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EFFECTS OF IONIZING RADIATION
ON STABILIZED PHOTO OPTICS

October 1969

AEC RESEARCH &
DEVELOPMENT REPORT

ROUTE TO	FILE NO.	LOCATION	FILE'S ROUTE DATE
Checked for	60013-2714		FEB 16 1970
L. J. Zahner	69997 Jhd		FEB 16 1970

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BNWL-1137

UC-40,
Radiation Effects
on Materials

EFFECTS OF IONIZING RADIATION ON
STABILIZED PHOTO OPTICS

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October 1969

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BATTELLE MEMORIAL INSTITUTE
PACIFIC NORTHWEST LABORATORIES
RICHLAND, WASHINGTON 99352

Printed in the United States of America
Available from
Clearinghouse for Federal Scientific and Technical Information
National Bureau of Standards, U.S. Department of Commerce
Springfield, Virginia 22151
Price: Printed Copy \$3.00; Microfiche \$0.65

EFFECTS OF IONIZING RADIATION ON
STABILIZED PHOTO OPTICS

J. H. Kleinpeter and W. J. Clare

ABSTRACT

Several nonbrowning lenses were tested for useful life in a radiation field. Included in the test were a 30-150 mm variable focal-length or "zoom" lens, fixed focal-length lenses in 1/2-in. f/2.5, 1-in. f/2.5 and 4-in. f/2.5 sizes, and suitable controls of conventional glass. All the nonbrowning lenses were useful beyond 10^9 rad total integrated dose, and the 1-in. f/2.5 was usable after 2×10^{10} rad. Coupons of the glasses used in the manufacture of these lenses were irradiated and tested for changes in refractive index and visible light transmission.

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INTRODUCTION

Many of the procedures and manipulations required in the nuclear industry must be performed remotely with several feet of shielding between the operator and the task being performed. This requirement has resulted in the development of many highly versatile manipulating tools covering the gamut from simple tongs to mechanical and electro-mechanical hands capable of very delicate motion and possessing great strength.

The problems associated with viewing have resulted in a wide variety of solutions ranging from mirrors to shielding windows and to very complex, highly versatile periscopes.

With the increase of radiation levels and the use of more massive shielding, direct viewing through high density glass or liquid shielding windows becomes less satisfactory. Use of lead glass shielding windows 4 ft in thickness is not uncommon. Light losses through windows of such thickness are high and the losses through even thicker windows would be almost intolerable.

Until the development of closed-circuit television, viewing was possible from a few rigidly fixed points and in only a narrow range of magnification. Television cameras, on the other hand, can be mounted on movable platforms or booms and can accept lenses with a wide range of focal lengths. Now, for the first time, viewing is not restricted to a direct line-of-sight arrangement of prisms and mirrors.

From the outset, radiation-induced darkening of the glass components of the viewing devices has been a serious problem and television viewing systems are no exception.

Glass exposed to a field of ionizing radiation tends to darken with exposure. This phenomenon is caused by the formation of color absorption centers accompanying the electron scattering. Electrons ejected from their normal positions are captured in lattice defects forming "f" centers which absorb in the visible spectrum. At the same time, the site vacated by the electron forms a "V" center which does not absorb light.

Two methods developed for solving this problem have been by (1) increasing the conductivity of the glass, and (2) shifting the color of the absorption band outside the visible spectrum. Increasing the electrical conductivity accelerates annealing by increasing the rate at which the electrons can escape the "f" centers and fill in the "hole" at the "V" center. Conductivity can be increased either by increasing the concentration of alkali metal ions or by raising the temperature of the glass. At temperatures between 100 and 500 °C, a 30° rise causes approximately an order of magnitude increase in conductivity for many of our common glasses. This effect, strictly a "rule-of-thumb" type relationship which should be used with caution, is included only to indicate the temperature necessary for reducing the annealing time to a practical level.

The wavelength of the color absorption band is, to a degree, a characteristic of the chemical makeup of the glass. The addition of even a small amount of certain chemicals can cause a shift in the wavelength of the "f" center absorption. One to 3% of cerium oxide will often shift the wavelength of the absorption band outside the visible spectrum, and the amount of ionizing radiation needed to cause a disturbing amount of darkening will be increased several orders of magnitude.

The addition of cerium oxide to a glass melt, however, adds an overall yellowish cast to the glass and reduces its light transmission capability. This radiation stabilizer thus must be added with caution and its benefits carefully balanced against its faults.

In addition to glass damage, the effect of ionizing radiation on electronic components of the lens-camera system must also be considered. Much progress has been made in the radiation hardening of these systems, and improvements in this field are expected to continue.

With the advent of the variable focal-length lens, the problem of remote lens change has been simplified. Several manufacturers, both in this country and abroad, have offered variable focal-length or "zoom" lenses adapted for remote operation of the diaphragm, focus, and zoom functions. Until recently, none of these lenses were made of nonbrowning glass. However, Wollensak, Inc. now offers several nonbrowning lenses suitable for use on television cameras. These are potentially useful in several phases of the operation and maintenance of the Fast Flux Test Facility. This report describes the study and evaluation of several of the nonbrowning lenses produced by Wollensak. Because of its superior manipulative potential in a remotely controlled and sustained operation, the variable focal-length or "zoom" lens has been studied in greatest detail and the results emphasized in this report. This study was a cooperative effort in which Wollensak furnished the lenses, Battelle-Northwest performed the irradiations, and both participated in interpreting and reporting the results.

As the study progressed, it became apparent that much useful information could be gained by irradiating each separate type of glass in these lenses as an individual entity rather than as part of a completed lens system. Included in this study, therefore, was the examination of 11 separate types of glass used in the design of these lens systems.

This work was undertaken under terms of Special Agreement BSA 510 and Prime Contract AT(45-1)-1830. The justification of the work and working arrangement is detailed in that contract.

EXPERIMENTAL PROCEDURE

The lens of primary interest for this test was the f/2.7, 30-150 mm nonbrowning remote-control zoom lens. A lens of similar specification but of conventional glass was used as a control. Lenses of 4, 1, and 1/2-in. focal lengths were also included as a test of other nonbrowning glass systems. In each case, a conventional glass control was included.

Two irradiation facilities were used in these tests. Both were of the swimming pool type with a cobalt 60 source. The more convenient installation was the one in 3730 Building of the Pacific Northwest Laboratories. Items to be irradiated in this facility were introduced into a position inside the array of cobalt 60 rods by means of a permanently positioned 2-in. OD tube. At the time of this test, the dose rate at this position was 2×10^7 rad/hr. A 4-in. standard weight steel pipe was also available for items too large for the 2-in. tubes. This pipe, located outside the array, was rated at 2.2×10^6 rad/hr at the time of this test.

The facility operated by Douglas United Nuclear at their 100K reactor site was used for items too large for the 4-in. pipe. This facility is equipped with a 6-in. pipe in the center of the cobalt fuel array. The dose rate at the time of this test was 2.2×10^6 rad/hr.

The exposure levels in these facilities were measured with chemical dosimeters at the time of installation. Subsequent monitoring was performed by means of ionization chambers or by calculation from the known decay rate of cobalt 60. In the strictest sense, dose rates expressed here are in terms of energy absorbed by the chemical dosimeter, but since most other field strength measurements will be on a similar basis, it would serve no useful purpose to convert these measurements to actual energy absorbed by the glass or by other material of the specific lens system.

During the course of the exposure, radiation heating caused a temperature rise in the lenses. For relatively long term exposures, the temperature stabilized at approximately 80 °C. Measurements of optical characteristics were made of the lens as soon as practical after removal from the source.

All lenses were inspected and light transmitting characteristics measured before the start of the test. After each increment of exposure, each lens was again inspected for physical operation and the light transmission measured. Performance of these inspections and measurements was planned after 10^6 , 10^7 , 10^8 , 10^9 , and 10^{10} rads total integrated dose. A television camera and monitor were also set up with a resolution chart to monitor resolution.

Light transmission was measured with a Gamma Model 700-W photometer equipped with a cosine receptor. The light source was a 500-W reflector-photoflood. To minimize fluctuations in light intensity, a Sorensen Model AP 1010 voltage regulator was used in the power line with an autotransformer to regulate the actual voltage to the lamp. A very sensitive voltmeter and ammeter were used to monitor power to the lamp. The general set-up is shown in Figures 1 through 5.

The lens under test was mounted on the photocell of the photometer and set up on a stand approximately 8 ft from the light source. The positions of the photocell and light source were not changed during the test. All external light was shielded from the test as shown in Figure 1.

Before irradiation, each lens was mounted on the photocell and the meter adjusted to read the light transmitted as 100%. The lens was then removed and the reading recorded as the photometer reading for that lens. This value varied slightly from lens to lens.

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FIGURE 1.
*General Arrangement of Equipment for Measurement
of Light Transmission of Test Lenses*

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FIGURE 2. *Light Transmission Measuring Equipment with
Lens and Photocell Uncovered*

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FIGURE 3. Light Source Showing Voltage Regulator, Autotransformer, Meters, and Photoflood Lamp in Test Position

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FIGURE 4. Photometer, Photocell, and Lens in Test Position

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FIGURE 5. General View of 3730 Building Irradiation Facility

After exposure to the colbalt 60 source, each lens was remounted on the photocell and its light transmission measured with all the mechanical adjustments the same as for the standard unirradiated measurement.

To observe the effect of irradiation on the resolution of the lenses under test, a Motorola Model S1120C camera and a General Electric Model 25B2 monitor were connected in closed circuit. Resolution was read directly from a RETMA 1956 resolution chart lighted at 28-30 ft-candles.

This resolution test was set up, not as an evaluation of the resolving capability of the lens but as a means of detecting gross changes in resolution. Because equipment for accurately evaluating lens resolution was not available, this method of monitoring was chosen rather than to ignore completely this aspect of lens performance. It should be pointed out that, inasmuch as the camera was not in good adjustment, these data are qualitative only. The chart was illuminated by ambient light from fluorescent fixtures about 15 ft above the floor. The light intensity at the position of the chart was measured to be 28-30 ft-candles. A Weston meter equipped with a cosine filter was used for this measurement.

The resolving characteristics of all lenses tested were well known for the unirradiated state. In the interest of time saving, therefore, no local measurements were made before the start of the irradiation. The first increment of exposure of the 1-in. f/2.5 lens required only three min. At the end of this first exposure step, and because the camera for the resolution test had not yet been located, no resolution reading was made on that lens after 10^6 rad.

The resolution in lines per inch reported here does not approach the resolution determined on an optical bench for these same lenses. The resolution does, however, reflect the limit

imposed by the camera-monitor system. The resolving power of the lens must be reduced below that of the camera-monitor combination to permit detection of any change. For a resolution test, the lens must be mounted on the camera, focused as accurately as possible on the chart, the iris diaphragm adjusted to the pre-selected figure, and the resolution read on the monitor. When the lens cannot be focused or the diaphragm adjusted, the resolving characteristic of the system cannot be determined. This situation occurred after exposure of the 1-in. f/2.5 lens to 10^9 rad and after exposure of the zoom lens to 10^8 rad. The other two lenses under evaluation operated easily after exposure to 10^8 rad. Resolution test results are reported on Table 1.

All lenses were inspected and light transmission determined before the start of the test. After 1×10^6 rad total exposure, each lens was inspected and light transmission determined. These data are reported in Table 2. The conventional glass lenses had darkened so severely at this point that they were totally useless for further test purposes.

The lenses were then returned to the source and the irradiation continued. All four of the stabilized lenses survived the 10^7 rad exposure and the test was therefore continued to 10^8 . The mechanical function of the zoom lens was inoperative at this point, with only the light transmission being measured. After 10^9 rad, the mechanical operability of the fixed focal length lenses was so seriously impaired that normal adjustments were not possible. Despite this, the 1-in. f/2.5 lens was irradiated to 10^{10} rad. At this point, all test lenses were returned to Wollensak for mechanical repair.

Inspection revealed serious damage to the organic parts. The lubricant was hardened and very viscous, plastic gears had been stripped as a result of the increased load, and the plastic clutch plates had deteriorated badly.

TABLE 1. Resolution in Lines Per Inch

Lens	Test f/No.	Total Integrated Dose, rad					
		10^6		10^7		10^8	
		Center	Edge	Center	Edge	Center	Edge
Zoom	Full open	450	300	400	300	(1)	
1/2-in. f/2.5	5.6 4	550	300	600	300	450	300
1-in. f/2.5	5.6			650	300	600	400 (2)
4-in. f/2.5	5.6 4	600	350	550	350	500	400

(1) At 10^8 rad exposure, the zoom lens was mechanically inoperative. For this reason, no resolution observations could be made.

(2) At 10^9 rad exposure, the 1-in. lens was mechanically inoperative. For this reason, no further resolution observations could be made.

TABLE 2. Light Transmission of Irradiated Lenses in Percent

Lens	Exposure, rad						Maximum (4)	
	0	10^6	10^7	10^8	10^9	10^{10}	As Irradiated	After Cleaning
N.B. Zoom	100	58	43	27 ⁽¹⁾	9 - 30 ⁽²⁾ (1.2×10^9)		(2×10^9 rad)	(2×10^9 rad)
N.B. 1/2-in. f/2.5	100	55	65	52	16		31 (2×10^{10} rad)	29 (2×10^{10} rad)
N.B. 1-in. f/2.5	100	98	98	97	89	84 ⁽³⁾	73 (2×10^9 rad)	81 (2×10^9 rad)
N.B. 4-in. f/2.5	100	69	77	69	58		62	65
Std. Zoom	100	0						
Std. 1-in. f/1.5	100	0.4						
Std. 4-in. f/2.5	100	0.4						

(1) After 10^8 rad, the mechanical movements were frozen and an oil-like coating was noted on the glass.

(2) There was an oil-like film on the glass after this exposure. Light transmission with the film was 9% and 30% after cleaning. The "oil" may have come from diaphragm lubricant.

(3) After 10^9 rad, the mechanical adjustments would not operate. However, irradiation was continued to 10^{10} rad.

(4) When inspected at the Wollensak factory after this irradiation, a film was seen on the glass. Light transmission measurements were made before and after removal of the deposit.

The zoom lens was reassembled after all optical parts had been cleaned. The plastic gears were replaced with metal, the clutch plates with carbon, and a dry film lubricant used on all contact surfaces. The fixed focal length lenses were cleaned, degreased, and lubricated with a dry film lubricant.

All four lenses were then returned to Battelle-Northwest for further irradiation. The 1/2-in. and the 4-in. lenses were each given an additional 10^9 rad, while the 1-in. lens was given an additional 10^{10} rad. The zoom lens was exposed to 1.1×10^9 rad. The mechanical functions of this lens were operated at the end of each increment while still in the radiation field, then removed, inspected, and returned to the irradiation facility. Unfortunately, the lack of a camera at this time compelled termination of the resolution test.

Mechanical operations of the zoom lens ceased to function after 1.1×10^9 rad exposure, again from lubrication and plastic part failure.

In the meantime, Wollensak had prepared five coupons each of 10 different nonbrowning glass blank materials and four coupons of an eleventh type of glass. These coupons were cut to 0.500 in. by 0.500 in. by 2.0 in. and polished on two opposite long faces.

Samples were identified by manufacturer's name, the index of refraction, and the dispersion, or "V" value. The code used the manufacturer's initial and two three-digit numbers separated by a hyphen. The first group of numbers constituted the last three digits of refractive index for the Sodium "D" line, and the second group denoted the dispersion value without the decimal point. The samples were:

BL 517-645
BL 541-599
BL 573-574
PM 603-502

S 612-581
BL 617-366
PM 620-602
BL 649-338
PM 681-320
S 714-279
S 520-617

BL - Bausch & Lomb., Rochester, New York
S - Optical glass distributed by Fish-Shurman Corp., New Rochelle, N. Y.
PM - Sovirel Department, Parra-Mantois, Paris, France.

One of the five coupons of each sample was kept as a control, and one of each of the other four exposed to 10^7 , 10^8 , 10^9 , and 10^{10} rad. In the case of the BL 573-574, the 10^7 exposure was omitted because of the lack of a fifth coupon.

After irradiation, each coupon was measured for light transmission throughout the visible range on a Beckman DB 200 double beam spectrophotometer. This measurement was compared to a similar scan of the unirradiated control. No attempt was made to minimize or standardize the time lapse between removal from the radiation field and the light transmission measurement. In no case was the delay longer than 72 hrs.

These results were reproduced as recorded, with a trace for each exposure level on the same graph. As can be readily seen in Figures 6 through 16, the loss is much less at the red end of the spectrum than at the blue end. This result might suggest the incandescent or sodium vapor lights to be much more desirable for use with television viewing systems than the mercury vapor lights, so often used in high level radiation cells.

In the case of the actual spectrophotometer scans, the light transmission of each sample at each radiation level is compared to that of air throughout the visible spectrum (Figures 6 through 16).

FIGURE 6. *Percent Light Transmission of Sample S 714-297 Compared to Air Versus Wavelength of Visible Light*

FIGURE 7. *Percent Light Transmission of Sample PM 681-320 Compared to Air Versus Wavelength of Visible Light*

FIGURE 8. Percent Light Transmission of Sample BL 649-338 Compared to Air Versus Wavelength of Visible Light

FIGURE 9. *Percent Light Transmission of Sample PM 620-602 Compared to Air Versus Wavelength of Visible Light*

FIGURE 10. *Percent Light Transmission of Sample BL 617-366 Compared to Air Versus Wavelength of Visible Light*

FIGURE 11. Percent Light Transmission of Sample S 612-581 Compared to Air Versus Wavelength of Visible Light

FIGURE 12. *Percent Light Transmission of Sample PM 603-502 Compared to Air Versus Wavelength of Visible Light*

FIGURE 13. *Percent Light Transmission of Sample BL 573-574 Compared to Air Versus Wavelength of Visible Light*

FIGURE 14. Percent Light Transmission of Sample BL 541-599 Compared to Air Versus Wavelength of Visible Light

FIGURE 15. Percent Light Transmission of Sample S 520-617 Compared to Air Versus Wavelength of Visible Light

FIGURE 16. Percent Light Transmission of Sample BL 517-645 Compared to Air Versus Wavelength of Visible Light

Upon return to Wollensak, the refractive index of each sample was again determined. These data are presented in Table 3.

CONCLUSIONS

It appears that, optically, the nonbrowning zoom lenses can provide acceptable service well beyond 10^9 rad total exposure. At this point, a loss of two to three stops can be expected. This loss normally can be tolerated, since that amount of leeway is designed into the total system.

The mechanical operation of the lens was adequate but sluggish after 1×10^9 rad total exposure. Careful choice of components and lubricants should extend the mechanical life to well beyond this exposure.

Of the fixed focal length nonbrowning lenses tested, the 1-in. f/2.5 was the best. Light transmission after 2×10^{10} rad exposure was reduced much less than one stop. The focus and iris movement were both very stiff after 1×10^{10} rad because of internal corrosion of the brass parts. The cause for this corrosion has not been isolated.

The 4-in. f/2.5 lens lost less than one stop after exposure to 2×10^9 rad. There was no impairment of its mechanical function after 1×10^9 rad.

The greatest reduction in light transmission, sustained by the 1/2-in. f/2.5 lens, occurred two to three stops after 2×10^9 rad. There was no impairment of its mechanical function after 1×10^9 rad.

The irradiation and measurement of light transmission and refractive index of the various glass samples has indicated that the radiation stability of the nonbrowning glass offered lens manufacturers is quite good. These measurements also disclosed that loss in light transmission does not follow a

TABLE 3. *Effect of Gamma Radiation
on the Refractive Index of Glass*

Glass Sample Identification						
Total Dose, rad	S 714-297	PM 681-320	BL 649-338	PM 620-602	BL 617-366	S 612-581
Refractive Index, λ_0						
0	1.71388	1.68061	1.65071	1.62067	1.61752	1.61232
10^7	1.71393	1.68061	1.65076	1.62067	1.61712	1.61238
10^8	1.71393	1.68072	1.65076	1.62067	1.61717	1.61238
10^9	1.71388	1.68072	1.65076	1.62067	1.61717	1.61250
10^{10}	1.71407	1.68098	1.65082	1.62074	1.61723	1.61267

Glass Sample Identification					
Total Dose, rad	PM 603-502	BL 573-574	BL 541-599	S 520-617	BL 517-645
Refractive Index, λ_0					
0	1.60301	1.57075	1.54125	1.52029	1.51720
10^7	1.60295		1.54130	1.52034	1.51715
10^8	1.60301	1.57209	1.54130	1.52034	1.51715
10^9	1.60301	1.57129	1.54135	1.52040	1.51720
10^{10}	1.60301	1.57239	1.54141	1.52045	1.51725

straight line relationship with radiation dose. In fact, some samples were found to recover to a remarkable degree. The observed changes in refractive index were, with one exception, less than 0.001. This result would indicate no detectable loss in resolution by lenses made from these glasses for television systems (see Table 3).

A filmy deposit was noted on several of the completed nonbrowning lenses, especially the zoom and the 1-in. f/2.5. This film was seen on the zoom lens after a total dose of 1.2×10^9 rad, and on the 1-in. lens after 2×10^{10} rad. It should be noted here that the zoom lens was cleaned after the first 1×10^8 increment and the 1-in. lens was cleaned after the first 1×10^{10} increment. The source of this film was possibly the oil or grease used to lubricate the mechanical components of the completed lenses. On the other hand, a film was deposited on five of the 12 glass coupons irradiated to 10^{10} rad. In the case of these coupons, each was wrapped individually in new aluminum

foil, and so far as is known, there was no contact with any organic material during irradiation. This would suggest that we may expect some such deposit at extremely high doses regardless of the nature of the lubrication.

These tests demonstrate that, in some cases, the nonbrowning lenses are superior to their conventional counterpart by as much as 10,000 to 1. The nonbrowning zoom lens appears to be superior to its conventional glass counterpart by about 2,000 to 1.

NOTES ON SPECTROPHOTOMETER SCANSNote 1.

After exposure to 10^{10} rad, Sample S714-297 was coated with an opaque deposit which rubbed off with some difficulty. For the irradiation, the samples were wrapped in aluminum foil to prevent contact between samples. All samples for each exposure were packed together in one foil-coated package.

Four others of the 10^{10} rad coupons also were found to be coated after irradiation. None was as dense or as difficult to remove as was the coating on Sample S714-297.

Note 2.

Sample PM681-320. Light film deposit on surface on 10^{10} coupon.

Note 3.

Sample BL648-338. Light film deposit on surface of 10^{10} rad coupon.

Note 4.

Sample BL617-366. Very small amount of film deposit on surface of 10^{10} rad coupon.

Note 5.

Sample S520-617. Very light film deposit on surface of 10^{10} rad coupon.

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