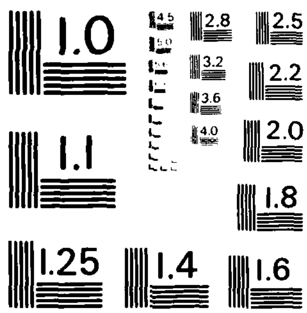
AD-A145 409   THE EFFECT OF TEMPERATURE ON THE RADIATION INDUCED   1/1
LOSSES OF LARGE DIAMET..(U) ROME AIR DEVELOPMENT CENTER
GRIFFISS AFB NY   J A WALL DEC 83 RADC-TR-83-288

UNCLASSIFIED   F/G 20/6   NL

END
DATE
FILMED
10-84
DTIC



MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS-1963-A

(12)

AD-A145 409

RADC-TR-83-288
In-House Report
December 1983

THE EFFECT OF TEMPERATURE ON THE RADIATION INDUCED LOSSES OF LARGE DIAMETER GPS AND GBS CORE OPTICAL FIBERS

James A. Wall

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

ROME AIR DEVELOPMENT CENTER
Air Force Systems Command
Griffiss Air Force Base, NY 13441

RADC-TR-83-288 has been reviewed and is approved for publication.

APPROVED:

BOBBY L. BUCHANAN
Chief, Radiation Hardened Elec Tech Branch
Solid State Sciences Division

APPROVED:

HAROLD ROTH
Director, Solid State Sciences Division

FOR THE COMMANDER:

JOHN A. RITZ
Acting Chief, Plans Office

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) RADC-TR-83-288	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Rome Air Development Center 6b. OFFICE SYMBOL (If applicable) (ESRE)	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State and ZIP Code) Hanscom AFB Massachusetts 01731	7b. ADDRESS (City, State and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State and ZIP Code)	10. SOURCE OF FUNDING NOS.

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT NO.
61102F	2306	J3	01

11. TITLE (Include Security Classification) The Effect of Temperature on the Radiation Induced Losses of Large Diameter GPS and GBS Core Optical Fibers

12. PERSONAL AUTHOR(S) James A. Wall

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Yr., Mo., Day)	15. PAGE COUNT
In-House	FROM ______ TO ______	1983 December	16

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB. GR.	Optical fibers; Radiation effects; Temperature dependence

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Large diameter (125/200 μ core-clad ratio) germanium-phosphosilicate (GPS) core and germanium-borosilicate (GBS) core optical fibers were tested for their radiation induced losses under continuous and transient radiation exposures at temperatures [illegible] 125°C. Under continuous irradiation, the GPS core fiber showed a rate of induced loss more than double that of the GBS core fiber at +25°C and a regular increase in induced loss with increasing temperature. The rate of induced loss for the GBS core fiber at +125°C was less than twice that at +25°C while at -55°C it was more than 20 times the +25°C rate.

Following continuous irradiation the GPS core fiber showed significant annealing of induced loss only at +125°C while the loss induced in the GBS core fiber annealed at both +125°C and -55°C.

(over)

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS ☐	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL James A. Wall	22b. TELEPHONE NUMBER (Include Area Code) (617) 861-4031 22c. OFFICE SYMBOL (ESRE)

DD FORM 1473, 83 APR EDITION OF 1 JAN 73 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

19. (Contd)

At 1 μsec after exposure to a 20 nsec x-ray pulse the loss induced in the GBS core fiber was greater than the induced loss for the GPS core fiber by approximately a factor of 2 at -55°C, 3 at +25°C, and 10 at +125°C. In both fibers the losses observed following an x-ray pulse were greater at lower temperatures.

Contents

Illustrations

Tables

The Effect of Temperature on the Radiation Induced Losses of Large Diameter GPS and GBS Core Optical Fibers

I. INTRODUCTION

In the application of optical fibers to military systems large diameter fibers with high numerical apertures are considered among the most practical because of their high source coupling efficiencies and relative ease of handling in the field. The Wright Aeronautical Laboratories (AFWAL) had selected this type of fiber for the implementation of a fiber optic avionic data buss design, but no information was available on the nuclear radiation response of the fibers over the specified operating temperature range of -55 °C to +125 °C. Because RADC/ES had an on-going in-house and contractual program for the development and testing of radiation hardened optical fibers, AFWAL requested that we provide them with the required radiation effects data.

The optical fiber that AFWAL had selected for the data buss had a core/clad ratio of 125/200 μm and a nominal numerical aperture of 0.25. The fiber had a germanium phosphosilicate (GPS) core. Previous tests at room temperature on smaller diameter fibers had shown that GPS core fibers had better recovery from induced loss following exposure to transient radiation than fibers with germanium borosilicate (GBS) cores. However, when exposed to steady-state radiation the GPS core fibers showed as much as an order of magnitude greater induced loss than GBS core fibers exposed to the same total radiation dose. It was, therefore,

(Received for publication 28 February 1984)

decided to also perform tests on GBS core fibers having the same physical dimensions and optical properties as the GPS core fibers.

The optical fibers tested were prepared by Gallileo Electro Optics Corp. under contract F19628-78-C-0099 and were essentially unjacketed versions of that company's commercial product. The fibers had core-clad ratios and numerical apertures within the previously mentioned specifications and losses of less than 6 dB/km at 850 nm. To distinguish these fibers from others prepared under the contract the GPS fiber was labeled WP-6 and the GBS fiber WP-7. In addition to preparation of the fibers, the contractor also designed and built to our specifications a special temperature control chamber for use with the RADC radiation sources. Real-time steady state and transient tests of the fibers were performed at -55 °C, +25 °C, and +125 °C. All tests for a particular fiber were performed on fiber taken from a single draw in order to avoid variations in results that could be caused by differences between preform fabrication and drawing processes.

2. EXPERIMENTAL PROCEDURES

The temperature control chamber designed for the tests was constructed of all low atomic number materials, except for the heating elements which were located some distance from the fiber position, in order to avoid perturbation of the radiation dose at the sample position. The walls were double plywood with fiberglass insulation and the sample chamber was aluminum. The chamber was divided horizontally by aluminum baffles to one of which was mounted a 900 W heating element used to attain temperatures up to +150 °C. The lower part of the chamber served as a liquid nitrogen reservoir. The fibers were wound on 13-cm diameter, 1.5-cm thick aluminum reels which mounted on the upper end of a moveable aluminum strut. The base of the strut rested on the bottom of the chamber so that it served as a cold finger when the reservoir was filled with liquid nitrogen. A low-power heating element attached to the strut controlled the lower temperatures, measured by a thermocouple, at the sample position.

Temperatures were maintained to within ±1 °C by proportional controllers and thyristor packs mounted in a console that could be located up to 25 m from the chamber and radiation sources. The console also included a digital thermometer for continuous temperature monitoring and an automatic liquid nitrogen fill controller which, in conjunction with a 60 liter pressurized dewar, could maintain the low temperatures for at least 6 hours.

The steady-state irradiations were performed using the RADC ^{60}Co source. 75-m lengths of fiber were wound on the aluminum reels and mounted in the temperature control chamber. An additional 3 m of fiber at each end of the fiber coil served as input and output leads. The chamber and fiber were positioned in the cobalt cell so the fiber would be exposed to a dose-rate of about 300 rads/min when the ^{60}Co source was raised from its shield. The input and output leads of the fiber were passed through a port in the cobalt cell shield wall. The input lead was butt-coupled to the pigtail of an 850-nm temperature stabilized light emitting diode (LED) operated in the continuous mode and the output lead was coupled to a PIN photodiode-amplifier detector. The output of the detector was connected to a chart recorder and a digital voltmeter to continuously monitor fiber transmission. The chart recorder was also used to monitor recovery of the induced loss after the irradiation.

Dosimetry was performed using an ionization chamber and thermoluminescent dosimeters (TLD's). The TLD's were attached directly to the fiber reels in quadrature to measure the total dose received by the fiber. The ionization chamber could not operate at the temperature extremes used in these tests, so it was located outside and adjacent to the temperature control chamber in a position where it received approximately the same exposure as the fiber. The ionization chamber readout (Victoreen Radocon II) was set to read accumulated dose and its output connected to a second pen on the chart recorder so that fiber transmission and accumulated dose could be measured simultaneously. Following the irradiation the TLD's were used to calibrate the dose indicated by the ionization chamber.

The transient tests were performed using the RADC flash x-ray generator which produces a 20 nsec pulse of nominal 2 MeV peak energy. Tests were performed at two dose-rates of nominal 10^8 rads/sec and 10^9 rads/sec. A thermoelectrically cooled 820-nm laser diode operated in continuous mode was used as the source input to the fiber and a PIN photodiode and 50 MHz bandwidth amplifier was used as the detector. The source was located in the irradiation area but out of the x-ray beam. The output lead of the fiber was coupled through a fiber-optic link to the detector located in the experiment control area. The output of the detector was connected to four oscilloscope inputs and a chart recorder with time base to obtain a time span from less than 50 nsec to more than 60 sec. Dosimetry was performed using a small PIN diode in direct contact with the fiber on the reel, except at +125°C where the PIN diode could not be operated. In the latter case, dose-rate was estimated from the average of dose-rates measured in preceding "shots" at lower temperatures in the same position relative to the flash x-ray target.

As for the steady-state irradiations, 75-m lengths of fiber were used for the transient tests. New lengths of fiber were used for each irradiation with the exception of the tests at 10^8 rads/sec where it was found in preliminary trials that the results of several "shots" on the same fiber were indistinguishable from one another. It was also found that the results of two or three irradiations of the same length of fiber at 10^9 rads/sec appeared identical, but it was decided to maintain the use of fresh fiber for each irradiation at this level.

Before presenting the radiation test results, it is important to mention significant changes in fiber transmission observed during variation of temperature. The greatest changes were observed during heating. As the fibers were heated from room temperature, the detected light output dropped steadily until at +125° C it was less than 10 percent of the initial value for the GPS core fiber and less than 50 percent of the original value for the GBS fiber. It is possible that these losses in transmission were due, at least in part, to stress produced in the fibers by expansion of the aluminum reels. However, it is difficult to explain the observed difference between the amount of loss in transmission for the GPS and GBS fibers since they were essentially identical except for core composition.

As the fibers were cooled a drop in signal was also observed, but not nearly as severe as with increasing temperatures. For both the GPS and GBS fibers the detected light output was above 90 percent of its initial value at -55° C. In either case, however, once the final temperature had been reached signal fluctuations were observed as the temperature cycled around its control point even though the temperature variations were only in the ± 1° C range. These fluctuations in detected output have an important bearing on the accuracy of the steady-state test results. Without the fluctuations the estimated accuracy is ± 1 dB/km. At -55° C and +25° C the fluctuations change this to ± 2 dB/km. At +125° C for the GBS core fiber this same order of accuracy probably holds, but for the GPS core fiber, due to the severe loss of signal, the accuracy is probably reduced to no better than ± 10 dB/km. For the transient tests estimated accuracy is ± 3 dB/km based on the readability of oscilloscope photographs. Because of the short time spans over which the transient measurements were made, the signal variations should not change this. However the loss of signal at +125° C for the GPS core fiber probably reduces the accuracy to ± 6 dB/km due to the decrease in signal-to-noise ratio.

3. RESULTS OF STEADY-STATE TESTS

Figure 1 shows the radiation induced loss as a function of dose for the GPS core fiber (WP-6). At any given dose the induced loss increases monotonically with increasing temperature. Figure 2 shows the comparative data for the GBS core fiber. At +25° C the induced loss at any dose is about one-half that of the GPS core fiber. The induced loss is higher at +125° C but still much lower than that of the GPS core fiber. At -55° C however there is a large increase in the rate of induced loss with dose and the induced loss at any dose is much greater than that of the GPS core fiber at any temperature. To facilitate the comparison of these results, Table 1 shows the initial rates of induced loss in dB/km-krad measured in the 0-1 krad range.

The data in Table 1 is for comparison purposes only and it should be clear from the non-linearity of the plots shown in Figures 1 and 2 that the initial rates of induced loss cannot be extrapolated linearly to estimate induced loss at higher doses.

Following the irradiations the fibers were maintained at the test temperatures for several hours to observe any annealing of induced loss that might occur. Figure 3 shows the observed recovery of induced loss for the GPS core fiber. Although there was some slight annealing during the first few minutes after irradiation at all temperatures, this fiber shows significant continuous annealing only at +125° C. Figure 4 shows the observed recovery of induced loss for the GBS core fiber. At +25° C and +125° C the annealing looks similar to that of the GPS core fiber. The -55° C data however shows a very high annealing rate. Even so, the induced loss at -55°C remains much higher than the losses at +25° C and +125° C. These results are clarified by Table 2 which shows the induced losses one hour after the irradiations.

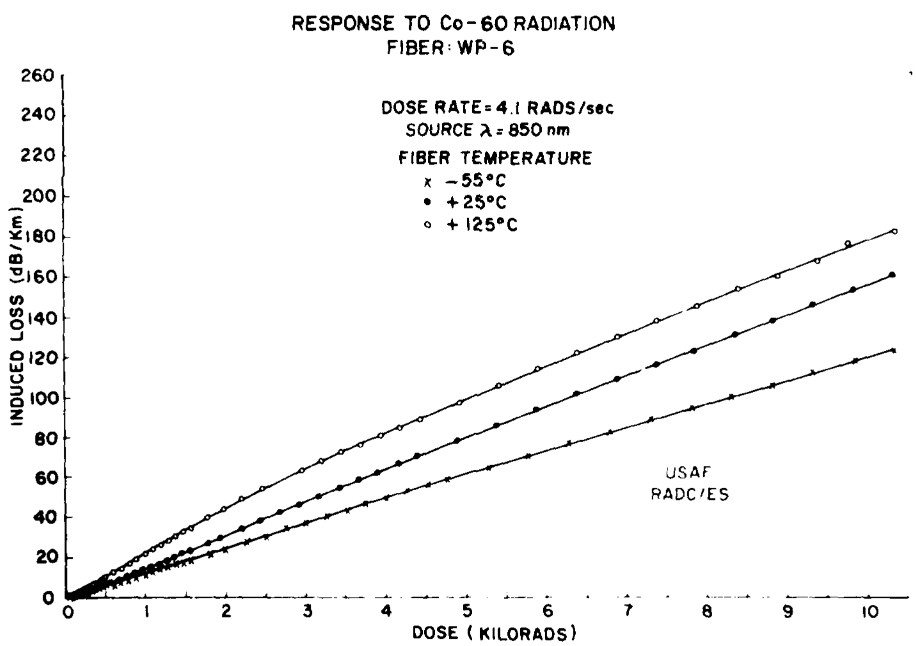


Figure 1. Induced Loss vs Dose for Steady-State Irradiation of GPS Core Optical Fiber

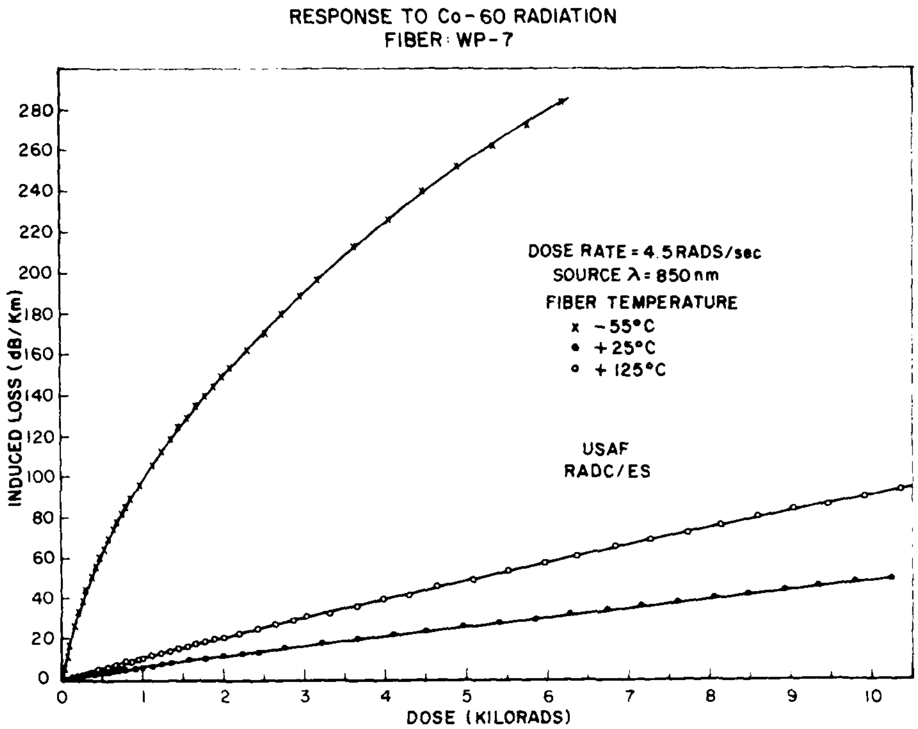


Figure 2. Induced Loss vs Dose for Steady-State Irradiation of GBS Core Optical Fiber

Table 1. Initial Rates of Induced Loss (dB/km-krad)

T (°C)	GPS (WP-6)	GBS (WP-7)
-55	12	160
+25	16	6
+125	23	11

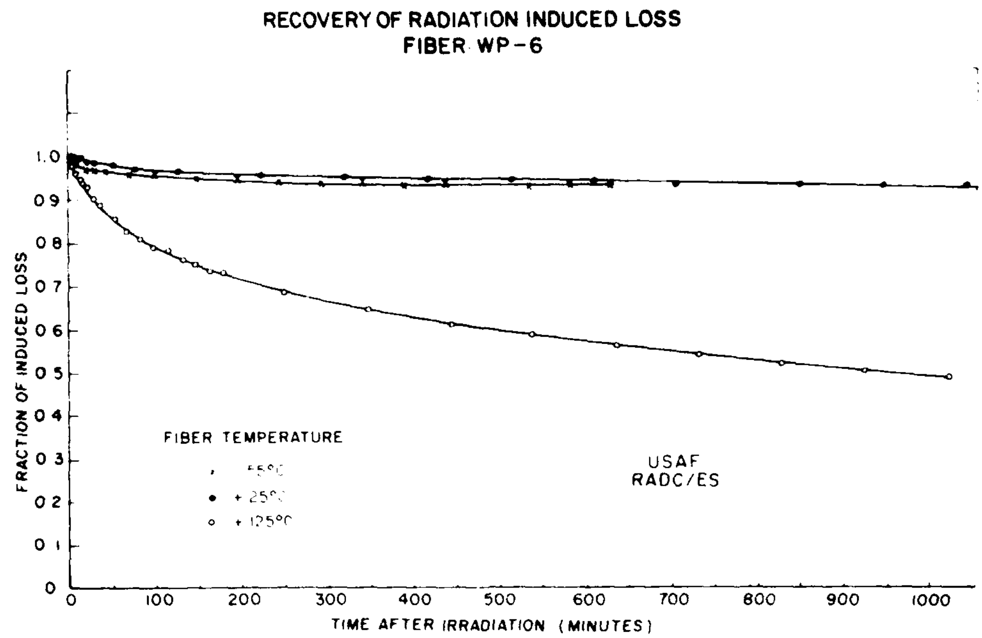


Figure 3. Recovery of Induced Loss for GPS Core Fiber Following Steady-State Irradiation

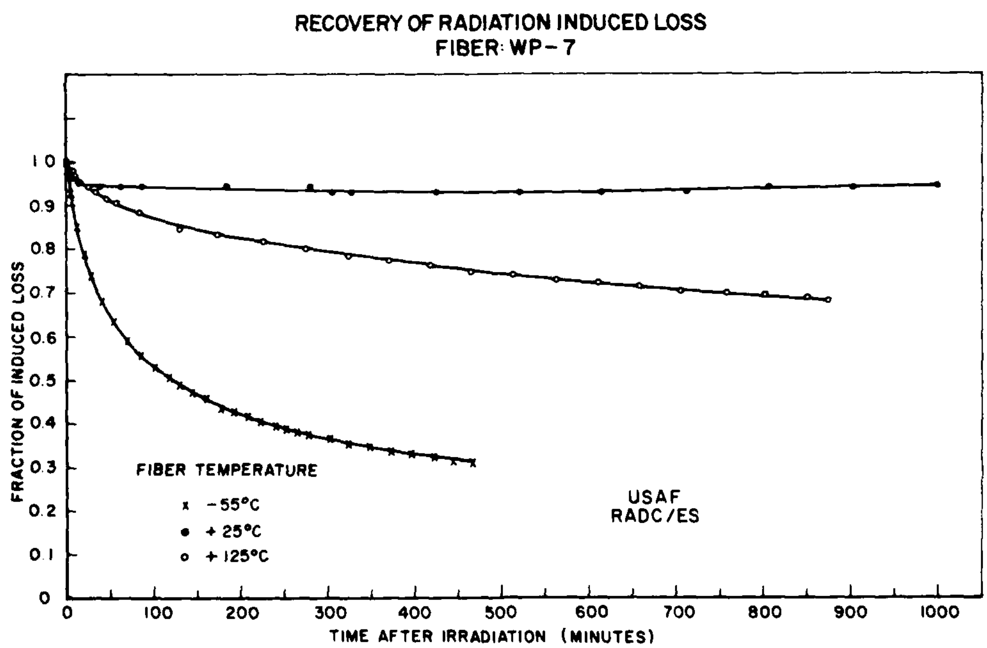


Figure 4. Recovery of Induced Loss for GBS Core Fiber Following Steady-State Irradiation

Table 2. *Induced Loss One Hour After Irradiation*

T (C°)	GPS (WP-6)			GBS (WP-7)		
	Lo	L	L/Lo	Lo	L	L/Lo
-55	119	115	0.96	363	224	0.62
+25	155	152	0.98	51	48	0.94
+125	178	150	0.84	92	84	0.91

Lo = loss at end of irradiation (dB/km)

L = loss one hour after irradiation

An interesting observation was made following the annealing tests at -55° C. Both the GPS core and GBS core fibers were reheated to +25° C where they showed the same residual losses as those measured when they were irradiated at that temperature. Unfortunately, similar tests could not be made following the annealing at +125° C because of the previously mentioned changes in fiber transmission with increasing temperature.

4. RESULTS OF TRANSIENT RADIATION TESTS

Figure 5 shows the induced loss as a function of time following irradiation of the GPS core fiber with a nominal 10^9 rad/sec flash x-ray pulse. Here, and for the other transient test results, the data has been normalized to a dose-rate of 10^8 rads/sec. This facilitates comparison of the data since the flash x-ray generator does not necessarily produce the same dose-rate from pulse to pulse even though all other irradiation conditions remain constant. To obtain the actual measured induced losses multiply the indicated normalized induced losses by the actual dose-rate shown on the figure divided by 10^8, that is, in this case multiply by 11.

The data in Figure 5 show that for the GPS core fiber the transient induced loss increases with decreasing temperature. This is the opposite of the temperature dependence observed during the steady-state radiation tests. However, in the transient tests we are observing recovery from a high initial loss obscured by Cerenkov radiation generated in the fiber. The transit time of the Cerenkov radiation in the fiber is estimated to be about 500 nanosec. Therefore, we cannot determine the temperature dependence of the initial induced loss, particularly since the data shows slower recovery of induced loss at lower temperatures. The initial induced loss at higher temperatures could be greater than that at lower temperature but the loss may have decreased significantly by the time the losses became observable.

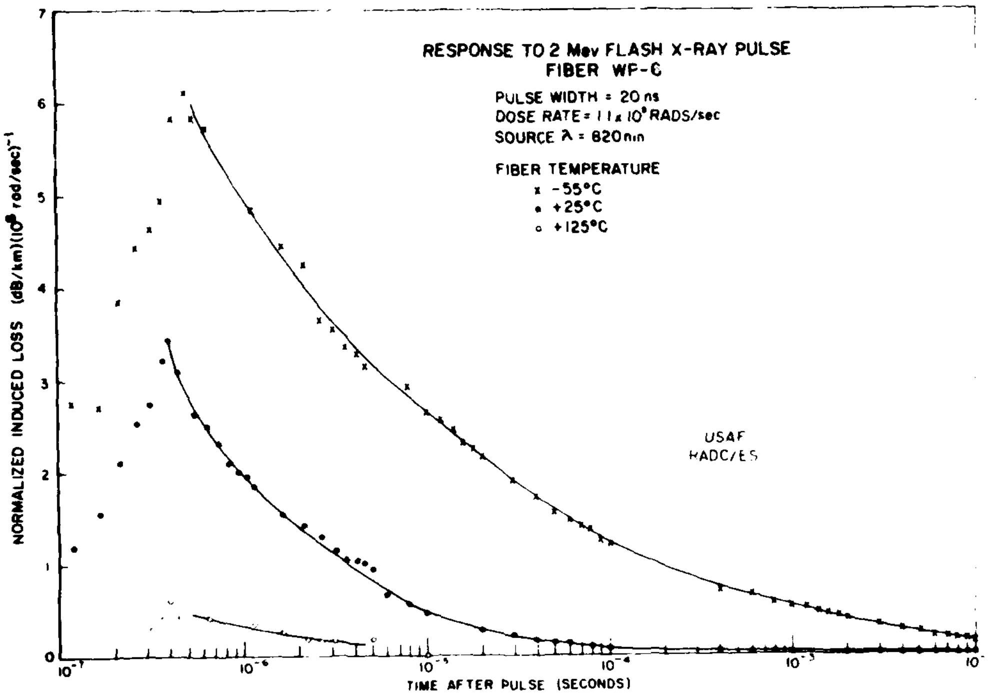


Figure 5. Transient Response of GPS Core Fiber

The GPS core fiber was also irradiated at a nominal dose-rate of 10^8 rads/sec, but the induced losses were too small to give meaningful recovery data within experimental error. However, the maximum observed induced losses were approximately proportional to dose-rate. For both the 10^8 rad/sec and 10^9 rad/sec irradiations recovery of the induced losses was essentially complete by 10 msec after the pulse at all temperatures.

Figure 6 shows the induced loss as a function of time for the GBS core fiber following irradiation with a nominal 10^9 rad/sec flash x-ray pulse. As for the GPS core fiber the observed losses increase with decreasing temperature. The induced losses are significantly greater than those observed for the GPS core fibers and the recovery rates are slower. Although recovery of the induced losses at +25° C and +125° C is essentially complete in less than 10 msec after the x-ray pulse, loss was still observed up to 60 sec after the pulse at -55° C. (Data in the msec range at -55° C has been omitted because of overshoot in the oscilloscope trace that was not detected until the photographs of the transients were analyzed in detail.)

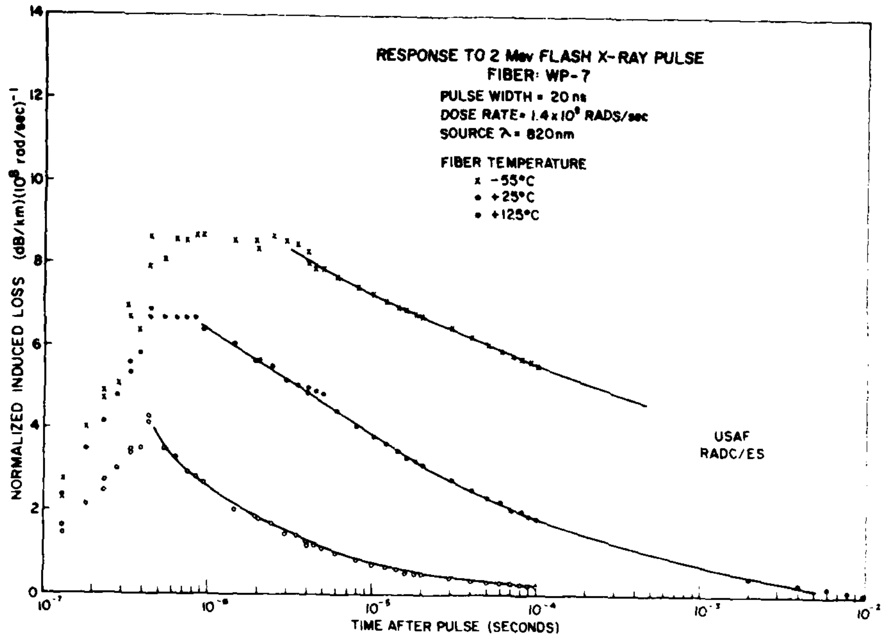


Figure 6. Transient Response of GBS Core Fiber Exposed to Nominal 10^9 rad/sec X-ray Pulse

For a quantitative comparison of the transient responses of the GPS core and GBS core fibers, Table 3 shows the induced losses 100 μsec after exposure to the nominal 10^9 rad/sec flash x-ray pulse (the data has been corrected for deviations from the nominal dose-rate).

Table 3. Induced Loss (dB/km) 100 μsec After 10^9 rad/sec X-ray Pulse

T (°C)	GPS (WP-6)	GBS (WP-7)
-55	12.3	56
+25	0.9	19
+125	0.5	2.1

The GBS core fiber was also irradiated at a nominal dose-rate of 10^8 rads/sec and the results are shown in Figure 7. Unlike the corresponding irradiation of the GPS core fiber the induced losses were clearly measurable. Comparing Figure 7 with Figure 6, the normalized induced losses for the 10^8 rad/sec x-ray pulse are approximately 1.4 times greater than those observed for the 10^9 rad/sec pulse at all temperatures. This shows that the transient induced losses for the GBS core fiber are not proportional to dose-rate.

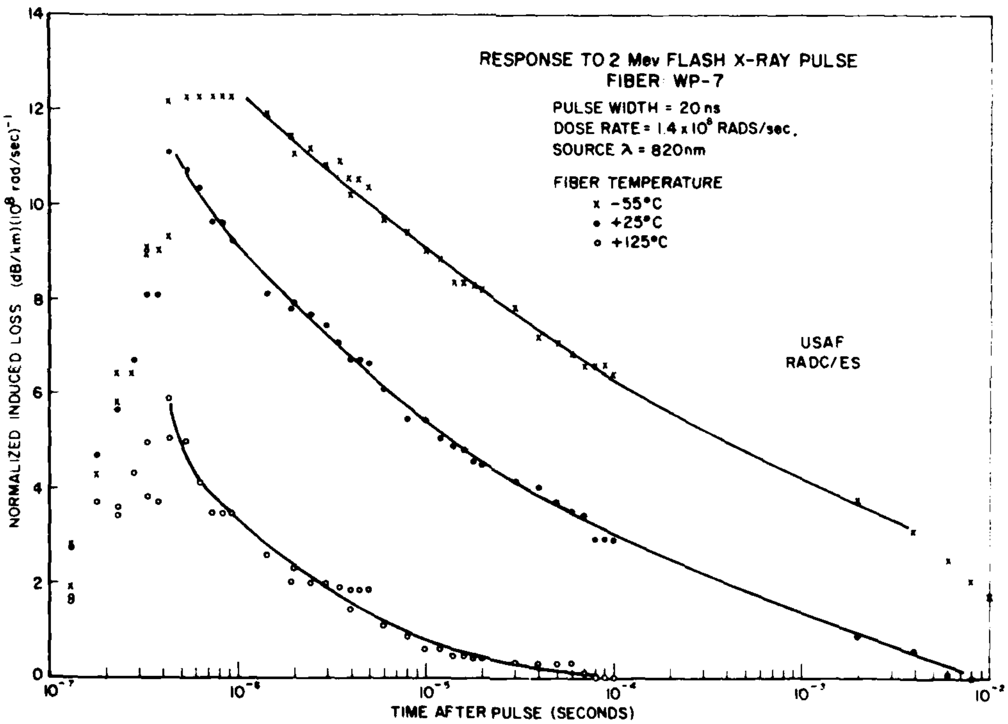


Figure 7. Transient Response of GBS Core Fiber Exposed to Nominal 10^8 rad/sec X-ray Pulse

5. SUMMARY OF RESULTS

The results of the radiation response tests of the large diameter GPS core and GBS core optical fibers may be summarized as follows:

5.1 Steady-State Irradiation

(a) For irradiations at +25° C and +125° C the loss induced in the GPS core fiber was approximately twice that induced in the GBS core fiber for any given total dose.

(b) The loss induced in the GPS core fiber increased monotonically with temperature while the loss induced in the GBS core fiber was a multivalued function of temperature.

(c) At -55° C the loss induced in the GBS core fiber was more than an order of magnitude greater than the loss induced at +25° C.

(d) Significant recovery of induced loss after irradiation was observed only at +125°C for the GPS core fiber while the GBS core fiber showed recovery at both +125° C and -55° C, but at -55° C the loss induced in the GBS core fiber remained significantly greater than the loss of the GPS core fiber eight hours after irradiation.

5.2 Transient Irradiation

(a) Following exposure to a 20 nanosec x-ray pulse, both fibers showed increased induced loss with decreasing temperature.

(b) The maximum observed induced loss in the GBS core fiber was 2 to 10 times greater than that for the GPS core fiber following exposure to an x-ray pulse.

(c) The rate of recovery from induced loss for the GPS fiber was at least twice that of the GBS fiber after exposure to an x-ray pulse.

(d) The transient x-ray induced loss was approximately proportional to dose-rate for the GPS core fiber but the induced loss per unit dose-rate was greater for the GBS core fiber exposed to a lower dose-rate.

It must be understood that the results of the tests reported here are applicable only to the specific optical fibers tested. Although other experience with radiation effects studies on smaller diameter fibers of similar generic compositions showed the same general trends as those reported here, differences in specific composition or fabrication processes could produce significantly different radiation responses in fibers that may appear equivalent to those tested.

MISSION
of
Rome Air Development Center

RADC plans and executes research, development, test and selected acquisition programs in support of Command, Control Communications and Intelligence (C^3I) activities. Technical and engineering support within areas of technical competence is provided to ESD Program Offices (POs) and other ESD elements. The principal technical mission areas are communications, electromagnetic guidance and control, surveillance of ground and aerospace objects, intelligence data collection and handling, information system technology, ionospheric propagation, solid state sciences, microwave physics and electronic reliability, maintainability and compatibility.

Printed by
United States Air Force
Hanscom AFB, Mass. 01731

ATE

LME