric correction factor since the shape differed from that of an infinite plane, which is how the walls or floor of the duct would look to the detector.

A conservative estimate of the accuracy of the readings is ±10%, provided the distance from detector to wall remains 0.5 in. Since this could not always be assured for the wall readings, an additional 20% was added, resulting in an overall accuracy of ±30% for the recorded readings. See Table 1 for a listing of the detector type and the calibration data.

Table 1. Detector type and calibration data

DETECTOR CHARACTERISTICS

1. Sensitivity: beta and gamma radiation

2. Construction: Geiger-Muller tube with end window of mica; lead on all sides except window

3. Front-to back and front-to-side ratio: 12.25:1, checked with Cs-137 source at ORNL

4. Efficiency of detection using TC-99 source:
   a. Contact: 7.35%
   b. At 0.5-in. distance: 5%

5. Detector Model No.: LND-7231

KNOWN CALIBRATION SOURCE CHARACTERISTICS

1. Type of radiation: beta (100%)
2. Energy of radiation: 0.292 MeV
3. DPM: 12,700
4. Element used: Technetium with isotopic weight of 99
5. Half-life: 212,000 years

DETECTOR READINGS USING TC-99 SOURCE

1. Contact: 560 CPM
2. At 0.5-in. distance: 380 CPM

DETECTOR CALIBRATION

$$\frac{380\text{ CPM}}{12{,}700\text{ DPM}}\ \text{CF} = 0.05\ \frac{\text{CPM}}{\text{DPM}}$$

where the correction factor, CF, is assumed to be 1.7 to correct for geometric effects and energy differences between technetium and cesium betas.*

B. RADIATION MAPPING RESULTS

With the detector fastened to the crawler as shown in Fig. 2, the ductwork floor and right-hand wall were inspected for beta and gamma radiation. The detector was ~0.5 in. from these surfaces during the inspection. Of course, the detector was repositioned from that shown in Fig. 2 for inspection of the wall. The readings taken are presented in Tables 2 and 3. All of the readings shown in these tables were taken in section 3 of the duct as shown Fig. 16.

Table 2. Floor inspection

DISTANCE (From duct entry, Section 1)	INSTRUMENT READINGS	CPM[a] (X1000)	DPM[b]/in.^{2} (X1000)
7 ft. 5 in.	280	56	1120
9 ft. 0 in.	360	72	1440
9 ft. 3 in.	200	40	800
7 ft. 10 in.	150	30	600
8 ft. 3 in.	210	42	840
9 ft. 2 in.	400	80	1600

[a]CPM: counts per minute = reading x multiplier (always 200).
[b]DPM: disintegrations per minute = CPM/(efficiency).

*Nicholas Tsoulfanidis, *Measurement and Detection of Radiation*. New York: Hemisphere Pub. Co., 1983, pp 250 and 256.

Table 3. Right side wall inspection

DISTANCE (From duct entry, Section 1)	INSTRUMENT READINGS	CPM[a] (X1000)	DPM[b]/in.^{2} (X1000)
7 ft. 5 in.	120	24	480
7 ft. 7 in.	100	20	400
7 ft. 8 in.	100	20	400
7 ft. 10 in.	100	20	400
8 ft. 2 in.	100	20	400
7 ft. 0 in.	120	24	480
6 ft. 0 in.	120	24	480
7 ft. 7 in.	100	24	480
6 ft. 9 in.	110	22	440
6 ft. 10 in.	100	20	400
7 ft. 8 in.	150	30	600

[a]CPM: counts per minute = reading × multiplier (always 200).
[b]DPM: disintegrations per minute = CPM/(efficiency).

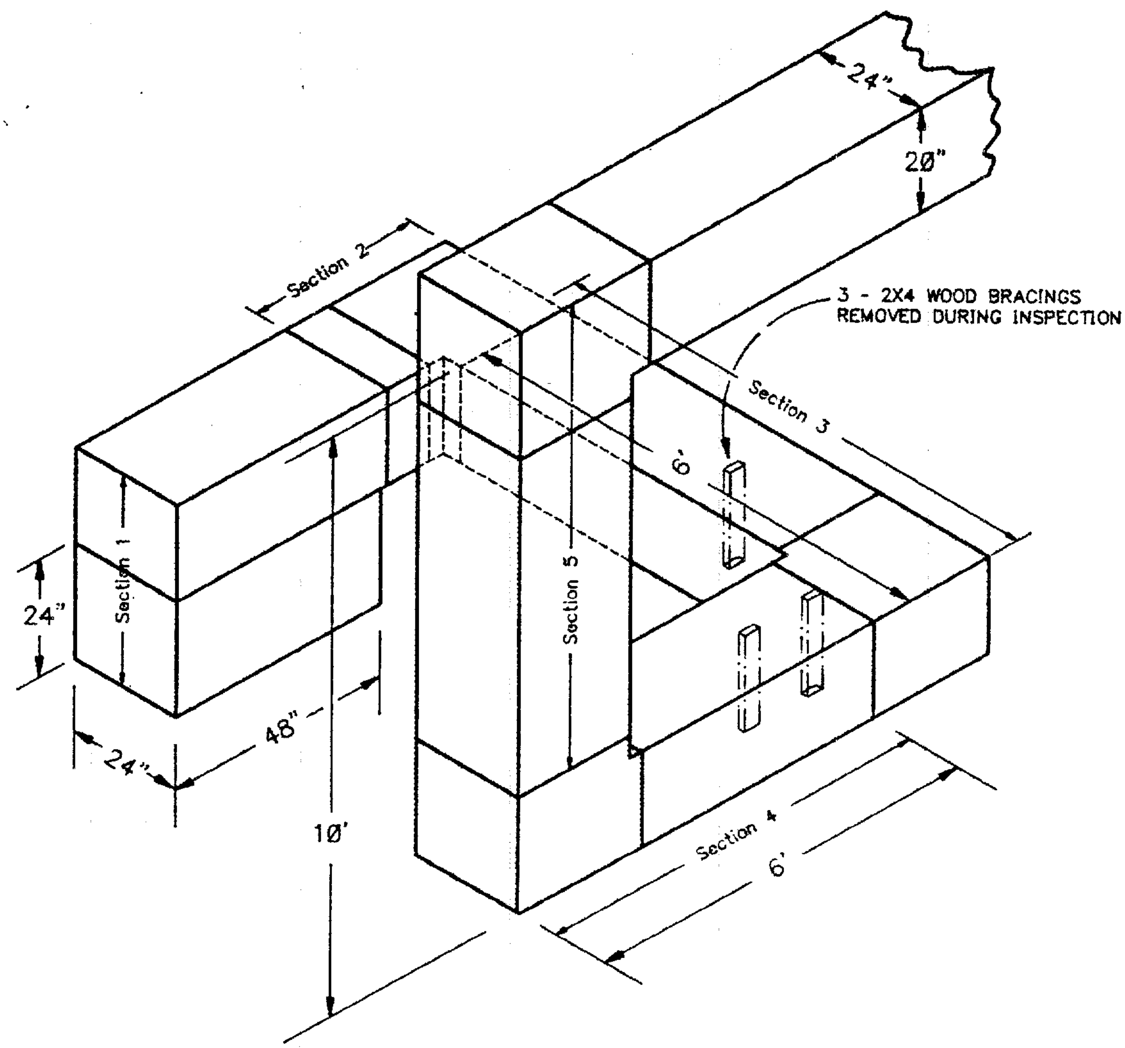

Fig. 16. Drawing of actual duct.

IV. PHYSICAL INSPECTION RESULTS

The duct appeared quite rough (see Figs. 7 and 17) when viewing at it through the TV camera. For this reason, some personnel concluded that the duct wall surfaces might be concrete, not metal. When the magnet showed that it was indeed metal, it became apparent that what was being observed was a buildup of dirt caked onto the lining. This was further substantiated when the 2x4s were moved, pushing the dirt aside and showing in places a shiny metal lining beneath (see Figs. 18-20). Also, dirt buildup could be seen at the turns at the end of the third section of duct, as shown in Fig. 21.

When the crawler was initially inserted into the duct, one of the first things observed was a piece of 2x4 (probably used for bracing during construction) standing vertically in the path of the CCA in the third section of the duct, as shown in Fig. 22. It was a standard wooden 2x4, and from the coarseness of the grain it appeared to be made of pine. The 2x4 had to be removed to allow the inspection to proceed. Because concrete had been poured on the top of the duct, the 2x4 was wedged in quite tightly. A suited person leaned into the duct and rapped the 2x4 sharply with a crowbar to dislodge it. It moved, splintering at the bottom end as it did so. This was visible from the camera. When the 2x4 was removed, it was found to be covered with dirt. When the fourth section of the duct was investigated, two additional 2x4s were noticed (see Figs. 17, 23a, and 23b), and these also were removed. The approximate original positions of all removed 2x4s are shown in the drawing of the actual duct (see Fig. 17). A summary of this manual removal operation follows.

1. The anticontamination clothing consisted of a full cloth suit with a plastic outer suit and double-thickness rubber gloves. Two hoods and a full-face respirator were worn. All seams were taped with water-resistant duct tape.

2. Total personnel time in the duct was 2 min.

3. Contamination levels on the surface of the anticontamination clothing at personnel egress were a maximum of 100K DPM/in.^{2} (beta) and 2.5K DPM/in.^{2} (gamma).

4. Contamination levels inside the duct were a maximum of 190K DPM/100 cm^2 (beta, gamma) smearable, with 15 mrad/h noted at the hole through which the camera was lowered from the mezzanine.

V. CONCLUSIONS

The overall inspection effort was successful. All ductwork sections were visually inspected, and it was verified that the embedded ductwork was welded metal with apparently complete coverage. This should make future decontamination efforts much easier. The contamination levels were assessed, and it was determined that decontamination of the embedded ductwork would be required. The entire inspection activity including set-up, inspection, and decontamination of the equipment for offsite release required 4 days.

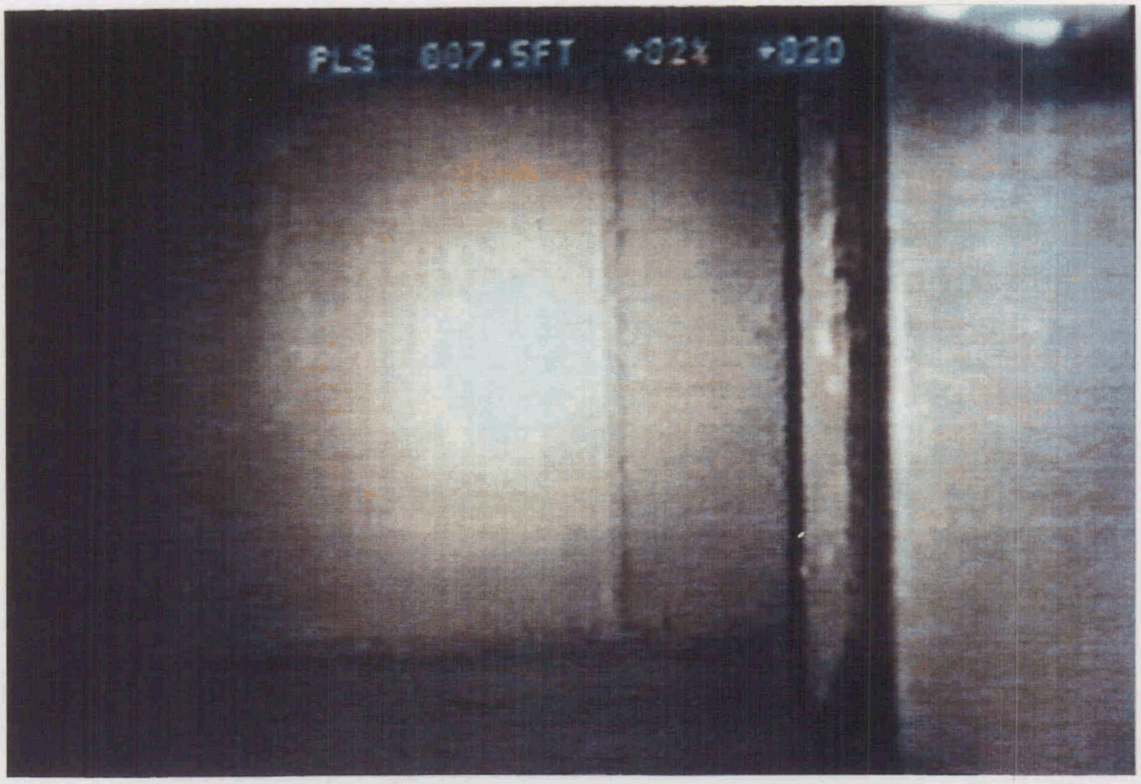

Fig. 17. End of section 3 showing 2×4 in beginning of section 4.

Fig. 18. Spot where 2×4 was dragged on floor of section 3.

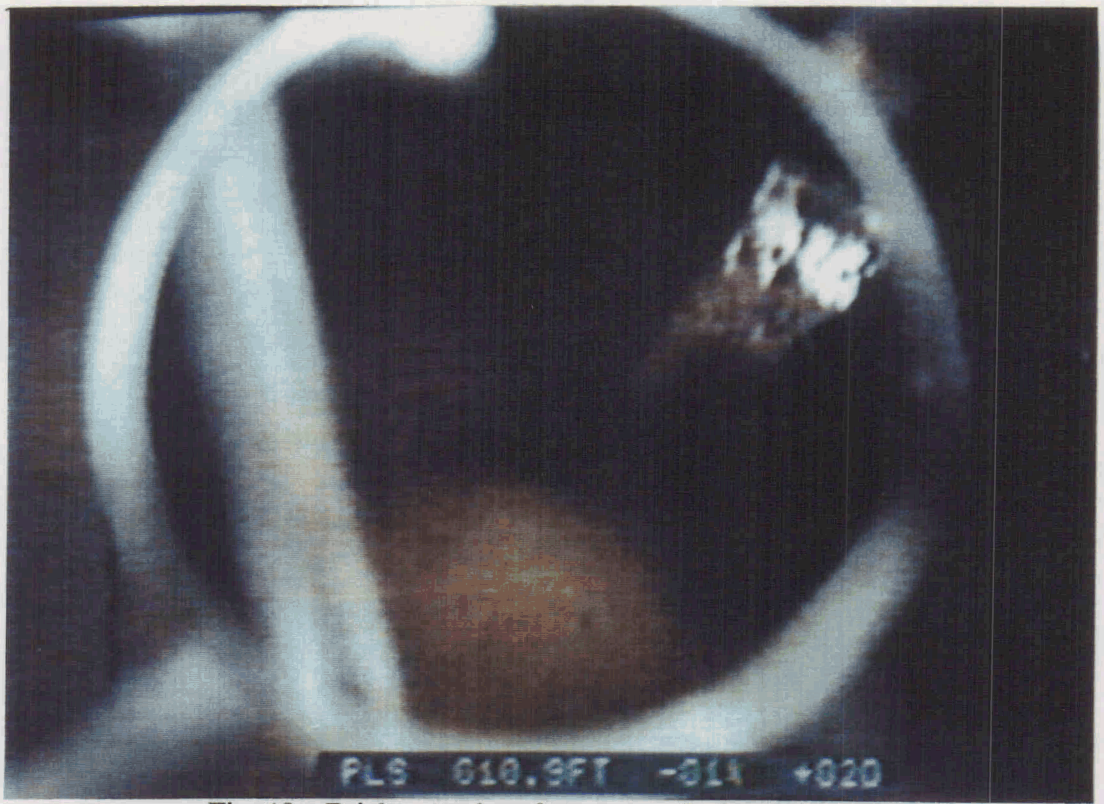

Fig. 19. Bright metal surface on roof of duct in section 4 where wedged 2×4 was removed.

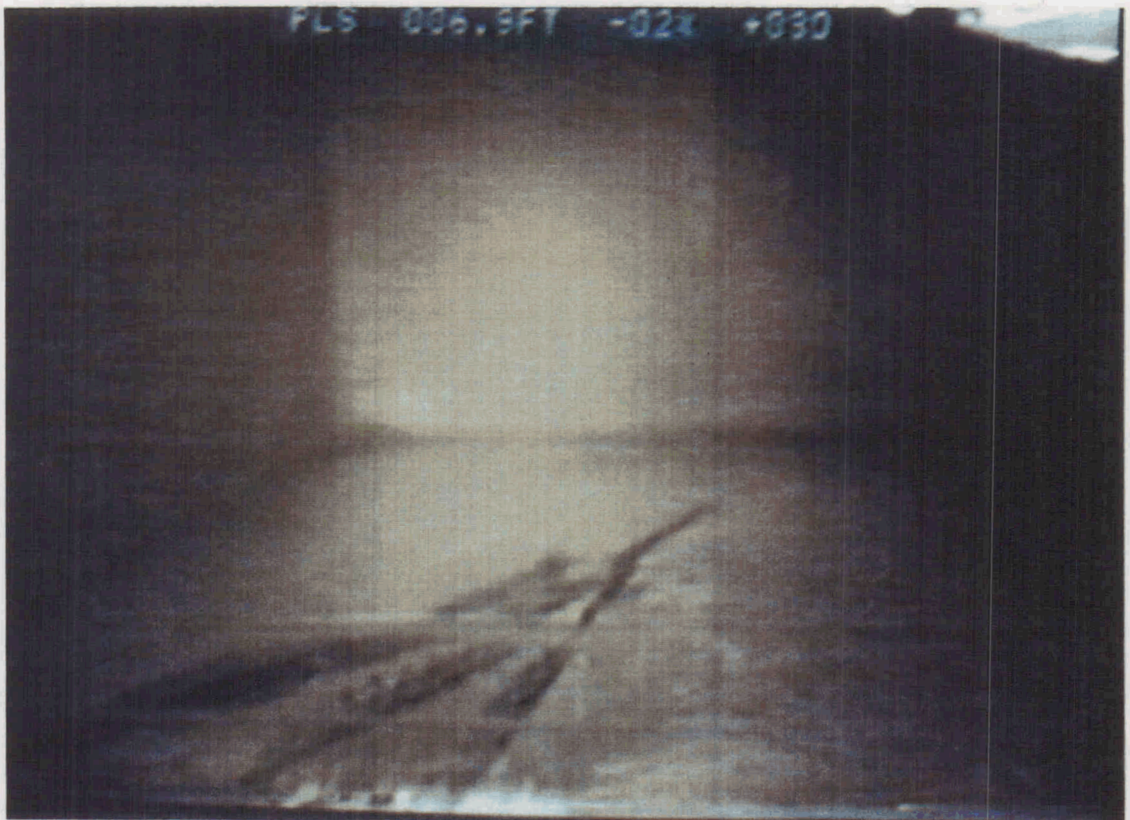

Fig. 20. Section 3, showing skid marks where 2×4 was removed.

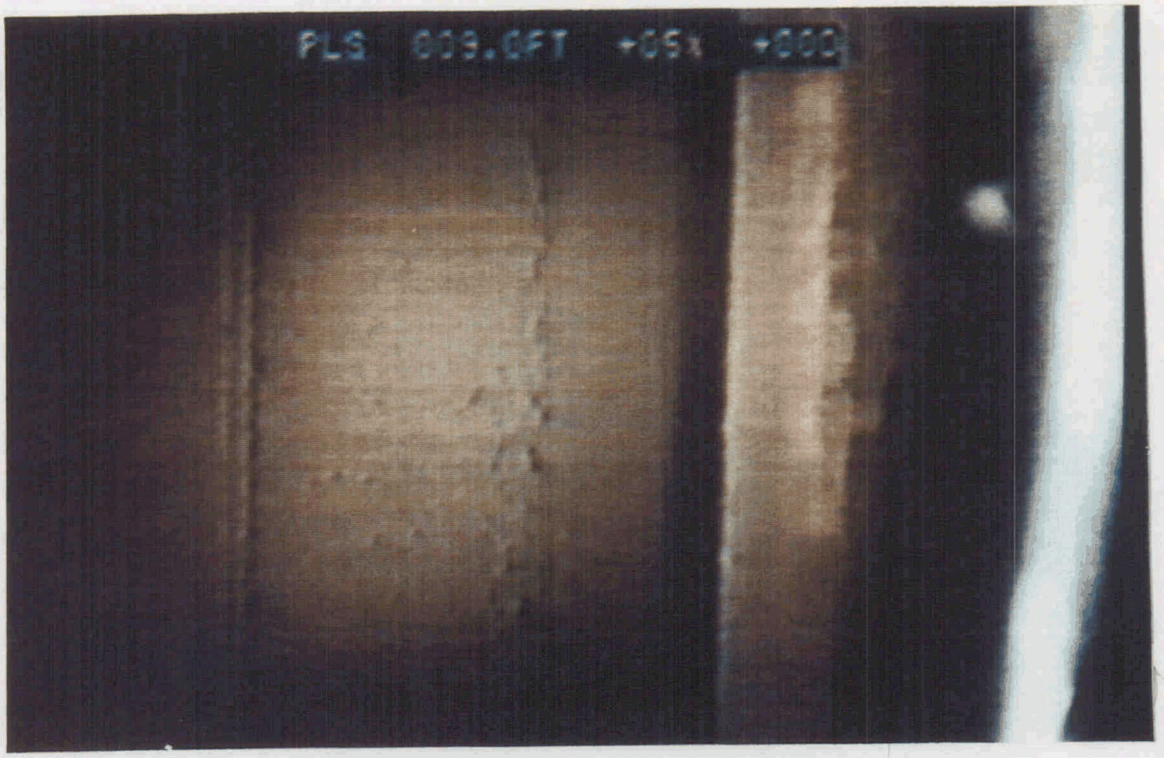

Fig. 21. Dirt buildup at end of section 3.

Fig. 22. View of 2×4 at beginning of section 4.

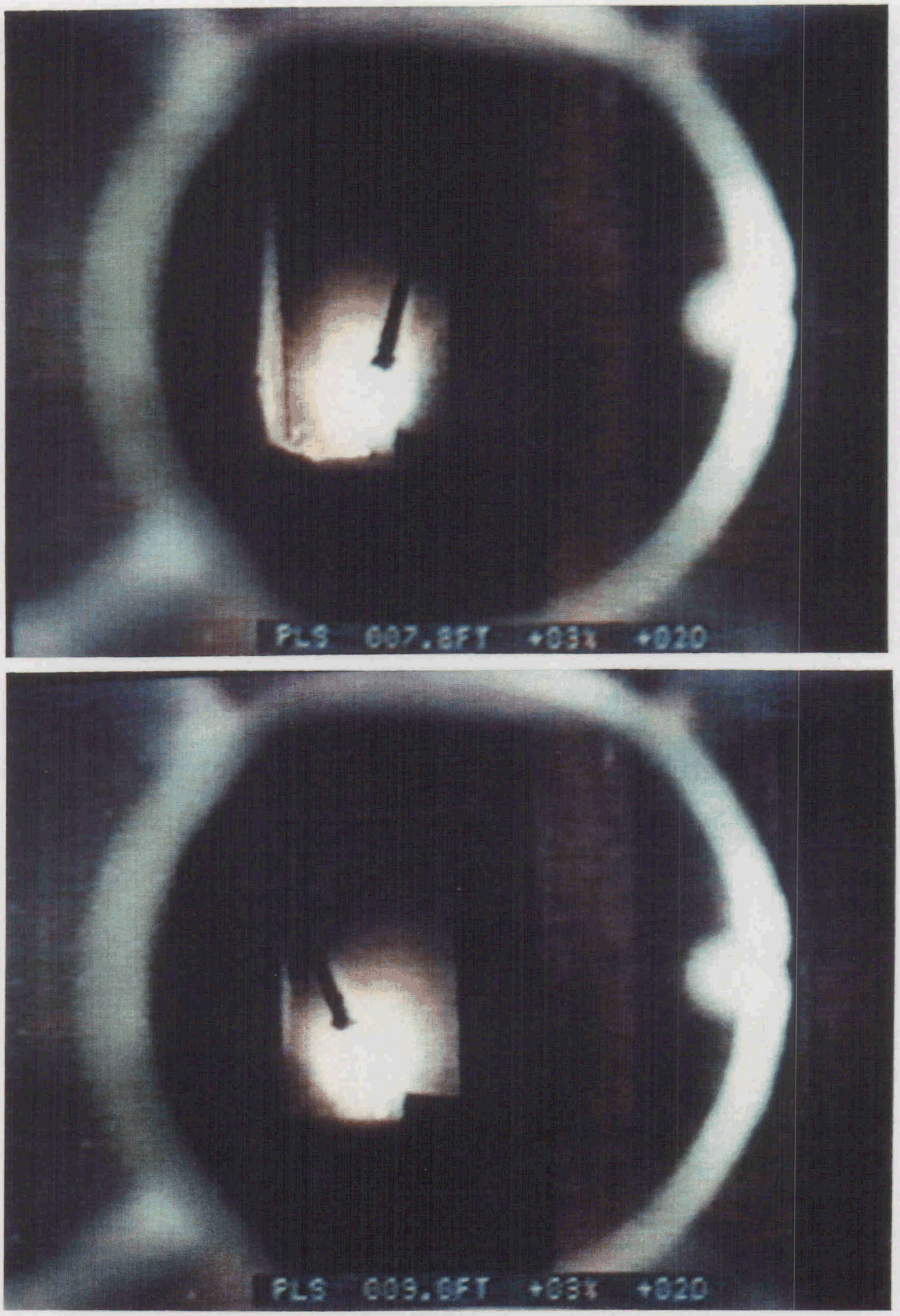

Fig. 23. Two views of unexpected portion of section 4 as viewed with mirror attachment looking right from vehicle showing lamp on cord.

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