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GEO-CENTERS, INC.

GC-TR-83-249

PREPARATION AND CHARACTERIZATION OF OPTICAL WAVEGUIDES FOR SENSOR AND COMMUNICATION APPLICATIONS

PREPARED FOR
THE U.S. NAVAL RESEARCH LABORATORY
WASHINGTON, D.C. 20375
UNDER CONTRACT NUMBER
N00014-82-C-2137

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MARCH 1983

Introduction

In support of the Optical Materials Section of the Optical Sciences Division of the Naval Research Laboratory (NRL), Geo-Centers, Inc. has undertaken a technical effort with three basic elements:

(a) Study the long term effects of ionizing radiation on fiber optic transmission lines.

(b) Develop support hardware for the drawing of experimental fiber optic cables.

(c) Determine specified physical properties of optical fibers, e.g. tensile strength, index profile and optical density.

Partial results of these efforts have already been reported at professional meetings and directly to sponsors in private communications. This report summarizes the total technical effort conducted under the referenced contract.

Radiation Effects

Two basic physical mechanisms adversely affect the transmission characteristics of optical fibers when exposed to ionizing radiation: fluorescence and scattering. Incident ionizing radiation induces fluorescence in the glass material and its inherent impurities resulting in an optical "noise" signature being superimposed upon the data signal. Since this optical noise is usually "off band" from the signal carrier frequency, it can usually be filtered out and its effect minimized.

However, scattering centers, introduced in the glass and its impurities, result in a significant increase in attenuation due to the loss of scattered light from the optical waveguide. The degree and persistence of scattering is a function of the elemental constituency of the fiber, the total dose and dose rate of the radiation, and time after irradiation.

As an extension of data previously taken on fibers subjected to radiation at rates of 10^4 RADs/minute and the time-dependent attenuation for some hours following exposure, an investigation was begun on the response of these same fibers to much lower radiation levels. One RAD per day was chosen as a compromise between time constraints and radiation levels expected in environments of submarine rock formations, high altitude vehicles or nuclear power plants.

Monitoring a fiber's response to such low levels over a year's time demanded a system fundamentally different from that employed for the higher dose rate study. To this end a special system using an Optical Time Domain Reflectometer (OTDR) was developed. The trace of the OTDR gives the transmission profile of a given fiber. By comparing the slopes of successive OTDR traces, one can chart the progression of radiation damage as small as tenths of a dB/Km in kilometer lengths of fiber over a period of weeks (see Figures 1 and 2). In order to distinguish purely radiation-induced losses from coincidental losses, it was necessary to minimize ambient effects. In unirradiated fibers, microbending primarily accounts for sensitivity to aging and temperature fluctuations, an asset to many sensor applications.

Microbending and stresses were largely eliminated by winding the lengthy fibers under negligible tension. A "zero-tension winder" was designed and deployed and is now in regular use in fiber fabrication.

The first report of the low-dose rate study included a comparison with data from higher dose rates, some of which had been previously collected. Results presented at the 1982 Meeting of the American Ceramic Society at Bedford, Springs, PA indicated that differences in damage versus rate might be explained by time-dependent recovery in some classes of fibers (see Figures 3 and 4). It is well known that a sizable fraction of the induced loss following a rapid exposure may anneal to lower permanent levels, an effect known as "fading." The second phase of the experiment has focused on determining the existence or non-existence of a purely rate-dependent permanent loss mechanism. Because the damage in the one-RAD/day group occurred continuously over several months, that induced loss could be considered permanent. After an initial exposure, the short lengths subjected to higher dose rates would be faded for a similar period, then remeasured. Again, the OTDR was used to ensure long-term accuracy. In obtaining a meaningful loss profile with the OTDR, hundreds of sample points are needed, implying sample lengths of hundreds of meters. To utilize the typically thirty-meter lengths of the higher dose rate samples, the OTDR was modified to provide a "dual boxcar" function, enabling accurate signal and numerical averaging in conjunction with a computer. With the new interfacing, the computer can direct the boxcar placement randomly, and can select the OTDR's internal averaging modes to minimize data acquisition time. At highest resolution, the system can resolve .01 dB compared to a pre-modification figure of .1 dB best case. A drift rate of about .2 dB per hour was simultaneously eliminated. It was possible, therefore, to measure the .06 dB attenuation presented by 30 meters of state-of-the-art fiber with considerable detail. Returning to the low dose rate long lengths, the computer has replaced a chart recorder so that data reduction is simplified.

In a slightly separate area, some preliminary investigations into refractive index alterations by irradiation have been performed on three commercial preform sections using a York Technologies Preform Profiler.

Fiber Production

After an NRL tower for drawing preforms into fibers became available, one of the support mechanisms required was a controller for spooling completed fiber at a reasonable tension. In the summer of 1982 a controller was implemented based on an optical deflector for minimizing tension and wear. Recently the control circuitry was upgraded and the deflector modified to where fiber is spooled at somewhat lower tension than that seen on received commercial spools.

Preform production, known as CVD (for Chemical Vapor Deposition) utilizes a precision gas flow manifold for proper control over glass layer composition. The manifold will eventually be included in the overall computer control scheme. Interfacing circuitry has been designed and electronic components procured.

Fiber Characterization

A variety of special characterization tasks were performed for specific applications. One of the first was the construction of a proof tester, a machine to proof the fiber's tensile strength. Portions of this machine saw use in the early stages of the "zero-tension winder."

A high resolution fiber refractive index profiler is needed to complement the fiber fabrication program. The profiling method selected was a variation of Stewart's Refracted Near-Field technique. Acquisition of suitable translation stages for the sub-micron resolution required has been problematic. The apparatus will depend on close integration with a computer controller, and some software has been written to control a set of translators.

In performing the cut-back method of measuring inherent optical density, accurate fiber length measurement is fundamental. In October 1982, the U.S. Department of Commerce called on NRL/Geo-Centers, Inc. to confirm some fibers for export on the basis of minimal inherent optical density. A rapidly constructed length counter with an accuracy of around .03% served to disqualify several fibers as being of too high quality for export.

FIGURES FROM RADIATION STUDIES*

Figure 1: Configuration of the low dose rate experiment. Figure shows the gamma source, placement of the reference and irradiated portions of the fiber, and the components of the OTDR.

Figure 2: Sequential OTDR traces of a single fiber with reference and irradiated regions indicated.

Figure 3: Results of low dose rate exposure for four fibers. Dose is plotted against a log scale, and a linear least-squares curve is fitted to the data sets. Induced loss correlates with core phosphorus content; the highest curve represents a fiber with over 15% phosphorus; the lowest, a pure silica core fiber.

Figure 4: A summary of damage per unit dose at rates spanning seven orders of magnitude. Fibers with significant phosphorus content do not "fade" or recover, and damage response is nearly identical at all rates.

*Figures have not been published and are not for outside circulation.

LOW DOSE RATE CONFIGURATION

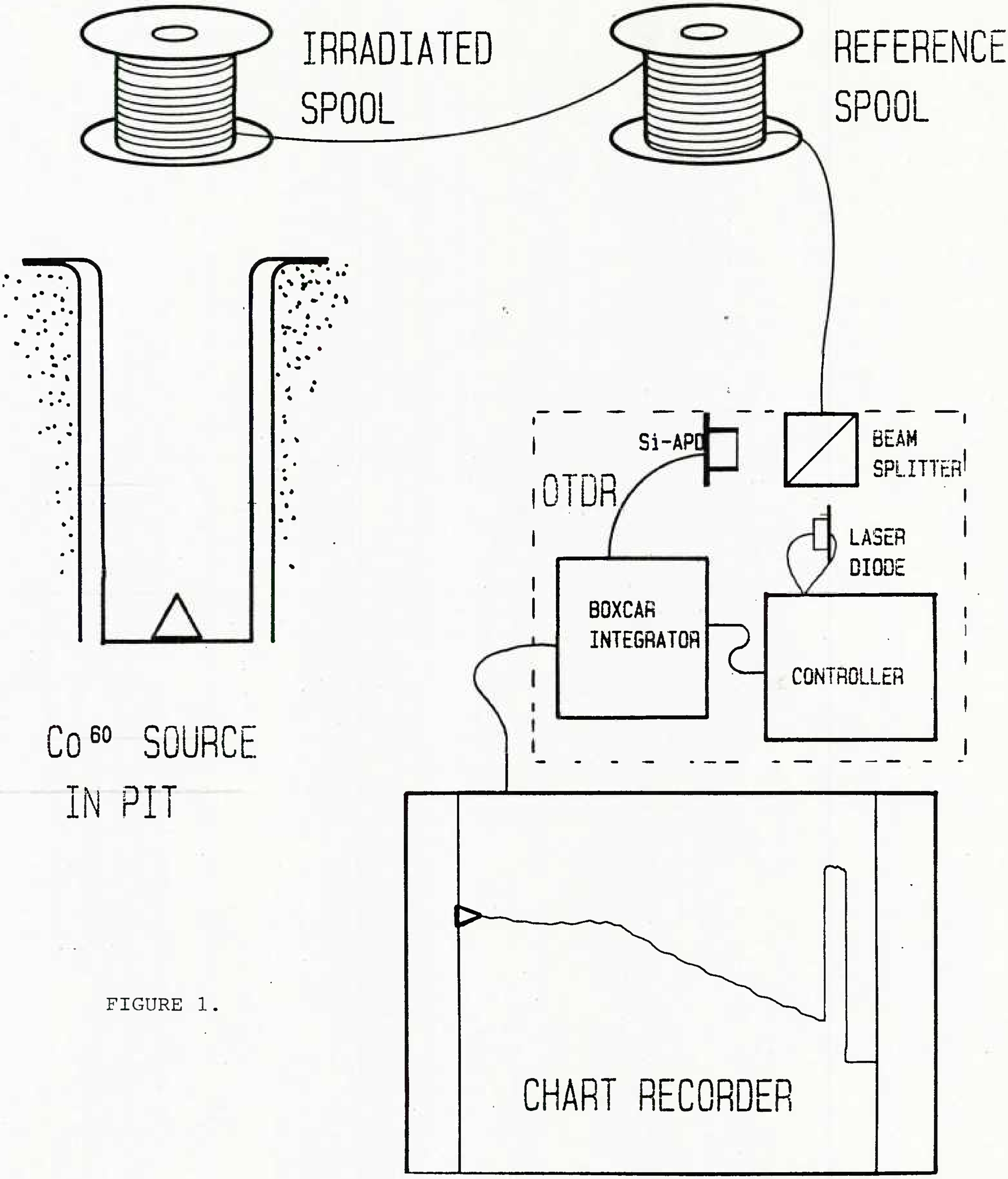

FIGURE 1.

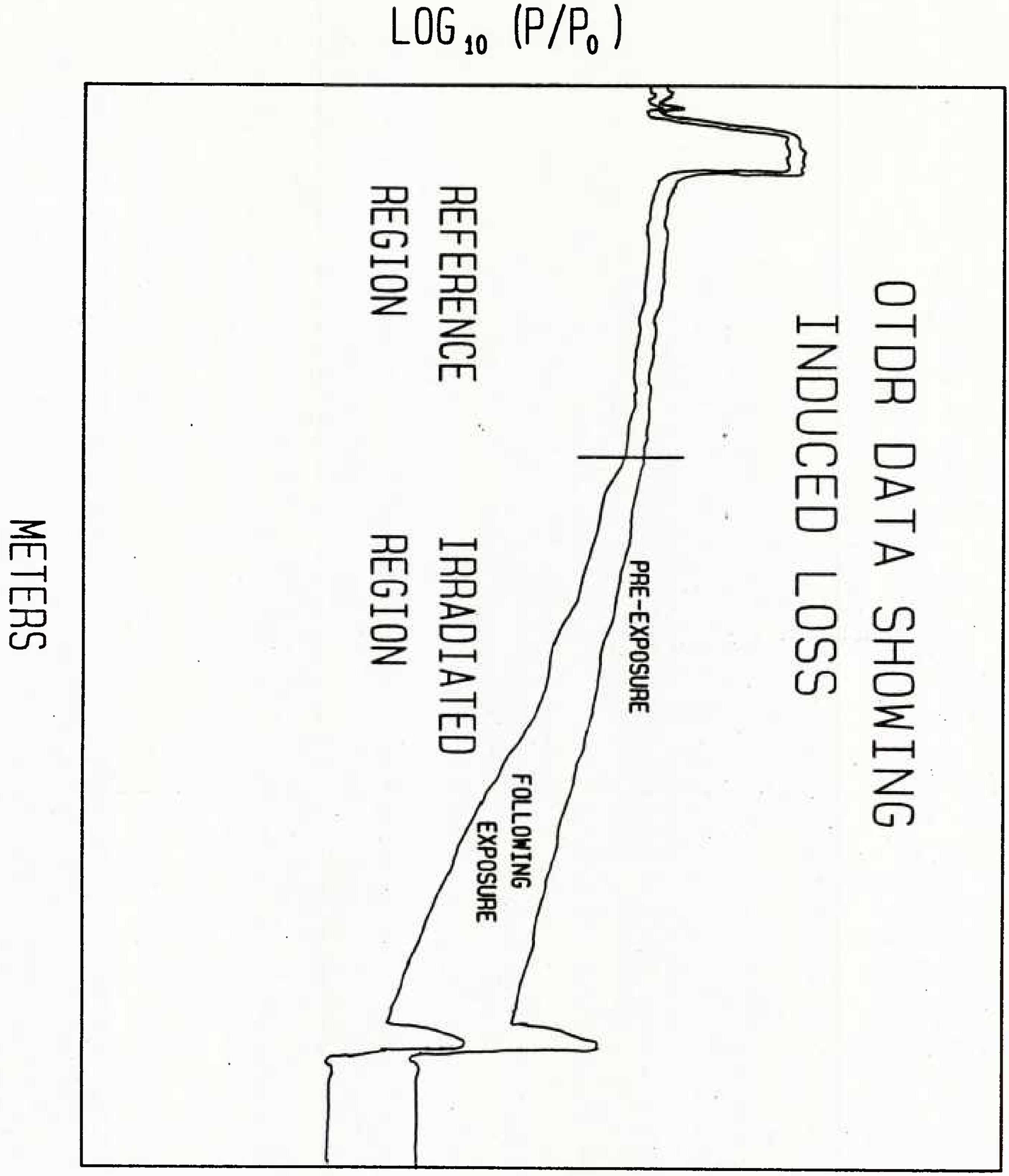
LOG10 (P/P0)
OTDR DATA SHOWING INDUCED LOSS
REFERENCE REGION
IRRADIATED REGION
PRE-EXPOSURE
FOLLOWING EXPOSURE
METERS

FIGURE 2.

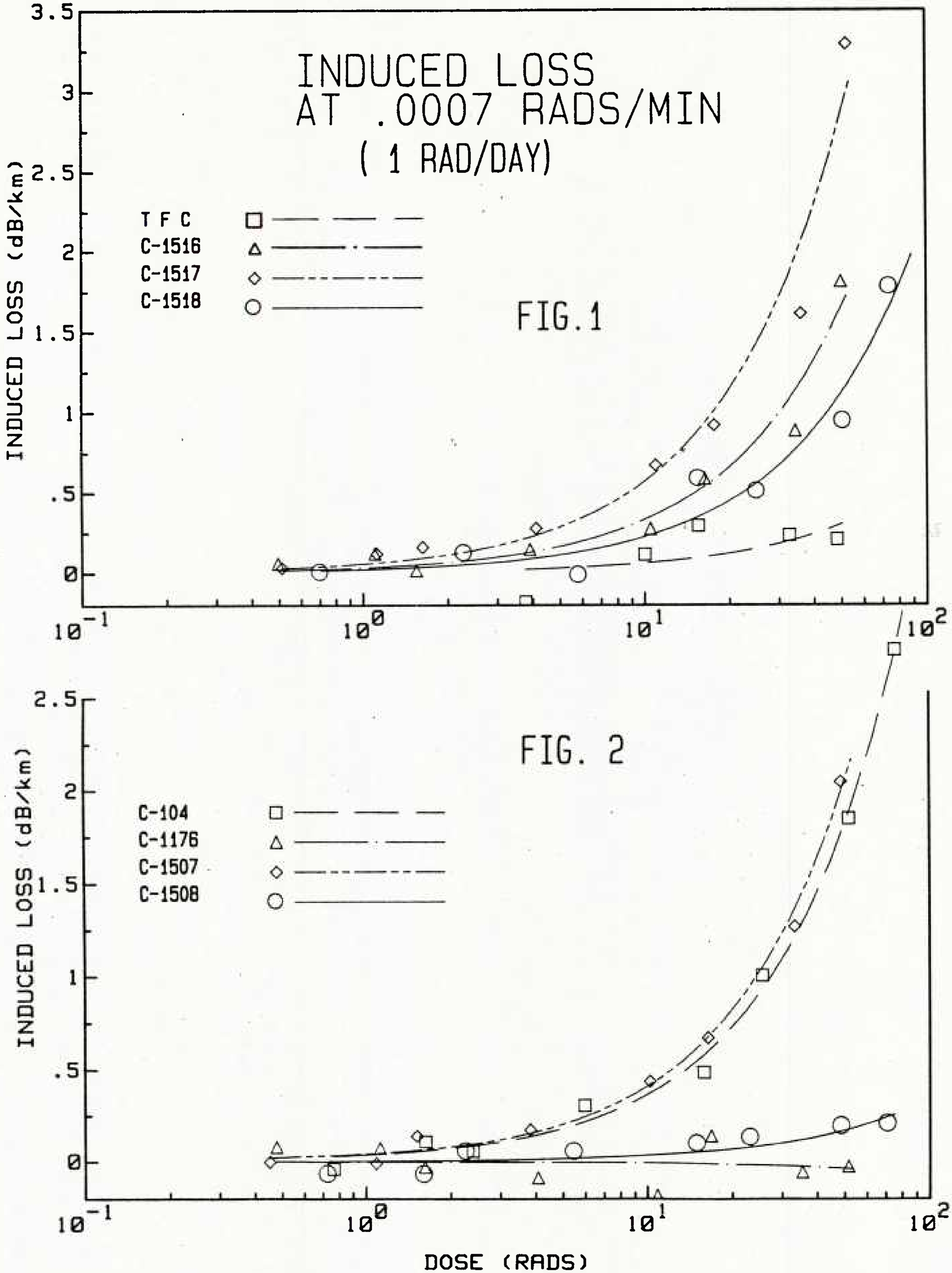
INDUCED LOSS
AT .0007 RADS/MIN
(1 RAD/DAY)
FIG.1
T F C
C-1516
C-1517
C-1518
INDUCED LOSS (dB/km)
3.5
3
2.5
2
1.5
1
.5
0
10^-1
10^0
10^1
10^2
FIG. 2
C-104
C-1176
C-1507
C-1508
INDUCED LOSS (dB/km)
2.5
2
1.5
1
.5
0
10^-1
10^0
10^1
10^2
DOSE (RADS)

FIGURE 3.

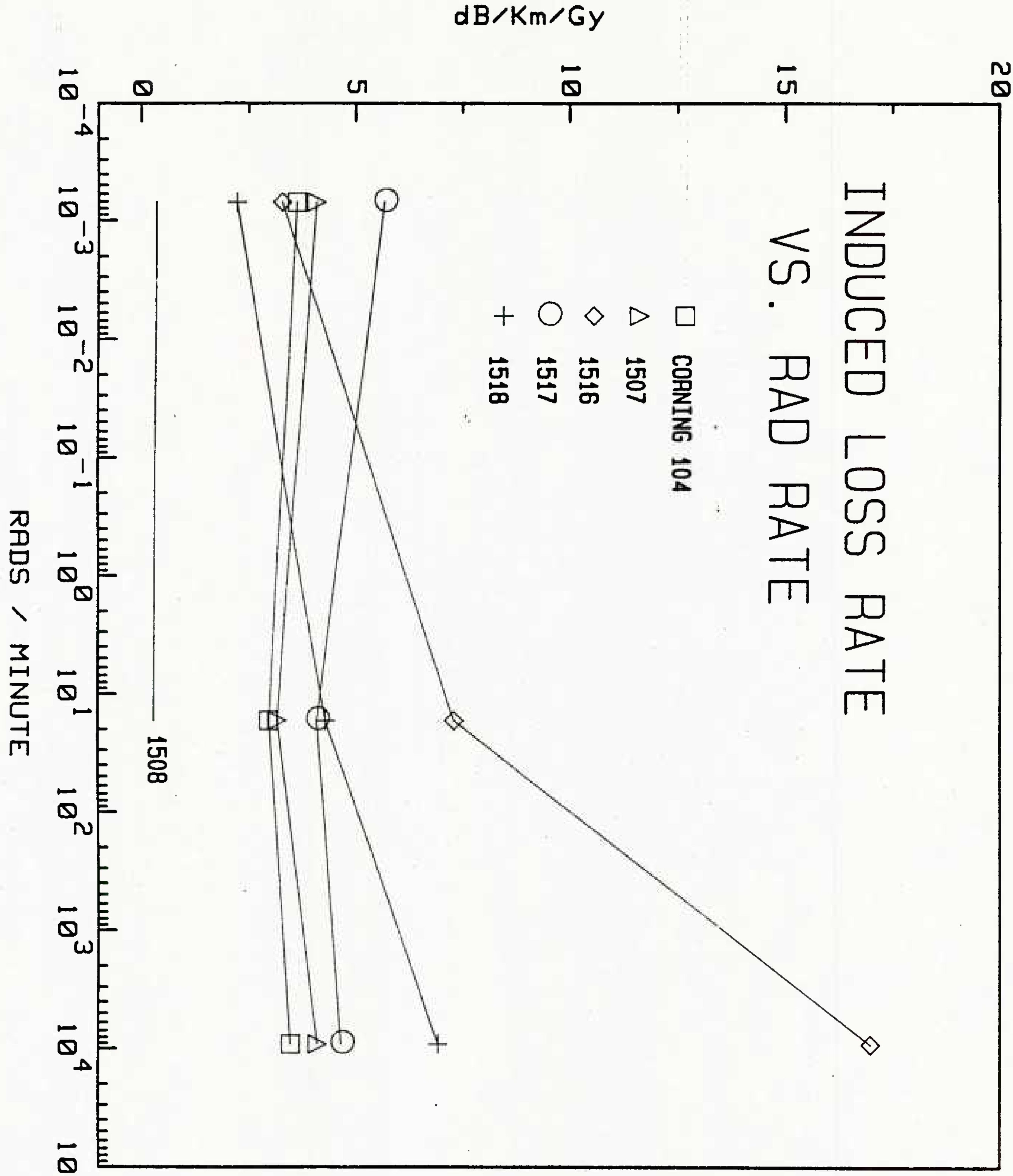
INDUCED LOSS RATE
VS. RAD RATE
CORNING 104
1507
1516
1517
1518
1508
dB/Km/Gy
0
5
10
15
20
RADS / MINUTE
10^-4
10^-3
10^-2
10^-1
10^0
10^1
10^2
10^3
10^4
10^5

FIGURE 4.