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PRELIMINARY ELECTRO-OPTIC EVALUATION OF PROTOTYPE SURFACE MODE LIQUID CRYSTAL SHUTTER FOR NUCLEAR FLASHBLINDNESS PROTECTION

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A preliminary evaluation was performed on a prototype Surface Mode Liquid Crystal Shutter (SMLCS) device manufactured by Optical Shields, Inc., in order to determine whether such a device could provide equal or improved nuclear flashblindness protection (NFP) over the currently used EEU/2P lanthanum-modified lead zirconate titanate (PLZT) goggles manufactured by Honeywell.

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PRELIMINARY ELECTRO-OPTIC EVALUATION OF PROTOTYPE SURFACE MODE LIQUID CRYSTAL SHUTTER FOR NUCLEAR FLASHBLINDNESS PROTECTION

EXECUTIVE SUMMARY

A preliminary evaluation was performed on a prototype Surface Mode Liquid Crystal Shutter (SMLCS) device manufactured by Optical Shields, Inc. The activation and closure times were measured to determine whether such a device could provide equal or improved nuclear flashblindness protection (NFP) over the currently used EEU/2P lanthanum-modified lead zirconate titanate (PLZT) goggles manufactured by Honeywell. In addition, a basic optical characterization was performed to include spectrophotometry, haze, and laser densitometry. The device sent to Armstrong Laboratory (AL) was an off-the-shelf SMLCS designed for use in an electronic welding helmet. Optical Shields, Inc., added an infrared (IR) cut-off filter to make it more suitable for the NFP application. However, the application of this IR filter coating was not optimized, and one side of the SMLCS was not suitable for testing. Therefore, all tests were performed on only one side of the device. For these reasons, and in order to meet initial program goals, a full-scale evaluation was not performed. Only basic performance characteristics were assessed since the military version of the SMLCS will most likely be different from this prototype.

Results

Spectrophotometry was performed on the device in both its clear and dark states at various angles and rotations to determine spectral optical density, spectral transmittance, photopic and scotopic luminous transmittance, mean ultraviolet (UV) transmittance, and chromaticity coordinates. Both the photopic and scotopic luminous transmittance were measured to be 34.0% at normal incidence, zero degree rotation perpendicular to the normal axis. The photopic and scotopic luminous transmittance dropped to 18.2% and 15.5%, respectively, at 45° off normal. These transmittance values are not absolute measurements but are only good for relative changes due to the inherent polarization dependency of the SMLCS. The mean UV transmittance was 0.0% for all test conditions. Likewise, chromaticity coordinates were within the neutrality limits for all circumstances.

The SMLCS was found to be very sensitive to the polarization of the incident light source. The spectrophotometer used during this evaluation is rather strongly polarized in one plane (linear polarization). After an orthogonal 90° rotation with respect to the incident beam direction the results were vastly different. The photopic and scotopic luminous transmittance dropped to 6.1% and 5.1%, respectively. To obtain a true transmission reading, a randomly polarized broadband light would have to be used as the source and transmission

measured with a photometer. Plans are underway to perform such measurements.

Haze measurements were taken at 12 locations on the device and averaged 0.26%. These values are well within the established military standard, MIL-V-43511B, which specifies that haze must not exceed 2.0%.

All activation and closure times were measured at the center point of the right half (side with the undamaged IR filter coating), normal incidence, and no rotation in the perpendicular axis. The activation time in this report is defined as the time from trigger source flash to the start of closure. The closure time is defined as the time it takes to go from open state transmission to a transmission of 0.1% (3 optical densities) after the trigger source flash. Measurements were made for 3 separate cases: (1) using a linearly polarized 514-nanometer (nm) wavelength laser as the probe; (2) using a randomly polarized broadband (white light) source as the probe; and (3) using the broadband light source as the probe beam with a Schott glass KG3 IR filter in front to completely block all of the IR radiation past 950 nm.

The activation time was 62 microseconds (μs) for all three test cases. The closure time had a mean of 111.83 μs with a standard deviation of 5.25 μs for the Argon laser; 103.05 μs mean and standard deviation of 4.26 μs for the broadband light source without KG3 filter in place; and 85.51 μs mean and standard deviation of 4.55 μs for the broadband light source with KG3 filter in place.

Additionally, the time to switch from the dark to the clear state was measured to be approximately 15 ms for all three test cases.

BACKGROUND

A Surface Mode Liquid Crystal Shutter (SMLCS) was developed by Optical Shields, Inc., Menlo Park, Calif., and is currently being sold as a high speed optical shutter (light valve). These Surface Mode Device (SMD) technology light valves are currently used as 3-D imaging devices, automatic gain control on video cameras, and eye protection for welders. Optical Shields, Inc., is currently developing this technology for a system that will protect military personnel and equipment from nuclear flashblindness.

According to the Human Systems Center/Human Systems Program Office (HSC/YAGO) RAMTIP Project Plan "Liquid Crystal Technology for Nuclear Flashblindness Protection," personnel in the B-2 System Program Office previously determined that the switching speed was fast enough in the SMLCS to provide nuclear flashblindness protection. Based on this switching time data obtained in late 1989, HSC/YAG went forward with a buy of a single SMLCS incorporated in an HGU-56/P helmet via an existing Army contract to acquire Thermal Flashblindness Protective Devices (TFPD).

Nuclear Flashblindness Protection - PLZT

The visible thermal emission from a nuclear explosion is capable of producing ocular injuries from great distances due to the extremely large amount of energy released in a detonation. As a result, eye protection having sufficient optical density (OD) across the emission spectrum is required. Since a high attenuation of the incident light is required to protect the retina from injury, a passive neutral density filter would severely restrict normal vision. Therefore, a dynamic neutral density filter capable of "switching" from clear to opaque in a sufficiently short time to prevent adverse eye effects is the system of choice. Such a system would have to provide an open state transmission high enough to allow aircrew members to perform vision tasks that are necessary in the absence of a detonation and does not significantly increase mission risks.

A number of concepts and devices were considered, including photochromics, ultraviolet (UV) pumped photochromics, various mechanical devices, polarization schemes, thermal curtains, and eye patches (5). A reasonable solution was found only after Sandia Laboratories achieved optical transparency in lanthanum-modified lead zirconate titanate (PLZT) in the early 1970s. In 1975, they began to develop this PLZT material into a goggle format for the U.S. Air Force (USAF) to provide ocular nuclear flash protection. These goggles were only accepted by certain commands after lowering the open state transmission specification from 70% to 20%.

The EEU-2/P Flashblindness Goggles are currently in the USAF inventory. Each lens is constructed with thin sheets of PLZT sandwiched between crossed polarizers. A photodetector, mounted behind each lens, senses a high-intensity light flash and triggers the control circuit to discharge a voltage which is applied across the PLZT lenses. The lenses are in the "open" or transparent state with the voltage (28V) applied. If the light level doubles in less than 100 μs, the control circuit will discharge and reduce the optical transmission to approximately 0.1% (3.0 OD). The average switching time from 20% to 0.1% is approximately 150 μs. A final OD of 4.1 is reached shortly thereafter (1).

Operation of the Surface Mode Device

The proposed TFPD replacement is a high-speed light valve containing a SMD, an optical sensor, and an electronic drive circuit (Fig. 1)(2). The SMD is clear when a sustaining voltage of approximately 5V is applied across the cell. Optical Shields, Inc., claims that the shutter can be driven from a transmission of 23% (0.65 OD) to a transmission of 0.003% (4.5 OD) in less than 75 μs, and will switch from the dark to the clear state in less than 1,200 μs (2).

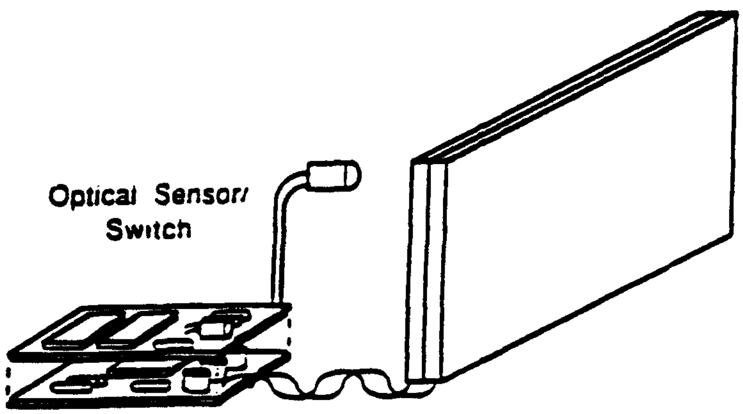

Figure 1. High-speed light valve components (2).

The SMD cell is shown in Figure 2 and consists of a 7 μm thick, birefringent nematic liquid crystal material sandwiched between transparent electrode surfaces and crossed polarizers (3). With 5V applied, the material directly next to the substrate maintains its original orientation while the material in the center of the cell orients in a direction parallel to the applied electric field (4). Changing the applied voltage causes changes in the surface layer which in turn alters the cell optical properties (2). Due to the birefringent characteristics of the nematic liquid crystal, the phase of polarization of the light passing through the cell is shifted by a degree proportional to the thickness of the surface layer. Since the surface layer thickness is dependent upon the applied voltage, the optical properties will vary with varying voltages (6).

The clear state operation of the light valve is shown in Figure 3. Randomly polarized light passes through the first polarizer to become linearly polarized, then passes through the liquid crystal cell where it is resolved into two components. The ordinary component is aligned parallel to the long axis of the liquid crystal molecules while the extraordinary light component is aligned perpendicular. The ordinary component travels faster through the surface layer of the cell and undergoes a 180° shift in relation to the extraordinary component. This action results in an effective 90° polarization rotation which will allow for passage through to the analyzer (2).

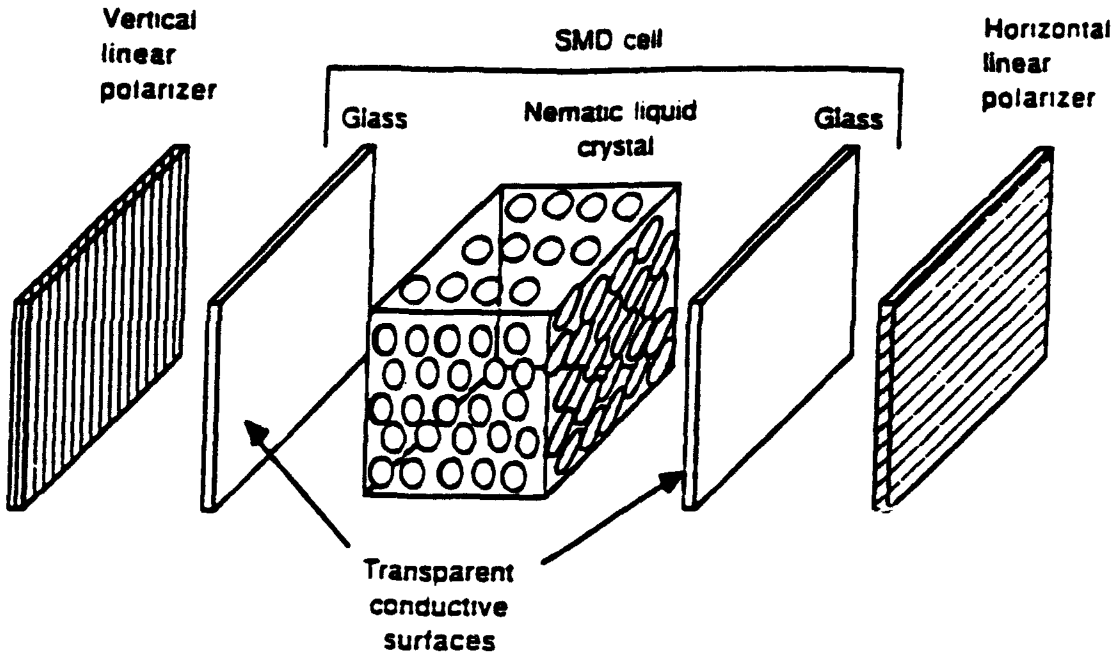

Figure 2. SMD cell.

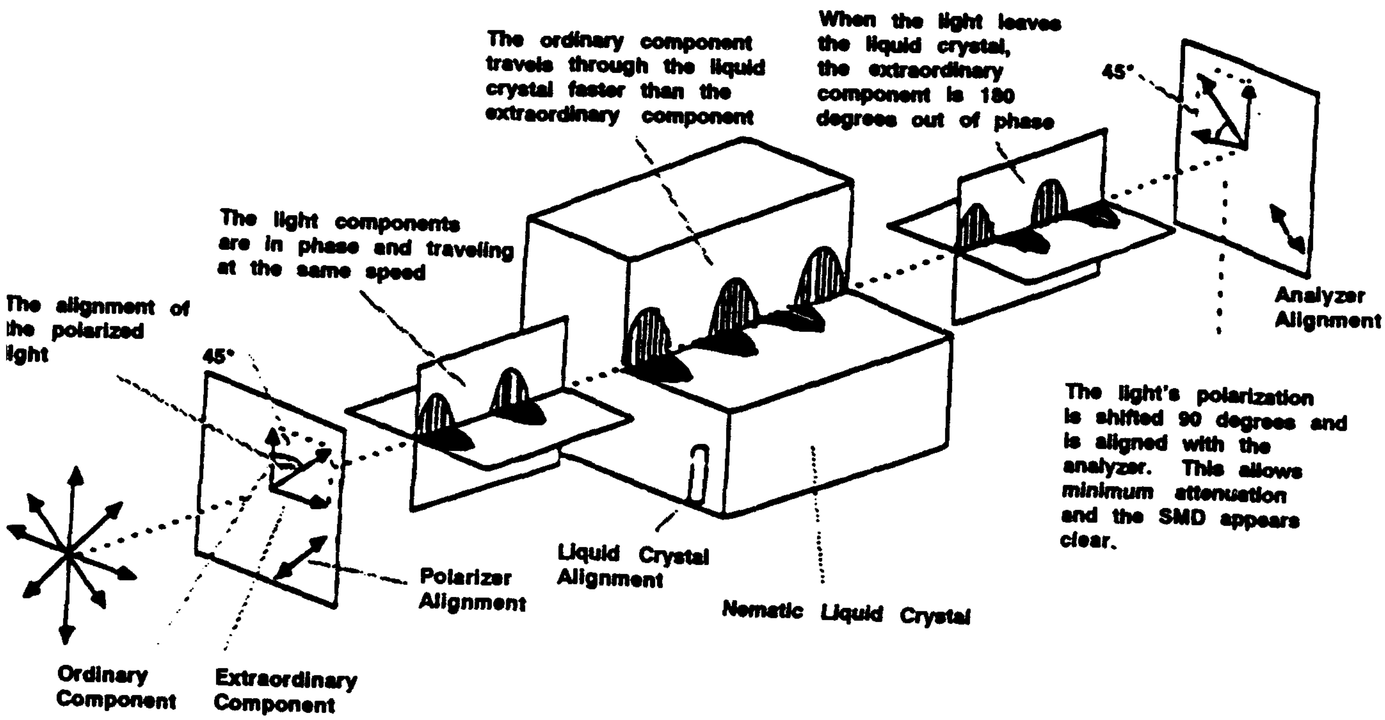

Figure 3. Clear state operation of light valve.

For dark state operation, the voltage is discharged in order to orient all of the liquid crystal material parallel to the electric field. In this state, linearly polarized light travels through the cell parallel to the long axis of the crystal and is therefore unaffected by the birefringent properties. Since the ordinary and extraordinary component of light will travel through the cell at the same speed, the two components are in phase and the direction of polarization will not change. The light will then strike the analyzer 90° out of alignment and be absorbed.

EXPERIMENTAL METHOD

Spectrophotometry

Spectral scans were performed on the material in both the open and closed state at 0, 15, 30, and 45 degrees with respect to normal. The SMLCS was also tested after rotating the device 90° in a plane orthogonal to the incident beam. All measurements were made through the center of the lens having the undamaged infrared (IR) filter coating. A Perkin-Elmer Lambda 9 UV/VIS/NIR spectrophotometer was used to obtain spectral transmittance, spectral optical density, mean UV transmittance, photopic and scotopic luminous transmittance, and chromaticity coordinates. The spectral range scanned was from 200 - 1200 nm in 1-nm increments.

Haze

The haze of an optical element is that percentage of transmitted light which, in passing through the material, deviates from the incident beam by forward scattering outside of a 2.5° cone. Haze was determined by a Hazeguard XL-211 Hazemeter. The system was calibrated with a GTS-2202 test standard and is accurate ±0.1% for samples having a haze less than 14%.

Activation and Closure Times

All activation and closure times were measured at the center point of the right half (side with the undamaged IR filter coating), normal incidence, and no rotation in the perpendicular axis. The activation time in this report is defined as the time from trigger source flash to the start of closure. The closure time is defined as the time it takes to go from open state transmission to a transmission of 0.1% (3 OD) after the trigger source flash.

Measurements were made for 3 separate cases: (1) using a linearly polarized 514-nm wavelength laser as the probe; (2) using a randomly polarized broadband (white light) source as the probe; and (3) using the broadband light source as the probe beam with a Schott glass KG3 IR filter in front to completely block all of the infrared radiation past 950 nm. A white light, xenon photoflash was used to simulate the nuclear flash and serve as the trigger source for the digital storage oscilloscope.

RESULTS

This section presents the data obtained from the experiments designed to evaluate the performance of the SMLCS. As mentioned earlier, a full-scale test was not completed on the prototype SMLCS because of the probable technical changes in the military version.

Spectrophotometry

Figures 4 and 5 depict the open state spectral OD and transmittance, respectively, of the prototype SMLCS as designed for use as a protective shield for welders goggles.

Figure 6 shows the spectral OD of the SMLCS in combination with a KG3 IR filter to completely filter the IR radiation past 950 nm. The addition of this filter, or a coating having the same spectral characteristics, may resolve possible problems which may cause the "leakage" of near-IR radiation. The addition of such a filter should not significantly lower the open state transmission.

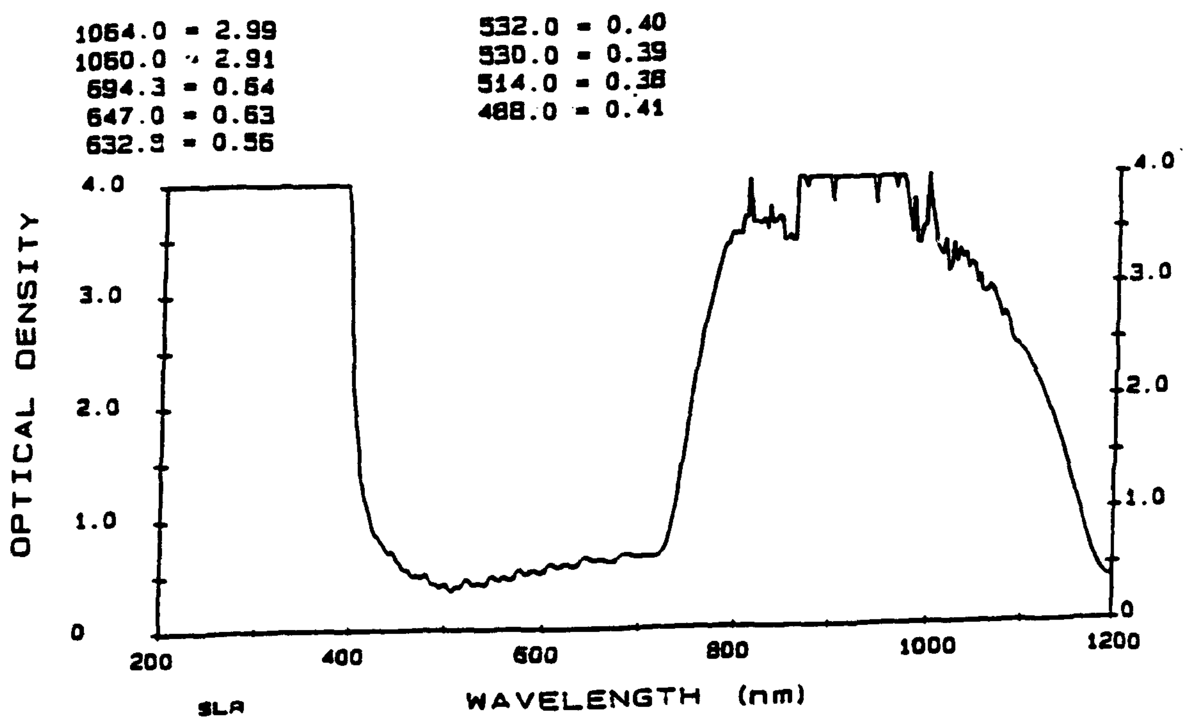

Figure 4. Spectral OD: SMLCS, open state, 0 degrees.

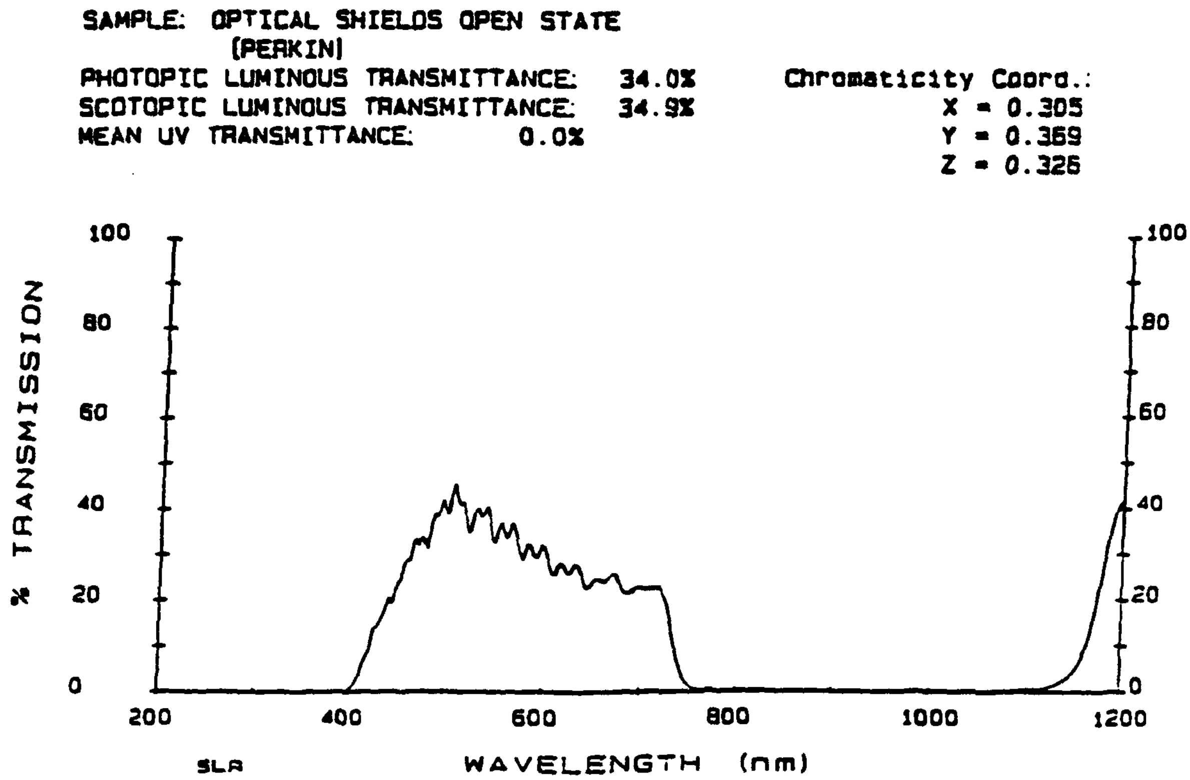

Figure 5. Spectral transmittance: SMLCS, open state, 0 degrees.

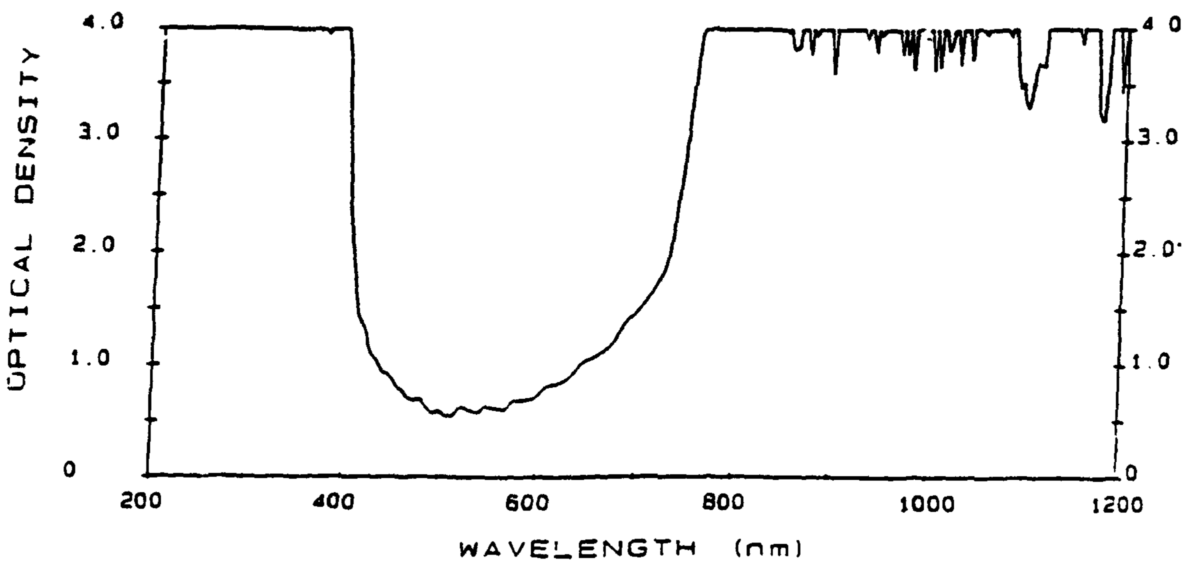

Figure 6. Spectral optical density: SMLCS + KG3 IR filter.

The fully closed state yields an attenuation factor of greater than four (4 OD) in the entire visible spectrum. The spectral optical density of the SMLCS is the closed state shown in Figure 7.

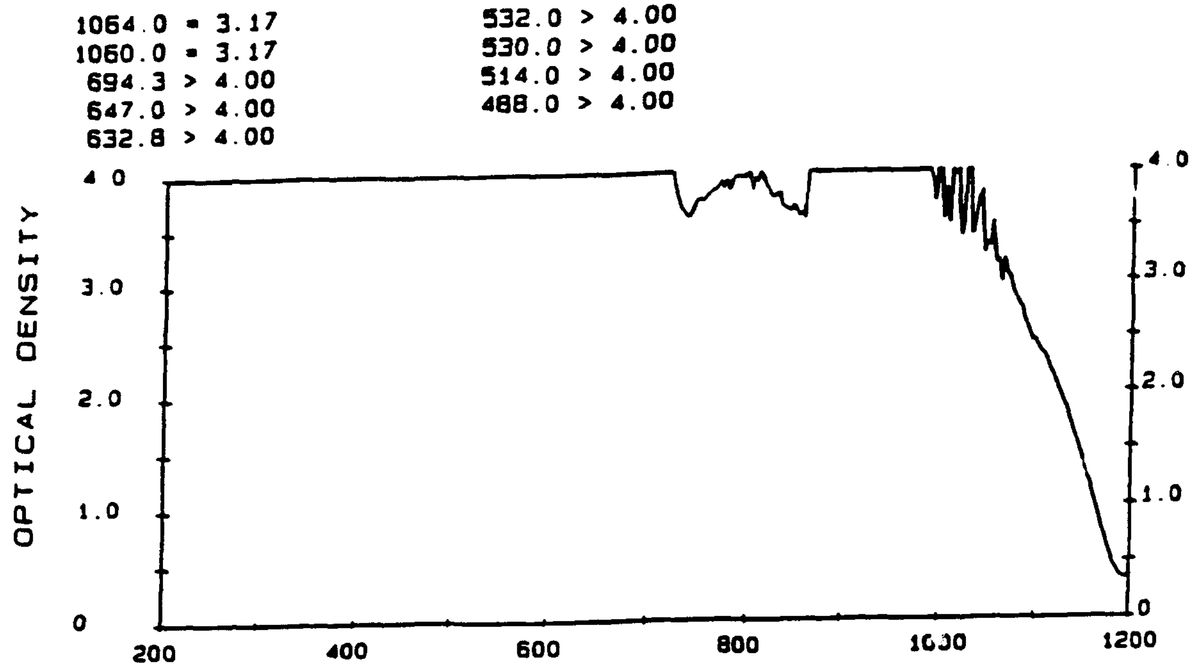

Figure 7. Spectral optical density: SMLCS, closed state, 0 degrees.

Figure 8 displays the minimal decrease in closed state protection in the near-IR spectral region. As shown in Figure 6, an improved IR filter coating could be incorporated to prevent this shift in protection from 1100 to 1000 nm as shown in Figure 8.

The variations caused by the polarization of the incident light are clearly shown in Figures 9 and 10. Figure 9 compares the spectral OD results when the device is rotated 90° with respect to the incident linearly polarized light from the spectrophotometer. Likewise, Figure 10 compares the spectral transmittance scans. The photopic luminous transmittance (dark adapted vision) changes from 34.0% to 6.1% and the scotopic luminous transmittance (dark adapted vision) changes from 34.9% to 5.1%.

Activation and Closure Times

The activation time was 62 μs for all three test cases (Fig. 11). The closure time had a mean of 111.83 μs with a standard deviation of 5.25 μs for the Argon laser (Fig. 12); 103.05 μs mean and standard deviation of 4.26 μs for the broadband light source without KG3 filter in place, and 85.51 μs mean and standard deviation of 4.55 μs for the broadband light source with KG3 filter in place (Fig. 13).

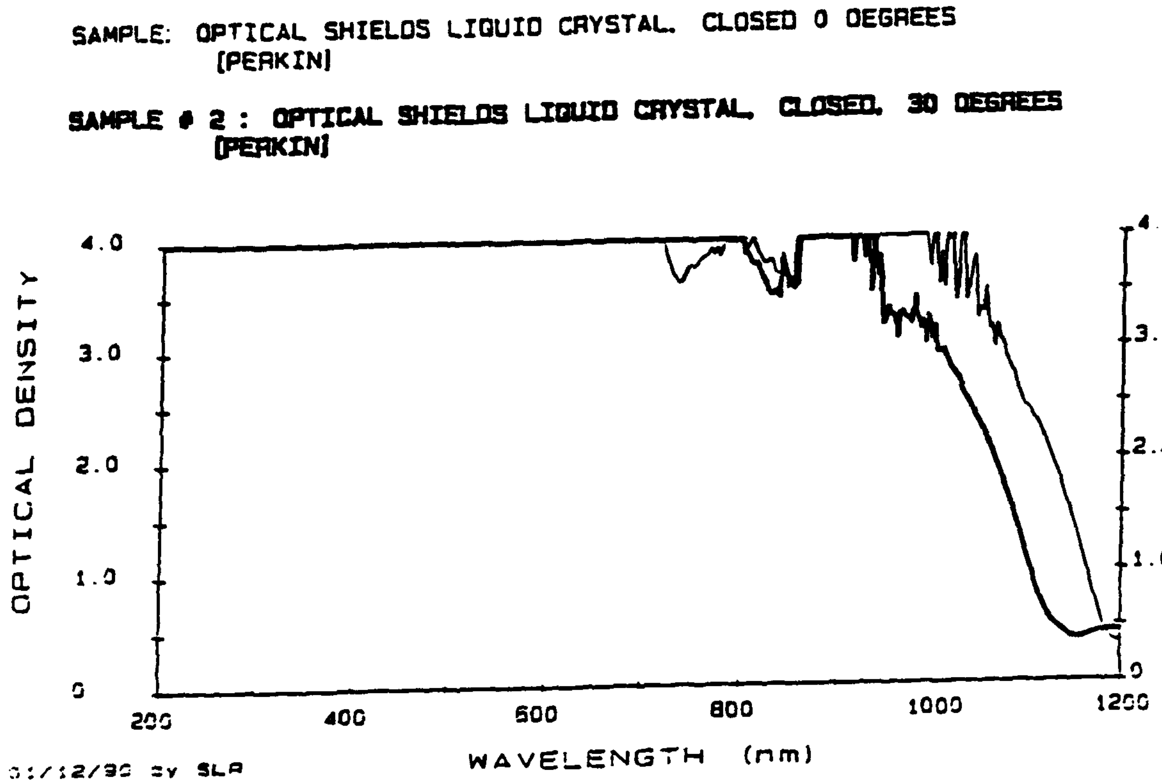

Figure 8. Spectral OD comparison: SMLCS closed state. 0 and 30 degrees in plane rotation.

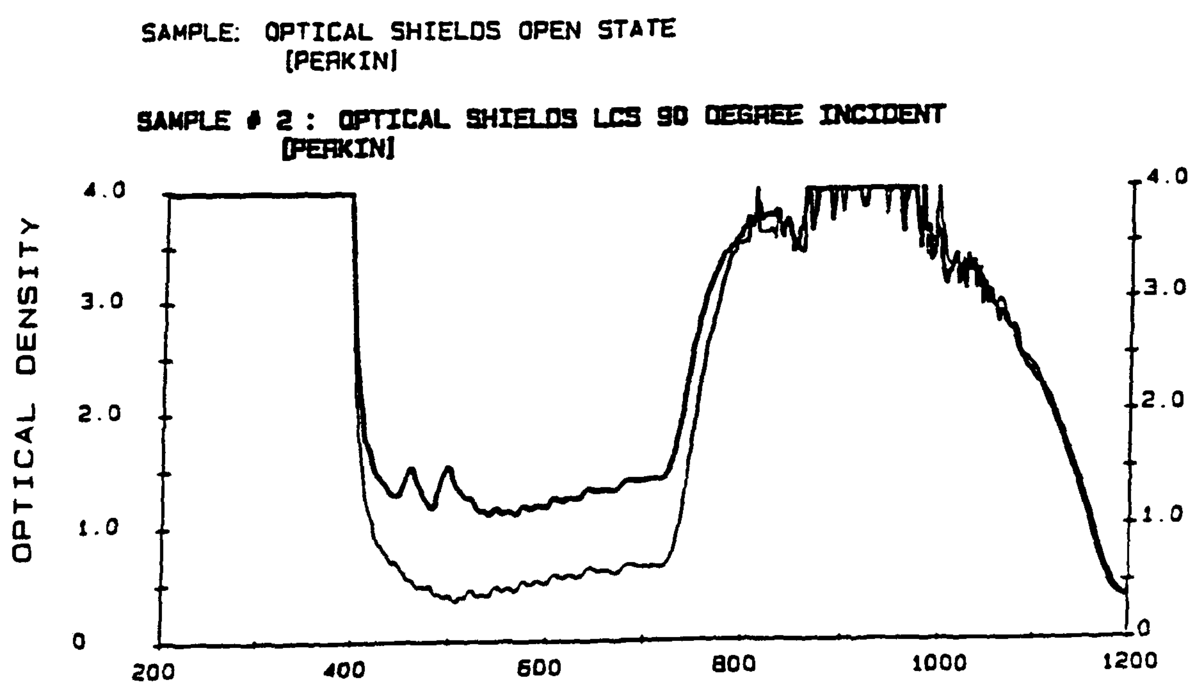

Figure 9. Spectral OD comparison: SMLCS open state. Normal incidence: 0 and 90 degrees.

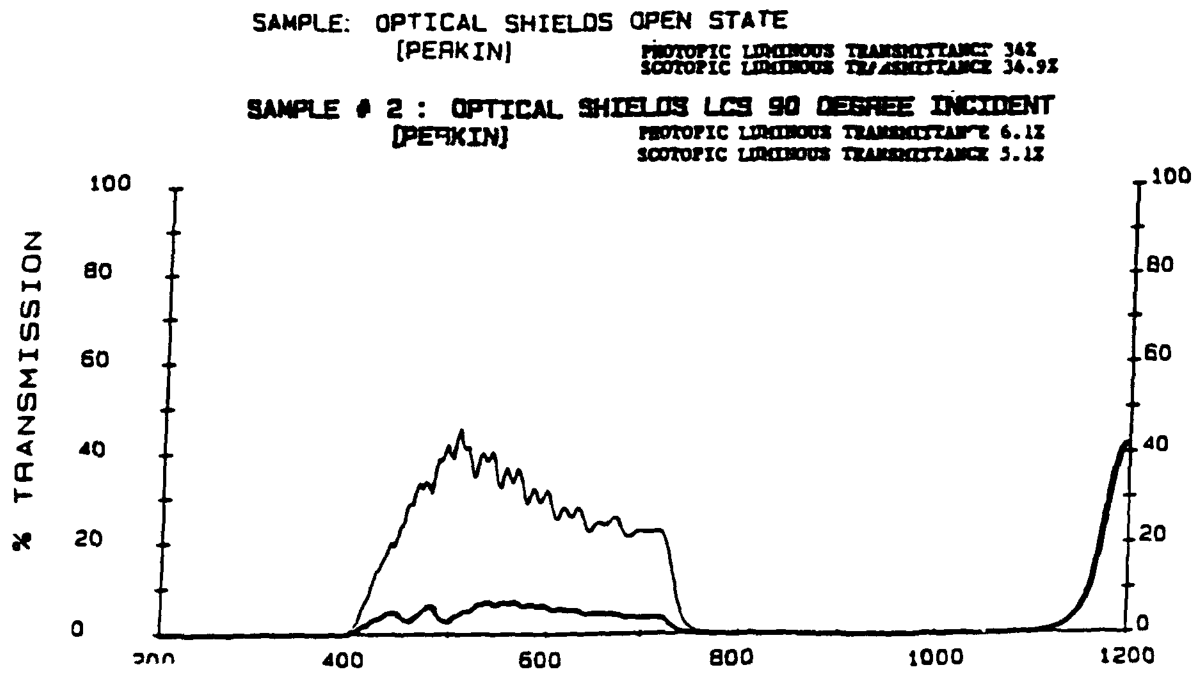

Figure 10. Spectral %T comparison: SMLCS open state. Normal incidence: 0 and 90 degrees.

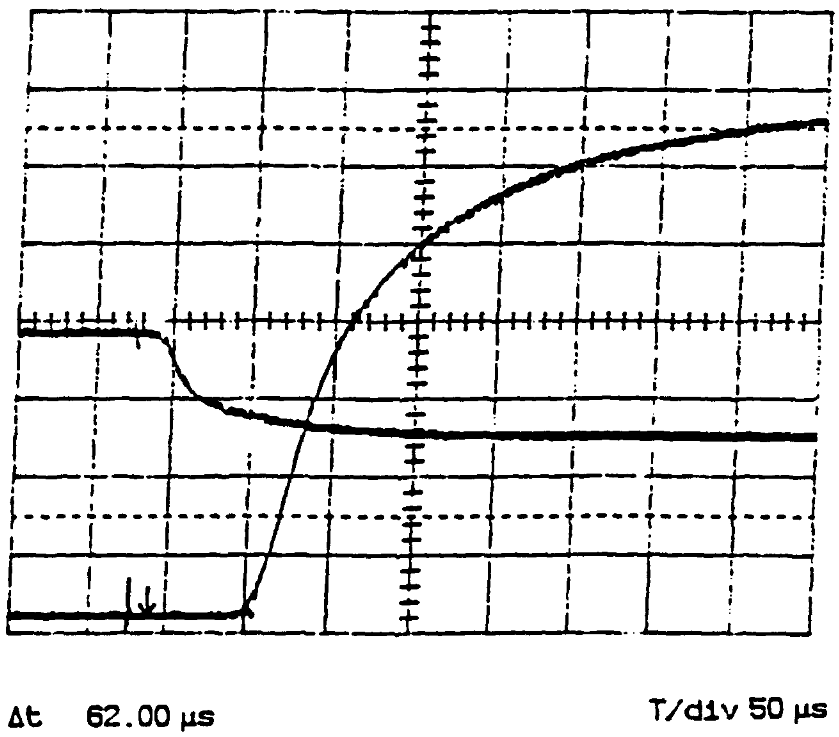

Figure 11. Typical activation time (62 μs). Upper trace is photoflash, lower trace is SMLCS response.

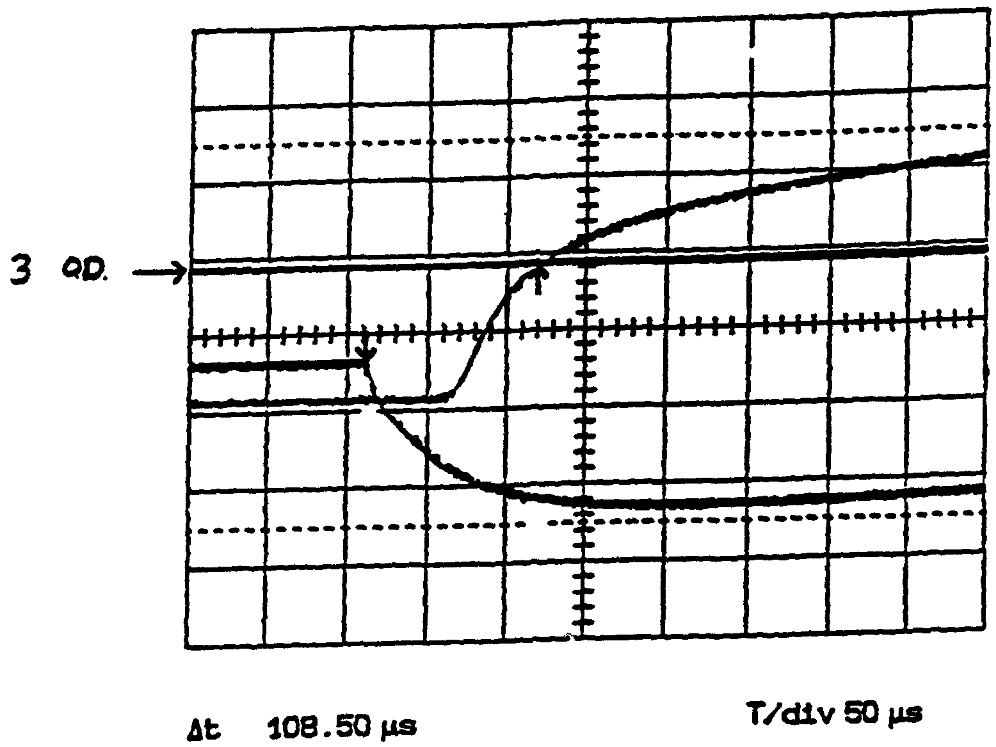

Figure 12. Typical closure time to 3 OD (108.50 μs) using the Argon-ion laser as a probe.

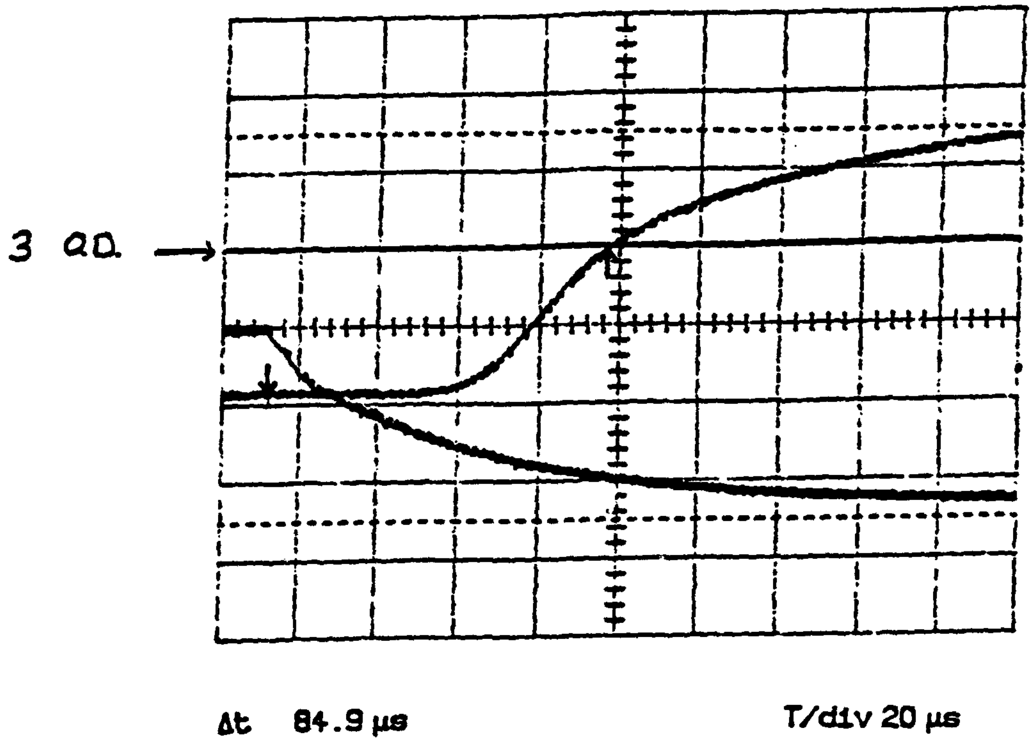

Figure 13. Typical closure time to 3 OD (84.9 μs) using the broadband light source as probe (IR blocked with KG3).

The activation times were not a function of the probe beam polarization angle or wavelength. We feel that this time could be significantly decreased with improved design of the electronics. The activation time of the currently used PLZT is only 12 μs.

The following table summarizes the closure time results. Apparent from these results is the polarization sensitivity of the device and the effect of near-IR radiation leakage.

Table 1. Closure Time Results

Case 1 ARGON-ION LASER (514nm) - Linearly polarized - coherent	Case 2 BROADBAND LIGHT SOURCE - randomly polarized incoherent	Case 3 BROADBAND LIGHT SOURCE (With KG3 Filter) - randomly polarized - incoherent
100.2	104.8	90.5
106.9	109.0	83.1
116.8	100.2	82.1
112.3	99.7	84.9
107.4	109.7	76.8
109.9	102.2	85.1
119.8	103.6	83.8
116.5	103.5	84.8
109.7	103.6	91.5
115.5	94.2	92.5
119.5		
112.8		
108.6		
109.7		
MEAN: 111.83	MEAN: 103.05	MEAN: 85.51
STD DEV: 5.25	STD DEV: 4.26	STD DEV: 4.55

The time to return to a fully open state did not change when tested during all three conditions. The fully closed to fully open time response was 15 ms for all cases (Fig. 14). This time response also appears to be a function of the electronics and the electro-optic nature of the SMLCS.

DISCUSSION

A full-scale test was not completed on the prototype SMLCS because of probable technical changes in the military version. Nevertheless, we feel that the data collected thus far depicts the SMLCS as technically feasible for NFP. Additionally, the limited evaluation performed will allow us to design more optimal test systems. From this evaluation we have gained vital information on the technical areas which require the most extensive investigation while testing the military version of the SMLCS nuclear flashblindness protection device.

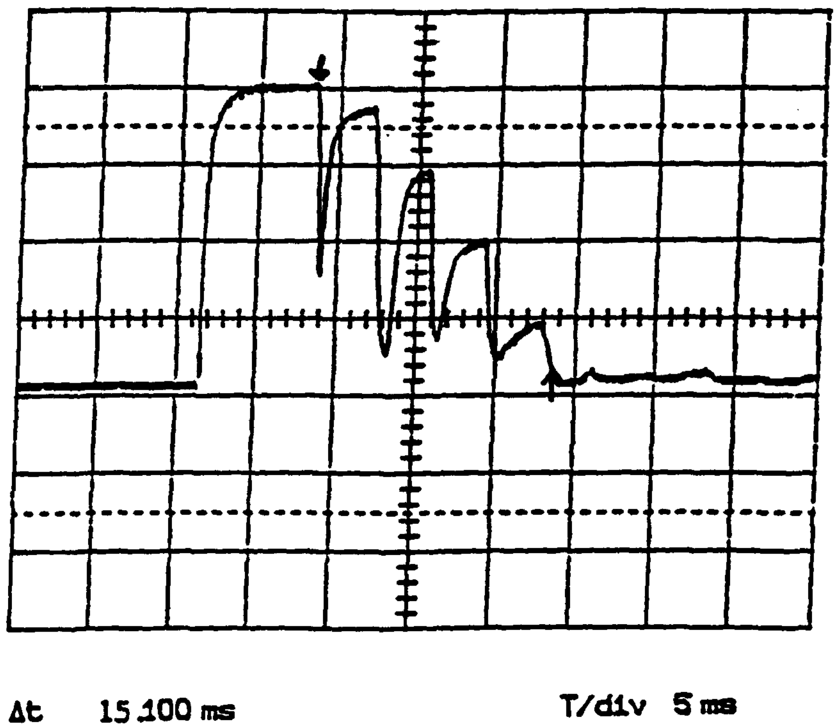

Figure 14. Typical time to return to open state transmission (15 ms).

The polarization sensitivity of the device should not be a major concern since the radiation from a nuclear detonation is randomly polarized as is most naturally occurring illumination, nor should there be any significant effects from the cockpit lighting since it should also be randomly polarized light.

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