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PROJECT REPORT**

NO. 107

**"NEUTRON RADIATION EFFECTS
IN FIBER OPTICS"**



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**UNITED STATES NAVAL ACADEMY
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"Neutron Radiation Effects in Fiber Optics"

A Trident Scholar Project Report
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ABSTRACT

The damage produced in optical fibers by fast neutrons has been studied with reference to the recovery of the fibers tested. The fibers were subjected to varying doses of neutrons. Individual wavelengths were monitored during the irradiation and post-irradiation recovery processes. Recovery rates for each particular wavelength were studied to determine the bleaching effect of the monitoring light at that wavelength. The wavelength was varied over the lower operating range of the fibers, 700 to 950 nm in increments of 50 nm.

Further measurements were taken to determine the bleaching effect of ultraviolet light. Theory suggests that damage caused by high energy neutrons, known to create absorption bands in the ultraviolet range, should show bleaching effects when high intensity ultraviolet light is transmitted through the fiber. Neutral density filters were utilized to determine the dependence of recovery on the intensity of ultraviolet light used. The bleaching effect of a white light source was also studied. Here again, it is believed that the input of high intensity light should be able

to bleach out any defects which may have been created
by the neutron irradiation.

ACKNOWLEDGEMENTS

Research is rarely done by one man alone; it is certain that had this author worked alone this project would not have achieved a portion of the success that it did. It is therefore necessary that I thank Drs. Mary Wintersgill and Richard Johnston for their efforts on my behalf in instruction and aid during this project. Special thanks are further extended to Grover S. Humphrey who operated the Naval Academy's neutron generator during the some 50 plus hours that irradiations were conducted.

Finally the author is deeply indebted to the research group in fiber optics at the Naval Research Laboratories, Washington D. C., headed by Dr. George Sigel, who were used as consultants during the project. Further, the NRL group supplied the fibers and other apparatus used in the project and so to them another thank-you.

Lastly, I must thank my fiancè Miss Ann Kellerman for putting up with me during the time it took to write this paper.

Mark J. Marshfield

05 May 1980

Annapolis, Md.

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INTRODUCTION

A century ago in 1880 a young inventor wrote home to his father, "I have heard articulate speech produced by sunlight! I have heard a ray of the sun laugh and cough and sing!" He went on to describe some possible applications, "Can imagination picture what the future of this invention is to be!....We may talk by light to any visible distance without any conductor." Using an intensity modulated beam of light this young inventor Alexander Graham Bell had communicated to his lab assistant through the aid of what he considered his greatest invention; "The Photophone". Limited due to nature's effects, the photophone as a device was doomed. However, the principles of voice transmission by modulated light beams were not. From the beginning of this century, especially during times of war, intense efforts were made to develop a photophone of reliable quality, due to its potential value as a communication device. The untappable quality and lack of need for poles and wire are obvious advantages. However this device would be limited to line of sight and relies on good visibility which restricts its usefulness. In the late 1940's various papers began to hint at the use of transparent

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rods, internally reflecting pipes, or lenses to guide modulated beams of light. Eventually in 1966 the first successful optical fiber for transmission of light along a closed path was developed. Since that time and from such humble beginnings as the "photophone" a huge industry has grown by leaps and bounds to the point today of actual employment of working systems based on fiber optic technology. The most obvious of these to the general public are the communication systems employed by the Bell Telephone System in Chicago and various other cities. Other less obvious aspects of our lives are affected; for instance on the television series Battlestar Galactica optical fibers were used to simulate in-flight-illumination of the windows of the Battlestar used in the sequence of pictures which showed the entire ship from the outside. Further, astounding medical applications have been made with specific application to being able to view into the human body through the use of fibers, giving doctors the ability to diagnose tumors and cancers which x-rays do not show. Today's fibers can have losses as low as two decibels (dB's) per kilometer. This means that a light signal transmitted down a fiber with a 3 dB/km loss would be reduced in intensity by 1/2 after 1 km of fiber. The normal house window can be considered black relative to a sample of optical fiber material, in fact

if 40 panes of normal glass were placed back to back light would not be transmitted from one side to the other.

The use of light to transmit voice modulated signals has capabilities far beyond today's technology. In fact our abilities to transmit through a fiber and detect the signals do not approach making full use of the fiber's capacity. For instance each fiber employed by Bell in one of its communication systems can carry 672 simultaneous voice transmissions. However, theoretically at least, one optical fiber could accomodate every telephone message, radio broadcast, and television program in North America simultaneously.

BASIC THEORY OF FIBER OPTICS

The theory of light transmission through optical fibers can be basically reduced to a good understanding of Snell's law.

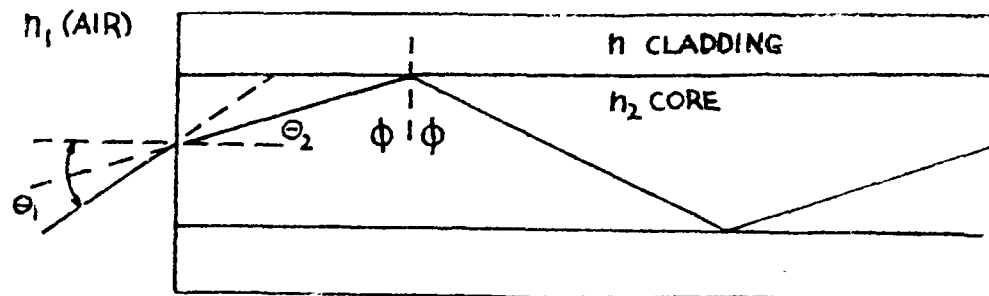


Figure 1: An optical fiber.

Snell's law says that light is refracted at an interface according to

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

where n_1 and n_2 are the refractive indices of the materials on either side of the interface. A special angle is represented on the drawing above; the initial angle. This angle and the refraction at the interface between the air and the fiber determines the initial striking angle of the light with the wall of the fiber. This initial striking angle determines then whether the light will remain in the fiber. Light striking the interface of the fiber between the core and the coating

(in a step index fiber) at greater than the critical angle, Θ_c , is reflected back into the core. This process continues to the end of the fiber where the light strikes the end face of the fiber and escapes.

There are basically two types of fibers, step index and graded index. In the graded index type of fiber the application of Snell's Law can be considered as one allows the number of interfaces at which reflection occurs to approach infinity. This process is then more appropriately titled refraction in the limit rather than reflection.

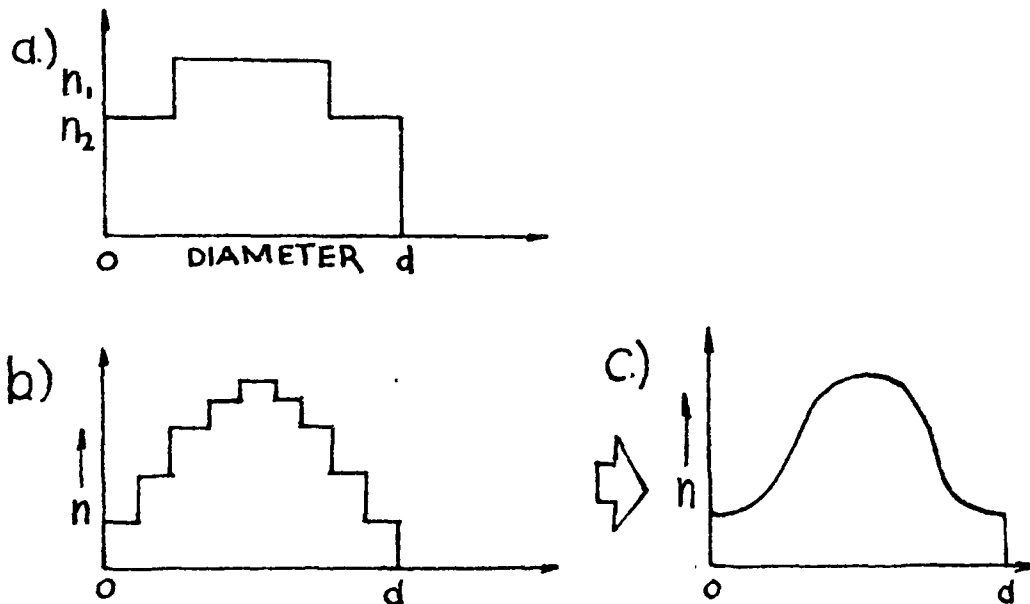


Figure 2: a. Step index fiber, b. Graded index approximation, c. Graded index actual.

Light may take many possible paths when transmitted down a fiber. Each different path is referred to as a mode. The light may take the shortest possible path if it passes through the center of the fiber. Of course the light has no control over the path it follows, it is determined by the direction of injection into the fiber, i. e. the special angle mentioned above. It may take the longest possible path always striking the interface at just more than the critical angle. A third possible path exists; the light could take the "skew" path. In this instance the light spirals through the outside layers of the fiber never actually passing through the center.

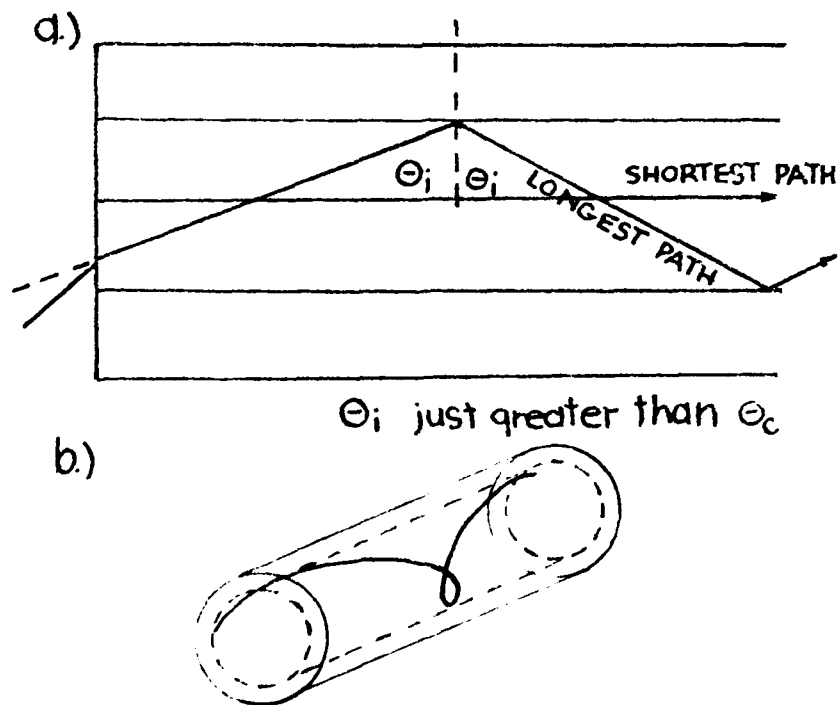


Figure 3: a. Shortest and longest path, b. Skew path.

When conducting an experiment it is necessary to try and work with just the single mode in order to provide the most consistent results. The reason behind this is that multiple modes cause spreading of the light signal as it traverses the fiber. This spreading is termed dispersion. This then appears as a loss although it is intrinsic and not induced by radiation or any other influence. Like many things around us, including our bodies, the silicon dioxide structure of optical fibers is susceptible to radiation damage.

Many studies have been done on various fibers to determine the effects of impurities on induced damage. Impurities are elements which either have been purposely introduced into the fiber's structure to increase the refractive index or are the result of the manufacturing process from which the fiber was made. Defects in the regular tetrahedral structure of silicon dioxide are also stress-induced by the manufacturing process of drawing a fiber. These impurities and intrinsic defects often can be identified as the causes or as contributors to various absorption peaks.

A fiber can be measured in two ways; the fiber's capacity to transmit light can be measured or the amount of light absorbed by the fiber can be used as a measure of its transmitting capacity at the various wavelengths. One must always be wary therefore of what

one is reading on (usually) the vertical scale of a graph of fiber ability, either the transmissivity or the absorption of the fiber. The formulae for transmission can be derived in the following manner. The equation for the intensity of light transmitted in the low reflection case for a material of thickness t is,

$$I_t = I_0 e^{-\mu t}$$

where the absorption coefficient is μ .

For example, a research group at the Naval Research Laboratories in Washington D. C., to which we owe figure 4, has conducted many tests on damage and induced loss. Note that their measurements are taken in absorption units. The radiation source used was a Cobalt-60 source.

A majority of the radiation studies have been done with an ionizing radiation source such as Cobalt-60 and the gamma rays it produces. One group which extended this was Maurer et al. who conducted tests with a neutron irradiation source and a gamma ray source in order to compare the types of damage produced by the different sources. From their results (figure 5) which are given in absorption units it can clearly be seen that the forms of the absorption spectra caused by both the gamma and the neutron irradiation are

basically the same.

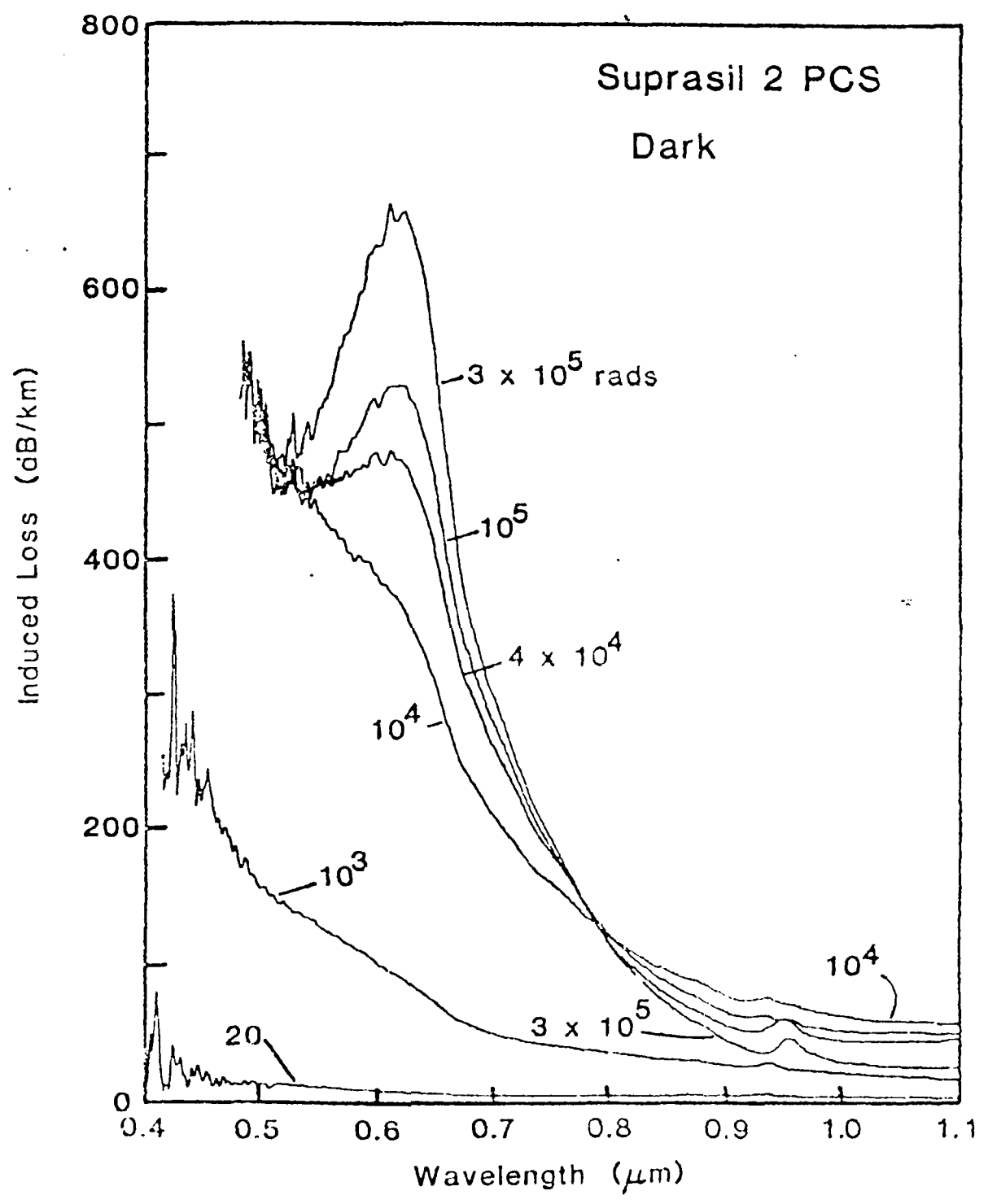


Figure 4

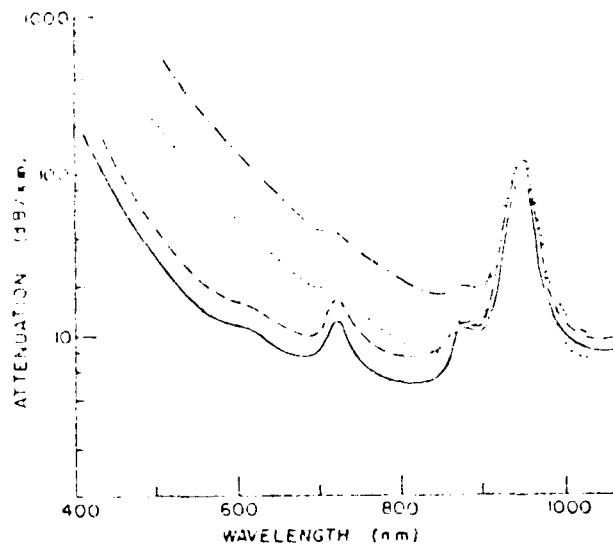


Figure 5: a. Neutron induced damage.

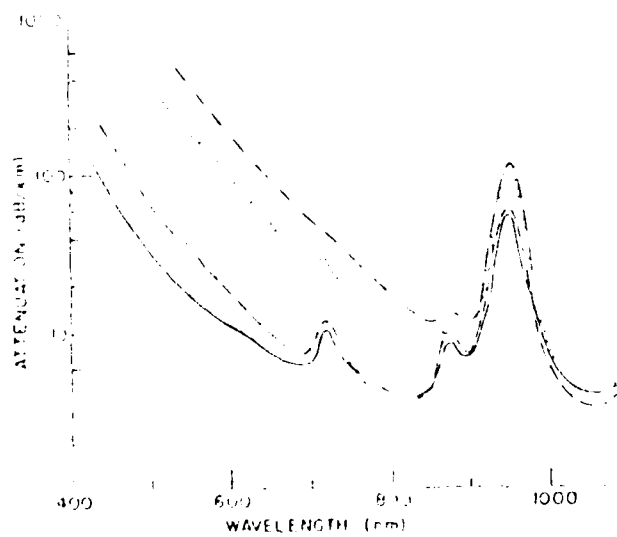


Figure 5: b. Gamma-ray induced damage.

However, it must be mentioned, one to two weeks elapsed between the actual neutron irradiation and the time when the fibers were measured. Therefore, it cannot be said that the transient effects or any thermally bleachable defects would have been observed in this experiment. Thermally bleachable centers are defects which are created but, due to energy imparted by room temperature, the defects are bleached out in a reasonably short period of time. Ideally it would be nice to fully understand the long term effects of neutron damage and then conduct irradiations holding the fiber at a low temperature (e.g. liquid nitrogen) in order to best observe the transient effects. Lacking this ability the next best thing to do is to take a spectrum as fast as possible and observe as much of the transient effects as possible.

The primary absorption peaks, which cannot be seen on the absorption spectra shown so far, occur in the lower wavelengths; in the ultraviolet range. The tails of these peaks carry over into the operating range of the fibers (roughly 700-1000nm) thereby causing losses and decreasing the fiber's transmission capacity. One of the suspected causes of these absorption peaks is the possibility of a dangling silicon bond.

The basic chemical structure of an optical fiber consists of amorphous silicon dioxide in a tetrahedral structure.

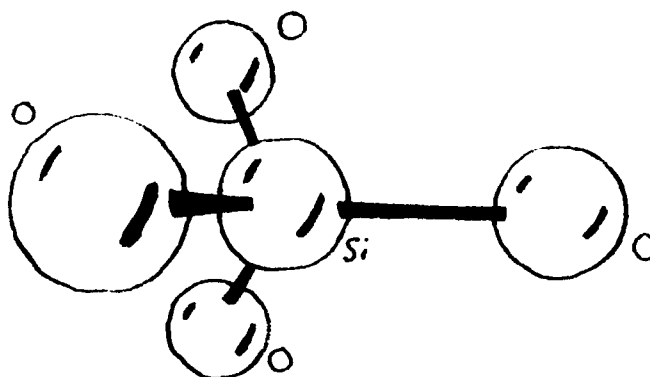


Figure 6: Silicon dioxide tetrahedral structure. In crystalline form the lattice is very regular but the manufacturing process causes it to be an amorphous solid. An amorphous solid is one which maintains the same basic component as the crystalline structure (in this case a tetrahedral group) but contains no regular lattice structure of its own. In the case of the defect mentioned above, a silicon dangling bond, a silicon with four sp^3 hybridized orbitals has only three oxygens with which it can bond rather than the usual four. The so called dangling bond (which gets its name exactly the way one can imagine it would) will then trap a hole. The resulting hole center can tend to absorb energy best at one particular wavelength (corresponding to excitation to the 1st excited state)

resulting in an absorption peak.

In the operating wavelengths various peaks have been described with primarily two bands of interest because of their generality to particular classes of fibers. In high OH fibers, so called wet fibers, one prominent band appears after irradiation at $\sim 630\text{nm}$ and the band seems to be partially photobleachable. This means the transmission of light down the fiber reduces the induced absorption in the 600-900nm range caused by the irradiation. In low OH fibers absorption bands are created at $\sim 760\text{nm}$ and $\sim 630\text{nm}$. The 760nm band is readily photobleached while the 630nm band can be reduced by photobleaching but still shows strong absorption.

The comparison of low OH vs. high OH fibers appears to support one theory which has been advanced for explaining the band centered near $\sim 630\text{nm}$. The suggestion is that an oxygen with only one silicon to bond to (i.e. a dangling bond once again, but at an oxygen site) can trap a charge and cause absorption. In the high OH fiber a higher percentage of the dangling bonds are occupied by hydrogen atoms and consequently in low OH fibers more charge trapping occurs during irradiation causing the much larger absorption peak.

A third type of optical band appears in the near infrared region. It is a very broad band with no clear center. Increased irradiation does increase the absorption across the whole of this band and it does not appear to be thermally bleachable. An interesting point about the first two types of these defects, specifically those in the operating range, is that they are subject to thermal fading and in some cases may consist mainly of transient effects.

EXPERIMENT

The laboratory apparatus was relatively unsophisticated. It consisted of the following; a tungsten white light source to be used as the monitoring light source, a diffraction monochromator to allow the selection of individual wavelengths, and a second order filter which was implaced when necessary to cut out second order diffraction lines. The next piece of apparatus through which the fiber passed was a microscope objective to focus the monitoring light onto the fiber to insure maximum transmission of the light down the fiber, and a mode stripper to remove all excess modes except those which are transmitted through the center of the core. The fiber then passed through the wall to the neutron generator. The fibers were coiled around small acrylic spools for ease of handling and so that a length of about 15 meters could be placed in front of the neutron generator's target for irradiation. Six meter leaders were left on each end to allow access through the radiation shielding (approximately six feet of concrete) to the experimental apparatus. After passing back through the wall the fiber was placed in contact with a silicon photodiode for measurement of the light successfully

transmitted. The option then existed to select a direct readout of the transmittance on a stripchart recorder or to select a log of the photodiode current with respect to a pre-selected reference current as the input into the stripchart recorder.

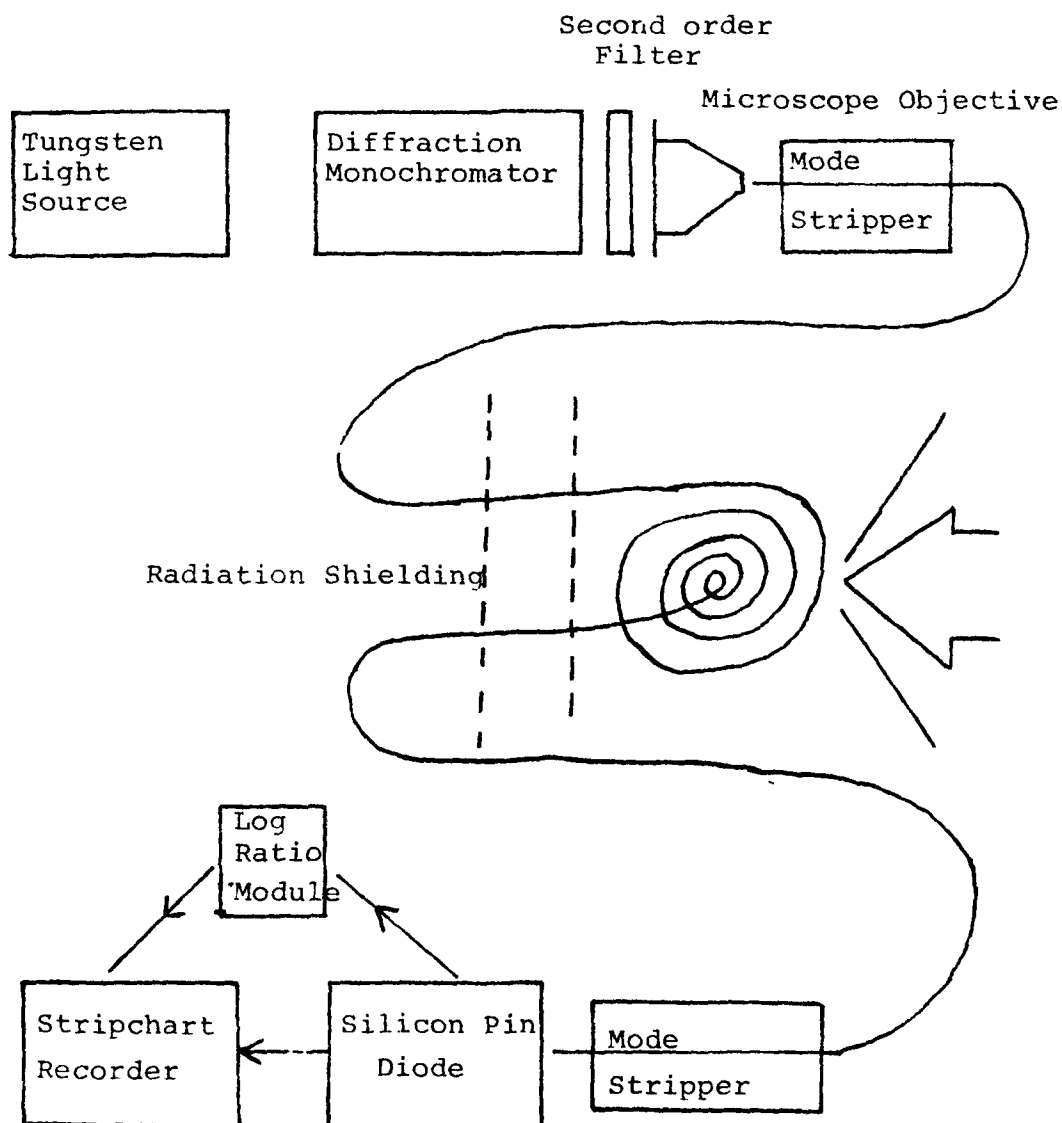


Figure 7: Lab Apparatus.

Once the fiber had been wound on a spool it was ready to be tested. Initially, the fiber must be passed through the radiation shielding. The fiber was passed through the wall by pulling it through a 3/8ths inch tube with a string. The tube and string were previously passed through the wall. The ends of the fiber must then be stripped and cut to insure a flat surface for light to enter and exit the fiber. When the ends are properly cut the fiber is then ready to be secured into the input and output "position control platforms." The input platform held the mode stripper for the input system and a small clamp type device to hold the input end of the fiber in one position. The platform allowed motion in three dimensions so that the fiber end could be positioned at the focusing point of the microscope objective (see Figure 7). The output end of the fiber was also held in one position by a small clamp type device. In this case the photodiode detector was positioned on a device which allowed movement in three dimensions and so it was not necessary for the clamp holding the output end to have this capability. When the input and output ends of the fiber had been properly aligned to insure maximum light transmittance the experiment continued. The preparatory procedures have been completed at this point and the data taking begins.

First of all the fibers were each characterized by taking an initial spectrum. This spectrum is then the data base for all further studies upon that particular fiber. The second step of the procedure is then to perform an irradiation of the fiber. During this step, the fiber's transmission capacity was monitored at one specific wavelength. In this way any peculiarities of the fiber in terms of type of damage created, either permanent or transient can be observed. By observing the fiber during irradiation we are also able to insure a measurable decrease in transmission. Attempts were made to monitor only intermittent periods of the total irradiation time. Intermittent monitoring proved infeasible due to the overall slow reaction time of the system. It was therefore determined to use only a continual monitoring process. It is noted here that even the light used to measure the fiber can cause bleaching of damage induced by the radiation. The measurements still represent a relative measure of the fiber's capacity after the irradiation period, and also simulate conditions of fibers in actual use.

Three distinct processes were followed in the immediate post-irradiation phases;

1. Immediate spectrum
2. Bleaching attempts

3. Long time observance

Immediate spectra were taken at various times throughout the project whenever it was deemed necessary to verify results. It was used as a tool to determine the overall effect of the neutron irradiation upon the entire spectrum of a fiber.

In the initial set-up attempts were made to bleach the damage with an ultraviolet light source. The ultraviolet light was a xenon-mercury source which operated at approximately 2500 volts. Experimental technique proved to be a problem with this area. In this phase the output was moved away from the fiber during the time period when ultraviolet light was being transmitted down the fiber to insure that the photodiode was not saturated with energy. As a result of this process the data taken was unreliable. It proved very difficult to return the photodiode to exactly the same position as the previous reading; something which seemed to be mandatory to achieve reasonable results. Subsequently it was decided to place neutral density filters in front of the inlet to the microscope objective. With this new set up neither the input nor the output require movement during a data run so that one would expect that better results should be obtained. The bleaching attempts began with 15 dB's

of neutral density filter in place. After several runs and several reductions in amount of neutral density filtering we began to make runs using no filters at all and realized that up to 8 volts of measured light transmission seemed to have no adverse effect on the operation of the pin diode.

In the case of the long-term recovery studies an attempt was made to determine the bleaching effect of the measuring light upon the fiber due to transmission for measurement purposes. The general lab-set up remained the same for this procedure. The study was conducted over the wavelengths of the lower operating range of the fiber as this tends to be the most easily damaged portion of the spectrum due to irradiation; bleaching by light in the range 700-950 nm in increments of 50nm was studied.

The procedure was that following an irradiation during which the fiber was monitored by the measuring light set at the wavelength to be studied the system was left with the monitoring light continually transmitted down the fiber. The whole system was then left for a period of approximately 12 hours. The long time bleaching effects at the various wavelengths were then compared.

When the attempts to photobleach with ultraviolet light had been almost exhausted, it was

learned from NRL literature and discussion with them that they had seen marked photobleaching by a white light source. Accordingly studies were begun similar in procedure to the ultraviolet bleaching attempts to determine if photobleaching of neutron damage centers by white light could be observed. The Naval Research Labs use a Cobalt-60 ionizing radiation source in general for their radiation damage and do not possess a neutron generator similar to the 14 MeV neutron generator at the Academy which was used to induce damage in the fibers of this experiment.

RESULTS

For this experiment there were two distinct sets of results; One set from the studies made to detect photobleaching from an outside source (i. e. from the ultraviolet light or white light sources) and one set of results from the data taken to observe the long term effects of the monitoring light. In both cases the third method of full spectrum observance was used to discern overall effects on the fiber of the neutron irradiations.

A. BLEACHING ATTEMPTS

The bleaching attempts proved to be somewhat disappointing in that very little effect was observed with our apparatus. The ultraviolet bleaching attempts were made on an ITT step index fiber. Two other fibers were tried prior to the ITT step index fiber but were too difficult to work with in order to be useful in obtaining results. The initial fiber tried was a Corning OVPO fiber (OVPO is a type of fiber made from the outside vapor phase oxidation production method.) This fiber was wound on a spool before this project began and after various methods were tried to improve what seemed to be an incredibly poor capacity to transmit light the fiber was observed to have a break

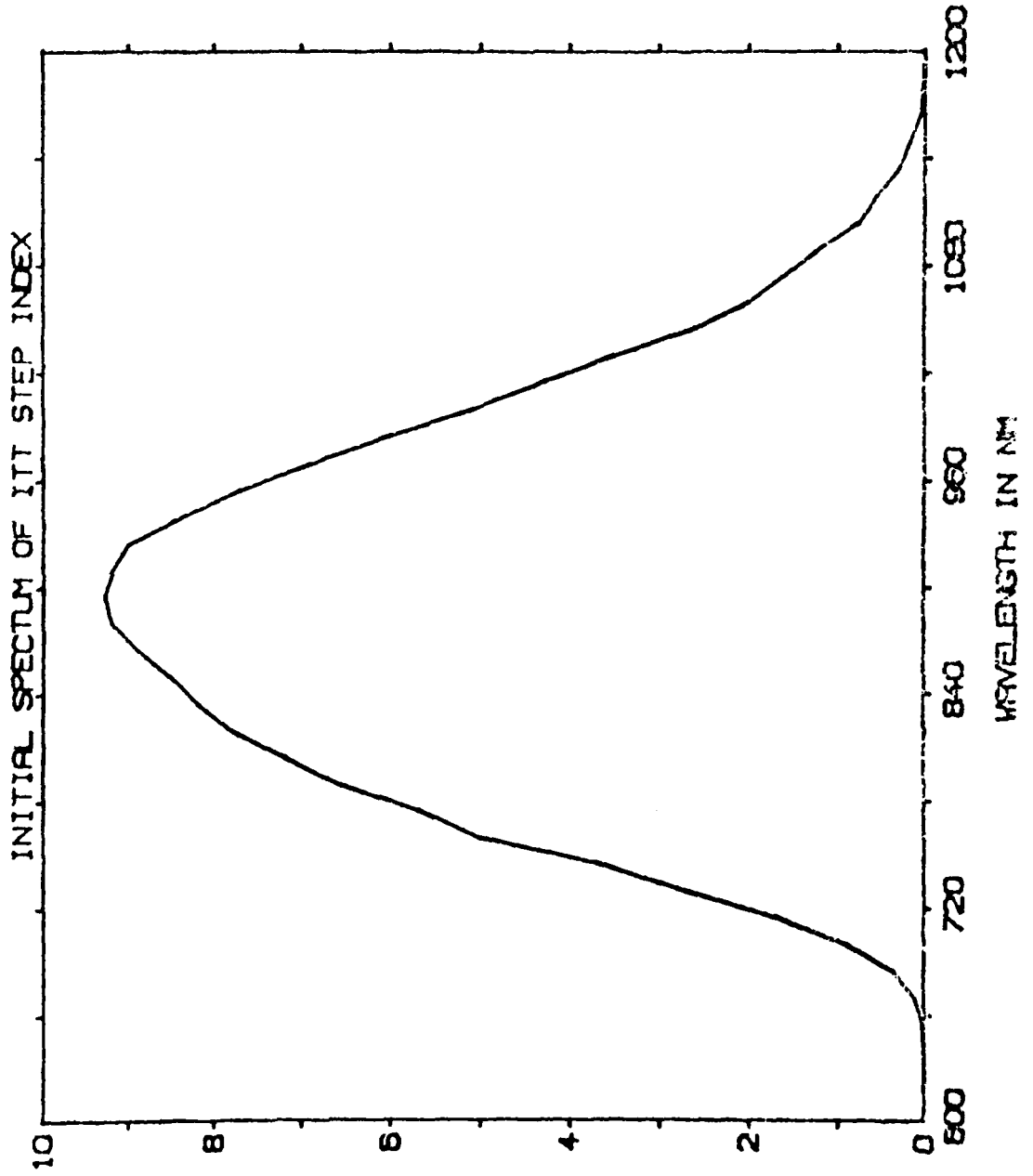
in that portion which was wrapped around the spool. This fiber was then removed from the apparatus and tests were begun on an ITT graded index fiber (this is different from ITT STEP index fiber.) The ITT graded index fiber had a coating which appeared similar to a teflon and required a strong acid and long soaking periods to remove the coating. This would not have been too bad had the core proved to be workable. This was not the case however as the core of the fiber broke frequently and very easily after the coating was removed. Because of this brittleness in the core this fiber was also abandoned from further attempts to gain data.

The bleaching attempts on the ITT step index fiber yielded erratic and inconsistent results. Just when it would appear that the light was photobleaching the fiber the next period of ultraviolet light transmission would appear to cause the fiber to deteriorate in capacity rather than stay the same or show an increase as is predicted. It was true, however, that in the general case the fiber did seem to be fully recoverable in the early recovery studies. In many of the cases it is noted the fiber did not recover during the ultraviolet bleaching attempts but did seem to recover when left in the dark laboratory overnight. Thus it appears that there were major problems in

maintaining a stable voltage supply and hence a stable, calibrated signal measuring system.

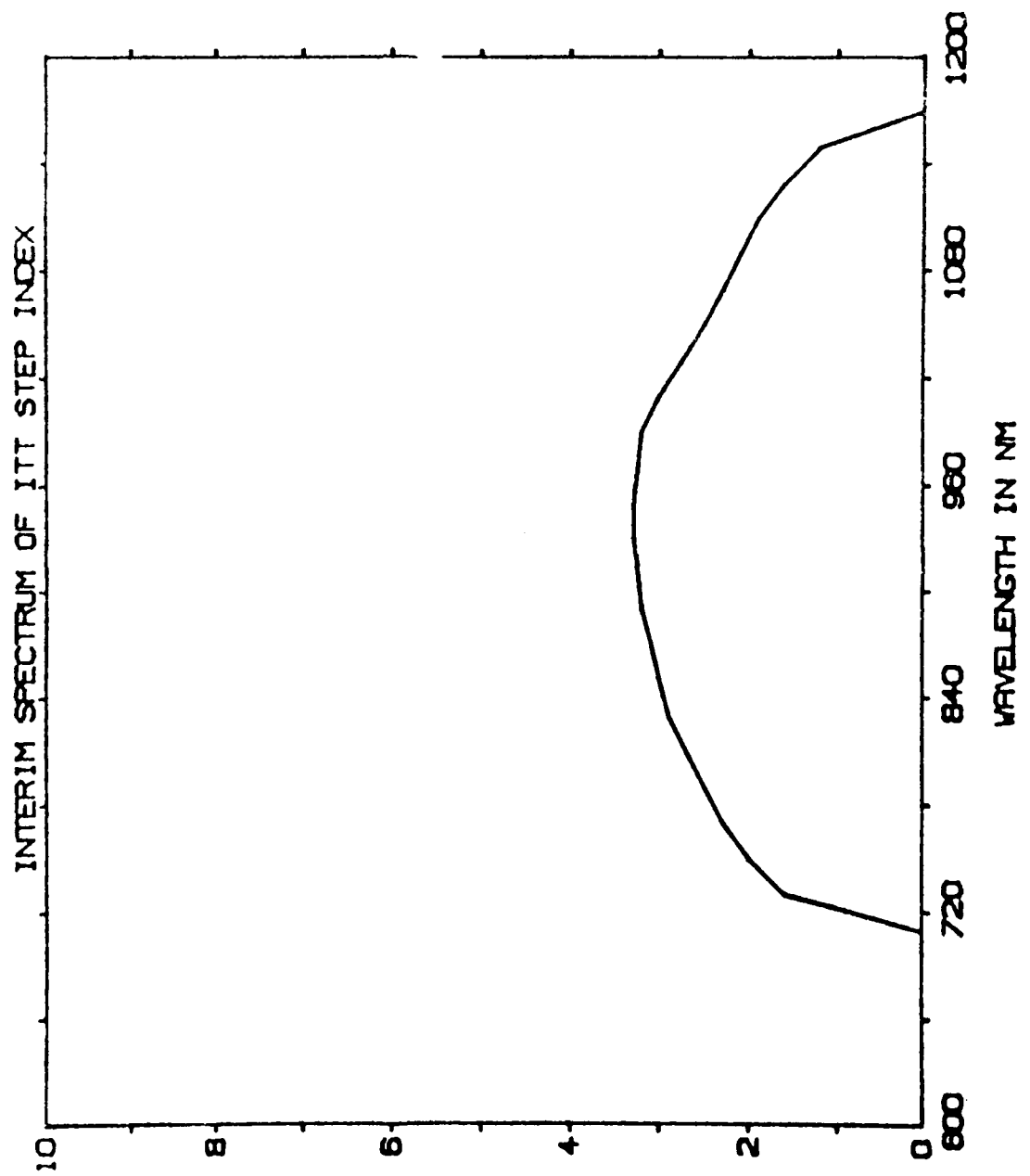
The fiber's capacity was significantly reduced over the entire spectrum during the course of the irradiations. The effects of the irradiations can be seen in figures 8, 9, and 10. The fiber had decreased significantly in transmission capacity by the time of figure 10. From the progression of figure 8 to figure 10 one can clearly see that the fiber which had once been able to transmit light at 680nm fairly well, now no longer transmits at all until roughly 780nm and does so only minimally at this wavelength. At the time of figure 10 the ITT step index fiber had received a dose of approximately 2.5×10^{15} neutrons/cm². At this point the fiber is severely damaged. The cause of the ITT fibers decrease in transmission capacity is most likely due to an increased absorption by the peaks in the ultraviolet region due to the irradiation. These peaks in particular seem to be resistant to photobleaching while the peaks in the operating range are photobleachable.

Attempts to recover the fiber through continued exposure to ultraviolet light showed promising results but overall the fiber's transmission characteristics remained far below its original capacity. It is noted that roughly twenty damaging exposures is considered



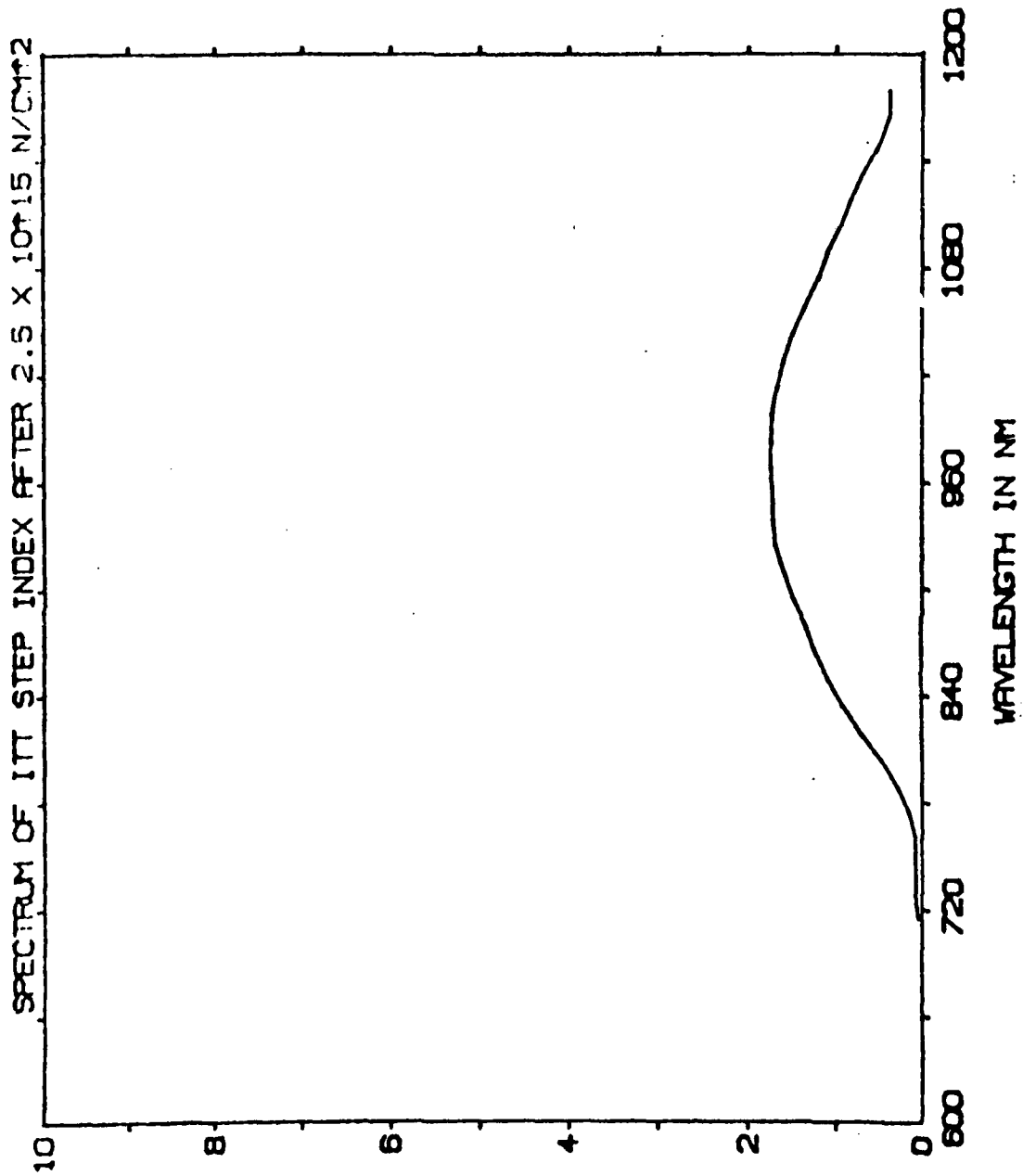
TRANSMISSIONS IN RELATIVE DB'S

Figure 8.



TRANSMISSIONS IN RELATIVE DB'S

Figure 9.



TRANSMISSIONS IN RELATIVE DB'S

Figure 10.

the usable lifetime of a recoverable fiber. The fiber's failure to recover and decreased ability to transmit light is therefore not totally unexpected by the stage shown in figure 10. So though the results achieved were inconclusive they tended to show that ultraviolet light has the ability to be a good bleaching source for optical fibers.

During these irradiation and recovery studies and also those discussed in the next section a distinct transient was observed. The fiber tended to recover to some extent very rapidly over a short period of time immediately following shut down of the neutron generator. This is best exemplified by sample figure 11. In sample figure 11 the period of irradiation is entering from the left side of the graph the sharp lower extremity point represents generator shut down. All points to the right of generator shut down represent bleaching of the fiber and an increase in capacity to transmit light.

B. LONG-TERM BLEACHING EFFECTS

The ITT step index fiber was also studied to determine the long-term bleaching effects of the monitoring light source itself. Wavelengths in the operating range 700-950nm were studied in increments of 50nm. A portion of these results are shown on figure

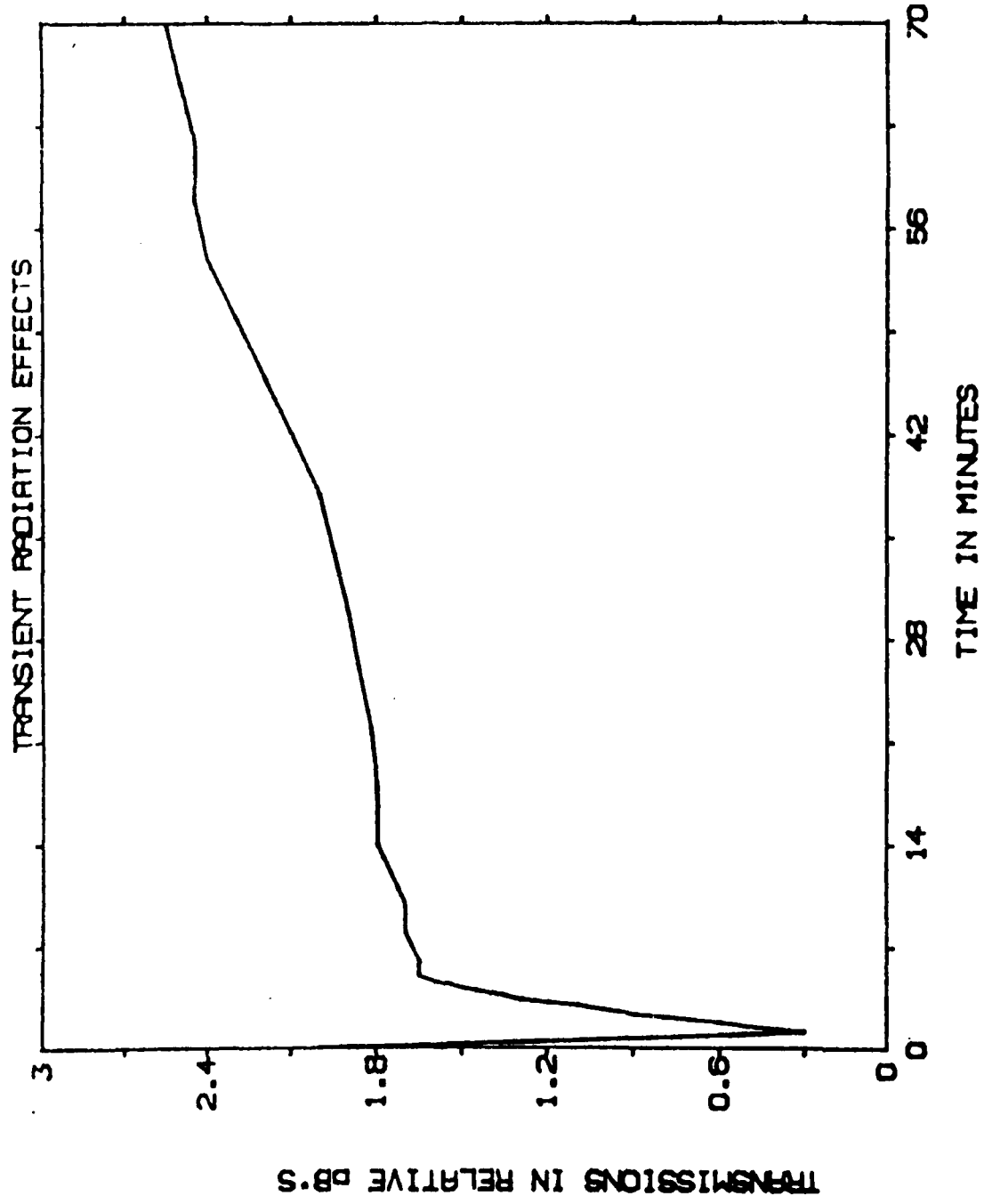


Figure 11.

12. It can clearly be seen on figure 12 that the 750nm light has returned to a better capacity than the 800nm light. The control factor on this portion of the experiment was that for each of the various wavelength runs was begun at a signal level of 0.9 volts on the stripchart recorder and lasted until the signal had decayed to a signal level of 0.1 volts. These results seem to show that the 750nm light was the best photobleaching wavelength over this span. This data is put in question however by the fact that the measurements were taken in sequence. This means that measurements at the higher wavelengths were taken when the fiber had received a higher total dosage. For the highest wavelengths this is especially true as the preceding runs required long irradiations to create sufficient damage to be easily measurable. As mentioned in the preceding section, the tail of the permanent damage peak in the ultraviolet region is probably carrying over into the the operating range and causing problems in obtaining significant results. So though a wavelength of 750nm looks like the optimum wavelength it must be held in question until further studies can be done.

When the studies of the ITT step index fiber were finished it was learned through information gained from the Naval Research Laboratories, Washington

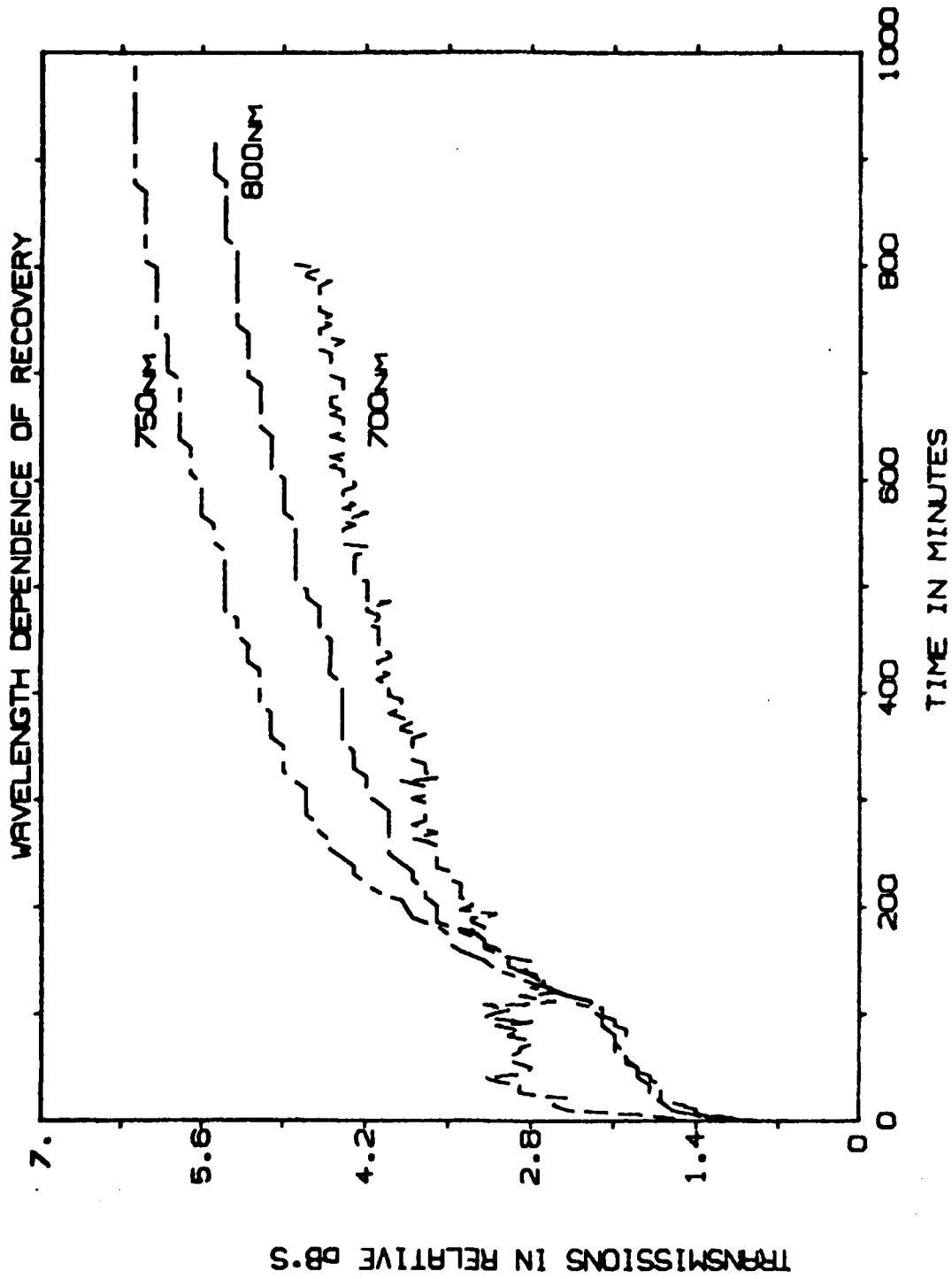


Figure 12.

D.C.(NRL) that a white light source could be a sufficient bleaching source. NRL conducts their studies with a Cobalt-60 gamma ray radiation source, therefore it was determined that we would attempt to bleach neutron irradiation defects with a white light source. This portion of the study encompassed two fibers; a Suprasil I and a Quartz et Silice fiber. Both of these fibers are plastic clad silica (PCS) fibers and it is generally accepted that PCS fibers are relatively radiation hard. The results of this study showed the fibers to be very resistant to neutron induced damage even over long-term irradiations of the order of two hours. A strong transient was observed in the irradiation phase of these fibers. When an irradiation was started the fiber's capacity would dip approximately to 85% of their initial transmission and at the end of the irradiation when the generator was shut down the fiber would increase in capacity a similar 15% of the initial transmission. Both of these jumps were instantaneous as far as the measuring apparatus was concerned, which is to say the increase occurred in less than one second. As a result of its radiation resistance these fibers would not photobleach to any appreciable extent even during the early irradiations. Apparently very little permanent damage is created and that damage which is being induced into

these fibers is not photobleachable.

DISCUSSION OF RESULTS

There were many methodology problems encountered in the laboratory during this project, especially the bleaching process. The initial method tried was to move the photodiode detector away from and to the left of the output end of the fiber in order to insure that it was not damaged when the high intensity ultraviolet light was transmitted down the fiber. This process caused very random results.

It was apparent that the photodiode was so sensitive to the differing positions of the fiber that it would be necessary to return the detector to the exact same position whenever it was moved away. This proved to be an impossibility with the apparatus being employed and so we abandoned the effort temporarily. One attempt to overcome these difficulties was to try placing neutral density filters between the fiber and the detector during ultraviolet transmission. In this manner the photodiode would only have to be moved in one direction not two; however, the data continued to be erratic and inconsistent under this new procedure. The last attempt to rectify this was to place the neutral density filters at the inlet to the fiber. This decreased the intensity of the ultraviolet light but

did allow us to take photobleaching data.

As was mentioned in the results section, the data however, still proved to be very unpredictable. The best data was that taken for the long-term bleaching effects of the monitoring light. The only problem with this data was that it was taken in sequence, and this could be a point of several problems. It is highly likely that the early runs, 700 and 750nm, were taken while the peaks in the ultraviolet wavelengths still had relatively little effect. If the peaks in this region began to affect the operating range after the cumulative dose had reached that of the 800nm run, then the higher wavelength data would be affected by the ultraviolet peak and the lower wavelength data would not. It is certain that the 900 and 950nm runs were affected by the ultraviolet peaks, as they required large amounts of irradiation time of the order of two hours. This argument also applies to the bleaching ability of the ultraviolet source. In the early runs about which we have very little data due to the methodology at the time, the fiber seemed to recover from 15 minute irradiations regularly back to its initial capacity. This was not true of the later runs and seems to suggest that in the early runs the major sources of absorption were in the operating range, perhaps the so-

called dangling oxygen bonds mentioned in the theory section. As the total dosage increased the primary influence on absorption in the operating range became the huge absorption peaks in the ultraviolet range. This explains why following irradiations in the later part of the study, the fiber did not fully recover.

Throughout the project we often observed power surges within the Rickover Hall complex which affected our data. On several occasions we observed surges in the evening and in the morning which seem to equate to the departure and arrival of the workers in these spaces. It is suggested that future attempts made in this area use a voltage regulator in order to avoid this problem.

SUMMARY AND CONCLUSIONS

1. Early data tended to show that ultraviolet light could be used successfully as a bleaching source for optical fibers.
2. In the ITT step index fiber the best bleaching wavelength for monitoring light source was determined to be 750 nm; with a need for further studies.
3. A voltage regulator is necessary to avoid interference of the regular system in Rickover Hall with the experimental system.
4. The ability to take a spectrum in a short pulse of light rather than through the use of a motor driven spectrometer would be a great improvement.

FOOTNOTES

1. E. J. Friebele, Photobleaching Effects on Optical Fiber Waveguides, (Naval Research Laboratory, Washington, D. C.), p. 9.
2. R. D. Maurer et al. "Effect of Neutron- and Gamma-Radiation on Glass Optical Waveguides," Applied Optics, September 1973, p. 2025.
3. Op.cit., Friebele, p. 4.