

Multitier Specification Applied to Modify the Hardness of an Essential NSEP Fiber Optic Link

David. F. Peach
Robert T. Adair



U.S. DEPARTMENT OF COMMERCE
C. William Verity, Secretary

Alfred C. Sikes, Assistant Secretary
for Communications and Information

NATIONAL COMMUNICATIONS SYSTEM

March 1988

PREFACE

This report is submitted as the primary deliverable for a study conducted for the National Communications System (NCS), Office of the Manager, Technology and Standards Office, Washington, DC, under Reimbursable Order 7-10215. Several other reports serve as background reports or are tools used to perform this study. The Multitier Specification is the primary tool used to evaluate the fiber optic telecommunication link studied in this report. The following referenced reports provide the background information described above.

Englert, T. J. (1987), Effects of radiation damage in optical fibers--A tutorial, 57 pp., NTIA Contractor Report 87-38, May, (NTIS Order Number PB 87-210308/AS).

Englert, T. J. (1987), Consideration of ionizing radiation shielding for optical fibers, NTIA Contractor report number not yet available.

Hull, J. A. (1987), NSEP fiber optics system study background report: Nuclear effects on fiber optic transmission systems, NTIA Report 87-227/NCS TIB 87-26, 115 pp., (NTIS Order Number not yet available).

Ingram, W. J. (1987), A program description of FIBRAM: A radiation attenuation model for optical fibers, NTIA Report 87-216/NCS TIB 87-22, 120 pp., NTIS Order Number PB 87-230868 (report only); PB 87-230678 (report and data disk).

Nesenbergs, M. (1987), Fiber optic networks and their service survival, NTIA Report 87-214/NCS TIB 87-9, 120 pp., (NTIS Order Number PB 87-186706/AS).

Peach, D. F. (1987), Multitier specification for NSEP enhancement of fiber optic long-distance telecommunication networks, Vol I: The multitier specification--An executive summary, 50 pp., NTIA Report 87-226/NCS TIB 87-24; Vol II: Multitier specification background and technical support information, 222 pp., NTIA Report 87-226/NCS TIB 87-25, (NTIS Order numbers not yet available).

The study reported here is an evaluation of a Mountain Bell fiber optic telecommunication link. Results of this study should not be construed to endorse or be critical of the Mountain Bell installation. The requirements used for this evaluation are not necessarily applicable to the intended use of this link. Units for distance used in presentation of the results are stated in English units because the fiber optic long-haul industry primarily uses those units in their documentation. Approximate metric units are included for reference.

This report includes data and information from industry, Government agencies, and literature. Certain commercial names are identified in this report to specify and describe some of the necessary information. Such identification does not imply exclusive recommendation or endorsement of the

companies or products by NTIA or NCS. The views, opinions, and/or findings contained in this report are those of the authors and should not be construed as an official NTIA or NCS position unless designated by other official documentation.

This report was completed with the assistance of representatives of Mountain Bell. The authors wish to thank those representatives of Mountain Bell for supporting the effort, and especially Mr. George B. McHenry, Jr., who contributed a great deal of his time to supply information and offer constructive ideas. The following representatives of NTIA's Institute for Telecommunication Sciences assisted in the successful completion of this report: Mr. Joe Hull--technical review, Mr. John Harman--graphics design, Mr. Bill Ingram--technical review and preparation of the information on alternate power sources, and Mrs. Lenora Cahoon--grammatical and format review. Ms. Eleanor Livingston, National Bureau of Standards, Boulder, CO, contributed with a technical and grammatical review. The authors wish to express their thanks to Mr. Ken Wadman, MITRE Corp., for his technical assistance and support.

CONTENTS

	Page
LIST OF FIGURES	vii
LIST OF TABLES	ix
ABSTRACT	1
1. INTRODUCTION	1
1.1 Background	1
1.2 Study Objectives	2
1.3 Participators in the Study	3
1.4 Benefits of the Study	4
2. SELECTED NSEP LINK	4
2.1 Mission Objectives	5
2.2 Description of the Selected Link	5
2.3 System Profile	5
2.4 Stress Analysis: Colorado Springs-to-Pueblo Link	9
3. HARDENING ENHANCEMENTS	14
3.1 Selective Hardening: Benefits and Limitations	14
3.2 Cable Upgrade Enhancements Required	15
3.3 Regenerator Upgrade Enhancements Required	15
3.4 Splice Box Upgrade Enhancements Required	17
3.5 Comparison of Original System Hardness and the Upgraded System Hardness	18
3.6 FIBRAM BER Analysis of Original and Upgraded System	22
4. PROJECTED STRESS PARAMETERS	22
4.1 Man-Made Events	26
4.2 Naturally Occurring Events	27
5. RESTORABILITY OF AN OPTICAL FIBER LINK	28
6. COST OF ENHANCEMENTS	29
6.1 Cable Placement Upgrade Costs	29
6.2 Regenerator Installation Cost Analysis	30
6.3 Cost of Splice Boxes (Handholds)	32
6.4 Summary of Costs to Upgrade the Fiber Optic Route	33
7. SUMMARY	37
8. CONCLUSIONS	38

CONTENTS (cont.)

	Page
9. ACKNOWLEDGMENTS	40
10. REFERENCES	40
11. BIBLIOGRAPHY	41
APPENDIX A: EXCERPT FROM THE MULTITIER SPECIFICATION	47
APPENDIX B: QUESTIONS TO BE ANSWERED PRIOR TO THE APPLICATION OF THE MULTITIER SPECIFICATION TO A FIBER OPTIC LINK	59
APPENDIX C: FIBER OPTIC LINK ROUTE MAPS	65
APPENDIX D: INFORMATION ON A TYPICAL ABOVEGROUND REGENERATOR STATION	73
APPENDIX E: INFORMATION ON A TYPICAL UNDERGROUND (CEV) REGENERATOR STATION	79
APPENDIX F: CONSIDERATION OF IONIZING RADIATION SHIELDING FOR OPTICAL FIBERS	85
APPENDIX G: RESTORABILITY OF AN OPTICAL FIBER LINK	121

LIST OF FIGURES

		Page
Figure 1.	Routing for Mountain Bell fiber optic communication link (Colorado Springs to Pueblo).	7
Figure 2.	"BER versus Time" graph for the existing fiber optic communication link.	24
Figure 3.	"BER versus Time" graph for the upgraded fiber optic communication link.	25
Figure C-1.	Routing for Mountain Bell fiber optic communication link (Colorado Springs to Pueblo).	67
Figure C-2.	Sheet 1 of route map summary.	68
Figure C-3.	Sheet 2 of route map summary.	69
Figure C-4.	Sheet 3 of route map summary.	70
Figure C-5.	Sheet 4 of route map summary.	71
Figure D-1.	View of the southwest corner of the regenerator building.	74
Figure D-2.	View of the south side of the regenerator building.	74
Figure D-3.	View of the "standby" diesel-powered generator.	74
Figure D-4.	View of the ac power control panel and ventilation fan located in the "standby" generator room.	75
Figure D-5.	View of the battery bank, which provides the dc power and serves as the uninterruptible power source.	75
Figure D-6.	View of the battery charging and monitoring circuit electronics.	75
Figure D-7.	Front view of the fiber optic connection/distribution chassis with protective cover in place.	76
Figure D-8.	Front view of the fiber optic connection/distribution chassis with protective cover removed.	76
Figure D-9.	View of the fiber optic cables showing the overhead routing.	76
Figure D-10.	Front view of the top portion of the regenerator electronics cabinet with the covers in place.	77

LIST OF FIGURES (cont.)

	Page
Figure D-11. View of the wiring on the rear of the alarm system electronics.	77
Figure D-12. View of three obsolete manually operated switchboards scheduled for removal from the Pueblo central office.	77
Figure E-1. View of the southeast corner of the CEV entrance.	80
Figure E-2. View of the CEV entrance with the lid up.	80
Figure E-3. View of the public utility service entrance control panel on the left and the CEV environmental control panel and sensors on the right.	80
Figure E-4. View of the fiber optic cable entrance into the top of the CEV.	81
Figure E-5. Front view of the fiber optic connection/distribution chassis with protective door open.	81
Figure E-6. View of the regenerator electronics and associated power supplies.	82
Figure E-7. View of the conventional copper wire pair circuits that exit the CEV.	82
Figure E-8. View of the CEV wall and a typical equipment rack mounting upright support post.	82
Figure E-9. Cut-away drawing of a standard CEV.	83
Figure E-10. Dimensions of available CEV's.	84
Figure G-1. A continuous UPS.	123
Figure G-2. A standby UPS.	125
Figure G-3. System performance degradation example: worst-case regenerator sections of FT3C Northeast Corridor (NCS, 1985).	137
Figure G-4. "BER versus Time" graph for AT&T single mode fiber operating at a wavelength of 1.3 microns in response to various levels of fallout radiation (Ingram, 1987).	138
Figure G-5. "BER versus Time" graph for AT&T multimode fiber operating at a wavelength of 1.3 microns in response to various levels of fallout radiation.	139

LIST OF TABLES

		Page
Table 1.	Hardness Level as it Relates to Protection Level	10
Table 2.	Multitier Specification Level of Protection for the Specific System being Studied	14
Table 3.	Fiber Optic Cable Protection Levels Before/After Upgrade to Get to Hardness Level 4	19
Table 4.	Splice Box Protection Levels Before/After Upgrade to Get to Hardness Level 4	20
Table 5.	Regenerator Site Protection Levels Before/After Upgrade to Get to Hardness Level 4	21
Table 6.	Data Used for Unhardened System	23
Table 7.	Data Used for Upgraded System	23
Table 8.	Cable Placement Cost Analysis	30
Table 9.	Estimated Costs to Upgrade the Two Regenerator Installations.	31
Table 10.	Estimated Costs for Hardening the Two Regenerator Sites During Initial Installation	32
Table 11.	Summary of System Element Enhancements Required to Upgrade the Entire Fiber Optic Route (including both regenerator stations) to a Level 4 (Maximum) Hardness	35
Table 12.	Summary of the Cost Ratios for Hardening of the Existing System	37
Table G-1.	Data Used for FT3C Northeast Corridor Model Using Single Mode Cable	136
Table G-2.	Data Used for FT3C Northeast Corridor Model Using Multimode Cable	140

MULTITIER SPECIFICATION APPLIED
TO MODIFY THE HARDNESS OF AN ESSENTIAL NSEP
FIBER OPTIC LINK

David F. Peach and Robert T. Adair*

The Multitier Specification was developed to provide guidelines and recommendations for improving the durability of the communication installations necessary for National Security/Emergency Preparedness (NSEP). The application of the Multitier Specification is considered beyond the installation and engineering requirements of typical commercial fiber optic systems. Five levels of hardness are defined in the specification. A link that could be important (may be asked to provide service) to the operation of the U.S. Space Command/NORAD was chosen as a candidate for this analysis. Based on the time-critical nature of the telecommunication traffic carried on this link and the stress expected, the Level 4 (Maximum) hardness was chosen as the target level for upgrade of this link. The elements of the existing system are classified into levels using the Multitier Specification. This report describes the enhancements necessary to mitigate the stress threat within the guidelines of the Multitier Specification and to raise the level of hardness to Level 4 (Maximum). The cost associated with the installation of these enhancements is included. Solutions to problems peculiar to the path specified for the link are described in terms of one suggested alternative. Also, an estimate of the additional initial investment required to harden the system to Level 4 (Maximum) is included.

Key words: cost projections; durability; enhancements; fiber optic link; guidelines; hardness level; Multitier Specification; National Security/Emergency Preparedness (NSEP); stress threat; telecommunication systems; U.S. Space Command/NORAD

1. INTRODUCTION

The Institute for Telecommunication Sciences (ITS) has formulated a Multitier Specification for use in effecting a durable terrestrial fiber optic telecommunication link (Peach, 1987).

1.1 Background

Each layer of the specification (guideline) is structured to provide a level of protection for stress categories of a more severe nature as defined in the specification document. The objective for the Multitier Specification is to define enhancements that could be implemented to harden a fiber optic,

*The authors are with the Institute for Telecommunication Sciences, National Telecommunications and Information Administration, U.S. Department of Commerce, Boulder, CO 80303-3328.

long-haul path (increase its durability) designated as a National Security/Emergency Preparedness (NSEP) route. Since a large percentage of Government communication traffic is carried by commercial systems, the specification is directed toward improvement of the durability of commercial installations rather than Government-owned systems.

Many of the ideas and concepts used in the specification were obtained from industry representatives. Distribution of the compilation of information (Multitier Specification) to the carriers in the marketplace has effected a transfer of this information to industry, which is the secondary objective of the work at ITS. The knowledge gained by industry and the application of ideas presented in the specification have improved the hardness of a typical fiber optic link being placed in 1987. The industry is becoming more aware of the need for the installation of a hardened system.

A coordinated set of enhancements to provide protection against all types of stress (man-made as well as naturally occurring events) has not been applied anywhere in the United States when installing a commercial system--at least no system has been advertised to provide that protection. Each carrier uses the enhancement that will achieve the necessary specific protection against a local threat or problem.

The basic definition and explanation of the Multitier Specification and its associated levels of hardness are presented in Appendix A. This appendix contains excerpts from the Multitier Specification, which should provide the reader with a basic working knowledge of the Multitier Specification and its terminology.

1.2 Study Objectives

It is the goal of this study to apply a set of enhancements, determined by the desired level of hardness, to a sample telecommunication link. The ideal situation, one that would provide the most comprehensive analysis, would be an existing fiber optic link with an NSEP mission. It has become obvious that almost any link between major population areas or along terrestrial thoroughfares will most likely carry emergency communication traffic of some type.

The Multitier Specification is designed to rate the hardness of an existing link and to determine the necessary enhancements to upgrade the hardness to a specified level. Although the Multitier Specification can be

used to specify enhancements, the intent is not to use the specification for design, but only as a design guideline. An existing fiber optic link would provide the opportunity to do both. And an upgrade from an obsolete, or lower capacity/technology, system would afford the opportunity to specify a newly designed link.

1.3 Participators in the Study

The study is intended to provide information that would benefit commercial telecommunication suppliers as well as Government users and suppliers. A second objective is to provide a study that involves an NSEP link that is necessary to maintain communication during an emergency caused by a natural event (weather, accident, or overload due to high demand holidays) or a national crisis event (threat of war, actual war response, sabotage, nuclear detonation, or a nuclear accident).

This study is requested by the National Communications System (NCS) to show application of the Multitier Specification to an actual commercial fiber optic link. The intent is to discuss those enhancements that can be added to a typical commercial link to improve the durability, when required for an NSEP use.

Executive Order 12472 defines the National Communications System mission (in part) as "The coordination of the planning for and provision of NSEP communications for the Federal Government under all circumstances, including crisis or emergency."

Key responsibilities of the NCS are to: seek development of a national telecommunication infrastructure that is survivable, responsive to NSEP needs of the President and the Federal Government, capable of satisfying priority telecommunications, and consistent with other National policies, serve as a focal point for joint industry-Government NSEP telecommunication planning; and establish a joint Industry-Government National Coordinating Center. This study is to support the National Security Telecommunications Policy as enunciated in NSDD-97... "the national telecommunication infrastructure must possess the functional characteristics of connectivity, redundancy, interoperability, restorability, and hardness necessary to provide a range of telecommunication services to support essential national leadership requirements."

The staff at NCS had suggested that a link with a tie point at the complex in Colorado Springs would be appropriate. A link located near ITS makes the

study more convenient and economical. The proliferation of fiber optic systems has been stimulated at the U.S. Space Command/NORAD complex in Colorado Springs because of the many advantages of the technology.

Mountain Bell, a Regional Bell Operating Company (RBOC) affiliate and a major supplier of service to the U.S. Space Command/NORAD complex, has allowed ITS to study a fiber optic link between Colorado Springs, CO, and points south. The link selected does not carry any secure traffic, which permits easy and unrestricted access to the facility. The facility and hardware are representative of the systems that could be used for either commercial or Government service. Parameters used for the study should apply for all NSEP use except those that require special protection or TEMPEST level hardening.

1.4 Benefits of the Study

The Mulitier Specification at present is unproven and needs additional refinement. Two primary benefits can accrue from this study: a maturing of the specification including some verification of validity; and a definition of method(s) for application.

This study is an application of the Mulitier Specification to a "real" situation. A critique of the study link is included with definitions of the appropriate assumptions. Any mention of deficiencies should not be considered a criticism of Mountain Bell or the equipment manufacturer. Positive comments should not be considered an endorsement of Mountain Bell or the equipment manufacturer, but only an evaluation of the enhancement value provided by the feature (hardware item or installation parameter).

The goal is to further define the attributes of each enhancement already installed and to provide recommendations for additional enhancements necessary to meet the hardness goal defined at the beginning of the study. A better understanding of the stress mitigation process will aid NCS in the attainment of their objective, which includes ensuring a more durable U.S. telecommunication infrastructure.

2. SELECTED NSEP LINK

Section 1 mentions the intent to evaluate an NSEP link that maintains an emergency telecommunication mission. This requirement is met because the link is integral to the network of telecommunication facilities that traverse the Colorado Springs community. Any commercial path that enters or exits a major

military or metropolitan area will at some time carry emergency traffic. The link selected for this study is a typical commercial link--one that is not Government-owned or -leased. Government traffic may be carried by the link if that link is selected for use.

2.1 Mission Objectives

The mission objectives are only defined in terms of "service" that may be carried over a commercial link. A specific mission could be analyzed if the link were to be placed in service for use by a designated user/owner. For purposes of this report the mission is defined as "necessary for emergency use."

2.2 Description of the Selected Link

The selected link, owned and operated by Mountain Bell, spans the distance from Colorado Springs, CO, to Pueblo, CO. The link terminates at a central office at each end. Two regenerators are necessary to relay the signal along the route. A data rate of 405 Mb/s is used to transmit data along the path. The equipment used has a data rate capability of 417 Mb/s.

2.3 System Profile

The path is profiled in terms of the parameters discussed in the Multitier Specification so that the level of hardness can be determined. The path is dissected into the major elements that can be classified for the level of protection provided. Design parameters, as well as environmental parameters, are considered when determining the level of protection. The path is divided into the following elements:

1. fiber optic cable
2. regenerator site
3. cable splices
4. the Central Office tie-point

The method of installation is documented and analyzed along with the type and design of the hardware used for each elemental area mentioned above. Features are noted that increase the resistance of the system to those stresses that are listed in the Multitier Specification. If features are incorporated that have not been evaluated in the Multitier Specification, an analysis is added. The goal of this analysis is to determine the type and magnitude of the protection provided.

The recommended enhancements involve modification of the environment surrounding each major element of the system. No attempt is made to redesign or modify the design of the system to improve the resistance to stress.

Appendix B contains an extensive list of questions that must be answered prior to application of the Multitier Specification to a fiber optic link. The answers to these questions provide the information required to perform the system analysis.

2.3.1 Colorado Springs-to-Pueblo Link

The link studied spans the service path between Colorado Springs, CO, and Pueblo, CO. A route map of this link is illustrated in Figure 1, which shows routing of the link relative to other geographic features in the area. More detailed route maps appear in Appendix C. This link is currently used for commercial traffic only, but could be used for Government-dedicated traffic if desired since the link ties into the public-switched nationwide telecommunication network (PSTN). Thus its use for NSEP purposes could be vital for emergency use during periods of crisis or emergency. The link represents a typical installation that could become a part of the necessary NSEP network.

This evaluation presents the level of hardness, based upon the amount of present protection from stress. The analysis includes the major stress categories that are discussed in the Multitier Specification. If other stress events seem appropriate for the specific location of this link, a discussion of the effects is provided. Detailed data is provided for each major component of the system as follows:

Fiber Optic Cable: Single-mode fiber optic cable is used for the entire route. An all-dielectric cable design is used, with a polyethylene outer sheath. The cable is a Siecior Type B Commercial (Industrial) with 6- and 10-fiber pairs. The 10-fiber pair cable is used through the urban area of the route from Colorado Springs to Fountain, CO (an exchange point on the route). The 6-pair fiber optic cable is used for the remainder of the route.

The cable is installed underground, at a specified depth of 48 inches (122 cm) except where obstacles preclude placing it at that depth. Existing underground conduits are used for placement of the cable through urban areas. The depth of these conduits is greater than 6 feet (1.8 m). Where possible,

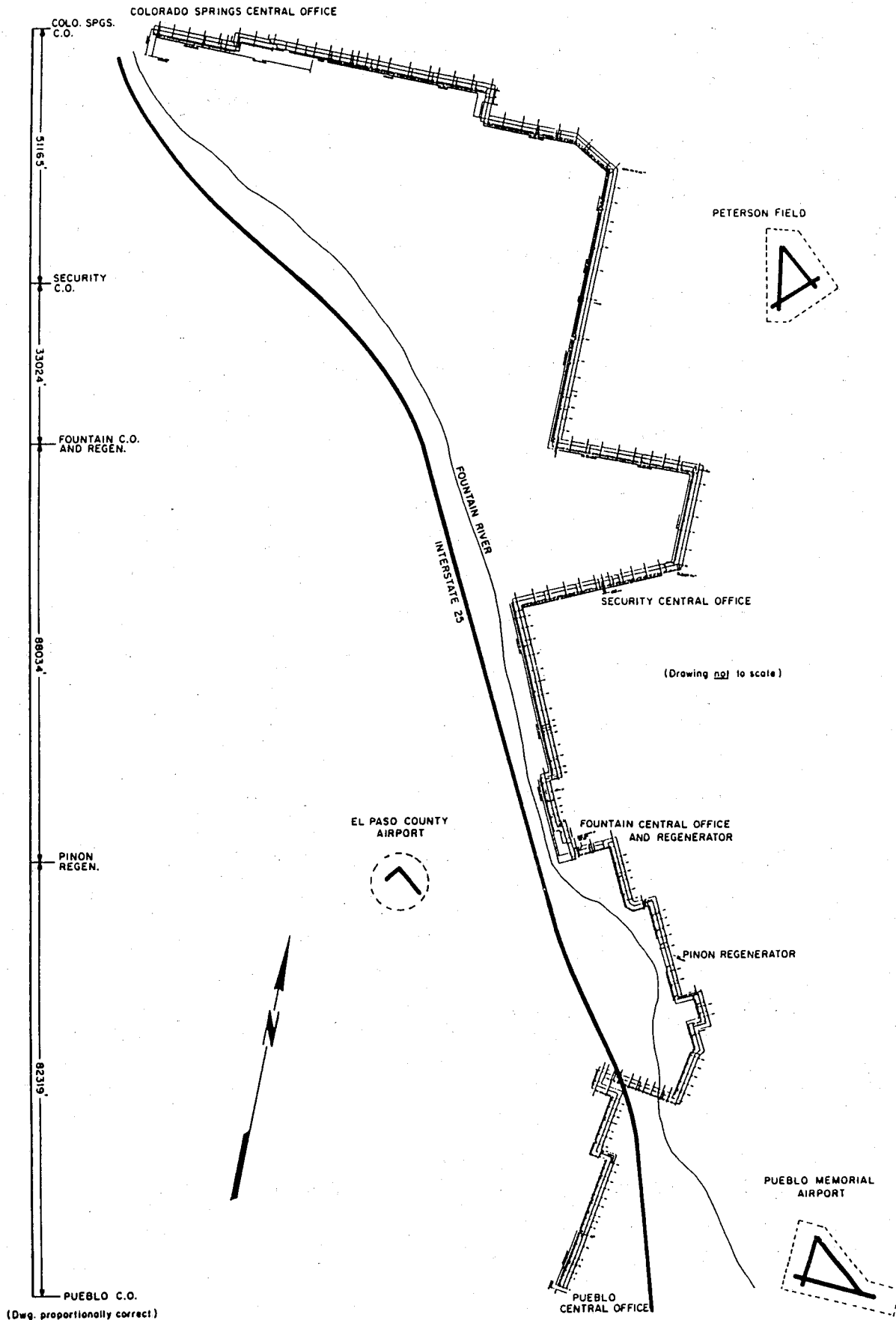


Figure 1. Routing for Mountain Bell fiber optic communication link (Colorado Springs to Pueblo).

the cable is plowed into the ground and placed inside a polyethylene conduit. The conduit is filled with a compound at the ends to prevent entry of moisture or other material. The installed cable lengths are 3 kilometers (approximately 10,000 feet).

Another cable, called a locate wire, is buried with the fiber optic cable but not as deep. It is buried 2 feet (0.6 m) below the surface. This cable consists of three copper wire twisted pairs. One pair is used for communication along the cable route. Numerous communication terminal points are provided for maintenance and operation personnel to use along the path. A second pair is used to carry intrusion alarm information back to the central office from the regenerator site. The third pair is a spare.

The "locate wire" acts as an aid in determining the location of the fiber cable using a standard locate device (designed to locate a metal cable).

A yellow, 6-inch (15-cm) wide, fiberglass warning tape is placed along with the locate wire at a depth of 2 feet (0.6 m). The message "Danger Fiber Optic Cable Below" is imprinted on the warning tape.

Cable Splices: The cable is spliced as required to connect standard length sections and at tie points for connections with side traffic. Fusion type splices are used. All splices are placed in a standard type of enclosure. The enclosure is then placed in a concrete shell splice box. The entire assembly is then placed underground with at least 24 inches (61 cm) of soil covering the splice box lid. The splice box has an open bottom that allows sufficient drainage for the splice enclosure to remain dry.

A "locate ring" is placed above the splice box as an aid in finding the splice box after back filling of the site has taken place. The ring provides a strong target for tracking with a standard cable-locator device.

Regenerator Site: The regenerator building is an aboveground structure constructed of cinder blocks and concrete. Appendix D contains photographs and information on a typical aboveground regenerator installation. Two rows of concrete blocks are laid at the base of the walls and cinder blocks are placed in rows above. The roof is constructed with a flat profile and a gentle slope. The voids in the cinder blocks are filled with vermiculite to aid in conservation of energy during heating and cooling. An electric-powered heating/cooling unit is installed to control the environment inside the

electronics room of the building. The doors are metal with rigid-foam insulation between the metal layers.

The building is divided into two rooms: an auxiliary power unit resides in one room along with the associated actuation and switchover equipment; the regenerator electronics and the battery bank are located in the second room. The system is designed so that the diesel motor and companion generator turn on immediately when the primary power grid fails. The battery bank is included for those circumstances when the power grid and the auxiliary power unit fail. A minimum of 8 hours of backup energy is provided from the batteries. The approximate current drain for the regenerator electronics is 3 amperes at 48 volts.

The regenerator building is situated on a concrete slab, poured with a reinforcing grid of rebar placed approximately 6 inches (15-cm) apart. A chain-link security fence with barbed-wire crown surrounds the building and a small parking area adjacent to the building. The fiber optic cable entry and egress is through the floor near [approximately 2 feet (0.6 m)] a building corner. A 4-inch (10-cm) diameter polyethylene conduit surrounds the inner duct and fiber optic cable assembly from about 4 feet (1.2 m) outside the building through the entry/exit of the building and to the ceiling inside the regenerator structure.

2.4 Stress Analysis: Colorado Springs-to-Pueblo Link

The objective of this section is to note the features of the installed system that are beneficial for a "hard" installation. A system is considered to be "hardened" when protective features (enhancements) are added to the facility design or installation, allowing it to withstand nuclear effects or natural disaster. The protection level denotes the extent of application of the possible protective features (enhancements). Table 1 is included to show the relationship of hardness level, protection level, and physical properties of a system.

A result of this analysis will be to assist in generating a list of enhancements that will be necessary to increase the hardness to a Level 4 (Maximum) hardness installation. The HEMP hardness Level 5 (Virtual) requires that a completely redundant parallel fiber optic path or link exist. This issue is not be addressed in this study.

Table 1. Hardness Level as it Relates to Protection Level

Hardness Level	Physical Properties	Protection Level
1	Surface/Aerial	Minimum
2	Surface with Conduit or Underground [1-2 ft (0.3-0.6 m)]	Moderate
3	Underground [3 ft (0.9 m)]	Significant
4	Underground [4 ft (1.2 m)]	Maximum
5	Parallel Paths	Virtual

Each major element of the link is analyzed separately. The hardness level for each element is stated as determined by the Mulitier Specification. No attempt is made to rate the level-of-hardness of the system as a link. The assumption is made that the system hardness is determined by the element with the lowest level-of-hardness.

2.4.1 Features That Contribute to the Hardness of Each Element

Fiber Optic Cable: The following features are beneficial in protecting the link from naturally occurring and man-made stress. A short discussion of the benefit of each feature is included. A more detailed discussion of the enhancement is available in the Mulitier Specification and the background information presented in that report.

1. All-dielectric cable - The elimination of all metal components from the fiber optic cable will reduce damage from both High Altitude Electromagnetic Pulses (HEMP) and lightning strikes. The absence of metallic parts makes it theoretically impossible for energy to couple from HEMP and nearly impossible for lightning to cause damage. Damage could occur from lightning if the cable were placed near a metal object that is struck by lightning. The heat or explosion at the point-of-entry may cause damage to the fiber optic cable. Therefore care must be taken when placing the cable, to ensure that the cable is located a sufficient distance away from these objects.

- 2. Placement in conduit - This additional expense (some carriers are placing the cable underground without a conduit) provides protection against rodents, damage due to the pressure of rocks against the cable, rocks shifting position due to freeze/thaw cycles, etc.
- 3. Polyethylene sheath - This provides excellent protection against chemicals and moisture. The durable nature of this material also prevents damage to the fibers from minor abuse during placement that could result in punctures, cuts, bruises, etc.
- 4. Underground placement - Placement at a depth of 48 inches (122 cm) locates the cable in an environment that is protected from effects due to most events of nature that occur on the surface of the Earth. Damage from agricultural diggings, construction diggings, etc., is minimized.
 - Placement of the cable at the 48-inch (122-cm) depth provides substantial protection from gamma radiation. The actual absorption factors are discussed in the Mulitier Specification.
 - Placement of the cable at a depth of 48 inches (122 cm) reduces the effect of the HEMP field. If the cable were to contain metallic components, the effect from HEMP would be minimized because of the attenuation provided by the soil covering. Estimates of the actual attenuation are included in the Mulitier Specification.

The design parameters of the cable and the physical parameters of the installation meet the criteria of a Level 4 (Maximum) hardness level installation.

Splice Box: The features that contribute to the protection of the cable and the splice are described here.

- 1. Rigid splice box - Placement within a rigid structure provides physical protection from naturally occurring and man-made events that may happen on the Earth's surface. The assembly of spliced fibers is contained within a closure. However, due to the fragile nature of the fibers it is imperative that the splice be protected from extreme mechanical stress (e.g., vibration, compression and tension stress, lateral and shear stress). Although the splice box is bottomless, if placed on a properly installed drainage pit, the splice

assembly will remain dry, reducing the rate of deterioration caused by moisture.

2. Watertight closure - The splice assembly, with the actual splices placed on a supporting tray, is surrounded by a rigid closure. A typical closure is a two-piece assembly. When the clamshell assembly is closed, it can be filled with a blocking compound and the two parts clamped or welded together. The closure provides a dry environment for the exposed fibers adjacent to the splices, minimizing deterioration due to moisture or chemicals.

The level of protection against naturally occurring events is enhanced by the use of a splice box (rigid structure). This installation should withstand total flooding for a short period of time. The watertight closure will ensure protection of the splices. However, the 24-inch (61-cm) layer of soil above the 4-inch (10-cm) thick concrete lid of the splice box does not provide adequate protection from gamma radiation or HEMP. The splice assembly (including the splice box) meets the suggested criteria, as defined by the Mulitier Specification, for a Level 2 (Moderate) hardness level.

Regenerator Site: The following features are beneficial in protecting and increasing the survivability of the regenerator including the cable, splices, patch panels, transmit/receive electronics, and other sensitive equipment that is necessary for the regenerator station operation.

1. Security fence/locked building - These precautions reduce the danger of damage from vandalism and sabotage.
2. Elevated building site - An elevated site provides protection from flooding that may occur in the vicinity. Since the regenerator is located near a major stream, the danger of local flooding is real.
3. Grounding practices - The National Electrical Code for buildings is observed and care has been taken to tie all metal mounting components within the building to ground potential using copper-clad conductors (#00 gauge).
4. Backup power system - A diesel motor/generator set is provided for power during those times when the primary power grid fails. The control system is designed so that the motor/generator will start within seconds of the absence of primary power. During

this short interval the parallel-connected battery bank will provide dc power for the electronics. The battery bank will provide approximately 8 hours of backup power if needed, but is not intended to act as a long-term power source.

5. Transient suppression - Transient suppression devices are included in the isolation transformer design. The isolation transformer interfaces with the primary power to the building. In addition, the battery bank, connected in parallel with the dc power supply, provides filtering of transients that may be present.

The regenerator site provides only a minimal amount of protection for the "heart" of this fiber optic link--the regenerator electronics that receive, regenerate (restore timing, phase, and amplitudes), and retransmit the information to the next receive site. Physical protection is provided by the security fence and the structure that reduce risk of damage due to vandalism and accidents. Adequate protection (grounding) is provided for mitigation of the effect of lightning, but transients resulting from a HEMP pulse will most likely cause upset. Very little protection from gamma radiation is provided.

The enhancements described meet the criteria for a Level 1 (Minimum) hardness installation as defined by the Multitier Specification.

2.4.2 Summary and Conclusions

The hardness level of each major system element is rated above. A summary of the rated levels is provided in Table 2. The hardware elements are classified separately from the installation (environment) of each element. The protection level is a subjective rating based upon the number of stress-eliminating enhancements installed ("1" signifying very little protection, while "10" signifies an installation with all feasible enhancements installed).

An overall rating is difficult to assess unless the specific stress type is considered. If the system is to be rated against all stress categories collectively, the composite system rating will obviously be determined by the least protected part, which would be a Level 1 (Minimum) in this case. However, if only naturally occurring events are considered, the rating would probably be a Level 4 (Maximum), since the designed installation is well protected from weather related events. This is common practice for the installing companies. When HEMP and gamma radiation are included in the stress

matrix, the rated hardness level drops to Level 1 (Minimum). We then conclude that, without a definition of stress threat, a protection level rating must be based on the resistance to all types of stress. This fiber optic system would than be rated as a Level 1 (Minimum) protected system.

Table 2. Multitier Specification Level of Protection for the Specific System being Studied

System Element/Task	Protection Level
Fiber Optic Cable	4
Splice	4
Splice Box	4
Regenerator Electronics	3
Regenerator Enclosure	1
Cable Installation	4
Splice Installation	2
Regenerator Enclosure Installation	3

3. HARDENING ENHANCEMENTS

The objective of this study is to verify the feasibility of the Multitier Specification to classify and specify the hardness of a fiber optic telecommunication system. An example of system classification has been completed using the Mountain Bell fiber optic link from Colorado Springs, CO, to Pueblo, CO. As stated earlier, the Mountain Bell installed system will be upgraded (on paper) to a Level 4 (Maximum) hardness system. Proposed enhancements, discussed in this section, will be recommended to modify the design or installation and as a result, to provide a Level 4 (Maximum) hardened link.

3.1 Selective Hardening: Benefits and Limitations

The magnitude and type of stress may not always be the same on the entire link. Separating the system into major elements allows us to apply different conditions to each component. The hardening enhancements can be added in the same manner. The result is that each element can be selectively hardened to meet the local threat.

For purposes of this report, we assume that the same threat exists along the entire route, i.e., all elements will see the same stress level and stress

types. The stress levels defined for Level 4 (Maximum) will be used to determine what enhancements are needed to upgrade each major element to a Level 4 (Maximum) hardened system as defined in the Multitier Specification.

3.2 Cable Upgrade Enhancements Required

The cable design used by Mountain Bell on the sample route meets the requirements of the Multitier Specification for a Level 4 (Maximum) hardened system. Three attributes fulfill this requirement:

1. use of an all-dielectric cable
2. use of a rodent-resistant cable sheath or conduit
3. the burial of the cable to a depth of 48 inches (122 cm)

All of these items have been implemented by Mountain Bell. The only concern is that the diameter of the conduit used as protection against rodents is less than the 2.1-inch (5.3-cm) diameter minimum requirement for rodent protection (See Section 4.2.8 of the Multitier Specification). Mountain Bell has not experienced a problem with its 1.33-inch (3.7-cm) outside diameter configuration.

The following enhancements would be required to fully comply with the Level 4 (Maximum), Multitier Specification recommendations:

1. Increase the conduit size to at least 2.1 inches (5.3 cm) to ensure rodent protection.
2. No earthquake protection is required since this is not in a high risk area.

3.3 Regenerator Upgrade Enhancements Required

The Regenerator Site, as installed by Mountain Bell, meets the criteria of a Level 1 (Minimum) hardened system as specified by the Multitier Specification. The following features determine this classification:

1. The regenerator enclosure (building) is located at ground level.
2. The enclosure structure is fabricated of cinder blocks without reinforcement. This is equivalent to a reinforced wood frame structure.
3. Limited protection from fire (prairie fire, accidents, etc.) is provided by the concrete and cinder block construction.
4. Very little gamma radiation protection is provided by the cinder block structure.

5. Protection from HEMP is minimal. The present structure provides negligible protection.
6. The regenerator electronics assembly is not protected from HEMP coupling by a HEMP box, transient protection devices, or enhanced grounding.
7. Minimal earthquake protection is provided by the regenerator building installation.

The above features limit the stress resistance of the regenerator installation. This installation appears to be very appropriate for a commercial installation located in this part of the United States. The structure provides more than adequate protection from the expected types and magnitudes of naturally occurring stress in this locality.

The upgrade of this regenerator site to a Level 4 (Maximum) hardness installation will require the following features and enhancements:

1. An underground structure with at least 48 inches (122 cm) of soil covering the entire structure will be necessary. If an access is required for maintenance and for ventilation, the placement of the sensitive equipment (fiber optic cable, regenerator electronics, and other equipment using semiconductor devices) within the structure must be such that 48 inches (122 cm) of soil or equivalent shield will be in the path of a gamma radiation source. The access port and the ventilation tower must extend above ground level a sufficient distance to avoid filling of the structure with water due to flooding that may flow over or around the site.
2. Transient protection of at least three stages must be installed as defined by the Multitier Specification.
3. An effective electrical grounding system must be installed for the regenerator site and the systems within the enclosure (See Multitier Specification Section 4.8).
4. The emergency power source capability should be extended to provide at least 14 days of backup power.

Placing the regenerator structure underground, at a 48-inch (122-cm) depth, will provide adequate protection from gamma radiation. See the Multitier Specification for the approximate absorption factors. Appendix E contains photographs and further information on a typical underground controlled-environment vault (CEV) regenerator installation. Implementation of an effective ground (See Multitier Specification Section 4.8) for the regenerator site and the equipment inside the enclosure, along with

installation of three stages of transient protection devices, will provide adequate protection from HEMP and lightning.

Since the locality of this installation does not have a high earthquake risk (See Section 4.4.3 of the Multitier Specification), the special features for protection against extreme earthquake may not be needed. An analysis of the structural strength of the foundation and the structure using the data provided in the Multitier Specification should be done to ensure that the regenerator site will withstand an earthquake projected to a 100 year "Return Period."

Extending the backup power capability to 14 days may be as simple as adding more fuel capacity. Caution must be taken when expanding the capacity since the volume of fuel may increase the risk of fire, increase the system susceptibility by increasing the risk of collapse of the fuel tank due to nuclear blast overpressure conditions, or increase the risk of rupture due to earthquake. An alternate power source may be in order if the expansion is not feasible or is too costly.

3.4 Splice Box Upgrade Enhancements Required

The splice box, as installed, is basically a very good installation except for the depth of burial. The poured concrete box structure should withstand any naturally occurring event, i.e., weather conditions, earthquakes (expected for this area of the United States), wet or dry conditions, and accidents.

The enhancement required to increase the level of protection to Level 4 (Maximum) hardness is to increase the burial depth to 48 inches (122 cm).

The present installation, used by Mountain Bell, is entirely adequate for protection from all expected naturally occurring events such as weather or accidents. Typically there are about 60 feet (18.3 m) of slack cable coiled in each splice box. The depth of soil covering the 4-inch (10-cm) thick concrete splice box lid is approximately 2 feet (0.61 m). This provides less than full protection from gamma radiation. The threat from HEMP is not a concern because there are no metallic components within the splice box. The accumulation of effects from gamma radiation, at each splice, would result in a substantial erosion of the design margin (excess available power above the errorless detection level).

3.5 Comparison of Original System Hardness and the Upgraded System Hardness

The improvement in the system installation in terms of hardness is substantially increased by the upgrade. A measure of this improvement is shown below. An objective measure of the protection level, based on a numerical scale where 1 is the lowest level of protection and 10 the highest level, is provided in Tables 3, 4, and 5. Table 6 of Appendix A provides a summary of the protection levels that can be expected for each hardness level.

3.5.1 Fiber Optic Cable

Table 3 illustrates the weaknesses and strengths of the installation before upgrade. The weaknesses are minimized by the upgrade, but not eliminated in all cases. This analysis includes the installation of the cable. Some of the line items reflect exposures that result from installation, e.g., the slack cable placed inside the splice box will expose the cable to gamma radiation at these points.

3.5.2 Splice Box

An analysis of the improvement in stress protection gained by upgrade of the splice box installation is provided in Table 4. The significant change resulting from the upgrade is an increase in burial depth of the splice boxes. The amount of soil above each box is increased from 24 inches (61 cm) to 48 inches (122 cm). Before upgrade, the slack cable inside the splice boxes would be exposed to gamma radiation causing a significant increase in attenuation of the transmitted signal.

3.5.3 Regenerator Sites

The regenerator sites are the weakest elements of the system. Several significant exposures are evident as shown in Table 5. Location of the structures at ground level exposes the installations to several naturally occurring events. Also, very little protection is provided against gamma radiation. Underground location of the regenerator sites provides a very stable and shielded environment for the regenerator electronics and associated equipment. Appendix F presents detailed information on ionizing radiation for optical fibers.

Table 3. Fiber Optic Cable Protection Levels Before/After Upgrade to Get to Hardness Level 4

Stress Parameter	Levels of Protection	
	Before Upgrade	After Upgrade to (Level 4)
1. Natural Events		
Ice	10	10
Snow	10	10
Rain	10	10
Wet Conditions	10	10
Dry Conditions	10	10
Flood	10	10
Water Erosions	10	10
Deep Frost	9	9
Wind	10	10
Earthquake	10	10
Lightning	10	10
Accidents on ROW (Rights of Way)	10	10
2. Extreme Hot/Cold	10	10
3. Blast from Explosion	10	10
4. Nuclear Blast Overpressure		
2 psi (Level 1)	10	10
10 psi (Level 4)	10	10
5. Gamma Radiation		
5000 rads	10	10
30000 rads	7	10
6. HEMP		
5000 V/m field strength	10	10
50000 V/m field strength	10	10
7. Sabotage Damage	10	10
Overall Protection Level	7	9

Table 4. Splice Box Protection Levels Before/After Upgrade to Get to Hardness Level 4

Stress Parameter	Levels of Protection	
	Before Upgrade	After Upgrade to (Level 4)
1. Natural Events		
Ice	10	10
Snow	10	10
Rain	10	10
Wet Conditions	10	10
Dry Conditions	10	10
Flood	10	10
Water Erosions	10	10
Deep Frost	10	10
Wind	10	10
Earthquake	10	10
Lightning	10	10
Accidents on ROW	10	10
2. Extreme Hot/Cold	10	10
3. Blast from Explosion	10	10
4. Nuclear Blast Overpressure		
2 psi (Level 1)	10	10
10 psi (Level 4)	10	10
5. Gamma Radiation		
5000 rads	10	10
30000 rads	7	10
6. HEMP		
5000 V/m field strength	10	10
50000 V/m field strength	10	10
7. Sabotage Damage	10	10
Overall Protection Level	7	10

Table 5. Regenerator Site Protection Levels Before/After Upgrade to Get to Hardness Level 4

Stress Parameter	Levels of Protection	
	Before Upgrade	After Upgrade to (Level 4)
1. Natural Events		
Ice	10	10
Snow	10	10
Rain	10	10
Wet Conditions	10	9
Dry Conditions	10	10
Flood	10	8
Water Erosions	10	10
Deep Frost	10	10
Wind	8	10
Earthquake	8	9
Lightning	10	10
Accidents on ROW	9	10
2. Extreme Hot/Cold	10	10
3. Blast from Explosion	6	10
4. Nuclear Blast Overpressure		
2 psi (Level 1)	10	10
10 psi (Level 4)	2	10
5. Gamma Radiation		
5000 rads	1	10
30000 rads	1	10
6. HEMP		
5000 V/m field strength	1	10
50000 V/m field strength	1	10
7. Sabotage Damage	7	10
Overall Protection Level	1	10

3.6 FIBRAM BER Analysis of Original and Upgraded System

In a recent NTIA/NCS report, W. Ingram describes a computer program (FIBRAM) that models the attenuation of optical fibers after simulated exposure to fallout gamma radiation (Ingram, 1987). FIBRAM can be used to estimate the changes in bit error ratio (BER) in response to a variance in the intensity of exposed radiation, the transmit power level, and/or the physical configuration of the fiber link. Further examples of the application of FIBRAM appear in Appendix G (Section G.3).

FIBRAM is used in this report to simulate gamma radiation exposure to the system described in this report and shown in Figure 1. The bit error ratios (BERs) are calculated for the current (original) system variables and for the upgraded variables. These variables are shown in Tables 6 and 7.

Section number 1 in Tables 6 and 7 represents 42 miles (67.6 km) of optical fiber that is covered with at least 4 feet (122 cm) of soil. The protection factor is 7,000 for both the original and upgraded systems. Section number 2 in the tables represents 2 miles (3.2 kms) of optical fiber that is buried 2 feet (0.6 m) underground and covered with a concrete cap. Its protection factor is increased from 50 (original) to 7,000 (upgraded) due to better protection for the cable splice enclosures. Section number 3 in the tables represents the photodiodes in the regenerator stations. Its protection factor is increased from 10 (original) to 7,000 (upgraded) because the improved regenerator stations are buried at least 48 inches (122 cm) underground.

The bit error ratios (BERs) of both the original and the upgraded systems are calculated in response to fallout levels of 0; 5,000; and 30,000 rads. The results are shown in Figures 2 and 3. It should be noted that in Figure 2, the curve representing 30,000 rads has a sharp upward slope at around 10^4 seconds. This is due to the failure of the photodiode receiver rather than the optical fiber. If the photodiode had not failed, the fiber would have traced a recovery curve similar to the 5,000-rads curve.

4. PROJECTED STRESS PARAMETERS

The maximum stress threat parameters expected for the Mountain Bell path are included below. These parameters are extracted from the Multitier Specification, where such parameters have been treated in the specification and projected based upon the stressful activity for this area of the country and typical weather-generated stress along the route. The engineering/maintenance

Table 6. Data Used for Unhardened System

Section Number	Protection Factor	Fiber Type	Length (meters)	Intrins. Loss (dB/km)
1	7000	SM, 1.3 μ m	67600	0.380
2	50	SM, 1.3 μ m	3220	0.380
3	10	n/a	photodiode	n/a
<u>Other Data</u>				
Total Transmit Power			0.16 mw ¹	
Max. Gamma for Photodiode			1500 rads	
Regenerator Type			11D/11E/11F	
Fiber Manufacturer			AT&T	

Table 7. Data Used for Upgraded System

Section Number	Protection Factor	Fiber Type	Length (meters)	Intrins. Loss (dB/km)
1	7000	SM, 1.3 μ m	67600	0.380
2	7000	SM, 1.3 μ m	3220	0.380
3	7000	n/a	photodiode	n/a
<u>Other Data</u>				
Total Transmit Power			0.16 mw ¹	
Max. Gamma for Photodiode			1500 rads	
Regenerator Type			11D/11E/11F	
Fiber Manufacturer			AT&T	

¹This value includes 45 cable splices with an average power loss of 0.2 dB each. It also includes two regenerator stations with an average power gain of 6.5 dB each.

BER vs Time

AT&T Single Mode, 1.3 microns

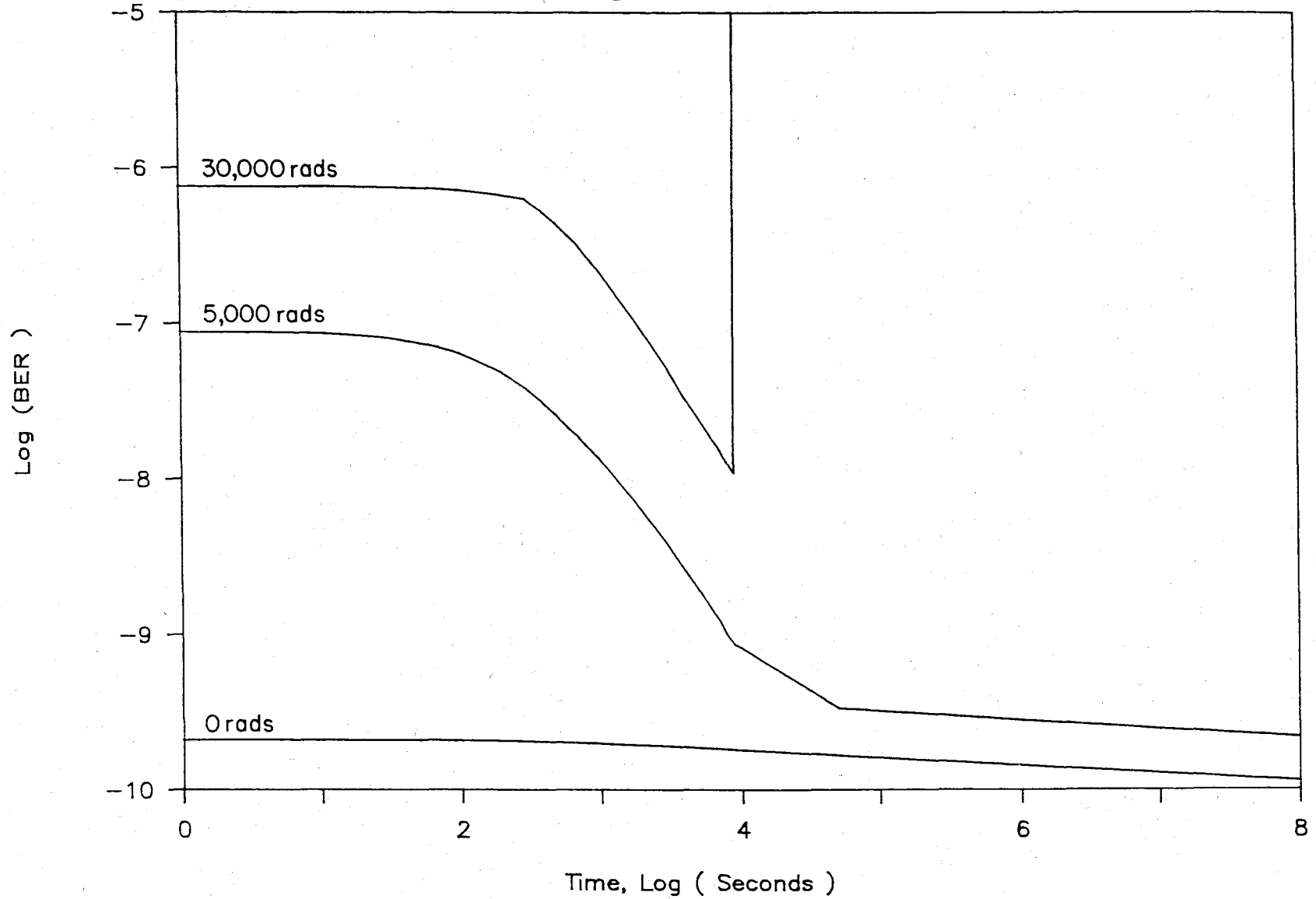


Figure 2. "BER versus Time" graph for the existing fiber optic communication link.

BER vs Time

AT&T Single Mode, 1.3 microns

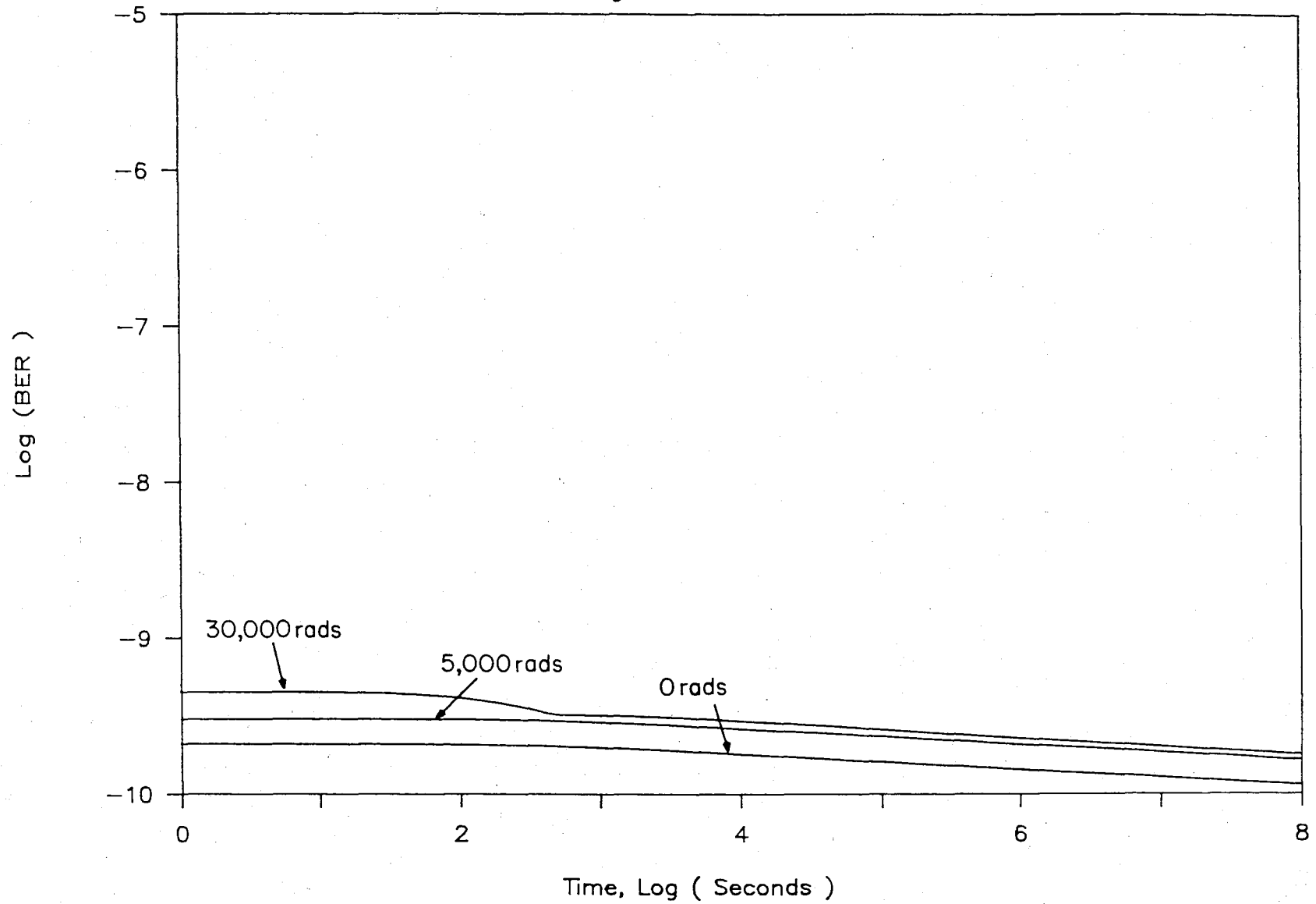


Figure 3. "BER versus Time" graph for the upgraded fiber optic communication link.

personnel responsible for the route have been consulted for an estimate of the stress when the parameters are not available in the Multitier Specification.

4.1 Man-Made Events

1. Prompt Gamma Radiation: Peak dose of 30,000 rads resulting from a high-altitude nuclear detonation. Prompt gamma radiation does not reach the Earth from high-altitude bursts.
2. Fallout Gamma Radiation: A maximum dose of 30,000 rads, resulting from a surface or near surface (in atmosphere) nuclear detonation, is suspended as fallout particles distributed over the Earth's surface. This dose results in a peak radiation dosage rate after 1 hour. The decay rate will depend upon the isotope source involved. The dose may vary slightly along the route due to variation in particle fallout.
3. HEMP: HEMP peak levels of 50,000 volts/meter (V/m) at ground level. The level would be constant along the entire fiber route. The HEMP pulse will be of a very short time duration, with an extremely fast buildup (rise time), as illustrated in the Multitier Specification.
4. Vandalism: Acts of vandalism are very random due to their extemporaneous nature. Damage results from the fact that the device is present. These acts generally consist of shooting at parts of the installation with a shotgun or rifle, throwing stones at exposed devices, kicking, or other types of abuse. High-power rifles up to 9 mm caliber and larger are used for hunting big game in remote areas such as the area where this system is installed (there is no size limit in caliber allowed for big game hunting). More advanced types of vandalism are now possible, because of our culture and lifestyle, e.g., driving into or over a device (terminal box or post) with farm vehicles or off-road recreational vehicles.
5. Sabotage: Consists of acts of vandalism that are premeditated. Deliberate damage can be inflicted quite easily, to surface mounted devices, with devices used for vandalism. In addition, interruption of a fiber optic system can be accomplished by strategically damaging an exposed device. Digging into the ground to expose a part of the system (e.g., a fiber optic cable) is also possible, especially in remote areas such as the area where the installation under study is located. Passive acts (e.g., optical tapping) of sabotage are also a threat, particularly on routes that carry secure or sensitive information. Intrusion of the lightstream is not as simple as coupling information from a wire, but is possible using off-the-shelf instruments without interrupting the system function.
6. Corrosion: Deterioration caused by toxic chemicals, industrial smoke, petroleum/gas leaks, steam or hot water, etc., are the

main causes. Long term exposure to ultraviolet radiation will also cause a type of deterioration. The possibility of placing the fiber optic cable near a deposit of radioactive material is also a concern. The material can be a result of an industrial dump or accident.

7. Nuclear Blast Overpressure: For purposes of this study and projected system upgrade, the overpressure expected will be 10 psi (0.7 kg/cm³) as defined by Multitier Specification Level 4 (Maximum).
8. Burst from Explosion: The maximum wind velocity associated with the 10 psi (0.7 kg/cm³) overpressure will be approximately 290 mph (467 km/h) as defined in the Multitier Specification (Section 3.1.3, Table 14).

4.2 Naturally Occurring Events

(100-year, or greater, "return period" events)

1. Snow: Snowfall accumulation to 30 inches (76.2 cm) with intermittent snowdrifts (snow and dirt mix) as high as 15 feet (4.6 m) or greater along the route above the installed cable and regenerator enclosure are possible. Periodic melting of snow will cause local flooding and extreme wet conditions.
2. Ice: Ice accumulation with coating of all exposed devices to 0.5 inch (1.3 cm) or greater can be expected during the lifetime of the system.
3. Wind: Constant winds to 90 mph (145 km/h) (annual extreme-mile wind), sustained for 40 seconds (equates to a 90 mph (145 km/h) wind defined in the Multitier Specification), can be expected along the route. Gusts of short duration, e.g., 100-foot (30.5-m) depth of wind, can be as high as 126 mph (203 km/h) (Hollister, 1970).
4. Rain/Wet Conditions: During the 100-year cycle a rainy period will occur that will cause local flooding and extreme wet conditions.
5. Dry Conditions: Extreme dry conditions can cause cracks to form in the earth resulting in parting of the cable or stress on the regenerator structure. This condition is not anticipated along the study route. Blowing dust and dirt can result during extended dry periods, causing deterioration of exposed devices.
6. Water Erosion: Washouts that expose the cable (and conduit) can be expected. A substantial protection (conduit or sheath) for the cable will be necessary.
7. Deep Frost: The frost line can be expected to go below 48 inches (122 cm) resulting in shifting of the earth, imbedded rocks, tree roots, steel conduits used to traverse roads, etc.

Lateral pressure on the cable could result along with the possibility of shear, compression and tension.

8. Earthquake: The study link is in a very risk-free area of the United States as illustrated by the data made available in the Multitier Specification (See Section 4.4.3). The horizontal velocity of the Earth's surface material is not expected to exceed 2 cm/s (0.78 in/s).
9. Lightning: The path of the study link lies in an area of Colorado where the lightning exposure factor is high. The exposure factor is a product of soil resistivity and the number of thunderstorm days. The high resistivity in the area causes the factor to be higher. The Multitier Specification (Section 4.7.1) shows a "lightning exposure factor" of 600-1,000 for the area. A typical normal lightning exposure factor is in the range of up to 600.
10. Accidents on rights-of-way: The fiber optic path is not along a major thoroughfare or railroad. The risk of accidents should be small.
11. Extreme Hot/Cold: The extremes for the location of this link will be between -48 °F (-26.7 °C) and 112 °F (44.4 °C) for the air temperature above the surface. The actual surface temperature, as noted by the Multitier Specification will be as low as -52 °F (-28.9 °C) and as high as 122 °F (50.0 °C) due to surface phenomenon.

5. RESTORABILITY OF AN OPTICAL FIBER LINK

Optical fiber links can carry hundreds or thousands of calls at a time. Regenerator stations serve to regenerate the optical signal. If one of these elements fails, communication along that route is severed. The causes of such failures usually come from one of the following categories:

1. power supply failure
2. element failure
3. optical fiber degradation

Power supply problems can usually be prevented by the judicious use of an uninterruptible power supply (UPS). This is described in Appendix G (Section G.1). Element failure can normally be circumvented by the use of on-line spare parts that can be switched into the network. This issue is addressed in Appendix G (Section G.3). Optical fiber degradation is caused by exposure to radiation, but can be muted by hardening of the fiber and by attenuating the radiation before it strikes the fiber. This is also described in Appendix G (Section G.3).

6. COST OF ENHANCEMENTS

The mechanics of this study involve the analysis of an actual fiber optic telecommunication link between two major cities and two smaller cities in Colorado. We have attempted to make this a practical analysis rather than a theoretical treatise. As a result, the information presented should be helpful to numerous fiber optic companies and Government agencies. The objectives for this study are

1. to estimate the cost to upgrade the protection level of the system
2. to project the least cost for the upgrade
3. to show cost feasibility of the upgrade.

All three of these objectives will be dealt with in this section of the report. The costs will be estimated for the particular installation being studied and may not apply to all installations, e.g., if this same installation were located in another geographic area where the stress risks are not the same, the costs would differ. The intensity of stress for a particular locality will vary as illustrated in the Multitier Specification. The specific stresses that are expected for the path studied in this report have been addressed.

6.1 Cable Placement Upgrade Costs

The enhancements required to upgrade the system to a Level 4 (Maximum) hardness are suggested in Section 3.2 of this report. A cost estimate for retrofitting the installation with these enhancements is included below. Estimates of the cost differential of the system enhancement during initial installation are also presented. It is recognized that sometimes the cost to retrofit a system is greater than if enhancements are done as part of a new installation.

Upgrade of the cable and cable installation is based upon the best information available concerning the deficiency area. For example, according to referenced literature a protective conduit at least 2.1 inches (5.3 cm) in diameter around the cable should be used to repel gophers and ensure adequate protection (Connelly and Cogelia, 1970). Recent data obtained from tests performed at Colorado State University, by Dr. Bruce A. Wunder, indicates that a 1.25 inch (outside diameter) conduit is probably sufficient protection in most installations. However, there is insufficient evidence to conclude that

the 1.25 inch diameter conduit will provide complete protection against rodents.

Mountain Bell decided to place the cable at a depth of 48 inches (122 cm). The company could have saved some money if they had placed the cable at a shallower depth, but the risk of damage and upset would increase significantly. Table 8 illustrates the cost differential for three common depths for the entire 44-mile (70.8-km) route. These cost estimates are typical and are representative of the 1987 competitive market.

Table 8. Cable Placement Cost Analysis

Depth	Installation Cost/Foot(Meter)	Total Route Placement Cost
2 ft (0.6 m)	\$0.67 (\$2.20)	\$156K
3 ft (0.9 m)	\$1.00 (\$3.28)	\$232K
4 ft (1.2 m)	\$1.50 (\$4.92)	\$348K

6.2 Regenerator Installation Cost Analysis

The goal of this study is to provide the information necessary to ensure a Level 4 (Maximum) hardness fiber optic regenerator installation. This analysis will consist of two separate cost options: the cost of renovating the existing installation, and the cost differentials resulting when implementing a new installation. These cost estimates have been offered by representatives of Mountain Bell (and the authors) and are considered to be accurate to within 10 percent.

6.2.1 Cost to Upgrade

The existing regenerator enclosures (buildings) are constructed at ground level as described in Section 2.3 of this report. Upgrade of the regenerator installations to meet the Level 4 (Maximum) criterion will require replacement of the enclosures with underground CEVs as described in Section 3.3. Since there are two regenerators, the upgrade will include replacement of both structures. The existing structure will still be required to house the backup power generators and will need appropriate modifications. In addition, the recommended transient protection and grounding system must be implemented as suggested in the Multitier Specification. Costs necessary to expand the

capability of the emergency power source to a capacity of 14 days will be included.

The fiber optic transmit/receive electronics can be transferred to the new underground structure without modification or additional cost. Placing the electronics away from the entry hatch will be necessary to avoid exposure to gamma radiation as discussed in Section 3.3. No additional cost will result from these design considerations. Table 9 illustrates the estimated costs to upgrade the existing regenerator installation.

Table 9. Estimated Costs to Upgrade the Two Regenerator Installations

System Element or Task	Upgrade Cost (\$K)
1. Regenerator enclosures (CEVs installed)	140
2. Installation of transient protection devices and grounding system	10
3. Expansion of backup power system to 14 days	14
Total	164

6.2.2 Cost to Harden a New Installation

The additional costs to provide a Level 4 (Maximum) (as compared to a typical installation such as the existing Colorado Springs to Pueblo link) hardened regenerator are

1. the cost of additional transient protection and earth grounds
2. the additional cost of an underground regenerator enclosure (CEV)
3. the costs of extending the emergency power to 14 days

The costs for a surface mounted regenerator enclosure and a CEV are about equal if made part of the initial design. Installation costs are included. For a new installation, the differential cost for extending the emergency power to 14 days is the same as quoted for the upgrade. Table 10 illustrates the estimated costs required to harden the regenerator site during initial installation.

Table 10. Estimated Costs for Hardening the Two Regenerator Sites During Initial Installation

System Element/Task	Approximate Added Cost (\$K)
1. Regenerator enclosure (CEVs installed)	Negligible
2. Installation of transient protection devices and grounding system	10
3. Expansion of backup power to 14 days	14
Total	24

6.3 Cost of Splice Boxes (Handholds)

The cost of commercially available fiberglass splice boxes is typically \$1,100. Concrete splice boxes were used in the fiber optic telecommunication link being analyzed in this document. Concrete splice boxes fabricated locally cost \$250 each. Typical boxes are 56 inches (142 cm) long and 24 inches (61 cm) wide and deep with 4-inch (10-cm) thick concrete walls and lids. They are installed with a minimum of 24 inches (61 cm) of soil covering the lid. The boxes are placed on a 1-foot (30-cm) thick bed of gravel to prevent settling and accumulation of condensation. Approximately 30 feet (9.1 m) of slack fiber optic cable (on each side of the splice) are contained in each splice box. This provides ample spare cable to perform a splice in a nearby van-mounted work space.

There are 45 splices in this link from Colorado Springs to Pueblo. It is estimated that 30 splices are contained in buried splice boxes. These splice boxes must be dug up and reburied to a depth of 4 feet (1.2 m) (without disturbing the existing splices) in order to upgrade this portion of the system to a Level 4 (Maximum) hardness. It is estimated that two persons with a backhoe could perform this operation on each splice box in 2 hours. This activity is estimated to cost \$200 for each splice box, which would be a total of approximately \$6,000 for this portion of the system enhancement.

6.4 Summary of Costs to Upgrade the Fiber Optic Route

The estimated costs of upgrading the separate elements of the fiber optic route under study in this document are summarized in Table 11. The costs of upgrading the system elements to a Level 4 (Maximum) hardness are listed along with the cost differential if the elements had been installed originally to meet the Level 4 (Maximum) hardness. The incremental costs to upgrade or to include enhancements in the original design are calculated and displayed in Table 11. Column headings are lettered so that the results of the calculations are clear to the reader. In some cases the cost of upgrading is minimal and in other cases it is substantial. Some elements could have been installed to attain hardness Level 4 (Maximum) originally with very little extra cost. For the projected use of this commercial system, there is no need to install a hardened system. The results of the analysis on the system in this document are in no way intended to imply that the system is not installed properly or adequately. The primary purpose of this document is to provide an example of the application of the Multier Specification to an actual, existing commercial fiber optic network that could carry NSEP traffic. The rights-of-way costs have not been addressed in this study since they will not be affected by the hardness level of the system. The original costs associated with the regenerator electronics installed at the regenerator sites and the central offices have not been addressed in this study since they will not significantly affect the hardness level of the system.

The cost figures contained in Table 11 are based upon the specific details of the system being studied. The actual dollar amounts were determined using the following assumptions:

1. Route design cost:
 - a. The total design cost includes equipment specification, special system design and layout for each regenerator station, and route layout.
 - b. A cost of \$0.30/foot (\$0.99/m) was used for determining this cost.
 - c. This cost will be within the 10 percent allowance for designing a "hard original" system.
 - d. Redesign costs of \$10K will be required for upgrade of the system.

2. Cable material cost:
 - a. The cable base cost was \$1.90/foot (\$6.27/m) for 44 miles (70.8 km) of cable.
 - b. A sales tax and shipping cost overhead of 8 percent of the cable base cost was used to determine the total material cost.
 - c. This cost will be the same for a "hard original" system.
3. Miscellaneous overhead costs:
 - a. This line item includes costs for several types of materials including warning tape, posts to mark the route, warning signs along the route, special conduits needed to place cable under obstacles, and other special fees incurred during the installation of the system.
 - b. A cost equal to 6 percent of the cable base cost was used to determine this cost.
 - c. This cost will not change when installing a "hard original" system.
4. Cable placement and upgrade costs:
 - a. Original cable placement costs were \$1.50/foot (\$4.92/m) for 44 miles (70.8 km).
 - b. The upgrade costs for cable not originally buried to the 48-inch (122-cm) depth required can only be estimated at this time. The actual costs to upgrade this portion can only be determined at the time of installation due to varying local conditions. Costs to uncover the original cable and bury or otherwise protect it to the equivalent of the 48-inch (122-cm) depth are estimated at \$4.50/foot (\$14.75/m) for 2 miles (3.2 km).
 - c. The cost of installing the 2 miles (3.2 km) of obstructed cable in a hardened fashion originally is estimated to cost \$3/foot (\$9.84/m) in addition to the \$1.50/foot (\$4.92/m) unobstructed cable installation cost. Alternate routing of the cable during the original installation could have possibly reduced this cost (depending upon rights-of-way, local obstacles, etc.).
5. Regenerator enclosure upgrade costs:
 - a. Typical existing buildings to enclose the two regenerator stations are estimated to cost \$60,000 each.
 - b. Prefabricated CEVs installed in the ground are estimated to cost \$65,000 each.

- c. The upgrade or enhancement costs are estimated as the cost of installing two new CEVs and adding a cost of \$5,000 each to transfer the fibers and electronics to the CEVs from the original buildings. The heating/cooling and operating costs associated with CEVs should actually be less than those costs for similar size conventional buildings.

Table 11. Summary of System Element Enhancements Required to Upgrade the Entire Fiber Optic Route (including both regenerator stations) to a Level 4 (Maximum) Hardness

System Element or Task	Costs (in thousands of dollars)					
	A	B	A+B	C	(A+B)-C	C-A
	Existing System	Upgrade of Existing System	Upgraded Existing System	Hard Original System	Differ. Between Upgraded & Hard Original Systems	Differ. Between Hard Orig. & Existing Systems
1. Route Design	70	10	80	70	10	0
2. Cable Material	476	0	476	476	0	0
3. Misc. Overhead	26	0	26	26	0	0
4. Cable Placement	348	48	396	380	+16	+32
5. Regenerator Enclosures	120	140	260	130	+130	+10
6. Transient Protection	0	10	10	10	0	+10
7. Regenerator Backup Power Sources	4	14	18	14	+4	+10
8. Splice Boxes	7.5	0	7.5	7.5	0	0
9. Splice Box Installation	6	6	12	8	+4	+2
TOTALS	1057.5	228	1285.5	1121.5	+164	+64

Regenerator enclosure costs are based upon the fact that prefabricated CEVs placed in the ground (ready for the installation of the regenerator

electronics and its associated equipment) cost approximately the same as an aboveground building. Thus the cost of regenerator enclosures hardened to Level 4 (Maximum) would add no significant additional cost during the original system construction. The CEVs are less convenient for normal use, which is the primary reason they were not installed in the system being studied here. Also a hardened system is not required for this particular telecommunication link.

6. Transient protection costs:

- a. The upgrade costs include \$5,000 for installing transient (EMP and lightning) protection in each new regenerator enclosure (CEV).
- b. The costs for transient protection would be the same if installed as part of the design for a hard original system.

7. Regenerator backup power source upgrade costs:

- a. The cost of shielding the existing diesel-powered generator for HEMP hardening is estimated to be \$5,000 for each regenerator installation.
- b. The cost of purchasing and installing (underground) a 500 gallon diesel fuel tank is estimated to be \$2,000 for each regenerator installation.

8. Splice box (upgrade) costs:

- a. The cost for concrete splice boxes is \$250 at each of the 30 splice locations.
- b. The same splice boxes could be used for a hard original design.

9. Splice box installation costs:

- a. The cost of installing the 30 splice boxes in this link originally is estimated to be \$200 each.
- b. The cost of uncovering these splice boxes and burying them 2 feet (0.6 m) deeper (without disturbing the splices) is estimated to be \$200 each.
- c. The cost of installing the splice boxes at the 48-inch (122-cm) depth during the original system construction phase is estimated to be approximately \$67 each more than at the 24-inch (61-cm) depth.

The information contained in Table 11 is based upon estimated costs of labor and supplies in the local area at the time this document was produced. These cost figures may not be appropriate for other locations and are subject

to normal inflation as time passes. The relative costs are significant since they illustrate the benefits and economics of installing a hardened system during its original construction phase.

Table 12 summarizes the cost of upgrade and the cost of installing a hardened original system in percent of the original cost. The significant result of this analysis is that a 6 percent additional cost during the original installation would have produced a Level 4 (Maximum) hardened system (hard original), while upgrading of the originally installed system would cost 22 percent more. The savings between an upgraded system and a hard original system for the owner of the system would be \$164K. The additional owner investment for the original installation of a Level 4 (Maximum) hardened system would be \$64K, or 6 percent of the existing system cost.

Table 12. Summary of the Cost Ratios for Hardening of the Existing System

Cost Ratio Based on:	Cost of:			
	Existing System	Upgrade of Existing System	Upgraded Existing System	Hard Original System
Cost of Existing System	--	22%	122%	106%
Cost of Upgraded Existing System	82%	18%	--	87%
Cost of Hard Original System	94%	20%	115%	--

7. SUMMARY

The Multitier Specification is applied to modify the hardness of an existing fiber optic telecommunication link. This commercial link between two major cities and two smaller cities in Colorado is considered to be an

essential NSEP link. This is due to its close proximity to the U.S. Space Command/NORAD complex near Colorado Springs, Colorado. It is also due to the fact that typically a large percentage of Government and military traffic is carried on commercial systems.

An analysis of this fiber optic link was performed and the hardness level of the system as it presently exists was assessed using the guidelines of the Multitier Specification. The major elements of the system were studied individually using the Multitier Specification to determine the existing hardness level and the enhancements required to upgrade the link to a full Level 4 (Maximum) hardness. This information is then used to estimate the cost increments required to upgrade all portions of the system to this desired hardness level. The particular enhancements were suggested such that minimal costs would be incurred while achieving the desired system upgrade. These costs were then tabulated and compared with the cost of the original system and with the projected cost of the installation of a hardened system initially. These estimates substantiate the fact that the hardening of a system during the original installation is the most economical. However, for the system studied here, the costs of the enhancements are quite reasonable, especially when calculated on a per circuit-mile (circuit-kilometer) basis. Furthermore, this application of the Multitier Specification illustrates the excellent cost effectiveness of upgrading the existing system. Without this detailed analysis, one might assume that the system enhancement costs would be so excessive that a new hardened link should be installed. The analysis of the particular fiber optic link presented in this document clearly illustrates the cost effectiveness and feasibility of enhancing this existing system to the hardness Level 4 (Maximum).

8. CONCLUSIONS

The preceding cost analysis for the system enhancements required to upgrade the telecommunication link to a hardness Level 4 (Maximum) has provided some important information. Table 11 presents the estimated cost of upgrading the entire link to hardness Level 4 (Maximum). These costs of approximately \$218K are 45 percent of the total original cost (approximately \$0.5 million) for the construction and installation of this 44-mile (70.8-km) fiber optic telecommunication link. Since this link contains 6 (4 active) fiber pairs (each of which can carry approximately 6,048 circuits) the upgrade cost per

circuit-mile (circuit-kilometer) is very low. The actual circuit-mile (circuit-kilometer) cost for the Level 4 (Maximum) enhancement to the particular link described in this document is approximately \$0.14 (\$0.09). It should be noted, however, that this figure is based upon the full capacity of the system and not the current lesser use of the system. Also it should be noted that the fiber optic cable is placed at the Level 4 (Maximum) hardness depth [48 inches (122 cm)] over 95 percent of the route during the original installation. This reduces the system upgrade costs significantly. An all-dielectric, single-mode, fiber optic cable was chosen for the original installation of this system. This type of cable presents a definite economical and technical (HEMP hardness) advantage for a hardness Level 4 (Maximum) system. In addition the regenerator sites lend themselves to the underground regenerator enclosure (CEV) retrofit. Likewise, the deeper burial of the splice boxes should be a relatively inexpensive part of the system enhancement due to the original routing of the link and the soil composition in the area.

Based upon the foregoing analysis of this specific fiber optic telecommunication link, one can conclude that it is far more economical to enhance this existing system to hardness Level 4 (Maximum) than to install a new link to achieve this hardness level. However, this may not be true for all installed systems.

A similar conclusion could not be drawn for a significantly large percentage of the existing fiber optic systems, primarily because a number of them use some sort of metallic central strength member or protective cover for the cable, and the cable is not usually buried to the hardness Level 4 (Maximum) depth. These two factors would probably dictate the considerable expense of laying new cable to achieve the desired hardness Level 4 (Maximum). The Multitier Specification must be applied in detail to each separate fiber optic system in question. An economic analysis would also need to be performed. This would allow the assessment of the hardness level as the system exists. Further application of the Multitier Specification would then provide the analysis to determine the cost and feasibility of enhancing the system in question to the desired higher level of hardness.

The Multitier Specification as applied to the actual fiber optic system studied in this document appears to be a capable tool to assess the hardness level of existing systems and recommend appropriate enhancements. The development of the cost of system enhancements to higher levels of hardness is

then straightforward. Further studies of additional sample links are needed to continue the validation of the Multitier Specification. More generalized statements can then be made regarding the usefulness of the Multitier Specification.

The Multitier Specification is also a capable tool to design fiber optic systems and assess the costs of various hardness levels of fiber optic telecommunication links as they are being implemented.

9. ACKNOWLEDGMENTS

The authors would like to express their sincere appreciation to the following people for their assistance in producing this document: J. A. Hull for technical support; J. M. Harman for graphics support; W. J. Ingram for computer-aided manuscript preparation; and K. Henderson for help in preparation of the manuscript.

We would also like to express our gratitude to Bill Cameron, Director, Network Distribution Services Construction and Engineering, and especially to George B. McHenry, Jr., Assistant Manager, Network Distribution Services - Engineering, Colorado Springs, Colorado Mountain Bell. Their many hours of cheerful cooperation and sharing of the in-depth details associated with the Mountain Bell fiber optic telecommunication link discussed in this document have made this study much more useful.

10. REFERENCES

- Connelly, R. A., and N. J. Cogelia (1970), The gopher and buried cable, Bell Laboratories Record, April, pp. 99-103.
- Hollister, S. C. (1970), The engineering interpretation of Weather Bureau records for wind loading on structures, Proceedings of technical meeting concerning wind loads on buildings and structures, Held at the National Bureau of Standards, Gaithersburg, MD, January 27-28, 1969, Building Science Series 30, (Superintendent of Documents Catalog Number 13.29/2:30, Washington, DC 20402).
- Ingram, W. J. (1987), A program description of FIBRAM: A radiation attenuation model for optical fibers, NTIA Report 87-216/NCS TIB 87-22, 120 pp., NTIS Order Number PB 87-230686 (report), PB 87-230687 (report and flexible disk), [National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22161].

Peach, D. F. (1987), Multitier Specification for NSEP enhancement of fiber optic long-distance telecommunication networks, Volume I: An Executive Summary, NTIA Report 87-226, 50 pp., Volume II: Multitier Specification background and technical support information, 222 pp., NTIA Report Number 87-226, NCS TIB 87-25, NTIS Order Number not yet available, December.

11. BIBLIOGRAPHY

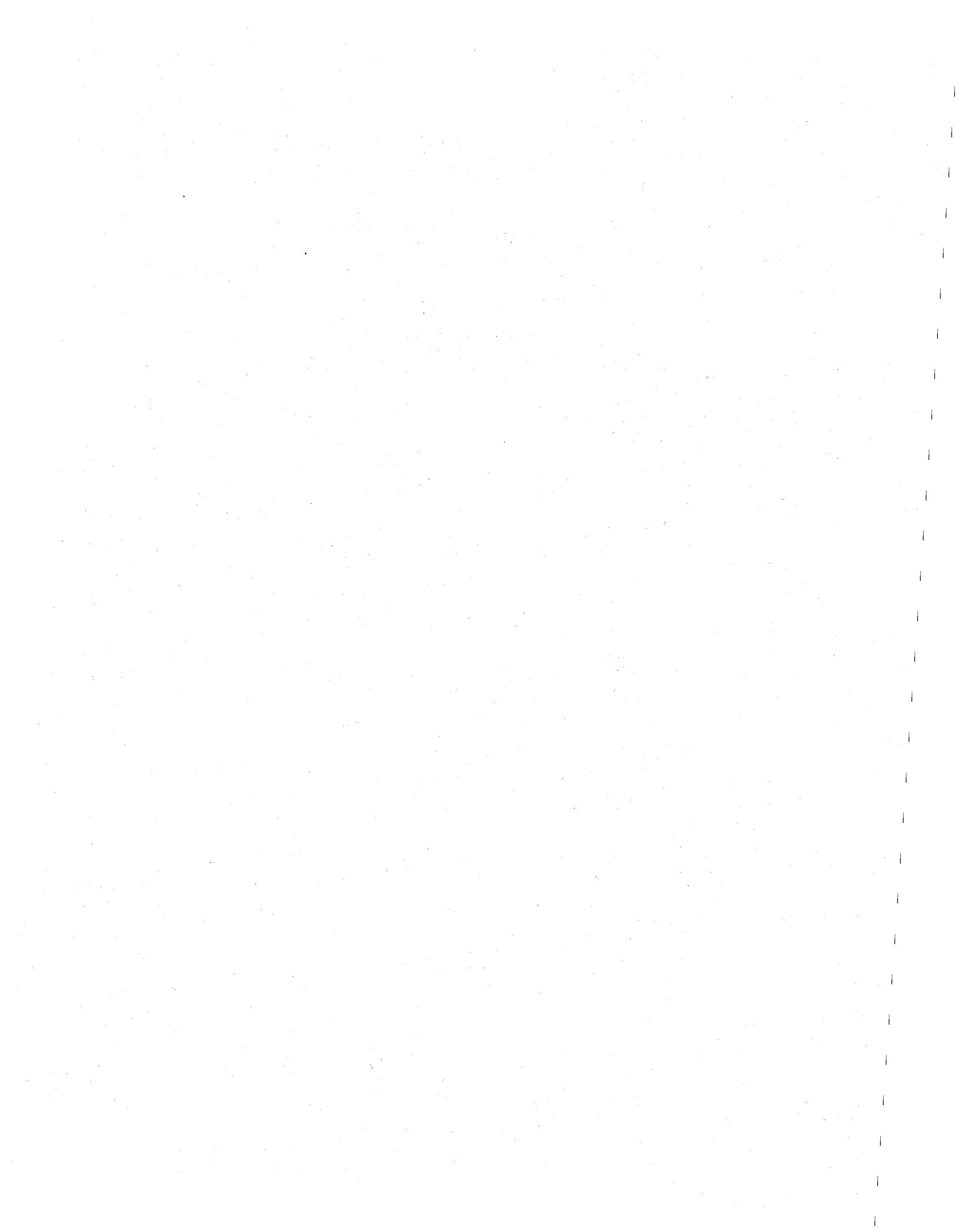
- Abe, K. (1986), Fiber and cable reliability, Proc. National Commun. Forum, Vol. XXXX, Book 1, September 29-October 1, (National Communications Forum, 505 North Lake Shore Drive, Suite 4808, Chicago, IL 60611).
- AEC (U.S. Atomic Energy Commission) (1960), Reactor Handbook, Vol. I: Materials, C. Tipton, Jr. (Ed.), (Interscience Publishers, Inc., New York, NY).
- AIHA (American Industrial Hygiene Association) (1982), Engineering Field Reference Manual, (AIHA, 475 Wolf Ledges Parkway, Akron, OH 44311-1087).
- Antinone, R. J. (1987), How to prevent circuit zapping, IEEE Spectrum, April, pp. 34-38.
- ASCE (American Society of Civil Engineers) (1961), Manuals of engineering practice, Number 42, Design of structures to resist nuclear weapons effects, (ASCE, New York, NY).
- ASTM (American Society for Testing and Materials) (1975), Standard method of test for indentation hardness of rubber and plastics by means of a durometer, ASTM Standard Designation D 2240-75.
- AT&T (1970), The gopher and buried cable, Bell Laboratories Record, April.
- AT&T (1982), Outside plant engineering handbook, (AT&T Technologies, Inc., Indianapolis, IN).
- AT&T (1985), Telecommunication electrical protection, (Customer Information Center, order select code 350-060, Indianapolis, IN).
- BDM (The BDM Corporation) (1983), DNA EMP course study guide, BDM/W-82-305-TR, January, (Defense Nuclear Agency, Washington, DC).
- BDM (BDM Corporation) (1986a), DNA EMP COURSE Study Guide, Vol. 1, DNA-H-86-68-V1, BDM/W-85-1143-TR, May 27, (Defense Nuclear Agency, Washington, DC 20305-1000).
- BDM (BDM Corporation) (1986b), DNA EMP COURSE Study Guide, Vol. 2, DNA-H-86-68-V2, BDM/W-85-1143-TR, May 27, (Defense Nuclear Agency, Washington, DC 20305-1000).
- Bell, Trudy E. (1985), The main event, the decision to divest: Incredible or inevitable?, IEEE Spectrum 22, Number 11, November.

- Booz, Allen & Hamilton (1984), Electromagnetic pulse (EMP) task force status report to the industry executive subcommittee, January 12, (National Communications System, Washington, DC 20402).
- BTL (Bell Telephone Laboratories) (1975), EMP engineering and design principles, Second Printing, (Loop Transmission Division, Technical Publications Department, Whippany, NJ).
- CCITT (The International Telegraph and Telephone Consultative Committee) (1985), Construction, installation, jointing and protection of optical fibre cables, (International Telecommunication Union, Geneva, ISBN 92-61-02421-1).
- Cogelia, N. J., G. K. LaVoie, and J. F. Glahn (1976), Rodent biting pressure and chewing action and their affects on wire and cable sheath, Proc. Int. Wire and Cable Symp., Cherry Hill, NJ, pp. 117-124.
- DCA (Defense Communications Agency) (1981), DSN design practices for high-altitude electromagnetic pulse (HEMP) protection, Draft B, June 1, (DCA, Washington, DC).
- DCPA (Defense Civil Preparedness Agency) (1972), EMP protection for emergency operating centers, TR-61A, (Federal Emergency Management Agency, Washington, DC), May.
- DCPA (Defense Civil Preparedness Agency) (1976a), Shelter design and analysis: Fallout radiation shielding, TR-20, Vol. 1, June, (Federal Emergency Management Agency, Washington, DC).
- DCPA (Defense Civil Preparedness Agency) (1976b), Shelter design and analysis: Protection factor estimator with instructions, TR-20, Vol. 2, February, p. 44, (Federal Emergency Management Agency, Washington, DC).
- Denny, H. W. (1983), Grounding for the Control of EMI, (Don White Consultants, Inc., Gainesville, VA).
- DNA (Defense Nuclear Agency) (1971), DNA EMP Awareness Course NOTES, DNA 2772T, August, (DNA, Washington, DC 20305).
- DOD (Department of Defense) (1982), Grounding, Bonding, and Shielding for Electronic Equipments and Facilities, MIL-HDBK-419, January 21, (Naval Publications Office, 5801 Tabor Ave., Philadelphia, PA 19120).
- DOD (Department of Defense) (1984), Grounding, bonding, and shielding for common long haul/tactical communication systems including ground based communication-electronics facilities and equipments, MIL-STD-188-124A, February 2, (Naval Publications Office, 5801 Tabor Ave., Philadelphia, PA 19120).
- Englert, T. J. (1987), Effects of radiation damage in optical fibers--A tutorial, NTIA Contractor Report 87-38, May, (NTIS Order Number PB 87-210308/AS).

- FEMA (Federal Emergency Management Agency) (1980), EMP threat and protective measures, TR-61, April, (FEMA, Washington, DC).
- FEMA (Federal Emergency Management Agency) (1982), FEMA attack manual, Chapter 2, CPG2-1A2, May, (FEMA, Washington, DC).
- FEMA (Federal Emergency Management Agency) (1983), Radiation safety in shelters: A handbook for finding and providing the best protection in shelters with the use of instruments for detecting nuclear radiation, (Civil Preparedness Guide) 2-6.4, September 23, (GPO: 1985-483-703:32781, Superintendent of Documents, Washington, DC 20402).
- FEMA (Federal Emergency Management Agency) (1985), Protective construction: Nuclear blast resistant design, TR-20, Vol. 4, March, (GPO 527-466/30494, Superintendent of Documents, Washington, DC 20402).
- FEMA (Federal Emergency Management Agency) (1986), Attack environment manual, CPG 2-1A4, Chapter 4, (FEMA, Washington, DC).
- FEMA (Federal Emergency Management Agency) (1986), Electromagnetic pulse protection guidance, CPG-2-17, January, (FEMA, Washington, DC).
- Fischer, D. K., E. Bow, W. F. Busch, and E. C. Schrom (1986), Progress towards the development of lightning tests for telecommunications cables, Proc. 35th Int. Wire and Cable Symp., pp. 374-386.
- Galuszka, Peter (1985), Unfazed by projections, carriers kindle the course of lightwave, Data Commun., pp. 72-73, April.
- Georgopoulos, C. J. (1982), Fiber Optic and Optical Isolators, (Don White Consultants, Inc., Gainesville, VA).
- Glasstone, S., and P. Dolan (1977), The Effects of Nuclear Weapons, (GPO 1977 O-213-794, Superintendent of Documents, Washington, DC 20402).
- Haber, J. B. (1987), Characterization of ambient terrestrial radiation for long haul fiber optic transmission systems, Proc. First Int. Military and Government Fiber Optics and Commun. Exp. (MFOC '87), Washington, DC, March 16-19.
- Horgan, John (1985), Safeguarding the national security, IEEE Spectrum 22, Number 11, November.
- Hull, J. A. (1987), NSEP fiber optics system study background report: Nuclear effects on fiber optic transmission systems, NTIA Report 87-227, NCS TIB 87-26, 115 pp., NTIS Order Number not yet available, December.
- Kao, C. K. (1982), Optical Fiber Systems: Technology, Design, and Application, (McGraw-Hill, Inc., New York, NY).
- McKay, G., W. Cousineau, B. Braham, and J. Rowe (1986), Qualification procedure for fiber optic cable design, Proc. 35th Int. Wire and Cable Symp., pp. 307-314.

- Miletta, J. R., M. Campi, R. J. Chase, and G. L. Roffman (1982), Defense switched network design practices for protection against high-altitude electromagnetic pulse, HDL-SR-82-2, (U. S. Army Electronics Research and Development Command, Harry Diamond Laboratories, Adelphi, MD).
- National Research Council (1984), Evaluation of Methodologies for Estimating Vulnerability to Electromagnetic Pulse Effects, (National Academy Press, Washington, DC)
- Naval Facilities Engineering Command (1986), High-altitude electromagnetic pulse environment, Design Manual 12.02, SN 0525-LP-300-9087, October, (200 Stovall Street, Alexandria, VA 22332-2300).
- NBS (National Bureau of Standards) (1970), Proceedings of technical meeting concerning wind loads on buildings and structures, held at the National Bureau of Standards, Gaithersburg, MD, January 27-28, 1969, R. D. Marshall and H. C. S. Thom (Ed.), Building Science Series 30, (Superintendent of Documents Catalog Number 13.29/2:30).
- NCS (National Communications System) (1978), EMP, lightning and power transients: their threat and relevance to EMP protection standards for telecommunication facilities, TIB 78-1, (NCS-TS, Washington, DC).
- NCS (National Communications System) (1985a), Assessment of nuclear fallout radiation on FT3C lightwave digital transmission system, TIB 85-11, November, (NCS-TS, Washington, DC).
- NCS (National Communications System) (1985b), FT3C multimode optical-fiber communication system EMP test and assessment, TIB 85-12, November, (NCS-TS, Washington, DC).
- Nelson, D. B. (1972), A program to counter effects of nuclear EMP in commercial power systems, ONRL-TM-3552, October, (Oak Ridge National Laboratories, Oak Ridge, TN).
- Nesenbergs, M. (1987), Fiber optic networks and their service survival, NTIA Report 87-214/NCS TIB 87-9, 121 pp., (NTIS Order Number PB 87-186706/AS), National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22161).
- Nicodemus, M. L., and N. B. Guttman (1980), Probability estimates of temperature extremes for the contiguous United States, May, (National Climate Center, National Oceanic and Atmospheric Administration, Asheville, NC 28801).
- Pittock, A. B., T. P. Ackerman, P. J. Crutzen, M. C. MacCracken, C. S. Shapiro, and R. P. Turco (1986), Environmental Consequences of Nuclear War, Scope 28, Vol. 1: Physical and Atmospheric Effects, (John Wiley and Sons, New York, NY).
- RAND Corporation (1987a), Feasibility of using interstate highway right-of-way to obtain a more survivable fiber optics network, RAND Report Number R-3499-DOT/NCS, Volume I, (The RAND Corporation, Santa Monica, CA 90406-2138).

- RAND Corporation (1987b), Feasibility of using interstate highway right-of-way to obtain a more survivable fiber optics network, RAND Report Number R-3500-DOT/NCS, Volume II, (The RAND Corporation, Santa Monica, CA 90406-2138).
- Rockwell International (1982), Baseline study of the EM vulnerability of systems, April, (Rockwell International, Anaheim, CA).
- Shah, J. (1975), Effects of environmental nuclear radiation on optical fibers, BSTJ 54, Number 7, pp. 1207-1213.
- Sims, R. E. (1987), A HEMP hardened fiber optic repeater terminal, Proc. First Int. Military and Government Fiber Optic and Communications Exposition (MFOC-87), Washington, DC, March 16-19.
- SRI International (1983), Draft military standard for EMP protection of ground-based C³I facilities, (SRI International, Menlo Park, CA).



APPENDIX A

EXCERPT FROM THE MULTITIER SPECIFICATION

The following appendix is an unchanged (unedited) excerpt taken from Section 4 of Multitier Specification for NSEP enhancement of fiber optic long-distance telecommunication networks (Peach, 1987). References cited in Appendix A are also included as entries in either Section 10 (References) or Section 11 (Bibliography) of this report. The original figure and table numbers in the excerpt have been retained from the original referenced document to maintain consistency with that document. Therefore the figure and table numbers in Appendix A do not follow the numbering sequence used for the subsequent appendixes.

4. LEVELS OF HARDNESS--MULTITIER SPECIFICATION

4.1 Background

The levels of hardness are determined by the physical parameters of the system components and their environment, the functional component design parameters, and the strategic placement of the components of the system within the environment. The ensuing sections of the report describe these parameters for each of the selected levels of hardness.

The goal is to develop a specification (guideline) with succeedingly higher levels of resistance to stress. An attempt has been made to select meaningful measurement parameters in building the levels of hardness. Absolute levels of stress tolerance are impossible to define because the fiber optic technology is new (and rapidly changing), has only limited experience, and the stress conditions being considered are hypothetical or unknown.

The cost associated with the upgrade to succeeding levels of the specification is not dealt with here. A number of unique situations must be dealt with in constructing and designing a fiber optic path; thus development of a typical cost figure that can be applied to any path would not be feasible.

Figure 1 illustrates the intent of the specification to be a tool for use in specifying or classifying the hardness level of a fiber optic path. The definition of the stress expected (threat) must be defined by the user of that path--possibly determined by the type of traffic to be transmitted along the path.

The Multitier Specification is a compilation of data and experience from several sources. Figure 2 illustrates these inputs. Radiation tests were done on the AT&T FT3C fiber optic telecommunication system (NCS, 1985a). A separate set of tests were done on the AT&T 5ESS switch to determine susceptibility to EMP fields (NCS, 1985b). The results of these tests, plus input from industry design and installation practices, have been used to define the levels of the Multitier Specification.

The intent is for each successive level to be more hard than the preceding level. As enhancements are added or environments are modified to provide protection, the exposure to other types of stress-causing hazards may be increased. For example, placing system elements underground for additional protection against weather will increase the likelihood of damage caused by rodents. Table 5 illustrates the improvement areas as the hardness level is increased. The table also lists the areas of increased exposure (risk areas).

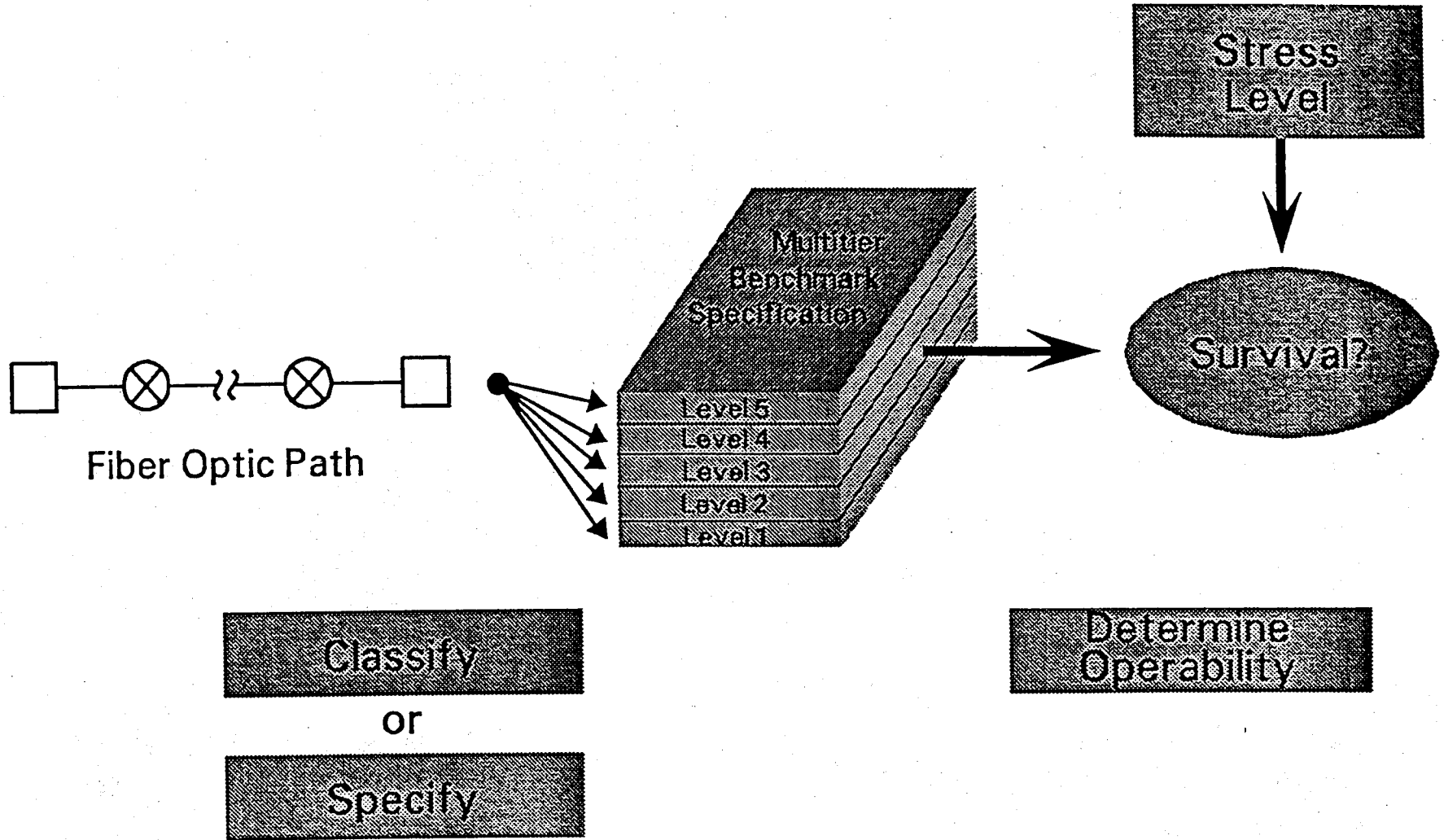


Figure 1. Multitier specification as a tool to classify or specify.

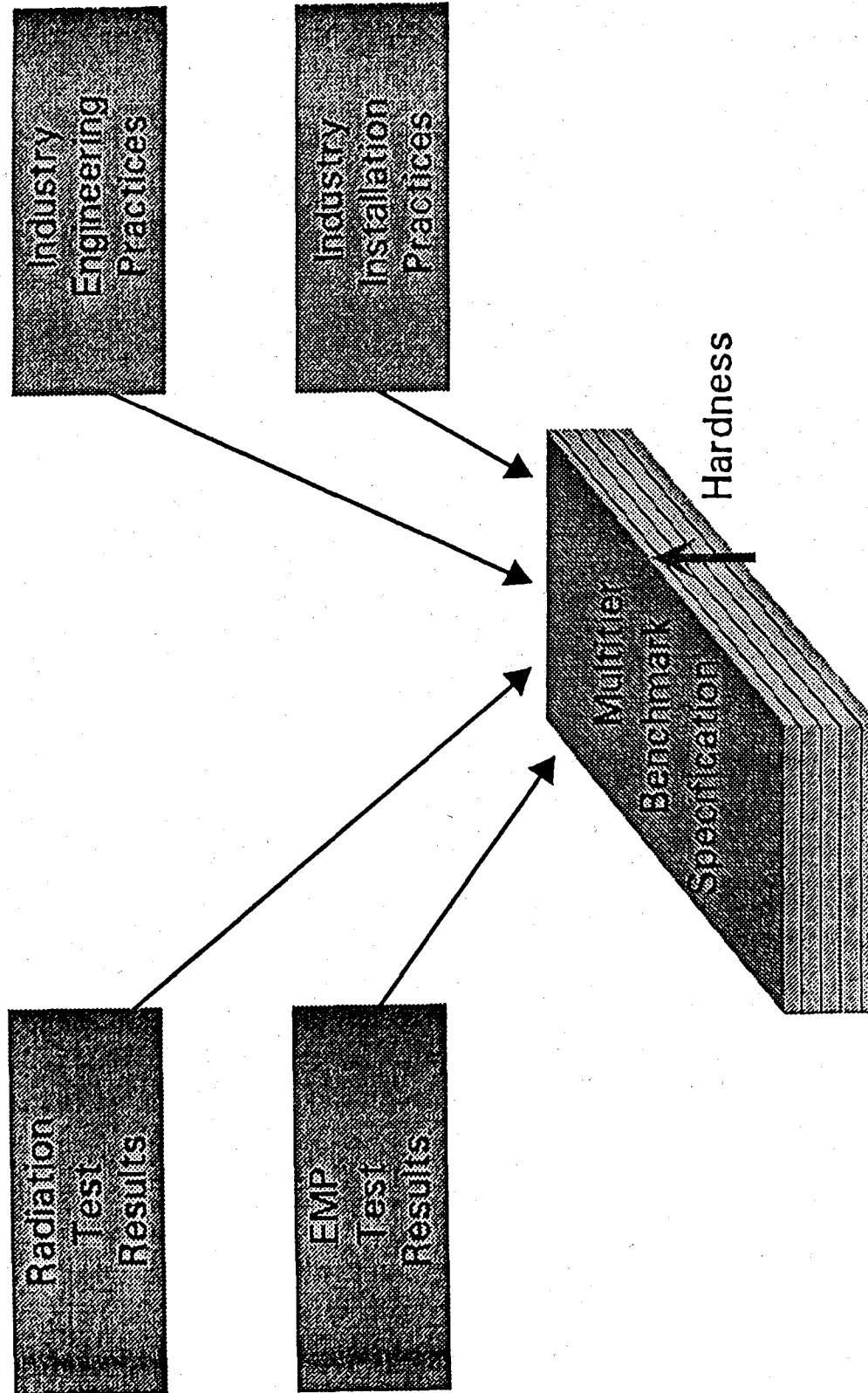


Figure 2. Inputs to the multitier specification.

Table 5. Incremental Stress Improvement Areas/Risk Areas

<u>HARDNESS LEVEL</u>	<u>IMPROVEMENTS</u>	<u>RISK AREAS</u>
Minimum (Level 1) • Surface/Aerial	---	---
Moderate (Level 2) • Surface (w/Innerduct) or Underground (12-24 in/.3-.6m) • w/ or w/o EMP Shield • Surface Enclosure	Nature Events Gamma Radiation EMP Blast Extreme Temps	Rodents Earthquake
Significant (Level 3) • Underground (36 in/.9m) • w/ or w/o EMP Shield	Gamma Radiation EMP Extreme Temps Accidents Vandalism	Earthquake
Maximum (Level 4) • Underground (48 in/1.2m) • w/ or w/o EMP Shield	Gamma Radiation EMP Extreme Temps Rodents Lightning	Earthquake
Virtual (Level 5) • Parallel Paths	All	HEMP

While the shortcomings (increased exposure) are of concern, the improvements (enhancements) at each level are designed to counteract the increased exposure.

The Multitier Specification was developed as a tool to aid in determining the hardness of a specified fiber optic telecommunication path. Another use for the Multitier Specification will be to assist in the hardness upgrade of a fiber optic link. An upgrade flow diagram is presented in Figure 3 to illustrate the options available for upgrade or for specification utilizing the Multitier Specification. As illustrated, at Levels 2 (Moderate) through 4 (Maximum), the design can be specified with or without an EMP shield. Installations that do not include an EMP shield will still yield protection from EMP damage because of the underground placement. The EMP shield will provide further attenuation of the EMP field for those paths that require the additional protection (e.g., for use in transmitting time-critical data or real-time information when EMP is expected).

Based on data available in unclassified documents, a guideline for protection against the two most devastating stress threats (HEMP and gamma radiation) have been developed for use in the Multitier Specification. The guideline for adequate attenuation and absorption of the EMP field and the gamma radiation energy is described below.

Gamma Radiation--The safe levels of exposure for equipment and the maximum defined threat are included as a basis for providing protection. The estimated doses are assumed to accumulate in a short period (several minutes).

Equipment safe dose level--100 rads
Estimated threat dose level--30,000 rads
Equipment protection factor required--300
Personnel safe dose level--50 rads
Estimated threat dose level--30,000 rads
Personnel protection factor required--600

HEMP--The attenuation level required to reduce the EMP field to levels that will not affect the operation of the equipment is included as a basis for providing protection.

Equipment safe level--50 V/m
Maximum threat level--50,000 V/m
Maximum attenuation protection factor required--1,000
Personnel safe level--unlimited

References to support these guidelines are provided in Volume II of this report. Data available in these references will provide information necessary to extend the limits if required. These limits are judged to be sufficient for

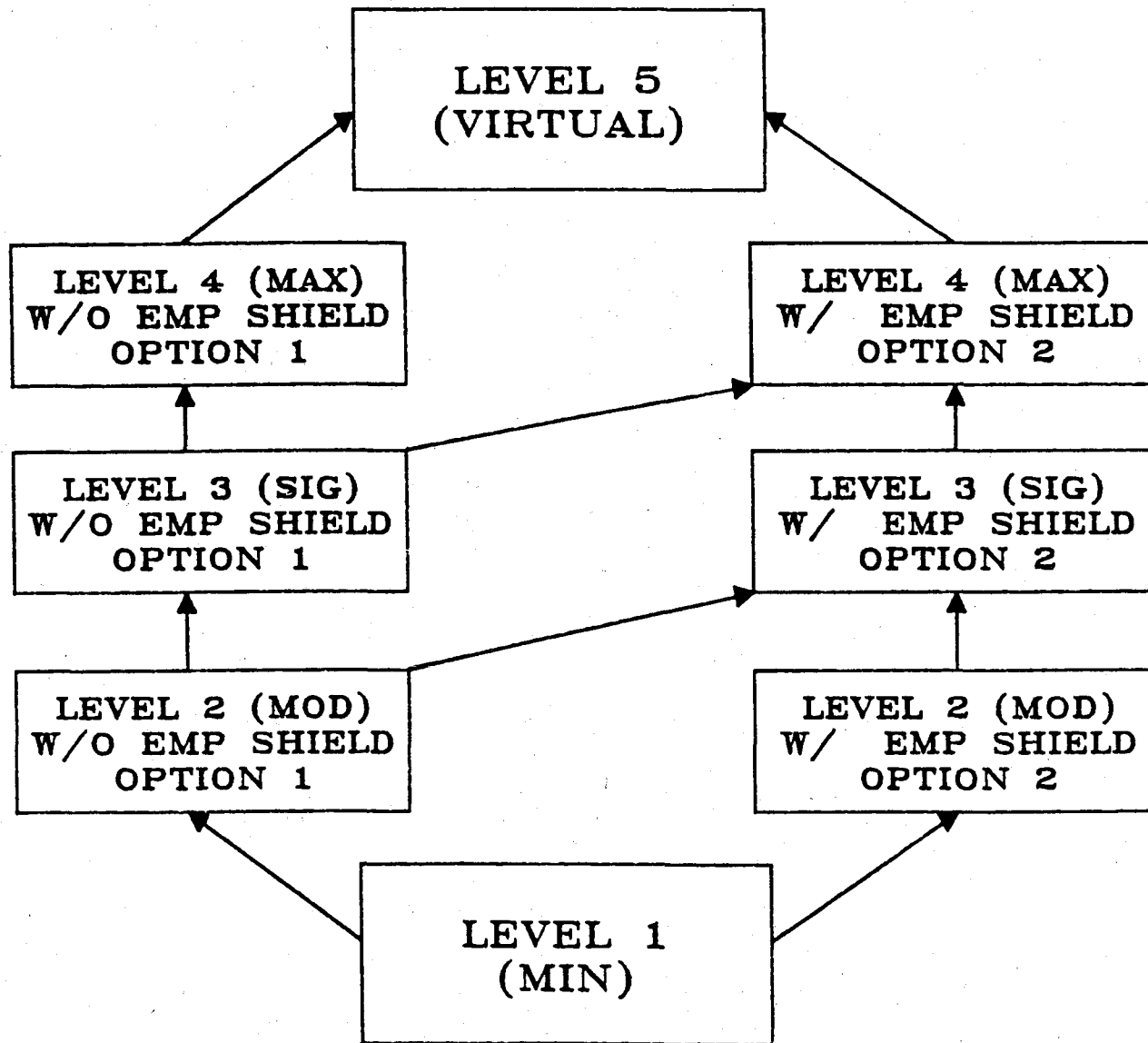


Figure 3. Multitier specification upgrade options.

use with commercial telecommunication systems used for traffic of a non-critical nature.

A true measure of the system stamina would be the "probability of survival" based on the protection level of the fiber optic system at each level of the Multitier Specification. This can only be completed if the stress threat is defined in parameters that can be mitigated. The limits of stress threat considered for this report, for events of nature, are the type of conditions expected on a daily basis plus those extreme events defined by "return intervals." A "return period" denotes the frequency of occurrence of a specified magnitude of the referenced event of nature. Man-made events of a random nature (e.g., vandalism, vehicle traffic accidents, etc.) are predicted based on historical data that describe the event, the severity, and the parameters of the damage (e.g., gun shot damage). A level of sabotage, caused by deliberately inflicting damage such as HEMP from a high altitude nuclear detonation or gamma radiation from a nuclear detonation within the atmosphere is described by the parameters above.

Table 6 illustrates an estimate of the relative protection provided by each level of the Multitier Specification using a numerical scale based on total effectiveness (full protection). It should be noted that full protection does not guarantee a degree of survivability. The numerical scale could be a measure of survival probability; however, it is not specifically intended to illustrate that parameter. Although 10 is the highest level of protection, it does not represent 100 percent survival. Man-made stress events that are deliberate will preclude 100 percent survival. Rather, the protection level should be viewed as relative with a level of 10 representing the best possible protection within the capability of technology readily available. The basis for full protection from EMP is a factor of 1,000 as suggested by NCS (1978) and substantiated by data compiled from other sources. Full protection of equipment from gamma radiation is estimated to be attained with an absorption factor of 300 (reduction of flux to a safe level of 100 rads), assuming a dose rate of 30,000 rads and photon energy of approximately 1 MeV.

The attributes of a system built to a particular hardness level of the Multitier Specification can be described in terms of the physical parameters of the installation and hardware, or in terms of the stress protection provided. Table 7 summarizes these parameters in a way that one can quickly create an image of the physical installation of a fiber optic system necessary to meet a

Table 6. Multitier Specification--Relative Level of Protection

1 - LEAST PROTECTION
10 - MOST PROTECTION

HARDNESS LEVEL	O P T I O N		RADIATION		EXTREME TEMP.	BURST /WIND	RODENTS	NATURE EVENTS (ICE, SNOW, FLOOD)
	1	2	@1MeV	@6MeV				
MINIMUM (LEVEL 1)	4	-	1	-	3	2	3	2
MODERATE (LEVEL 2)	6	10	3	1	6	5	10	7
SIGNIFICANT (LEVEL 3)	7	10	10	4	10	9	10	8
MAXIMUM (LEVEL 4)	8	10	10	7	10	9	10	9
VIRTUAL	10	10	10	10	10	10	10	10

Table 7. Multitier Specification-Physical Properties Summary and Protection Overview

Physical Properties	Minimal Hardness (Level 1)	Moderate Hardness (Level 2)	Significant Hardness (Level 3)	Maximum Hardness (Level 4)
<ul style="list-style-type: none"> o <u>Cable</u> 	Aerial	Underground 12-24 in. (0.3-0.6 m)	Underground > 36 in. (0.9 m)	Underground > 48 in. (1.2 m)
<ul style="list-style-type: none"> o <u>Regenerator Enclosure</u> 	> 25% of length	None	None	None
<ul style="list-style-type: none"> o <u>Regenerator Enclosure</u> 	Surface - wood frame reinforced	Surface - concrete reinforced with earth berm, but no earth cover. Bonded-rebar reinforced cage.	Underground > 36 in. (0.9 m)	Underground > 48 in. (1.2 m)
<ul style="list-style-type: none"> o <u>Heat (Fire Resistance)</u> 	Limited protection	Good protection	Excellent protection	Full protection
<ul style="list-style-type: none"> o <u>Blast (Wind) Resistance</u> 	1-2 psi (<70 mph)	2 psi (70 mph)	5 psi (150 mph)	10 psi (1,400 mph)
<ul style="list-style-type: none"> o <u>Wind Resistance</u> 	< 70 mph (1, 2, & 5-year events)	< 100 mph (1, 2, 5, 10, & 25-year events)	< 110 mph (1, 2, 5, 10, 25, & 50-year events)	> 130 mph (1, 2, 5, 10, 25, 50, & 100-year events)
<ul style="list-style-type: none"> o <u>Lightning</u> 	Minor lightning-frequent interruption	Moderate lightning-very little interruption	Heavy lightning-very little interruption	Multiple lightning strikes-very rare interruption
<ul style="list-style-type: none"> o <u>EMP</u> 	Structure Only: 10 dB atten.	Structure Only: 25 dB atten. Structure & Shield: 80 dB atten.	Structure Only: 40 dB atten. Structure & Shield: 80 dB atten. 2-stage TPD protection	Structure Only: 50 dB atten. Structure & Shield: 80 dB atten. 3-stage TPD protection
<ul style="list-style-type: none"> o <u>Gamma Radiation</u> 	None	Absorption factor = 35 dB at 1 Mev particle energy level	Absorption factor > 50,000 at 1 MeV particle energy level	Absorption factor > 2,000,000 at 1 Mev particle energy level
<ul style="list-style-type: none"> o <u>Regenerator</u> 	Limited protection	Absorption factor = 2 dB at 1 Mev particle energy level	Absorption factor > 50,000 at 1 MeV particle energy level	Absorption factor > 2,000,000 at 1 MeV particle energy level
<ul style="list-style-type: none"> o <u>Earthquake</u> 	None	None	None	None
<ul style="list-style-type: none"> o <u>Earthquake</u> 	Limited protection	Ground separation < 1 in. (2.5 cm)	Ground separation < 4 in. (10 cm) 2% slack in slack pits cable in PVC innerduct	Ground separation < 12 in. (0.3 m) 6% slack in slack pits cable in PVC innerduct
<ul style="list-style-type: none"> o <u>Regenerator</u> 	Survives 1, 2, & 5-year events	Survives 1, 2, 5, & 10-year events	Survives 1, 2, 5, 10, 25, & 50-year events	Survives 1, 2, 5, 10, 25, 50, 100, & 250-year events
<ul style="list-style-type: none"> o <u>Back-up Power Source</u> 	None	8-hour rechargeable battery	Sustains power for 7 days	Sustains power for 14 days
<ul style="list-style-type: none"> o <u>Rodent Protection</u> 	Limited protection	Good protection (service interruption minimal)	Excellent protection (service interruption rare)	Full protection (service interruption very rare)
<ul style="list-style-type: none"> o <u>Electrical Grounding</u> 	Standard electrical ground	Meaningful electrical ground (penetration to water table)	Meaningful electrical ground 2-stage TPD protection	Meaningful electrical ground 3-stage TPD protection

selected hardness level of the specification. In addition, if one knows the level of the installed system, the stress protection, for the major stress sources, can be determined without referencing Volume II of this report. Volume II will have to be consulted for more detailed information or for protection levels provided for stresses that are not included in Table 7.

APPENDIX B

QUESTIONS TO BE ANSWERED PRIOR TO THE APPLICATION OF THE MULTITIER SPECIFICATION TO A FIBER OPTIC LINK

- B.1 Fiber Optic Cable Specifics
- B.2 Conduit Specifics
- B.3 Cable Splice Specifics
- B.4 Cable Splice Box Specifics
- B.5 Cable Burial Specifics
- B.6 Cable Route Marking & Identification Specifics
- B.7 Regenerator Building Specifics
- B.8 Regenerator Power Source Specifics
- B.9 Regenerator Electro-Optics Specifics
- B.10 Fiber Optic Link Specifics
- B.11 System Layout Specifics
- B.12 Rights-of-Way Specifics
- B.13 Security, Maintenance, and System Recovery Specifics

APPENDIX B: QUESTIONS TO BE ANSWERED PRIOR TO THE APPLICATION OF THE MULTITIER SPECIFICATION TO A FIBER OPTIC LINK

B.1 Fiber Optic Cable Specifics

- a. Who is the manufacturer of cable being installed?
- b. Is the cable all-dielectric, shielded, or double shielded?
- c. Do you use a rodent/lightning protected cable?
- d. What is the usable maximum data rate of each fiber in the cable (1.7 Gb/s)?
- e. Is this data rate different for the 1.3 μm and the 1.5 μm windows?
- f. What is the cable strength member material (kevlar, fiberglass, or stainless steel)?
- g. Does the cable contain any metallic shield material (single or multiple layers, continuous or stranded)?
- h. If metallic shielded cable is used, how and where is it grounded (in relation to the regenerators, splice boxes, and central offices)?
- i. How is the cable protected against lightning (by grounding or by protection devices)?
- j. How is the cable protected against HEMP (how are the currents shunted away from the electronic enclosures)?
- k. How many fiber pairs are contained in the cable?
- l. Are the fibers single-mode or multimode?
- m. Is the fiber core free from phosphorus dopant?
- n. Are the fibers radiation hardened (what level of gamma radiation can be tolerated at the surface above the fiber? Are the fibers recovery enhanced or reduced loss enhanced)?
- o. What are the core/clad diameters of the individual fibers?
- p. What dopants are used in the fibers?
- q. What is the outside diameter of the cable?
- r. Is the cable designed to be rodent immune?

B.2 Conduit Specifics

- a. Is the fiber optic cable contained in a conduit over the entire route?
- b. What is the conduit material (pvc or polyethylene)?
- c. What is the outer diameter and wall thickness of the conduit?
- d. Does the conduit contain a gel or other filling material?
- e. Is the conduit sealed at each end?
- f. Is a compound conduit used such as small innerducts within a larger conduit?
- g. Is any type of gamma radiation-resistant conduit used? If so, how much absorption is provided?
- h. Where is conduit used in the system?
- i. What is the conduit diameter, wall thickness, and material
 1. at the entrance (and exit) of the central offices?
 2. at the entrance (and exit) of the regenerator buildings?
 3. at the sites where the conduit is suspended under bridges?

- j. What are the lengths of the metal conduits that span the bridges?
(Are all the span conduits metal?)
- k. What type and size of conduit is used when placing F/O cable under
 - 1. roadways?
 - 2. intermittent waterways?
 - 3. natural waterways?
- l. When crossing a right-of-way (ROW), does the conduit span the entire ROW or just the width of the road itself?
- m. How are the conduits sealed
 - 1. at the central office ends?
 - 2. at the regenerator buildings
 - a. underground outside the building?
 - b. inside the building?
 - 3. at the bridge span sites?
- n. Are the conduits pressurized to prevent water entry?

B.3 Cable Splice Specifics

- a. Are all splices the Advanced Rotary splices?
- b. Are any fusion splices used in the system?
- c. What is the maximum allowable signal loss specification (in dB) at each splice?
- d. Will the actual signal loss at each splice be measured?
- e. What is the expected average signal loss (in dB) at each splice?
- f. Are all splices accessible for future repair if necessary?
- g. How many feet (meters) of spare fiber cable are provided at each splice?

B.4 Cable Splice Box Specifics

- a. What are the dimensions of the splice boxes?
- b. Are they commercially available units?
- c. What materials are they made of?
- d. What is the wall thickness?
- e. What is the lid thickness and how is it attached?
- f. Is the box open or closed at the bottom?
- g. How does the F/O cable enter and exit the box?
- h. Is the top of the lid of any splice box less than 4 feet (1.2 m) below the surface?
- i. Are the splices encased in typical splice closures within the splice boxes?
- j. Do the splice boxes contain shelves to support the splices and the coils of spare cable length?
- k. Are the splice boxes resting on existing earth or fill material (such as sand) in the trench bottoms?
- l. Are the splice boxes marked with buried metallic devices?
- m. Are the splice box locations marked with aboveground markers?

B.5 Cable Burial Specifics

- a. Is the direct buried cable placed in a conduit or is it placed without additional protection?
- b. Are there any obstacles along the route that prevent the burial of the cable to the 4-foot (1.2-m) minimum depth?
- c. For areas where obstacles are encountered,
 1. what is the actual burial depth?
 2. what is the depth of soil and concrete covering the fiber optic cable in such areas?
 3. what are the lineal distances involved in each obstacle area?
 4. what are the conduit configurations and distances at each "over the ground" or "suspended in air" cable routing?

B.6 Cable Route Marking & Identification Specifics

- a. What location devices are used
 1. along the buried cable routes (i.e., a locate wire)?
 2. along the aboveground conduit routes?
 3. at the buried splice boxes?
 4. under bridge conduit routes?
- b. What location markers are used along the route?
 1. Ground level plates?
 2. Vertical stakes or posts?
 3. Location by distance and direction to local identifiable objects?
 4. Are there any signs or markers on the regenerator buildings?
- c. How are locations of buried cable and splice boxes found (detected)?
 1. Metal detectors?
 2. Other locate devices?
- d. Are warning tapes placed in the ground above the buried cables?
 1. Type?
 2. Size?
 3. Warning logo?
 4. Depth of burial?

B.7 Regenerator Building Specifics

- a. What are the building's dimensions?
- b. What building materials are used for the
 1. Floor?
 2. Walls?
 3. Roof?

4. Doors?
 5. Vents?
 6. Insulation?
- c. Does the building have heating and/or air conditioning?
- d. What are the dimensions and locations of the public service ac power entrances for
1. aboveground utilities?
 2. underground utilities?
 3. the power buss grounding
 - a. outside the building?
 - b. inside the building?
 4. Are there transient protection devices (such as metal-oxide varistors) in the ac power lines?

B.8 Regenerator Power Source Specifics

- a. What is the primary power source (public utilities)?
- b. What is the backup power source (diesel motor-generator set)?
- c. Uninterruptible power source (UPS):
 1. Are there lead-acid batteries?
 2. Are there gel-cell batteries?
 3. How long can the regenerator operate on the UPS only?
- d. Is there provision for the connection of an external emergency power source?

B.9 Regenerator Electro-Optics Specifics

- a. How many regenerators are in the link?
- b. What are the locations of each?
- c. What is the system margin (in dB) of each regenerator?
- d. How many active channels are in each regenerator station?
- e. How many "hot standby" channels are in each regenerator station?
- f. How many backup (spare) channels are in each regenerator station?
- g. What upgrade capabilities are available?
- h. What is the current data rate of the hardware?
 1. How many circuits are available for expansion?
 2. To what data rate can the existing hardware be expanded?

B.10 Fiber Optic Link Specifics

- a. What is the current data rate of transmission on the system (417 Mb/s)?
- b. What expanded data rate has been designed into the system (1.7 Gb/s)?
- c. How many active fibers does the system contain?
- d. How many "hot standby" fibers does the system contain?

- e. How many spare fibers does the system contain?
- f. What restoration time is projected for a cable cut?

B.11 System Layout Specifics

- a. Provide a simplified drawing of the system showing
 - 1. rights-of-way relative to identifiable landmarks.
 - 2. location of splices.
 - 3. location of regenerator buildings.
 - 4. location and length of obstacles.
 - 5. location and length of spans not buried.
- b. Provide a list of
 - 1. number of splices.
 - 2. number of regenerator stations.
 - 3. distance between regenerator stations.

B.12 Rights-of-Way Specifics

- a. What portion (distance) of the system lies on Federal land?
- b. What portion (distance) of the system lies on state land?
- c. What portion (distance) of the system lies on railroad land?
- d. What portion (distance) of the system lies on private land?
- e. At how many places does the unburied fiber optic cable cross a major thoroughfare or railroad right-of-way?

B.13 Security, Maintenance, and System Recovery Specifics

- a. If a cable is cut, will it be spliced at the break or will the cable be replaced between the two nearest splice boxes?
- b. If a major outage occurs at a regenerator station, are there provisions to reroute the traffic on parallel or competitor links?
- c. Will the fiber optic cable link route be inspected (by walking or driving) on a regular basis (weekly or monthly)?
- d. What other methods of system surveillance are planned?
- e. What kind of provisions are being planned for system maintenance?
 - 1. How much spare cable will be kept on hand?
 - 2. What spare regenerator electronics will be kept on hand?
 - 3. What UPS spares will be kept on hand?

APPENDIX C

FIBER OPTIC LINK ROUTE MAPS

John M. Harman

Figure C-1. Routing for Mountain Bell fiber optic communication link
(Colorado Springs to Pueblo).

Figure C-2. Sheet 1 of route map summary.

Figure C-3. Sheet 2 of route map summary.

Figure C-4. Sheet 3 of route map summary.

Figure C-5. Sheet 4 of route map summary.

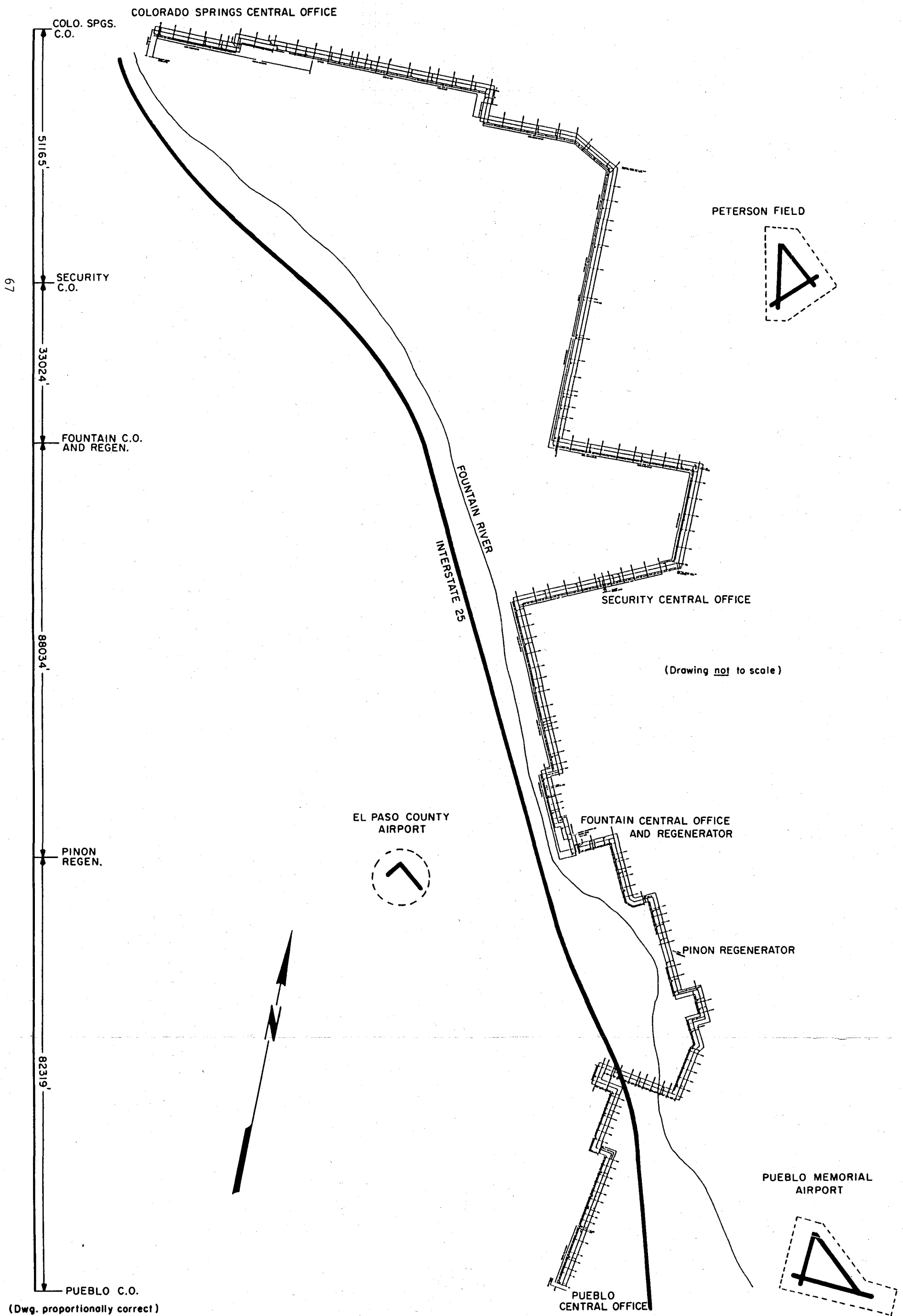


Figure C-1. Routing for Mountain Bell fiber optic communication link (Colorado Springs to Pueblo).

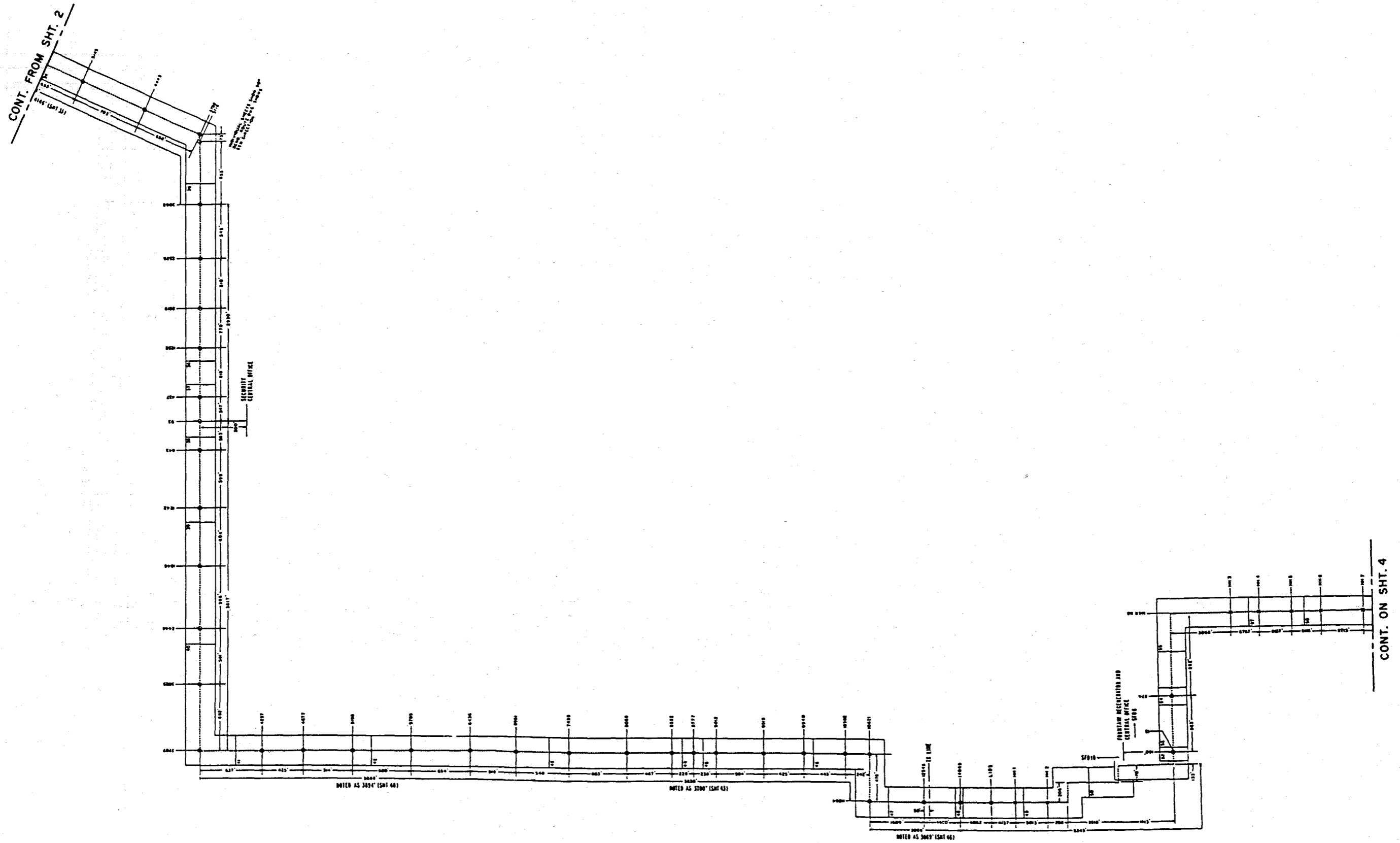
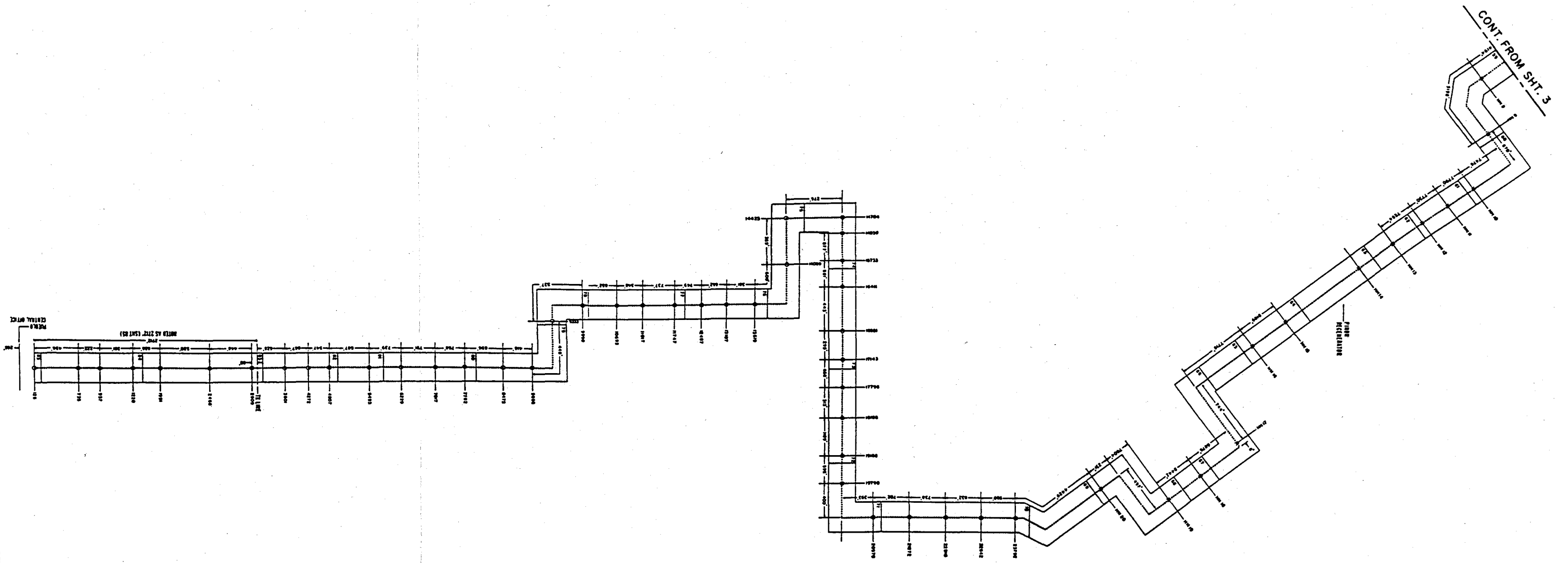


Figure C-4. Sheet 3 of route map summary.

Figure C-5. Sheet 4 of route map summary.



APPENDIX D

INFORMATION ON A TYPICAL
ABOVEGROUND REGENERATOR STATION

Photographs of the Pinon, CO, Regenerator Station in the Colorado
Springs to Pueblo Fiber Optic Link of the Mountain Bell System

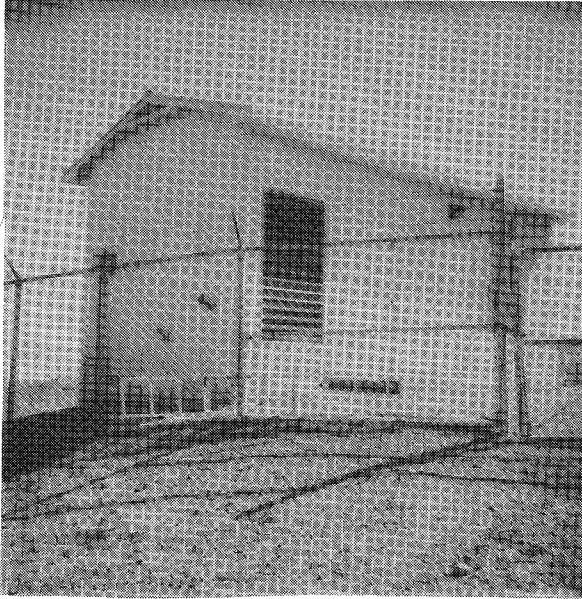


Figure D-1. View of the southwest corner of the regenerator building.

This view shows the security fence and the louvered air intake for the diesel-powered generating plant.

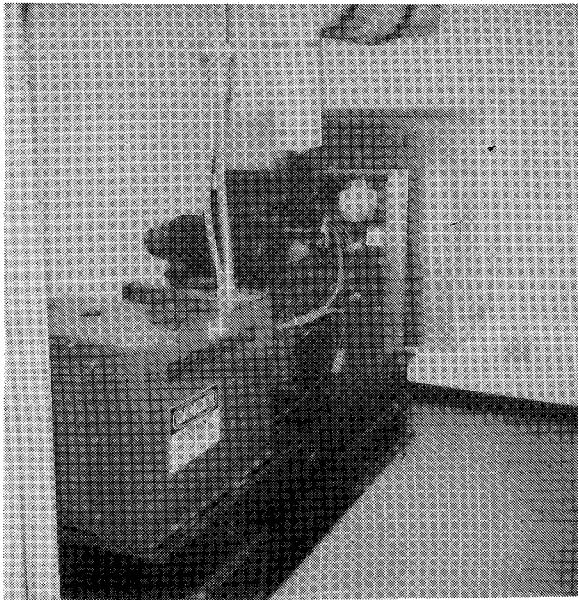


Figure D-3. View of the "standby" diesel-powered generator.

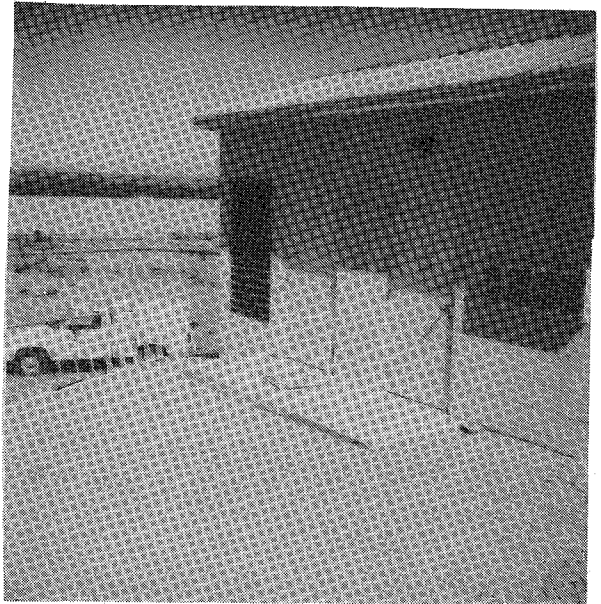


Figure D-2. View of the south side of the regenerator building.

This view shows the cinder block construction with metal roof and insulated steel doors. The room on the left houses the "standby" diesel-powered generator, and the air-conditioned room on the right houses the dc power source, the electronics, and the fiber optics.

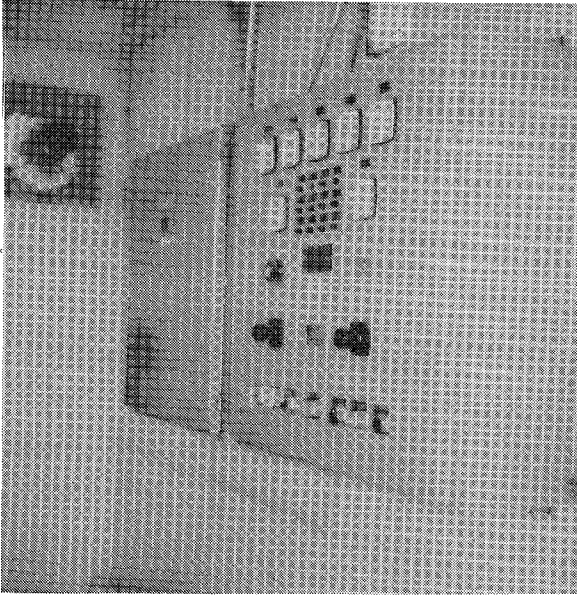


Figure D-4. View of the ac power control panel and ventilation fan located in the "standby" generator room.

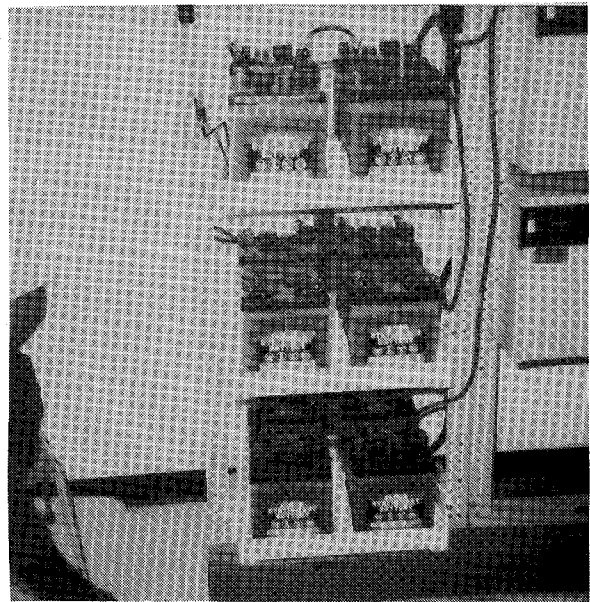


Figure D-5. View of the battery bank, which provides the dc power and serves as the uninterruptable power source.

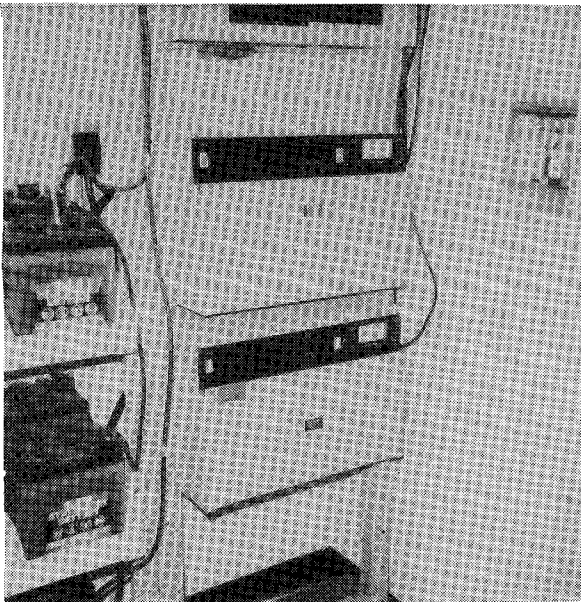


Figure D-6. View of the battery charging and monitoring circuit electronics.

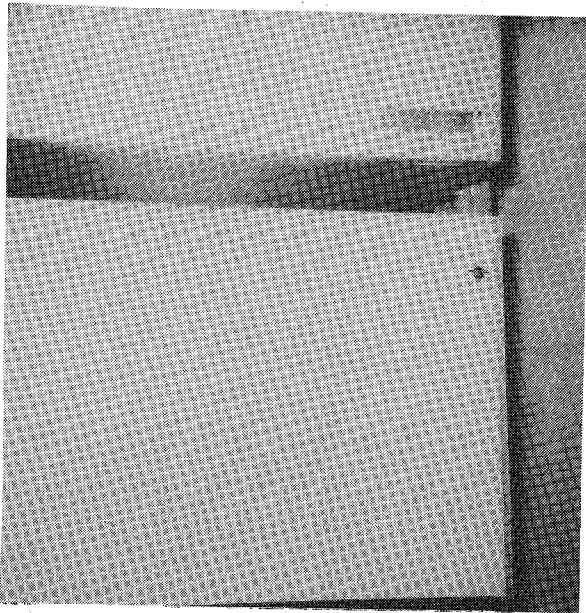


Figure D-7. Front view of the fiber optic connection/distribution chassis with protective cover in place.

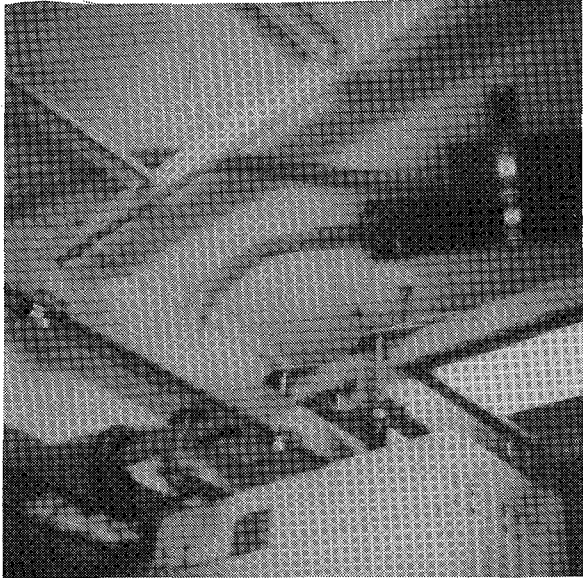


Figure D-9. View of the fiber optic cables showing the overhead routing.

The 4-inch (10.1-cm) diameter pvc conduit and the 1.5-inch (3.8-cm) flexible conduit feeding into the fiber optic connection/distribution chassis are shown. The top rear portion of the regenerator electronics cabinet is visible in the lower portion of the photograph.

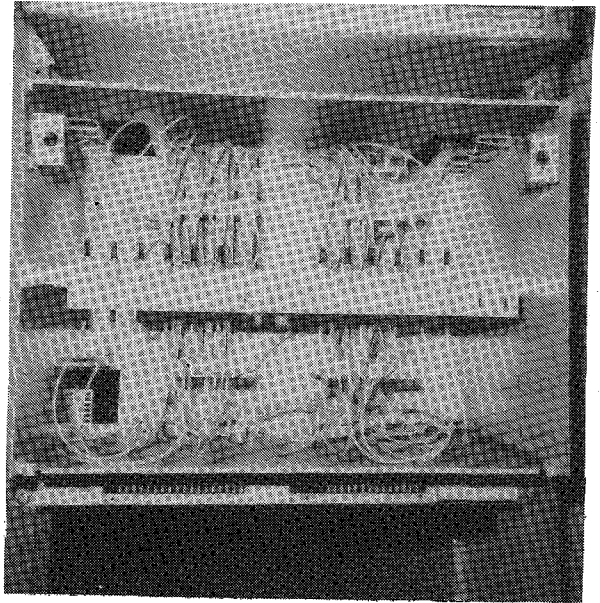


Figure D-8. Front view of the fiber optic connection/distribution chassis with protective cover removed.

Six fiber pairs, their connections, and the coils of spare fiber are visible. Three of the fiber pairs are active, one pair is on "hot standby" and the remaining two fiber pairs are spares.

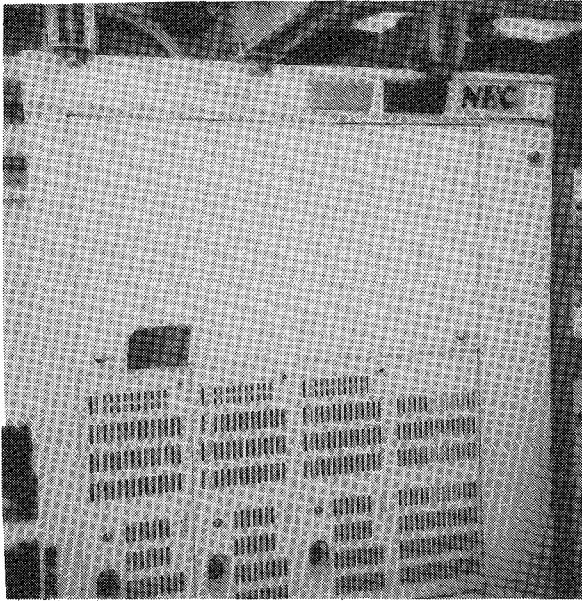


Figure D-10. Front view of the top portion of the regenerator electronics cabinet with the covers in place.

This regenerator system is an NEC model FD-39101A fiber optical line repeater capable of 405 Mb/s.

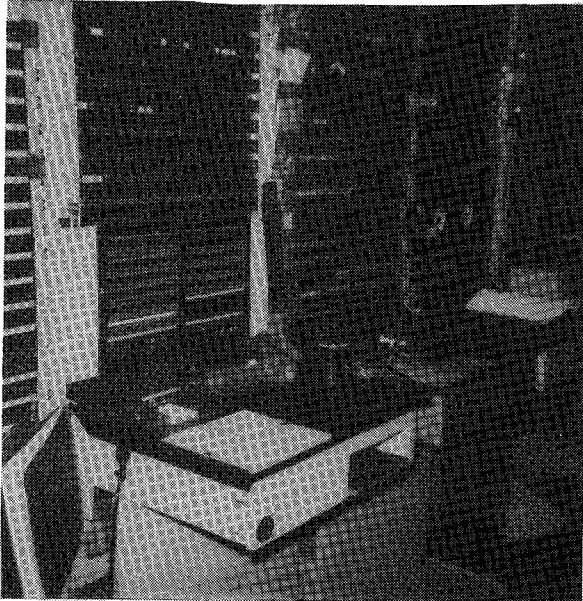


Figure D-12. View of three obsolete manually operated switchboards scheduled for removal from the Pueblo central office.

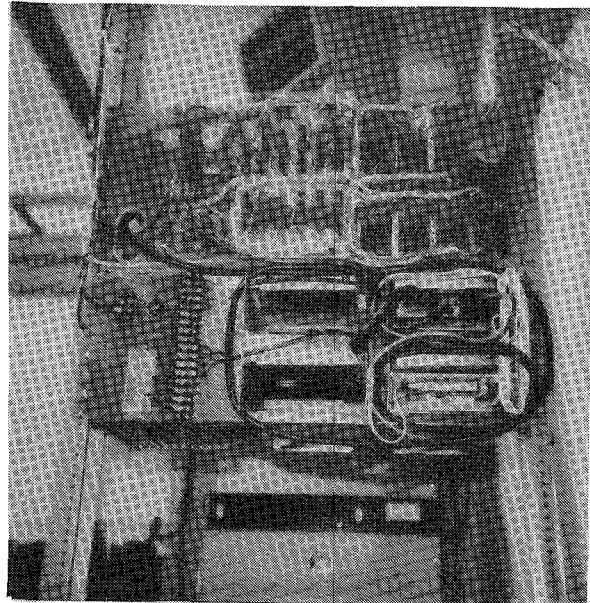


Figure D-11. View of the wiring on the rear of the alarm system electronics.

The regenerator building doors are alarmed. Also a 1.5 dB signal loss on the optical fiber will energize the alarm.

APPENDIX E
INFORMATION ON A TYPICAL
UNDERGROUND (CEV) REGENERATOR STATION

Photographs of the Colorado Springs Regenerator Station Located in
a Controlled Environment Vault (CEV) Located Adjacent to the
Easement Along the South Side of Garden of the Gods Road
1.5 Miles (2.4 Km) West of Interstate Highway 25.

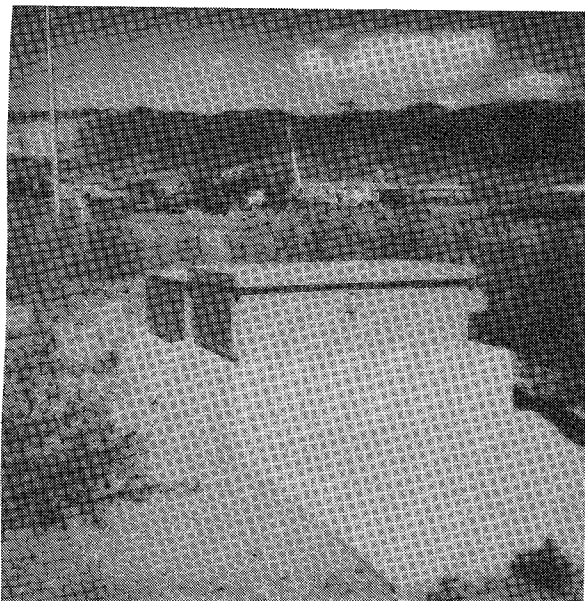


Figure E-1. View of the southeast corner of the CEV entrance.

The CEV entrance cover is in the foreground and the air-conditioning unit is located in the housing immediately behind.

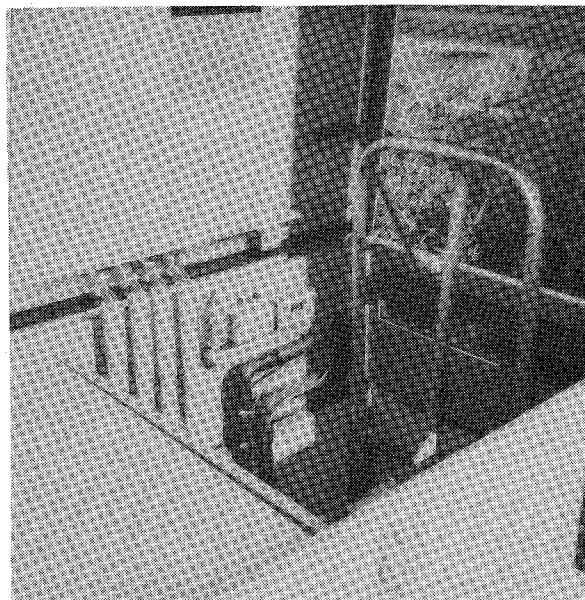


Figure E-2. View of the CEV entrance with the lid up.

The entrance ladder and some of the alarm circuit components can be seen. Note the cover lock in bottom foreground.

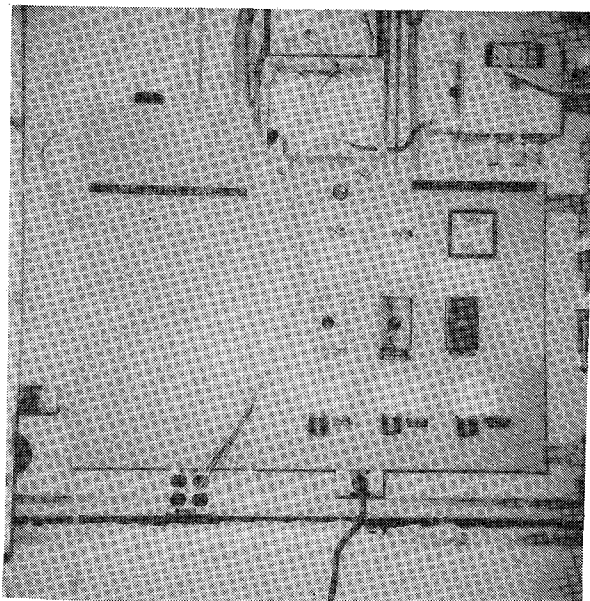


Figure E-3. View of the public utility service entrance control panel on the left and the CEV environmental control panel and sensors on the right.

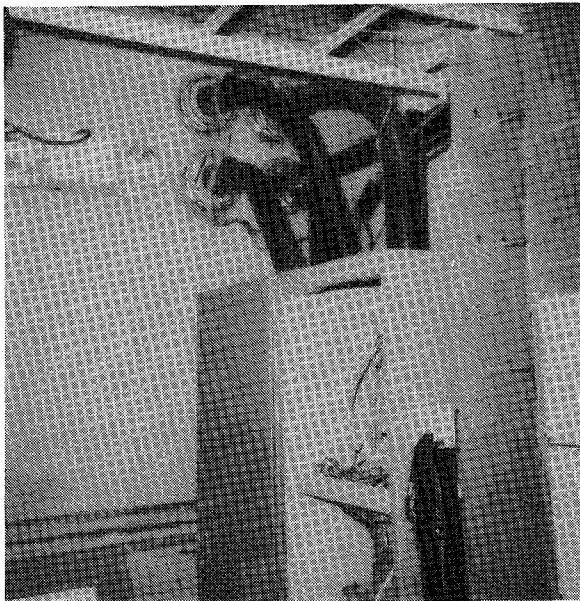


Figure E-4. View of the fiber optic cable entrance into the top of the CEV.

The cables are housed in 4-inch (10.1-cm) rigid conduit from the utility tunnel under the center of the road. Twenty-four fiber pairs enter the CEV at this point.

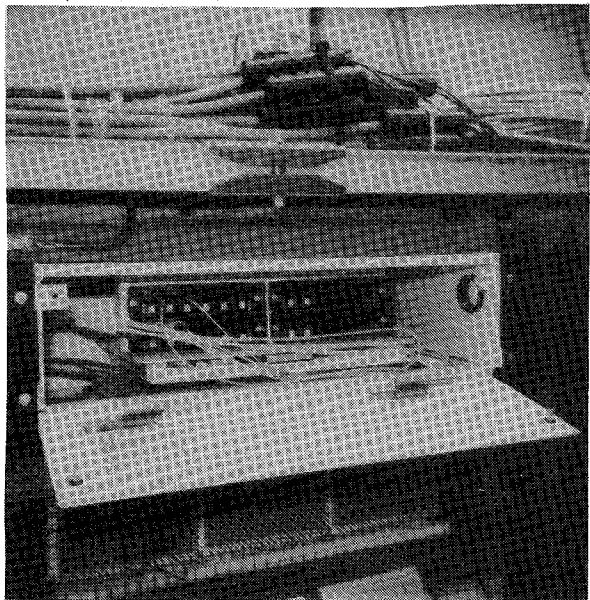


Figure E-5. Front view of the fiber optic connection/distribution chassis with protective door open.

The two fiber pairs being utilized in this installation can be seen in this photograph.

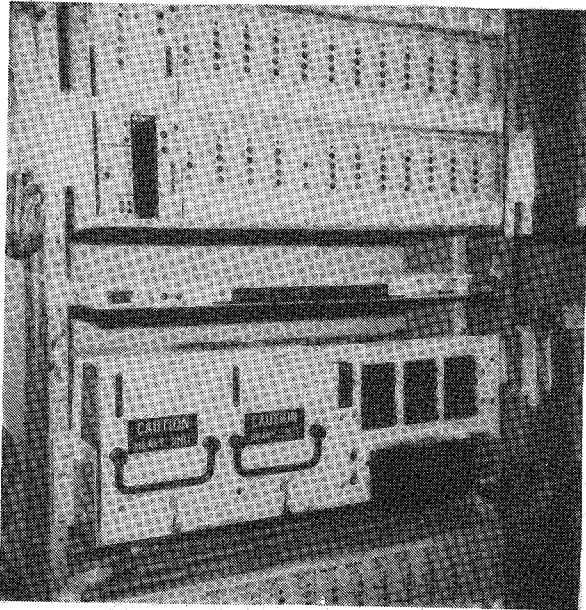


Figure E-6. View of the regenerator electronics and associated power supplies.

These units are AT&T model DDM 1000 dual DS3 multiplexers.

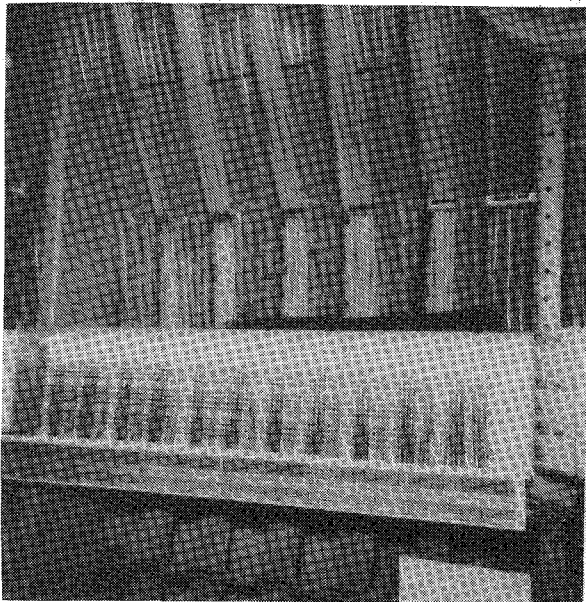


Figure E-7. View of the conventional copper wire pair circuits that exit the CEV.

The copper wire patch panel can be seen in the foreground.

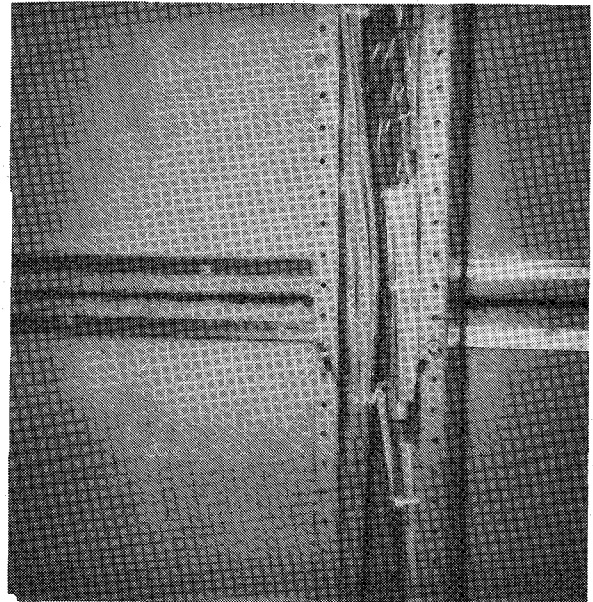


Figure E-8. View of the CEV wall and a typical equipment rack mounting upright support post.

The equipment support post contains a complete complement of wiring ready to connect to the electronic equipment when future expansion is required. The black horizontal line across the photograph is the nonhardening silicone type sealant used to seal the upper half of the CEV to the lower half. The CEV concrete wall thickness is 6 inches (15 cm) throughout.

**PRECAST CONCRETE
CONTROLLED ENVIRONMENT VAULT**

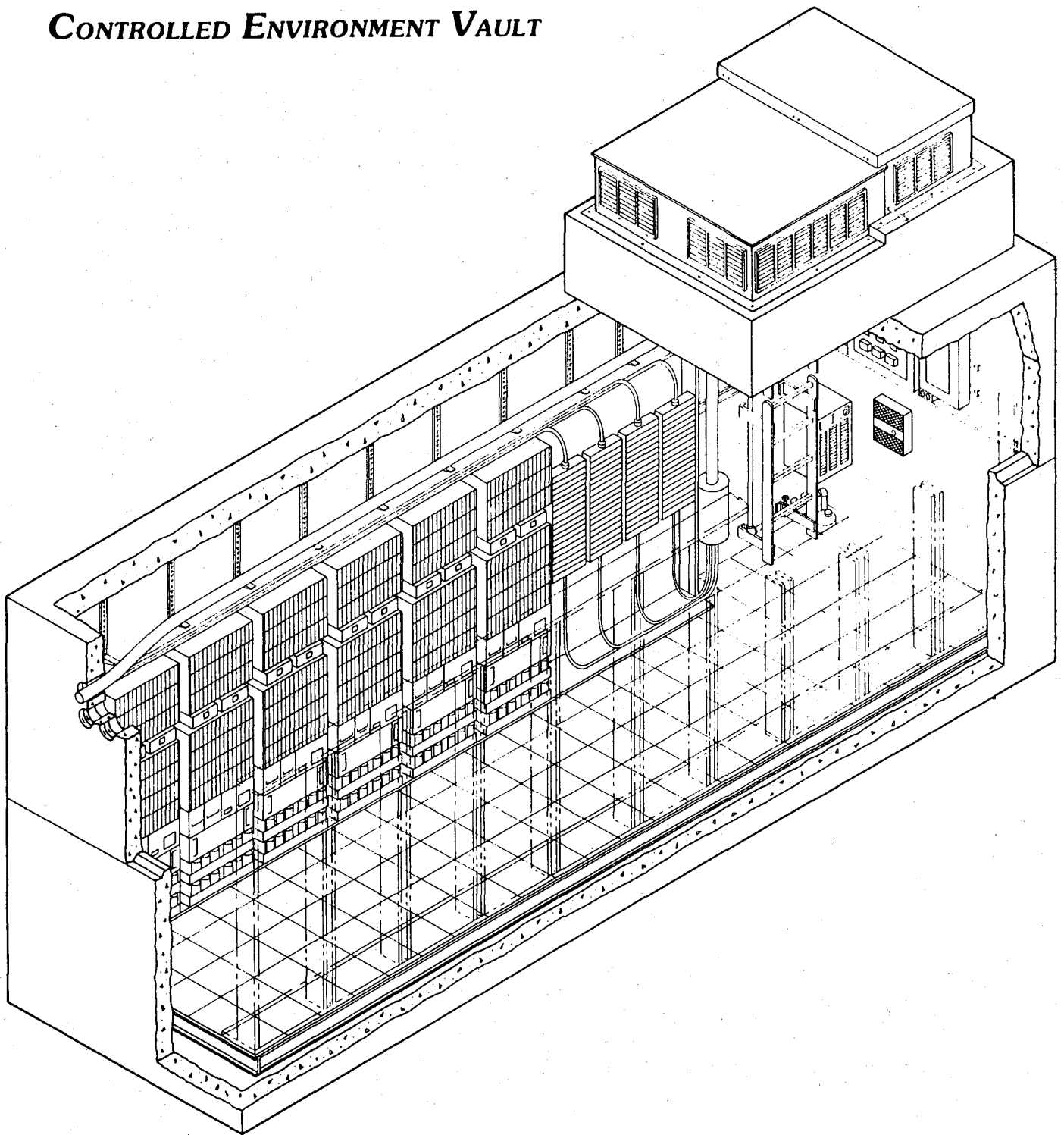
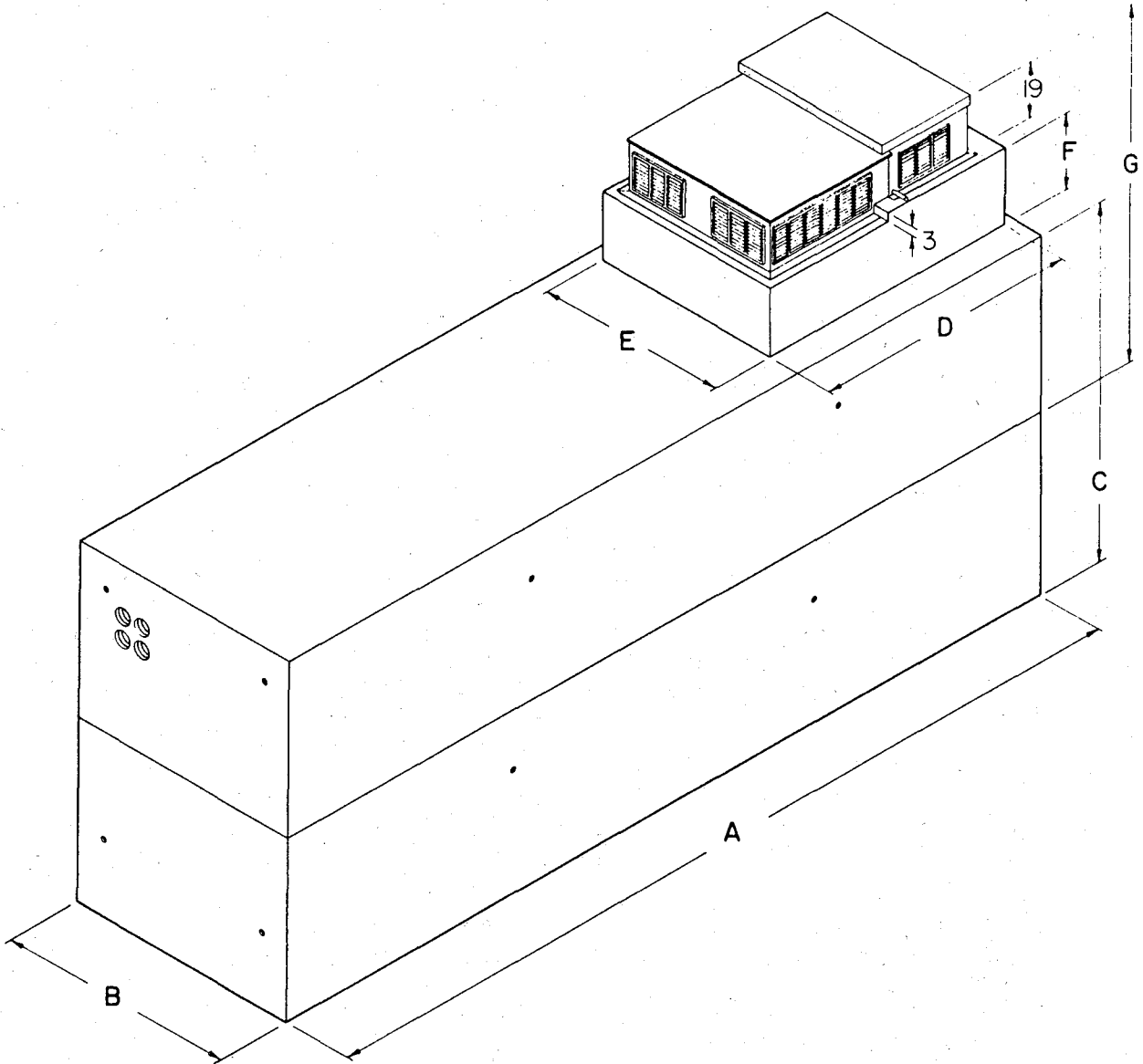


Figure E-9. Cut-away drawing of a standard CEV.



INSIDE DIMENSIONS FT.	WALL IN.	ROOF IN.	FLOOR IN.	A IN.	B IN.	C IN.	D IN.	E IN.	COLLAR HEIGHT (F)			RECOMMENDED HOLE SIZE		CASTING WEIGHT WITH COLLAR HEIGHT OF:			
									(27")G IN.	(36")G IN.	(48")G IN.	L FT.	W FT.	27"	36"	48"	
10 X 10 X 9	5	8.5	8.5	130	130	125	74	86	107.5	118.5	128.5	15	15	TOP	28,800	30,400	32,500
														BOTTOM	24,000	24,000	24,000
18 X 6 X 9	6	8	9.5	204	84	125.5	74	86	108	117	129	21	11	TOP	32,300	33,900	36,000
														BOTTOM	30,200	30,200	30,200
18 X 10 X 10	5	8.5	8.5	202	130	137	94	86	114.5	123.5	135.5	21	15	TOP	41,500	43,400	46,000
														BOTTOM	35,900	35,900	35,900
24 X 6 X 9	6	8	9.5	300	84	125.5	94	86	108	117	129	29	11	TOP	48,200	49,000	51,800
														BOTTOM	42,800	42,800	42,800

Figure E-10. Dimensions of available CEV's.

APPENDIX F

CONSIDERATION OF IONIZING RADIATION SHIELDING FOR OPTICAL FIBERS

T. J. Englert

A Brief Summary of the Physical Processes Involved in
Radiation Interaction with Matter and How these
Processes Relate to Shielding Considerations

TABLE OF CONTENTS

1. INTRODUCTION
2. UNITS COMMONLY USED IN RADIATION AND SHIELDING
 - 2.1 Energy Units
 - 2.2 Units of Radiation Dose
 - 2.2.1 The curie (Ci)
 - 2.2.2 The roentgen (r) and roentgen equivalent man (rem)
 - 2.2.3 The rad and the gray (Gy)
3. INTERACTION OF RADIATION WITH MATTER
 - 3.1 The Structure of Matter Relative to Radiation Absorption
 - 3.2 Penetration Range of Radiation in Matter
 - 3.3 Alpha Particle Interaction with Matter
 - 3.4 Beta Particle Interaction with Matter
 - 3.5 Gamma Interaction with Matter
 - 3.5.1 Photoelectric process
 - 3.5.2 Compton process
 - 3.5.3 The Pair-Production process
 - 3.6 Photonuclear Reactions
4. RADIATION ATTENUATION OR SHIELDING
 - 4.1 Shielding for Alpha Radiation
 - 4.2 Shielding for Beta Radiation (Electrons)
 - 4.3 Shielding for Gamma Radiation (Photons)
 - 4.3.1 Build-up factor in photon shielding
 - 4.4 Shielding Effects of Soils
5. SUMMARY
6. REFERENCES

FIGURES

- Figure 1. Diagrams depicting the concept of range.
(The diagrams shown here depict the concept of radiation penetration in an arbitrary material. The distance regions up to the straggling area should not be interpreted literally since they do not show the exponential behavior. The range can be seen to represent an average maximum distance of penetration).
- Figure 2. Range of alpha particles in air.
(Notations at points on the graph denote the radioisotope from which the alpha radiation is emitted).
- Figure 3. Range of electrons or beta particles in aluminum.
(Note that the range units are mg/cm^2 (Van Nostrand Scientific Encyclopedia, 1976). The range of electrons in most other solids will not be significantly different from values shown here since electron density changes rather slowly with atomic number).
- Figure 4. Diagrams depicting processes of photon energy absorption and scattering in matter.
- a) Photoelectric process
 - b) Compton scattering
 - c) Pair production
- Figure 5. (a) Contributions of photoelectric, Compton and pair-production processes to the absorption coefficient (units of cm^{-1}) for gamma radiation in lead.
(b) The total absorption coefficient (units of cm^2/gm) for gamma radiation in various materials, (Van Nostrand Scientific Encyclopedia, 1976).
- Figure 6. Radiation build-up process and relation to absorber thickness.
(a) Diagram showing the process of scattering of radiation in an absorber resulting in build-up.
(b) Build-up factor, B, for gamma radiation scattering from a lead shield. Note in particular the effect of shielding thickness on build-up.

LIST OF TABLES

Table 1. Relative Biological Effect (RBE) for Ionizing Radiation

Table 2. Beta Particle Energy Loss as Bremsstrahlung

Table 3. Mass Attenuation Coefficients for Gamma Rays of some
Representative Materials

Table 4. Some Soil Densities Useful for Shielding Calculations

CONSIDERATION OF IONIZING RADIATION SHIELDING
FOR OPTICAL FIBERS

Thad J. Englert*

A brief overview of nuclear radiation processes is presented. Units of radiation energy and dose are discussed. Interactions of radiation processes with matter are analyzed in order to understand radiation and its energy. Range is discussed in relation to structures of matter in representative materials. Specific emphasis is placed on interaction of these radiation processes with soils in order to consider the ultimate effects of radiation on optical fibers located in a medium of soil and soil types. The shielding effects of soils are analyzed for the purpose of understanding radiation damage to any buried cable which may contain optical fibers.

Key words: absorption coefficient, atomic structure, bremsstrahlung, build-up, buried cable, ionizing radiation, nuclear particle absorption, optical fibers(s), photon absorption, radiation damage, radiation shielding, soil attenuation, x-ray absorption.

1. INTRODUCTION

The superiority of optical fibers in many applications of communications and data transmission is widely accepted. Deterioration of the optical quality of this type of fiber has been found to result when these fibers are exposed to ionizing radiation (Friebele, et al., 1985), however, prompting further considerations of fiber use in radiation environments. The radiation

*The author is with the Department of Electrical Engineering, University of Wyoming, Laramie, Wyoming.

environment might be caused by natural conditions, such as that surrounding an optical fiber cable buried in a region with relatively large quantities of naturally-occurring radioisotopes, or man-made regions of concentrated radiation such as those near or in a reactor or fallout following a nuclear event. In either case the problems of shielding the cable from ionizing radiation are similar. This report is a brief summary of the physical processes involved in radiation interaction with matter and the relation of these processes to shielding considerations. It is assumed that the reader has some previous knowledge of atomic structure and the kinds of particles or photons associated with radioactivity (Englert, 1987).

Since the units used to describe and measure radiation and radiation dose are often confusing, some time will be given to these topics. Some sample calculations in shielding will also be presented with the hope of providing some clarification.

2. UNITS COMMONLY USED IN RADIATION AND SHIELDING

The unit of energy most commonly used to describe radiation is the electron-volt (eV). One electron-volt is that amount of potential energy of an electron in an electric potential of one volt or that amount of kinetic energy of an electron after acceleration through one volt. As the name "electron-volt" implies, 1 eV of energy is the product of the electron's charge times one volt. (A quick review of your basic physics text will refresh your memory. The product of electric charge times electric potential yields energy or work units.)

The conversion from electron-volts to joules is straightforward:

$$1 \text{ eV} = (\text{magnitude of charge on electron}) \times (1 \text{ volt}) \quad (1)$$

$$\begin{aligned} &= (1.6 \times 10^{-19} \text{ coulomb}) \times (1 \text{ volt}) \\ &= 1.6 \times 10^{-19} \text{ J.} \end{aligned}$$

We see that 1 eV is a relatively small amount of energy. Energies associated with atomic transitions (electron transitions from one energy level to another) are on the order of a few eV to several tens of eV. These transitions give rise to electromagnetic radiation (photons) whose energies fall approximately within the spectral range from infrared (or possibly larger wavelengths) to X-rays. Nuclear transitions, however, such as those of radioactive decays, involve energies from several tens of eV to several millions of eV. The radiation from nuclear transitions includes not only high-energy photons (gamma rays) but also particles with charge and/or mass. We shall discuss nuclear radiation in greater detail in a later section.

2.1 Units of Radiation Dose

The systems of units used for measuring radiation dose are at best confusing. In principle any given system of units is an attempt to quantify the amount of energy, or perhaps the number of radiation particles, absorbed by some material. Necessarily those individuals involved in aspects of physiological disorders or malfunctions must concern themselves with biological effects, while others who may be involved in shielding from, or transport of radioactive materials, must concern themselves with changes in the materials's physical and/or mechanical characteristics. We shall briefly consider each of the systems of units associated with these aspects of radiation dose.

2.2 The Curie (Ci)

The curie (abbreviated Ci) is a measure of the amount activity of a given source of radiation. In simplest terms this unit indicates the number of radio-active decays occurring per unit time. Specifically,

$$1 \text{ Ci} = 3.7 \times 10^{10} \text{ becquerel} \quad (2)$$

where the becquerel (Bq) is an SI derived expression in sec^{-1} .

We should note that the curie unit tells us nothing about the total energy per second emitted from the radioactive decay of a sample. Perhaps an example is in order here:

Suppose we have a sample of N_0 radioactive nuclei of the same kind and that their decay results in a stable (non-radioactive) material. The number of radioactive nuclei remaining after a time t is given by

$$N(t) = N_0 e^{-\lambda t} \quad (3)$$

where λ is the disintegration or decay constant. The decay constant, λ , is related to the half-life, $T_{1/2}$ (the time, t , required for $N = N_0/2$), by

$$\lambda = \frac{\ln 2}{T_{1/2}} \quad (4)$$

The decay rate, disintegration rate or activity, R , is found by

$$\begin{aligned} \frac{dN}{dt} &= -\lambda N_0 e^{-\lambda t} \\ &= -\lambda N(t). \end{aligned} \quad (5)$$

The negative sign here indicates that the number of radioactive nuclei is decreasing. Since the decay of a nucleus creates the emission of some radiation, the activity R is simply

$$R(t) = \lambda N \text{ (disintegrations per unit time)} \quad (6)$$

We note that the activity R is also described by the decay law,

$$R = R_0 e^{-\lambda t} \quad (7)$$

Thus a radioactive sample which contains 10^{23} nuclei at $t=0$, whose half-life is 1 sec, and will have an activity R of,

$$\begin{aligned} R &= \left(\frac{\ln 2}{T_{1/2}}\right)N \quad (8) \\ &= \left(\frac{.693}{1 \text{ sec}}\right) (10^{23}) \\ &\approx 6.93 \times 10^{22}/\text{sec} = 1.87 \times 10^{12} \text{ Ci} \end{aligned}$$

A sample with the same number of atoms but with a half-life of 10 years has an activity

$$\begin{aligned} R &= \frac{\ln 2}{10 \text{ years}} \times 10^{23} \\ &\approx 2.2 \times 10^{14} \text{ atoms/sec} \quad (9) \end{aligned}$$

$$= 5.94 \times 10^3 \text{ Ci}$$

Thus the activity is greatly influenced by the half-life of the material.

2.3 The Roentgen (R) and Roentgen Equivalent Man (rem)

These two sets of units are included in the same section since they are closely related. The roentgen unit is a measure of radiation energy loss in terms of ionization of air that is exposed to the radiation, while the rem is an attempt to include the relative effects of different types of radiation in human tissue. The definitions are as follows:

1 R = that amount of X- or gamma-radiation interacting with air,
so as to cause ion pairs amounting to a total charge of
 3.56×10^{-10} coulombs in 1 cc of air at standard conditions.

The rem is an attempt to relate the ionizing capabilities of various types of radiation to their relative interaction with human tissue,

$$1 \text{ rem} = (1 \text{ r}) \times (\text{RBE}) \quad (10)$$

where "RBE" is the relative biological effect for the specific type of radiation. Table 1 shows accepted values (Van Nostrand Scientific Encyclopedia, 1976).

Table 1. Relative Biological Effect (RBE) for Ionizing Radiation

<u>Radiation Type</u>	<u>RBE</u>
X- and gamma	1
beta	1
alpha	20
fast neutrons*	10
slow (thermal) neutrons	5

*"Fast" neutrons are those within the approximate energy range of 0.1 MeV to 10 MeV. For energies greater than 10 MeV the RBE increases rapidly.

2.4 The Rad (rd) and the Gray (Gy)

From an engineering point of view, for radiation damage^e in materials, the rad is probably the most useful and least ambiguous. This unit was adopted, perhaps out of some frustration, by the International Commission on Radiological Units in 1953.

1 rd = 0.01 joules of absorbed radiation energy per kilogram
of material, irrespective of the type of radiation.

1 Gy = 100 rads

3. INTERACTION OF RADIATION WITH MATTER

The interaction of ionizing radiation with matter occurs in various modes, depending on the type of radiation as well as the energy of the radiation particles and photons. Consideration of the processes of radiation energy absorption by materials becomes especially important if we are to understand and compensate for radiation damage in optical devices and if we are to provide effective shielding of optical devices from damaging radiation.

Although the interaction of radiation with materials is quite varied, there is sufficient uniformity to allow us to treat this interaction according to the general categories of charged particles, neutral particles and photons. Before we address the specific behavior of the various types of radiation and how they interact with matter, some general properties of matter are presented as well as a brief look at the statistical nature of radiation absorption.

3.1 The Structure of Matter Relative to Radiation Absorption

A complete understanding of the structure of matter at the atomic level at which interactions under consideration here would occur, would require a working knowledge of quantum mechanics and special relativity. This is beyond the scope, and intent, of this report. However we can gain a good deal of insight through some simple considerations.

The "absorption" of radiation by matter means that the radiation has given up its energy to the material through which it passes, by some mechanism or other. We shall discuss these processes in later sections, but it is sufficient that charged particles such as electrons and alpha particles, interact via coulomb forces, which are relatively long-range forces while electrically neutral radiation such as photons and neutrons must suffer nearly head-on collisions with constituent particles of the material in order to give up their energy.

Atomic structure is well known to consist of a positively charged central core (the nucleus) surrounded by a negative "cloud" of electrons. Atomic radii are on the order of 10^{-7} cm or less, while those of nuclei are on the order of 10^{-12} cm. An empirical formula for determining nuclear radii, r , is given by

$$r \cong 1.4 \times 10^{-13} A^{1/3} \text{ cm} \quad (11)$$

where A is the atomic mass number of the given element. We see therefore, that there is in effect a rather large fraction of empty space in the atom. It is no wonder that head-on collisions of radiation with electrons and/or nuclei of the material are rare events. The effect of the coulomb force, which extends beyond atomic dimensions, contributes to the interaction of ionizing radiation with those nuclei and electrons which make up the absorbing material.

3.2 Penetration Range of Radiation in Matter

The scattering or interaction of particles and photons as they propagate through matter is necessarily statistical. Thus when we refer to a distance of penetration by radiation into matter, commonly referred to as range, we really mean the average distance. It's a bit like throwing rocks into a dense thicket of trees. Some rocks will go farther than others, but if we threw enough rocks (all assumed to have the same mass and speed) we would find that their penetration into the forest would tend to cluster about an average. The variation about the average range is often referred to as straggling. (See Figure 1.)

We find that there are two convenient measures of range which we shall discuss briefly. An obvious kind of measurement is simply a linear distance, x , measured in units of length (cm, m, inches, etc.). A second kind of measure pertains to the amount of matter penetrated by the incident radiation with units of gm/cm^2 . At first glance, this may seem awkward, but a moment's consideration will show you that this measure of penetration actually makes good sense.

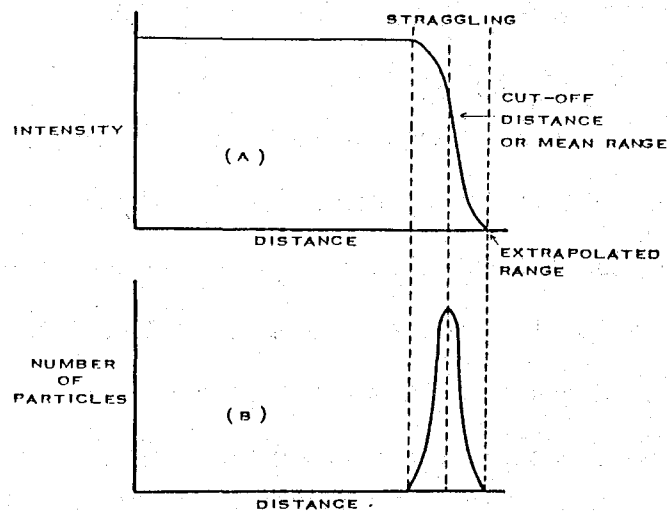


Figure 1. Diagrams depicting the concept of range.

(The diagrams shown here depict the concept of radiation penetration in an arbitrary material. The distance regions up to the straggling area should not be interpreted literally since they do not show the exponential behavior. The range can be seen to represent an average maximum distance of penetration).

Consider a slab of some material whose density is ρ (gm/cm³). A thickness of x_1 (cm) will represent a mass per square centimeter of ρx_1 (gm/cm²). A thicker slab will represent a larger mass per unit area and we can see that this method is indeed an indirect measure of the effective absorbing thickness. The amount of radiation energy lost in a given thickness of material will depend upon the type of radiation. This will become clear in the following sections.

3.3 Alpha Particle Interaction with Matter

Since the alpha particle carries two units of positive electronic charge, its electrostatic interaction with constituent charged particles in a piece of material is relatively strong. Furthermore, the large mass of the alpha particle limits to small speeds the kinetic energies associated with alpha decay. For example, a 5-MeV alpha particle travels with a velocity (v) of about 1.55×10^7 m/sec. This calculation is a simple solution of v from the classical kinetic energy equation: $E_K = \frac{1}{2} mv^2$. This low speed allows ample time for interaction with orbital electrons, which results in a large energy loss per unit path length as the alpha particle passes through a material. Ranges of alpha particles are therefore relatively small. Figure 2 shows the range of alpha particles in air.

We can immediately appreciate the fact that alpha radiation presents no particular threat when even a small thickness of absorber lies between the alpha source and the tissue or device requiring protection from radiation.

3.4 Beta Particle Interaction with Matter

The charge on the beta particle is one unit of electronic charge. We do not consider positrons here but shall discuss them briefly in the context of pair-production in a later section. Furthermore, the mass of the electron is

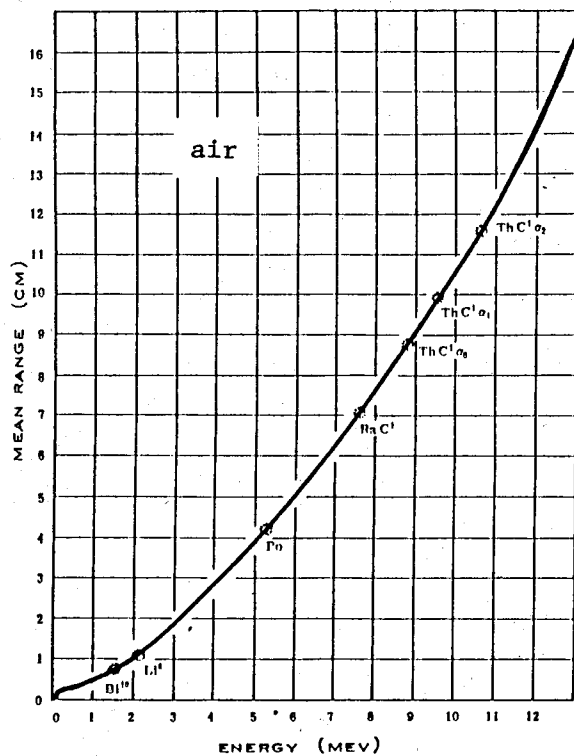


Figure 2. Range of alpha particles in air.

(Notations at points on the graph denote the radioisotope from which the alpha radiation is emitted).

only approximately $1/1836$ the mass of the proton, which leads to relatively large speeds for typical nuclear decay energies. A 5-MeV electron, for example, has a speed of $0.998 c$, where c is the speed of light. Techniques of special relativity must be used in calculating such speeds of beta particles. As such, the net result of these features is that beta particles exhibit much larger ranges of penetration in materials than those of alpha particles. Figure 3 shows the range of beta particles in aluminum. Note that the axes of this graph are logarithmic.

As a beta particle suffers scattering on its path through material, ionization of the constituent atoms may occur. A secondary process must also be considered, namely bremsstrahlung radiation. Each "collision" of the beta particle results in a change in its momentum, either in direction or magnitude, or both. These changes in momentum result in the emission of radiation due to these collisions. This is precisely the process used in X-ray machines wherein a beam of electrons is typically stopped by a heavy metal target. The emitted X-radiation is a result of the sudden deceleration of the electrons. We find that a significant fraction of beta-radiation energy goes into bremsstrahlung radiation energy as the beta particle traverses a material. Table 2 gives the fractional loss of energy to bremsstrahlung for several materials and beta energies.

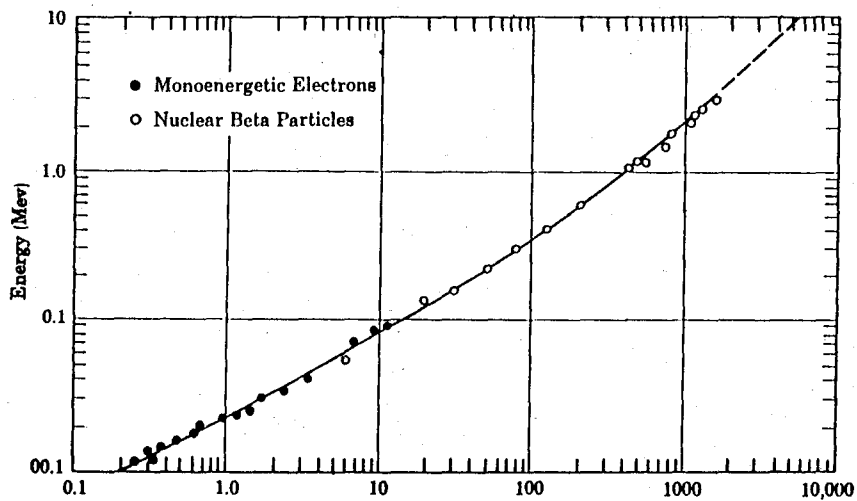


Figure 3. Range of electrons or beta particles in aluminum.

[Note that the range units are mg/cm^2 (Van Nostrand Scientific Encyclopedia, 1976). The range of electrons in most other solids will not be significantly different from values shown here electron since density changes rather slowly with atomic number].

Table 2. Beta Particle Energy Loss as Bremsstrahlung for Beta Particles [Bremsstrahlung, or "braking", radiation of photons arises from the deceleration of beta particles (or any charge) during collisions. The energy of bremsstrahlung photons falls within the broad range $E_{\text{photon}} < E_{\text{beta}}$].

a. Fractional energy loss of 2-MeV beta particles as bremsstrahlung

<u>Material</u>	<u>Fractional Loss as Bremsstrahlung</u>
Water	0.0136
Pyrex glass	0.0214
Soft glass	0.0232
Aluminum	0.0272
Iron	0.0512
Lead	0.147
Uranium	0.162

Note the effectiveness of higher Z materials.

b. Fractional energy loss as bremsstrahlung in lead as a function of beta energy

<u>Beta Energy (MeV)</u>	<u>Fractional Loss as Bremsstrahlung</u>
0.25	0.013
0.50	0.030
1.00	0.067
1.50	0.107
2.00	0.147

The photons thus produced will further contribute to ionization processes in the absorbing material, provided these bremsstrahlung photons are of sufficient energy. Photon-matter interaction is discussed in the following sections.

3.5 Gamma Interaction with Matter

A gamma photon is the electromagnetic quantum of energy given off during some radioactive decays. It would be misleading to imply that only gamma photons are capable of causing damage in materials since any high-energy photon can cause such effects. The point is that we really cannot distinguish between gamma photon and any other photon of the same energy. We therefore, for purposes of discussion here, make no differentiation between gamma radiation such as X-radiation, and lump all such electromagnetic radiation into the term photon.

Photon-electron interactions account for nearly all photon absorption in matter, at least within the range of photon energies pertinent to this report. Any one of three processes is possible; photoelectric, compton and pair-production (the likelihood of the specific process depending on the photon energy). Each process results in secondary electrons which subsequently interact with matter as outlined in Section 3.4. We shall discuss these processes separately. However, it should be kept in mind that they are competing processes. A beam of photons, with sufficient energy per photon, will likely exhibit all three processes as the beam interacts with matter. The relative amounts of photoelectric, compton and pair-production processes will depend on the energy of the photons making up the beam.

3.5.1 Photoelectric Process

Figure 4(a) depicts the generation of a photoelectron. Here the energy of the incident photon is completely absorbed by an atomic electron and the photoelectron thus created represents ionization of the atom. The kinetic energy E_e of the photoelectron is given by

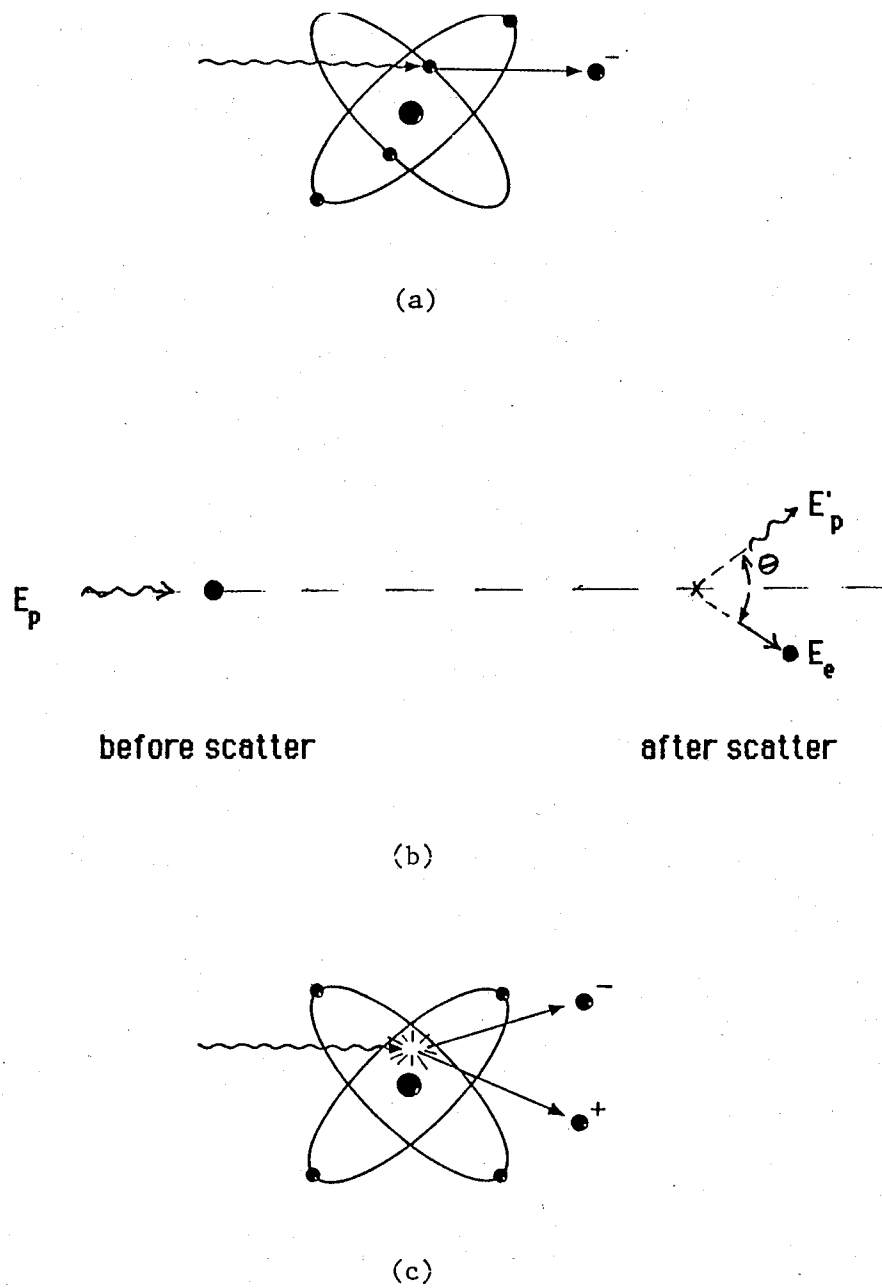


Figure 4. Diagrams depicting processes of photon energy absorption and scattering in matter.

- a) Photoelectric process
- b) Compton scattering
- c) Pair production

$$E_e = E_p - E_b \quad (12)$$

where E_p is the photon energy and E_b is the binding energy of the electron to the atom. Any momentum imbalance is taken up by the atom.

3.5.2 Compton Process

In the Compton process the photon-electron interaction is, in principle, treated much like an elastic collision, although special relativity must be used in the analysis. The scattered electron may be free, or at least $E_p \gg E_b$. Figure 4(b) depicts the Compton scattering process. Calculations using conservation of relativistic energy and momentum give the wavelength of the scattered photon, λ' , as

$$\lambda' = \lambda + 0.02426 \times 10^{-8}(1 - \cos\theta) \text{ cm} \quad (13)$$

where λ is the wavelength of the incident photon. The energy of the scattered photon E_p' is then

$$E_p' = hc/\lambda' \quad (14)$$

where h is Planck's constant and c is the speed of light. The difference in photon energies before and after scattering is the kinetic energy, E_e , taken up by the electron. We can readily see that maximum scattered electron energy occurs for head-on collisions, or at $\theta = 180^\circ$.

3.5.3 The Pair-Production Process

As the name implies, pair production results in the creation of an electron-positron pair. The positron is the antiparticle of the electron and is the same as the electron in all respects except that its charge is positive. Pair production begins to occur when the photon has an energy at least twice mc^2 where mc^2 is the mass energy of an electron. As a photon with $E_p > 2 mc^2$ passes within the vicinity of a nucleus, the photon may be annihilated, during which time the energy of the photon is converted into the mass energy of the electron and positron. Any energy in excess of $2 mc^2$ becomes kinetic energy of the particles thus created. Figure 4(c) depicts a pair-production event.

The electron proceeds on its way through the material, interacting with matter as described earlier. The positron also interacts with the matter, causing ionization in the same way as the electron. However, it ultimately results in relatively high energy gamma photons as we shall see.

Once the positron has lost sufficient energy, through collision processes, to reduce its speed sufficiently, it will form a short-lived bound system with an electron. The binding together of the electron and positron takes place via the coulomb interaction (attraction of two unlike charges). This combination annihilates the electron and positron which results in the production of two 0.511-MeV gamma rays. This is just a manifestation of energy conservation since $mc^2 = 0.511$ MeV for an electron. The two photons created by the annihilation of the electron and positron will then interact with the material as described in previous sections of this report.

3.6 Photonuclear Reactions

If a photon has energy $E_p > 10$ MeV it is possible for this photon to directly interact (collide) with a nucleus, causing the ejection of one or more nucleons (neutrons and protons).

The ejection of a neutron does not change the atomic number, Z , and so the remaining nucleus is an isotope of the same element represented by the nucleus before the collision. The ejection of a proton decreases the atomic number of the affected nucleus by 1 and so this new isotope is also a different element which may be radioactive. Often, however, this new isotope is radioactive and may decay via any of the radioactive decay processes, depending on the isotope.

It is further possible that combinations of nucleons may be ejected, resulting in new isotopes and/or new elements, which may also be radioactive. The reader is referred to the chart of nuclides, which may be found in the CRC Handbook of Physics and Chemistry.

4. RADIATION ATTENUATION OR SHIELDING

Shielding is perhaps a misnomer, although used extensively, to describe protection from radiation. Absorber might be a better word since it more accurately describes the processes involved in radiation "shielding". In effect, any shielding process really involves the absorption of the radiation energy before the particles and/or photons reach the object we wish to protect. The absorption processes are those interactions of radiation with matter described in the preceding sections.

We investigate the shielding qualities of several materials, depending on the type and energy of the radiation, and we also attempt to generalize shielding effects to facilitate calculations.

Before proceeding with the details of shielding, we briefly list five general principles involved.

1. All shielding occurs through processes of radiation absorption and scattering.
2. Thicker shielding is required for protection from electrically neutral radiation compared to that required for charged particles.
3. Although variations occur, for a given type of radiation, higher energies generally require thicker shielding.
4. The density and atomic number of shielding materials are the primary considerations for shielding effectiveness.
5. The shielding thickness required for reduction of radiation flux to an acceptable value depends on the incident flux. A half-thickness shield against a twice-lethal flux still allows penetration by a lethal flux; small consolation if you are the "shieldee"!

4.1 Shielding for Alpha Radiation

Because alpha particles lose a relatively large amount of their energy per unit path length in matter, very thin thicknesses suffice as discussed in Section 3.3 above. Figure 2 shows the range (average penetration) of alpha particles in air.

The range of alpha particles in substances other than air can be calculated by

$$R_{\text{substance}} = (\rho_{\text{air}}/\rho_{\text{sub}})R_{\text{air}}, \quad (15)$$

where ρ is the mass density and R is the range. For example, the density of air is about $1.29 \times 10^{-3} \text{ gm/cm}^3$ while aluminum has a density of 2.74 gm/cm^3 .

A 5-MeV alpha particle (see graph of Figure 2) has a range in air of about 4 cm. Thus $R_{Al} = 1.9 \times 10^{-3}$ cm. Aluminum foil is thus a fairly effective shield or absorber for alpha radiation.

4.2 Shielding for Electrons or Beta Radiation

As noted in Section 3.4 above, since the mass of an electron is smaller than that of a proton mass, electrons can generally be expected to travel with greater speeds than alpha particles and so their range is typically greater than that for alpha radiation. Even so, shielding from beta radiation can generally be accomplished with two centimeters of lucite, aluminum, or similar density material. The reader is reminded, however, that secondary photons are radiated when the electron or beta particle is slowed by collisions with the constituent particles of the material.

The attenuation of a beam of beta radiation is described adequately, for shielding purposes, by

$$I(x) = I_0 e^{-\mu x}. \quad (16)$$

Here x is the path length in the absorbing material, I_0 is the beam intensity or flux of beta particles onto the absorber and μ is the absorption coefficient.

The absorption coefficient, μ , is found in the literature (Chilton et al., 1984; National Council on Radiation Protection and Measurements, 1976) with units of cm^{-1} or $\text{cm}^2\text{gm}^{-1}$. The conversion from one set of units to the other uses the density, ρ , of the absorbing material and is given by

$$\mu'(\text{cm}^{-1}) = \mu(\text{cm}^2/\text{gm}) \times \rho(\text{gm}/\text{cm}^3). \quad (17)$$

A similar conversion is useful in calculating thicknesses of absorbers.

Example:

The thickness of aluminum required to reduce 1.71-MeV beta radiation to half its initial value (half-thickness) is

$$x_{1/2}(\text{gm/cm}^2) = 0.110 \text{ gm/cm}^2 \text{ (Chilton et al., 1984)}. \quad (18)$$

That is, the absorber is of such a thickness that the beta particle "sees" 0.110 gm/cm² of matter.

$$\rho_{\text{Al}} = 2.7 \text{ gm/cm}^3 \quad (19)$$

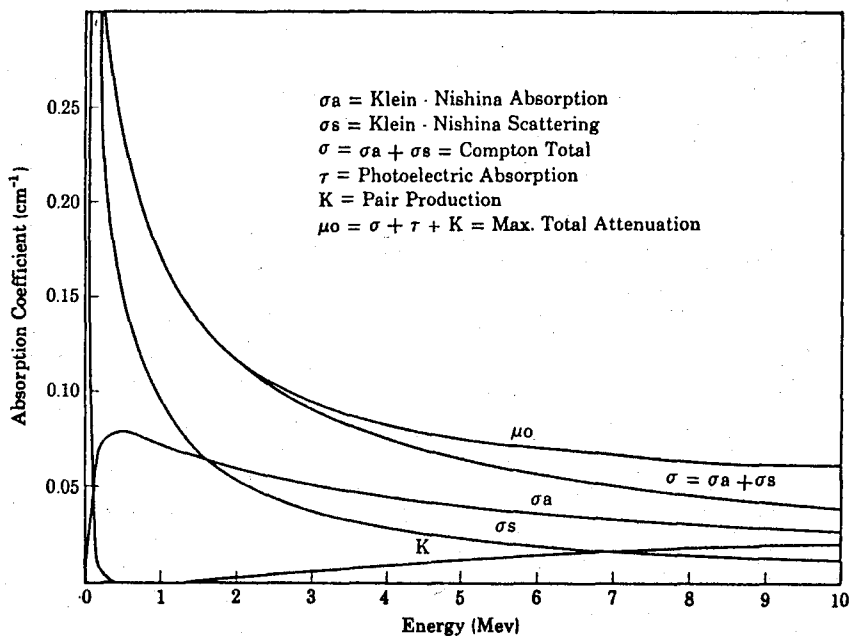
$$\begin{aligned} x_{1/2}'(\text{cm}) &= x_{1/2}(\text{gm/cm}^2)/\rho \\ &= 4.1 \times 10^{-2} \text{ cm}. \end{aligned} \quad (20)$$

4.3 Shielding for Gamma Radiation (Photons)

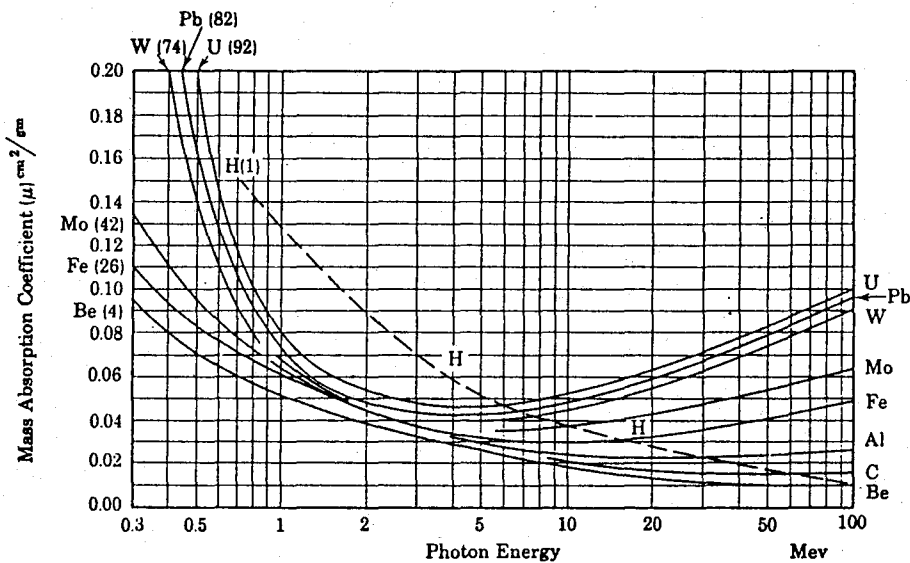
The attenuation of photons occurs via a combination of the photoelectric, Compton, pair-production processes, and to a lesser degree, photonuclear reactions at high energies. These reactions are discussed in Section 3.5. As with electrons, the attenuation of gamma radiation is reasonably well described by equation (16). Some minor exceptions to this exponential attenuation occur for photons and will be discussed briefly below. Figure 5(a) shows the contributions of the photon-electron interactions to the absorption coefficient for lead, for photons up to 10 MeV.

Figure 5(b) shows the total mass absorption coefficients for several materials for photon energies up to 100 MeV.

Example:



(a)



(b)

Figure 5. (a) Contributions of photoelectric, Compton and pair-production processes to the absorption coefficient (units of cm^{-1}) for gamma radiation in lead.
 (b) The total absorption coefficient (units of cm^2/gm) for gamma radiation in various materials (Van Nostrand Scientific Encyclopedia, 1976).

It is informative to compare the half-thickness of 1.7-MeV photons in aluminum to the half-thickness of 1.7-MeV electrons. (See Reference 2 for an explanation of half-thickness.) From Figure 5(b) $\mu \cong .05 \text{ cm}^2/\text{gm}$ for photons in aluminum.

$$I/I_0 = \frac{1}{2} = e^{-\mu x_{1/2}} \rightarrow 2 = e^{\mu x_{1/2}} \quad (21)$$

$$x_{1/2} = \frac{\ln 2}{\mu} \quad (22)$$

$$\cong 13.9 \text{ gm/cm}^2$$

Converting to a linear thickness,

$$\begin{aligned} x_{1/2}'(\text{cm}) &= x_{1/2}(\text{gm/cm}^2)/\rho_{\text{Al}} \\ &= \frac{13.9 \text{ gm/cm}^2}{2.7 \text{ gm/cm}^3} \\ &= 5.1 \text{ cm.} \end{aligned} \quad (23)$$

Thus the shielding thickness of aluminum for photons is nearly 125 times that for electrons for 1.7-MeV radiation. This clearly illustrates the need for thicker shielding for photons.

Table 3 is a partial list of mass absorption coefficients in various materials for photon energies up to 10 MeV. Two features should be noted. The absorption tends to decrease with energy up to 10 MeV and absorption coefficients tend to converge as photon energies approach 10 MeV. As seen in Figure 5, however, one must exercise some caution in extrapolation of these trends.

4.3.1 Build-up Factor in Photon Shielding

The exponential attenuation of gamma radiation or photons passing through a material is modulated somewhat by scattering of photons back into the original direction. This process is called build-up. Figure 6(a) depicts the build-up phenomenon and Figure 6(b) gives some representative values of the build-up factor, B, for photons in lead. The build-up factor is included as a multiplier in the attenuation equation,

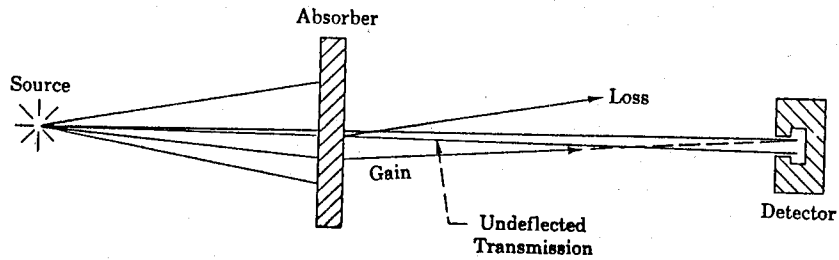
$$I(x) = I_0 B e^{-\mu x}. \quad (24)$$

The reader should notice that the build-up becomes more significant with increasing absorber thickness, d.

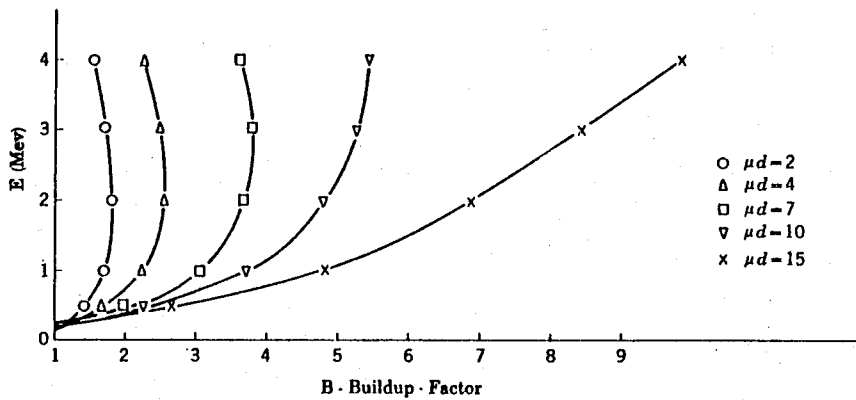
Table 3. Mass Attenuation Coefficients for Gamma Rays for
Some Representative Materials
(U.S. Department of Health, Education, and Welfare, 1970)

<u>Photon Energy</u>	<u>SiO₂</u>	<u>Air</u>	<u>Concrete</u>	<u>Polyethylene</u>
0.40	0.0959	0.0954	0.0963	0.109
0.50	0.0874	0.0870	0.0877	0.0995
0.60	0.0808	0.0805	0.0810	0.0921
0.80	0.0707	0.0707	0.0709	0.0809
1.00	0.0636	0.0636	0.0637	0.0727
1.50	0.0518	0.0518	0.0519	0.0592
2.00	0.0447	0.0445	0.0448	0.0507
3.00	0.0363	0.0358	0.0365	0.0405
4.00	0.0317	0.0308	0.0319	0.0345
5.00	0.0287	0.0275	0.0290	0.0305
6.00	0.0266	0.0252	0.0270	0.0277
8.00	0.0241	0.0223	0.0245	0.0239
10.00	0.0226	0.0204	0.0231	0.0215

Photon Energies in Units of MeV
Absorption Coefficients in Units of cm²/gm



(a)



(b)

Figure 6. Radiation build-up process and relation to absorber thickness.

- (a) Diagram showing the process of scattering of radiation in an absorber resulting in build-up.
- (b) Build-up factor, B, for gamma radiation scattering from a lead shield. Note in particular the effect of shielding thickness on build-up.

4.4 Shielding Effects of Soils

One of the more accepted means of cable disposition is burial beneath the Earth's surface. For purposes of applying the information in this report to shielding of optical fiber transmission lines, a separate section is dedicated to shielding due to soils.

Due to the variations in soil constituents and structure from one location to another, it is not possible to characterize shielding effects of soils as specifically as those of other materials. The situation is not as desperate and unwieldy as it might seem at first glance, however, since the required soil thickness for effective shielding can be calculated, if the soil density is known. Table 4 gives the densities of several soil types from which a worst-case scenario and shielding design may be determined. The following example is used to illustrate this point.

Example:

From Table 3 and Figure 5 we see that a safe estimate of the absorption coefficient for 1-MeV photons is about $0.07 \text{ cm}^2/\text{gm}$. The required half-thickness is then $x_{1/2}(\text{gm}/\text{cm}^2) = (\ln 2)/\mu = 10.12 \text{ gm}/\text{cm}^2$. If the device to be protected is buried in silty soil (see Table 4) the least density expected is $1.39 \text{ gm}/\text{cm}^3$. This gives a half-thickness of $x_{1/2}(\text{cm}) = 7.28 \text{ cm}$ using the same calculation techniques shown earlier. See the examples of Sections 4.2 and 4.3.

Table 4. Some Soil Densities Useful for Shielding Calculations (Hough, 1957)

<u>Soil Type</u>	<u>*Dry Density (gm/cm³)</u>
Standard Ottawa Sand	1.47 - 1.76
Clean Uniform Sand	1.33 - 1.89
Uniform Inorganic Silt	1.28 - 1.89
Silty Sand	1.39 - 2.03
Fine to Coarse Sand	1.36 - 2.21
Micaceous Sand	1.22 - 1.92
Silty Sand and Gravel	1.43 - 2.34
Clay	1.12 - 2.08

*Dry density is determined after baking at 105 °C for 24 hours.

An additional word of caution is in order here. The half-thickness calculated in the examples presented here is that thickness required to reduce the radiation flux to half its initial value. The addition of each successive half-thickness of absorber or shielding reduces the radiation flux by another factor of one-half. It may be necessary to have many half-thicknesses of shielding before the radiation flux is reduced to an acceptable level.

A convenient aid in planning cable burial, when radiation shielding becomes a consideration, may be obtained from the Soil Conservation Service of the United States Department of Agriculture. Although not yet complete, maps of the United States are available which show soil types.

5. SUMMARY

The foregoing data, comments and sample calculations are by no means exhaustive and are only intended to make the reader aware of problems and procedures associated with radiation shielding. The materials presented herein are not original but represent a brief consolidation of a vast quantity of works

accumulated over the decades of study of radioactivity and shielding. Application of the techniques of shielding for adequate protection of equipment and/or personnel from the harmful effects of ionizing radiation must surely be done on a situation-by-situation basis. Worst-case design of shielding in all instances is encouraged--the adage "What you can't see won't hurt you" does not apply here.

6. REFERENCES

- Chilton, A. B., J. K. Shultis, and R. E. Faw (1984), Principles of Radiation Shielding, (Prentice Hall, Inc., Englewood Cliffs, NJ).
- Englert, T. J. (1987), Effects of Radiation Damage in Optical Fibers--A Tutorial, 62 pp., NTIA Contraction Report 87-38, NTIS Order No. PB 87-210 308/AS, May.
- Friebele, E. J., K. J. Long, G. G. Askins and M. E. Gingerich (1985), Overview of Radiation Effects in Fiber Optics, Optical Materials in Radiation Environments, Proc. of SPIE, Vol. 541, Radiation effects in optical networks, pp. 70-88, March 6-7, (SPIE--The International Society for Optical Engineering, P.O. Box 10, Bellingham, WA 98227-0010).
- Hough, B. K. (1957), Basic Soil Engineering, (Ronald Press Co., New York, NY).
- National Council on Radiation Protection and Measurements (NCRD) (1976), Structural Shielding Design and Evaluation for Medical Use of X-Rays and Gamma-Rays of Energies Up to 10 MeV, NCRD Report No. 49.
- U.S. Department of Health, Education, and Welfare (1970), Radiological Health Handbook, Revised Edition, (U.S. Department of Health, Education, and Welfare, Washington, DC).
- Van Nostrand Scientific Encyclopedia (1976), 5th Edition, (Van Nostrand Reinhold Company, New York, NY).



APPENDIX G

RESTORABILITY OF AN OPTICAL FIBER LINK

William J. Ingram

- G. RESTORABILITY OF AN OPTICAL FIBER LINK
 - G.1 Uninterruptible Power Supply
 - G.1.1 Continuous UPS
 - G.1.2 Standby UPS
 - G.1.3 Batteries
 - G.1.4 Battery Grading
 - G.2 Power Supplies
 - G.2.1 Public Service
 - G.2.2 Fossil Fuel Generators
 - G.2.3 Solar Energy
 - G.2.4 Wind Energy
 - G.3 Recovery from Damage
 - G.3.1 Fiber Optics
 - G.3.2 Station Damage
 - G.3.3 Power Loss
 - G.4 References

APPENDIX G: RESTORABILITY OF AN OPTICAL FIBER LINK

Optical fiber links can carry hundreds or thousands of calls at a time. Regenerator stations serve to regenerate the optical signal. If one of these elements fails, communication along that route is severed. The causes of such failures usually come from one of the following categories:

1. Power supply failure
2. Element failure
3. Optical fiber degradation.

Power supply problems can usually be prevented by the judicious use of an uninterruptible power supply (UPS). This is described in Appendix G.1. Device failure can normally be circumvented by the use of on-line spare parts that can be switched into the network. This issue is addressed in Appendix G.3. Optical fiber degradation is caused by exposure to gamma radiation. This can be muted by hardening of the fiber and by attenuating the radiation before it strikes the fiber. This is also described in Appendix G.3.

G.1 Uninterruptible Power Supply (UPS)

An uninterruptible power supply is an invaluable piece of equipment for those installations where an unexpected power loss could disrupt critical operations. A typical UPS consists of an array of batteries, one or more ac/dc converters, and associated controlling electronics. The two major types of UPS that are used to provide uninterrupted electricity flow are 1) a continuous UPS and 2) a standby UPS.

G.1.1 Continuous UPS

The continuous UPS is, as its name implies, a UPS that supplies an unbroken stream of electrical power. The ac from a public utility is channeled through a rectifier and is used to keep a battery array fully charged. The output from this rectifier is also connected to an electrical inverter that converts the dc back into ac (Figure G-1). Since the battery array is inherently connected to the input of the inverter, if the incoming ac power fails, power for the inverter is automatically supplied by the batteries (Knurek, 1987).

In this type of system, the load is completely isolated from problems on the incoming ac line such as brownouts and transient power surges. Unfortunately, this kind of system suffers from the entropic power loss caused

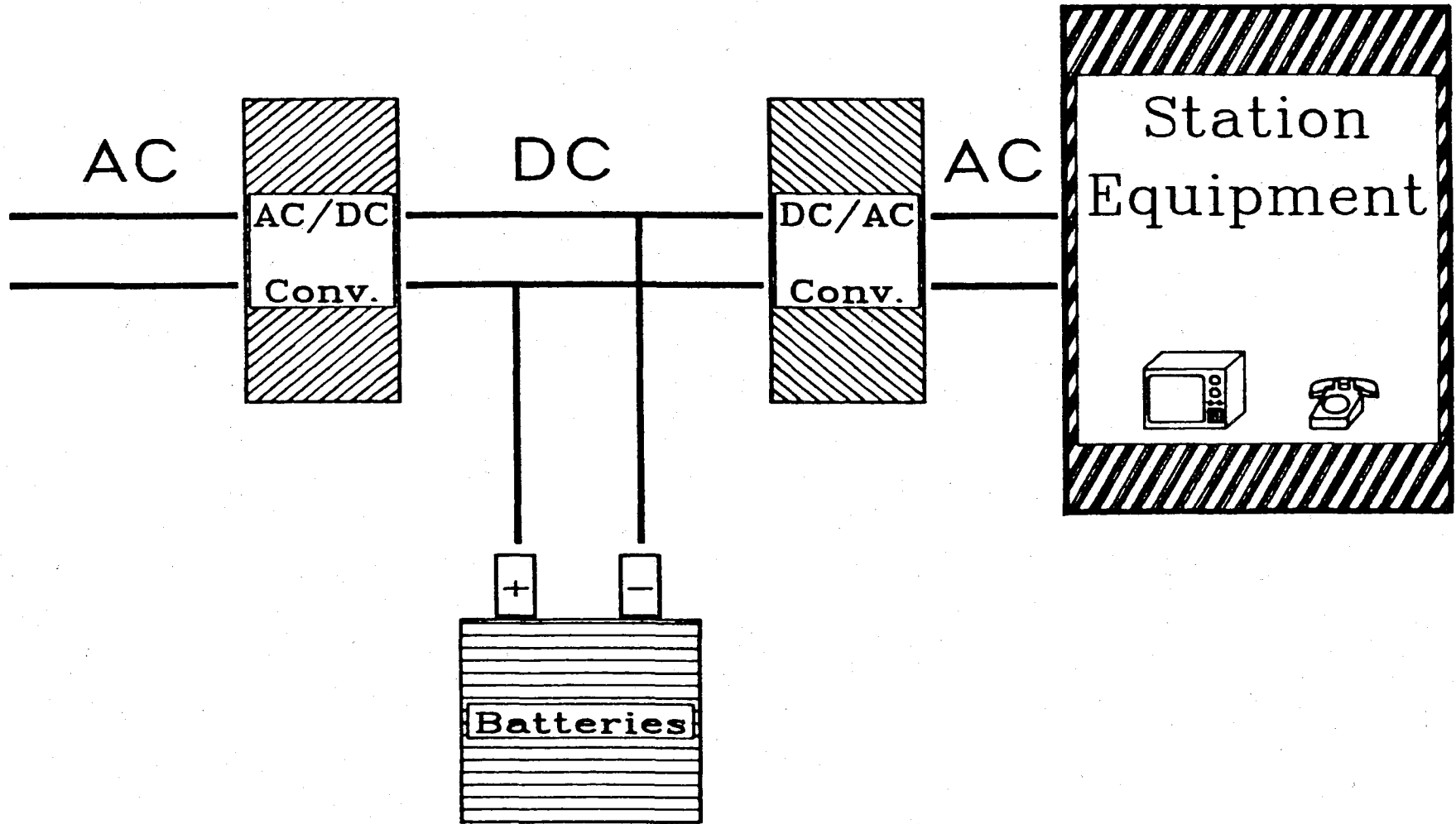


Figure G-1. A continuous UPS.

by the double conversion scheme. This constant power loss inherent in a continuous UPS is not very cost effective.

Most telecommunication equipment runs on 48 Vdc and so can be connected directly to the battery array. Additionally, the electrical inverter can be removed from the circuit if dc lighting and dc environmental controls are used in the station. This would result in a greater overall station efficiency.

G.1.2 Standby UPS

The standby UPS is more efficient than the continuous UPS because, under normal operating conditions, the commercial ac power is directly connected to the load (Figure G-2). None of the ac power is lost through a rectifier/inverter scheme. The ac power is also connected to a rectifier which keeps a bank of batteries fully charged. These batteries are connected to the input of an inactive dc/ac inverter. When sensors, attached to the commercial ac line, sense that the ac power has failed, the inverter is activated and begins producing ac power from the batteries while the commercial ac power is removed from the system. This battery-produced power is then used to supply power to the station load. Switchover takes 1.5 to 4 milliseconds which, for the majority of loads, is short enough so that the power service is considered to be uninterrupted. One drawback to this system is that power surges and brownout conditions may not be detected and may be inadvertently passed onto the load.

As in a continuous UPS, the telecommunication equipment will likely be directly connected to the 48 Vdc battery array. If the station contains no equipment that needs ac power, the electrical inverter can be eliminated from the setup and the standby UPS becomes a continuous UPS.

Many UPS systems need adequate air conditioning. In the event of an air conditioning failure, the UPS might overheat and likewise fail. This could mean no power at all, or worse yet, allow corrupted power to pass to telecommunication equipment.

G.1.3 Batteries

The size and type of batteries installed in a UPS is dependent upon the particular station site requirements. The cheapest and most widely used batteries are standard lead-acid batteries (e.g., automobile type batteries). Several rows of these batteries can be connected together to supply specific

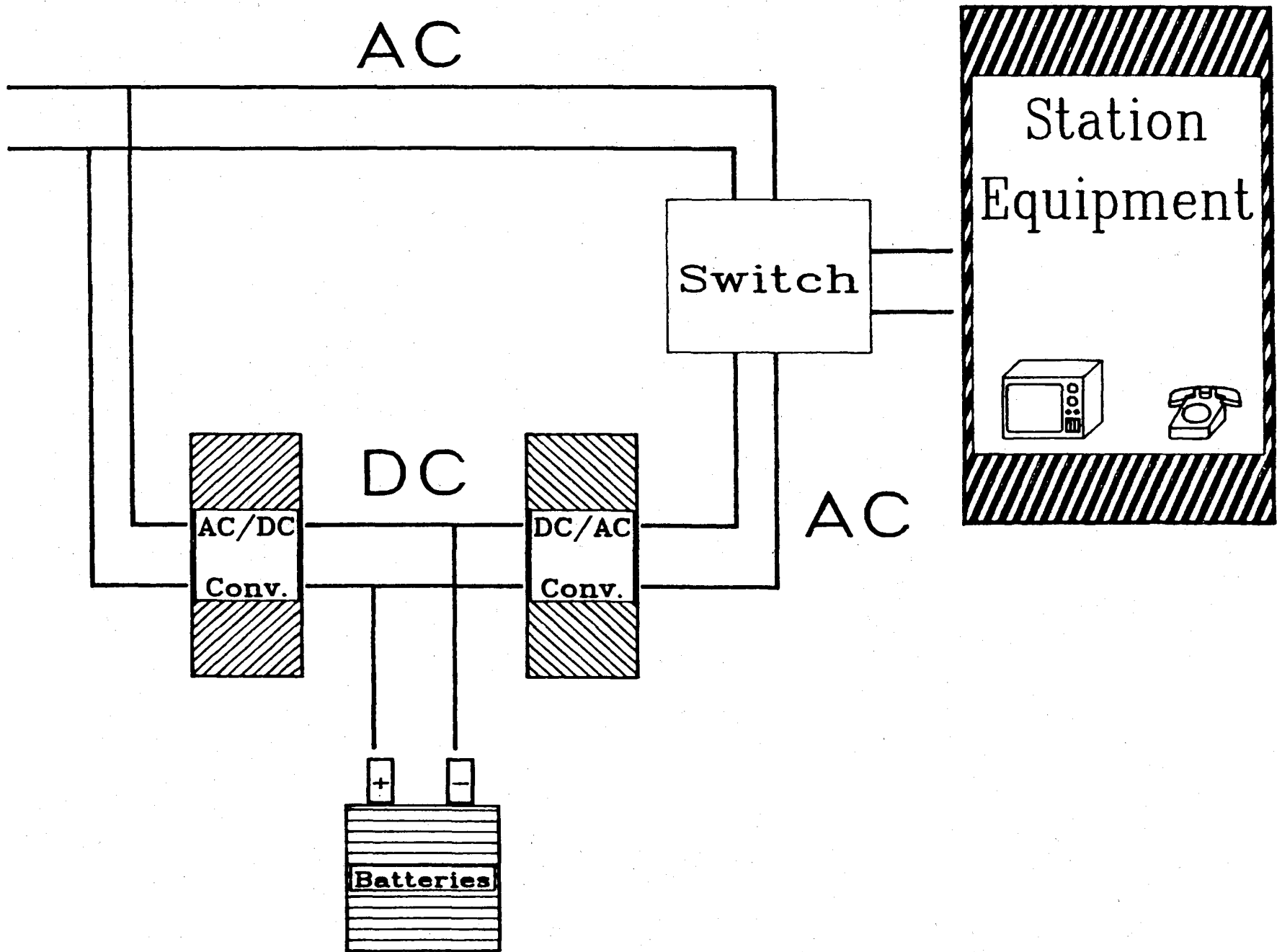


Figure G-2. A standby UPS.

power requirements for specific telecommunication needs. For example, a UPS that is designed to supply a week's worth of power to telecommunication equipment would typically need many more batteries than one designed to last only 30 minutes. Similarly, a UPS designed to supply power to a dozen equipment racks would need many more batteries than one designed for a single equipment rack.

The storage of lead-acid batteries can be bulky, messy, and dangerous, especially in those situations where the UPS must supply a substantial amount of electricity for a long period of time. The UPS is therefore usually housed in a large room specially designed for large numbers of unsealed batteries. Adequate drainage and ventilation facilities are needed to reduce hazards from escaping gasses and/or leaking acid.

Periodic maintenance is needed to replace lost water that is vented off as vapor during battery recharging (Wilson, 1987). In addition, most lead-acid batteries can only be recharged about 800-900 times before they need replacement (Maycock, 1981).

Sealed lead-acid batteries are being made that can reduce the hazards and inconvenience of a centralized UPS. These sealed batteries use gas recombination techniques to recover the oxygen and hydrogen gasses produced during recharging and recombine them back into water. Although these batteries are smaller and less powerful than unsealed batteries, several of them can be linked together to produce the same power output as regular lead-acid batteries. Since these batteries are smaller and fully self-contained, they can easily be incorporated directly into equipment racks with the equipment itself.

Equipment racks containing sealed lead-acid batteries mounted with the equipment they are powering, can then be transported as a whole unit. This method can be used to quickly replace a failed unit with a completely new spare unit. The down time would be greater if the failed equipment had to be first disconnected from the main power supply and then from the optical fibers themselves. Once the equipment (with batteries) has been removed from the circuit and replaced, the batteries can be extracted from the failed unit and incorporated into a new unit, which can then be used as a spare.

Such sealed batteries can also be useful in environments where the venting of gasses can cause immediate dangers such as an explosion. Also, potential

damage caused by vandalism and sabotage can be reduced by eliminating ventilation ductwork that is no longer needed when using sealed batteries.

G.1.4 Battery Grading

Backup battery protection is usually supplied by an array of similar-sized batteries with the same voltage ratings. In a typical installation, batteries are replaced throughout the life of a UPS. This results in batteries from different batches and maybe even different manufacturers being inserted into the array (Kindschuh, 1987). Consequently, the array will be made of battery cells that have slightly different voltages and/or power capacities.

Each individual battery cell has its own distinctive discharge curve showing output voltage as a function of time. Typically, a cell's voltage will remain constant (within 10 percent) for approximately the first 95 percent of its discharge cycle. When the cell is almost completely discharged, the voltage drops sharply (the voltage drop-off point) and the cell is considered to be fully discharged. In a battery array, the "weak link" theory applies. When any one individual battery cell becomes fully discharged, the voltage of the entire array drops accordingly. Premature discharge of a few "weak" cells can cause the array voltage to drop to less than 90 percent of its rated voltage. When this happens, the entire array is then considered to be discharged. Unfortunately, most of the batteries will still have around 10 percent of their power capacity left.

Battery cells with the same rated voltage may have vastly different actual power capacities. By defining several different power grades within a specific rated voltage, a cell's power capacity (and thus the voltage drop-off point), can be evenly matched with other graded battery cells. These matched cells can then be put into the same battery array. The batteries in such an array will tend to reach their drop-off voltages at approximately the same time.

Such grading will extend the life of an array by using each battery cell to its fullest capacity. When fully exercising and utilizing each battery, less strain is placed on any individual cell, extending the life of each battery and thus the entire array.

G.2 Power Supplies

G.2.1 Public Service

Electricity from public utilities can be a very cheap method of supplying electricity to a regenerator station. The cost of installing electrical cable from the regenerator station to a public service contact point will normally be the most expensive element. According to a representative of Public Service Company of Colorado (private communication, 1987), the installation cost is about \$15,000 per mile (\$9,300/km) for flat terrain and \$22,000 per mile (\$13,700/km) for mountainous terrain. Once the cable has been installed, the cost of the electricity is about \$0.07-\$0.10 per kWh, depending on the area of the country (Maycock, 1981).

The costs of maintenance for this power cable are borne by the public service company. Their maintenance responsibility ends at the customer's termination point, usually a power transformer. These maintenance costs have already been calculated into their normal electric utility rates.

Public service power is normally available at least 99.9 percent of the time. According to a representative of Public Service of Colorado (private communication, 1987), public utilities typically experience down times of less than one half hour per year.

Sometimes the electricity delivered by a public utility is not a precise 60-Hertz waveform. This can be caused by a fault at the generating facilities or by other customers' errant usage of electricity on the same power lines. This corrupted power can cause some equipment to function erratically and may cause irreparable damage to others. In applications where the regenerator stations must be active 100 percent of the time, this is unacceptable. By routing the public utility power through a UPS, faults such as voltage spikes and voltage dips can be muted. By integrating the public utility power with electricity from local sources such as diesel generators, photovoltaic cells, and/or wind turbines, additional faults such as blackouts and brownouts can be circumvented.

G.2.2 Fossil Fuel Generators

Fossil fuel generators, most often diesel type, can be used to provide power through a UPS. This power will be used to keep an array of batteries charged.

Such generators are quite cheap to install, typically costing less than a few thousand dollars. They are also very cheap to repair and maintain. Diesel generator technology is relatively simple and well known. Problems can easily be identified and repaired. Spare parts are readily available "off the shelf." Even if the generator is severely damaged, replacement would only cost a few thousand dollars and can be done fairly quickly. Unfortunately, the major expense comes during energy generation. Depending on the generator type, the fuel consumption rate can be up to several gallons per hour.

Estimates show that if diesel fuel delivered to a remote generator costs about \$2-\$3 per gallon, the electricity produced will cost about \$0.40-\$0.60 per kWh. If the cost of the generators and routine maintenance are amortized into the price, the electricity typically costs \$0.50-\$1 per kWh (Maycock, 1981).

G.2.3 Solar Energy

One alternative to electricity from public utilities or fossil fuel generators is to use photovoltaic (PV) cells. An array of these PV cells will often have a higher initial cost. To justify these costs, a solar array needs to have a useful life of several decades so that the initial costs can be satisfactorily amortized (Murr, 1980). Fortunately, estimates show that solar cells are generally designed for over 25,000 hours of operation, which can be more than 10 years of useful service (McVeigh, 1977). Including amortization and yearly maintenance costs, a typical PV array can generate electricity at a cost of between \$0.50-\$1 per kWh (Maycock, 1981).

Solar cells are often made from silicon or gallium-arsenide wafers that have been purified to where less than a few parts per million of unwanted impurities remain. Specific impurities are then reintroduced into the silicon that cause portions of these wafers to expel electrons when exposed to light. Other portions of the wafer that have been doped with other specific impurities will absorb these electrons. A wire connecting these two portions will transport these electrons, thus producing electricity. The technology needed to produce these PV cells is in its infancy compared to that of fossil fuel generators (McVeigh, 1977).

Typically on a sunny summer day at noon, about 1 kW of energy per square meter (0.1 kW/ft²) reaches the Earth's surface. Depending on the time of the year, the time of day, and the weather, this value can drop to almost zero.

Current PV cells can only convert 10 to 25 percent of the available energy directly into electricity (Maycock, 1981). Individual photovoltaic cells are manufactured to produce 1.5 volts at several milliamps. The overall wattage of a PV cell depends upon its size and construction. Several PV cells can be connected in series to form a bank of PV cells with a specific voltage. Several banks of PV cells can then be connected in parallel to supply a specific average amperage. The exact number of banks needed to produce a specific power level will be determined by the location, local weather conditions, and the average sunlight for the area. Although PV cells seem to take up a large amount of space, they have a much greater power-to-weight ratio than lead-acid batteries or fossil fuel generators.

Parabolic mirrors can concentrate the sun's rays onto the PV cells to produce far greater amounts of electricity. Consider, for example, that two PV cells ("A" and "B") are set up and each is 1 square meter (10.8 ft²) in area. These cells convert 15 percent of the sunlight falling on them to electricity. Assuming 1,000 watts of energy fall on each PV cell, this makes a total of 30 watts of electricity produced by the two cells. A second setup has been constructed next to the first one. One PV cell ("C") has been built, also with an area of 1 square meter (10.8 ft²) and an efficiency of 15 percent. Mirrors and concentrators have been placed on the second square meter (where PV cell "D" could have been built) and are used to reflect its 1,000 watts of sunlight onto PV cell "C." Cell "C" is now producing 30 watts of electricity. The same amount of electricity is being produced with only one PV cell rather than two. Assuming, for the moment, that the cost of the mirrors and concentrating equipment is less than that of a second PV cell, it is cheaper to use only a few PV cells and concentrate extra sunlight onto them.

PV cells will become cheaper as more companies begin to use automatic manufacturing processes to make them. Eventually, it may become cheaper to install large numbers of PV cells instead of using concentrators.

Parabolic arrays have been constructed that are 20 to 100 times as efficient as flat-surfaced solar arrays (Murr, 1980). These parabolic mirrors can produce temperatures as great as 300°C, necessitating the need for special high-temperature devices or adequate cooling systems. Another expensive element of a tracking parabolic array is the sophisticated system allowing the array to follow the sun's arc across the sky.

Another method of extracting as much electricity as possible from a given area of sunlight is to use filters to break up the sunlight into its component wavelengths. Specific wavelengths of light are converted into electricity with varying degrees of efficiency by different types of silicon PV cells. By using various filtering techniques, the specific wavelengths of light can be absorbed by the appropriate PV cells. In theory, these techniques could have about a 60 percent efficiency. In practice, only about 35 to 40 percent efficiency has been achieved (Maycock, 1981).

Photovoltaic arrays are susceptible to deterioration caused by dust, water vapor, and natural or man-made chemicals in the atmosphere. Periodic replacement of the protective outer coatings of glass may be necessary as they become pitted, scarred, or otherwise damaged by the elements.

G.2.4 Wind Power

Wind-powered machines have been around for thousands of years. In the "good old" days, wind machines consisted of simple sailing ships and wind-driven mills. Merchants were at the mercy of the weather conditions and could be crippled for several days, weeks, or even months without wind. In modern times, we still cannot control the weather, but we can store excess power generated during windy periods and use it when there is not enough wind to produce electricity.

A wind turbine that is generating electricity without the benefit of a battery backup would never be an acceptable power supply. Even a turbine with several days' worth of battery storage would only be marginally acceptable. Extended calm weather can cause the battery's power reserves to be completely drained, leaving the station without power until the wind begins again. On the other hand, if the wind velocity exceeds the capacity of the turbine, the turbine must be shut down to prevent damage to the turbines. If wind turbines are to be the only incoming energy source, the station will typically experience unpredictable periods of complete power loss. The duration of these power loss periods depends upon the specific location of the wind turbine. Accurate wind studies and sophisticated turbine designs, however, can help to minimize this down time.

Sophisticated analysis can determine the expected yearly energy output of a modern wind turbine. Such an analysis can help, for example, to determine

how many turbines would need to be set up to generate a predetermined average amount of electricity.

To estimate the energy produced by a wind turbine, the total energy available must first be determined. The kinetic energy, E_k , of a moving air stream is defined to be

$$E_k = \frac{1}{2} \rho A V^3 \quad (G-1)$$

per unit mass, where V is the velocity of the air (McVeigh, 1977). The mass flow rate, F_m , of air through a cross-sectional area, A , is

$$F_m = \rho A V \quad (G-2)$$

where ρ is the density of air. Combining (G-1) and (G-2), the total power available, E_m , in the air stream passing through the wind turbine is

$$E_m = \frac{1}{2} \rho A V^3 \quad (G-3)$$

Assuming the rotor blades are arranged in a circular array (e.g., an airplane propeller) and each has a length that describes a diameter D , the area traced by the blades is

$$A = \frac{\pi}{4} D^2 \quad (G-4)$$

By substituting (G-4) into (G-3), the maximum energy available, E_m , can be expressed as

$$E_m = \frac{\pi}{8} \rho D^2 V^3 \quad (G-5)$$

The actual power available, E_a , is less than E_m due to inefficiencies inherent in energy conversion. It can be expressed as

$$\begin{aligned}
 E_a &= \epsilon E_m & (G-6) \\
 &= K_r D^2 V^3
 \end{aligned}$$

where ϵ and K_r are terms associated with wind dynamics and the efficiencies of rotor power systems. The term K_r can be determined by analyzing the conversion factors of the turbine system.

The maximum amount of kinetic energy that could be extracted from a moving airstream is 0.59259 (ϵ_r) of the theoretical kinetic energy available. This was shown in 1927 by the German engineer Betz (McVeigh, 1977).

Not all of this extracted energy can be converted into usable power. Friction between the rotor blades and the air and friction between moving parts within the turbine can reduce the output power significantly. Many current wind turbine designs can produce rotor conversion efficiencies, ϵ_c , of around 75 percent.

Noting that the density of air, ρ , is 1.293 Kg/m³ (at 0°C, 760 mm Hg) and including the rotary systems efficiencies, K_r can then be calculated as

$$K_r = \frac{\pi}{8} \rho \epsilon_r \epsilon_c \quad (G-7)$$

$$= \frac{\pi}{8} \times \frac{1.293 \text{ Kg}}{\text{m}^3} \times 0.59259 \times 0.75$$

$$= 0.226 \text{ Kg/m}^3.$$

The actual power can then be found by combining (G-6) and (G-7) as

$$E_a = 0.000226 D^2 V^3 \text{ kW}. \quad (G-8)$$

The annual wattage of a wind turbine, E_y , can then be calculated by multiplying (G-8) by the number of hours in a year ($H=8766$ hours) and a factor K_s . This factor is a semiempirical factor associated with the statistical nature of wind energy and has been shown to be about 2.06 (Pontin, 1975). The typical average annual energy can then be expressed as

$$\begin{aligned}
 E_y &= K_s H E_a & (G-9) \\
 &= 4.08 D^2 V'^3 \text{ kWh}
 \end{aligned}$$

where the wind velocity, V' , is considered to be the mean annual wind speed. This mean annual wind speed is calculated as

$$V' = \sqrt[3]{\Sigma V^3} \quad (G-10)$$

When calculating V' , the mean of V^3 is used rather than the mean of V . A more accurate mean is achieved using this method because (G-8) shows that E_a is linearly related to V^3 rather than V . A transient linear increase in V will contribute far more to the energy total than an equivalent linear decrease will deduct.

As an example, consider a wind turbine erected at a regenerator station site with a mean annual wind speed of 6 m/s (19 ft/s). The rotor blades trace a circular area with a diameter of 5 meters (16 ft). The turbine itself has a life expectancy of 10 years. The turbine costs \$3,000 to buy and \$3,000 to set up. Annual maintenance on the turbine costs \$300. By amortizing the initial costs over ten years and adding in yearly maintenance, the annual cost of owning the wind turbine is \$900. Substituting the rotor diameter and wind speed into (G-9), the annual power output is calculated as 22,000 kWh. The cost of electricity in this example is \$0.041/kWh.

This final cost will, of course, be site specific. Many additional circumstances could affect this figure. The mean annual wind speed of an area can vary from almost zero to more than 20 m/s. Even if the mean annual wind speed is within acceptable limits, this does not mean that the wind blows at appropriate speeds all the time. Several wind turbine manufacturers claim that the annual cost of maintenance will normally be less than the \$300 used in the above example. The installation costs might be higher than this example if, for instance, a remote station site needs to have its wind turbine flown in by helicopter. Generally, the cost of electricity will remain under \$0.10/kWh.

G.3 Recovery from Damage

Regenerator stations will likely be damaged at some time or another. Much of this damage will come from natural sources such as earthquakes, weather, and

animals. The rest of this damage will be caused by man-made events such as vandalism, sabotage, or war. Most damage will consist of physical destruction of the devices. Some damage will be the result of either long-term mild radiation exposure or a sudden, massive dosage. Regenerator stations and fiber optic cables can never be designed to withstand all such damaging events. System elements that are designed to withstand most of this damage are usually quite cumbersome and expensive and still would not guarantee 100 percent survival.

A reasonable approach to this situation is to balance the cost of hardening the system against the additional degree of protection. Adequate consideration must be given to the losses incurred if the system were to fail. Separate studies would be needed for the hardening of the optical cable as well as for the regenerator station itself.

G.3.1 Fiber Optics

Optical fiber cable that has been exposed to appreciable amounts of gamma radiation will suffer some attenuation of its light transmission ability. The radiation striking the fiber will react with certain impurities in the fiber, causing electrons to be ejected from their ascribed positions. These free electrons and "electron holes" can act to absorb light, making the entire cable less light-conductive. This is known as fiber darkening.

Optical cable that has been damaged by this darkening effect will recover as the free electrons eventually fall back into the "electron holes." Although the fiber will continue to recover indefinitely, total recovery will never reach 100 percent.

In a recent NTIA/NCS report, W. Ingram describes a computer program (FIBRAM) that models the attenuation of optical fibers after simulated exposure to gamma radiation (Ingram, 1987). FIBRAM can be used to estimate the changes in bit error ratio (BER) in response to a variance in the intensity of exposed radiation, the transmit power level, and/or the physical configuration of the fiber link.

FIBRAM is used in this report to present several examples of the reaction of the bit error ratio to changes in the cable configuration and/or gamma radiation levels.

The first example will be based upon data taken from the FT3C Northeast Corridor lightwave digital transmission system as described in NCS Technical

Information Bulletin 85-11 (NCS, 1985). Figure G-3 shows a worst-case example of a regenerator section along the FT3C Northeast Corridor. Table G-1 shows the data used for this simulation.

Table G-1. Data Used for FT3C Northeast Corridor Model Using Single Mode Cable

Section Number	Protection Factor	Fiber Type	Length (meters)	Intrins. Loss (db/km)
1	4	SM, 1.3 μ m	30	0.380
2	7000	SM, 1.3 μ m	39390	0.380
3	1	SM, 1.3 μ m	580	0.380
4	10	n/a	photodiode	n/a
<u>Other Data</u>				
Total Transmit Power			10 μ watts	
Max. Gamma for Photodiode			1500 rads	
Regenerator Type			11D/11E/11F	
Fiber Manufacturer			AT&T	

The degradation of this system is to be simulated for the time period beginning immediately after radiation exposure and ending 90 million seconds (\approx 3 years) after exposure. The system is variously exposed to radiation dosages of 500; 1,000; and 5,000 rads. The bit error ratios are shown in Figure G-4 as a function of time.

The next example is also based upon data taken from the FT3C Northeast Corridor lightwave digital transmission system. Table G-2 shows the data used in this simulation.

This example shows the effect of varying the protection factor of the optical fiber strung across the bridge in Figure G-3 while keeping all other values constant. The bit error ratio is calculated beginning at the time of initial exposure and ending 90 million seconds (\approx 3 years) later. The bit error ratio is calculated for five different protection factors, 1, 2, 5, 10, and 1,000. The five graphs are shown together in Figure G-5.

By examining Figure G-5 at approximately 10^4 seconds after exposure, it can be seen that raising the protection factor of the bridge section from 1 to 10 results in the BER being reduced by a factor of more than 300 from approximately $10^{-5.5}$ to $10^{-8.0}$. Further improvement of the protection factor from 10 to 1,000 only improves the BER by about 25 percent from $10^{-8.0}$ to $10^{-8.1}$. A logical conclusion from this would be that a moderate amount of

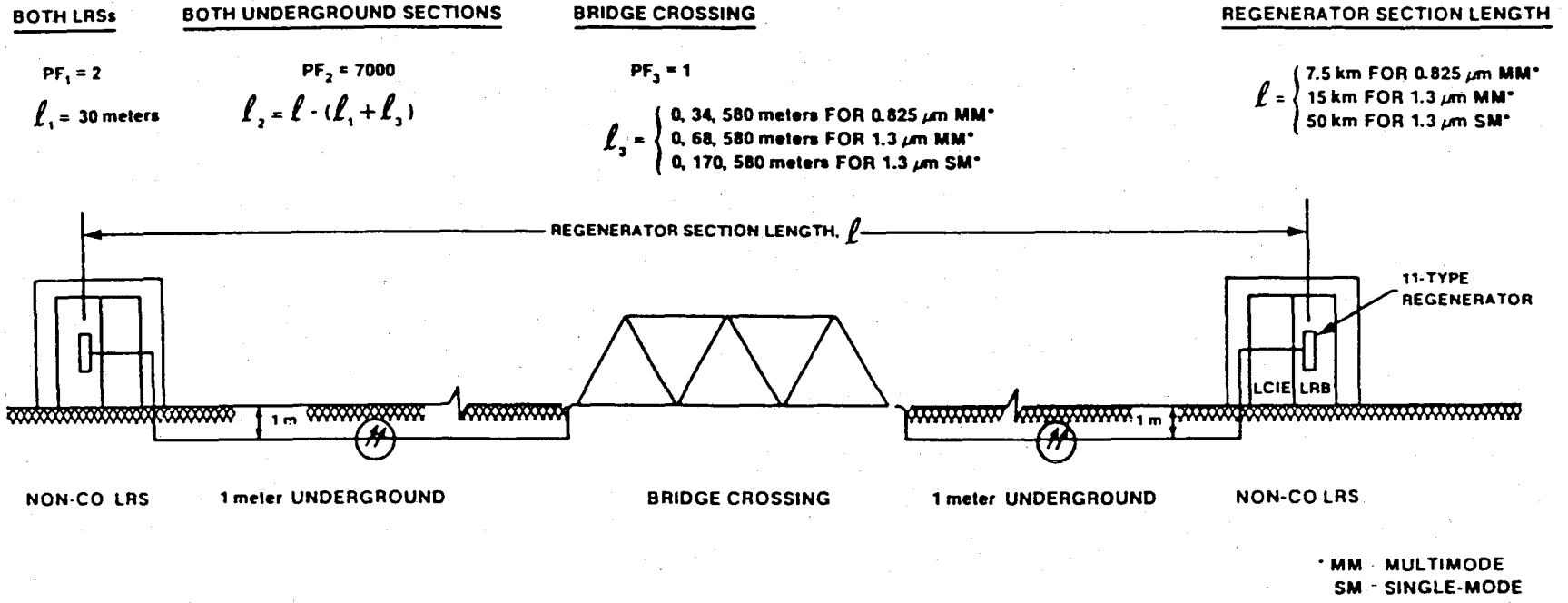


Figure G-3. System performance degradation example: worst-case regenerator sections of FT3C Northeast Corridor (NCS, 1985).

BER vs Time

AT&T Single Mode, 1.3 microns

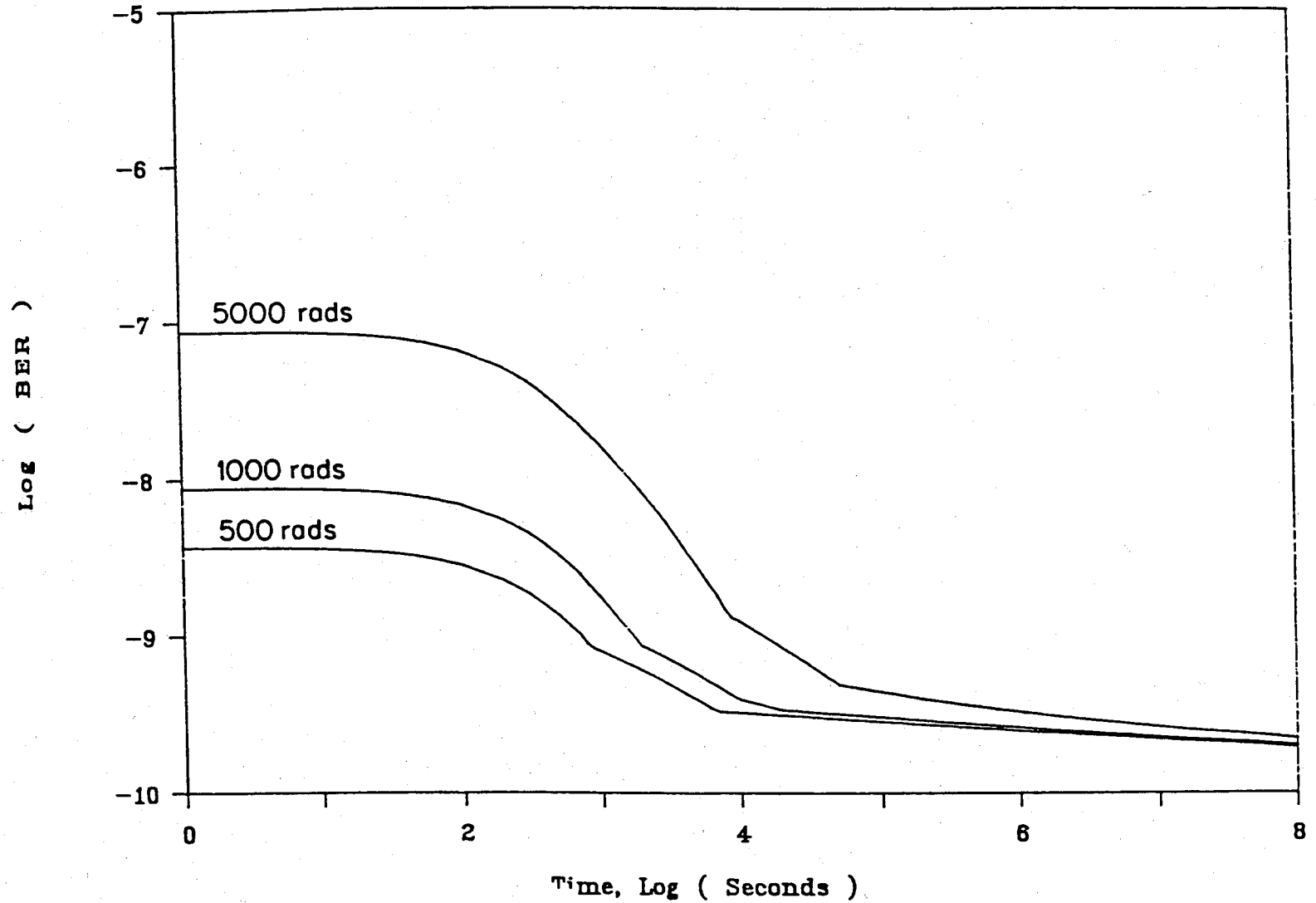
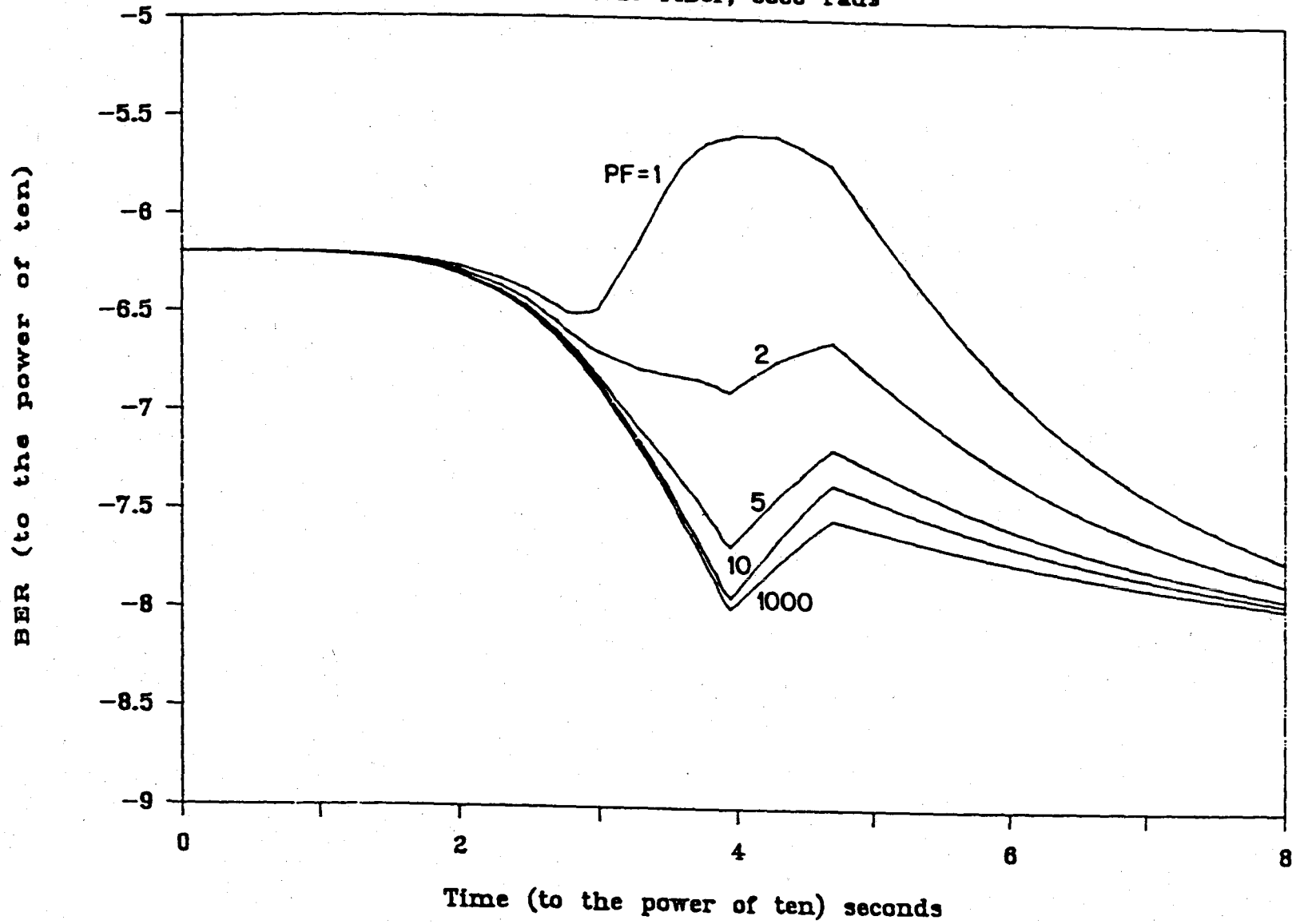


Figure G-4. "BER versus Time" graph for AT&T single mode fiber operating at a wavelength of 1.3 microns in response to various levels of fallout radiation (Ingram, 1987).

BER vs. Time

Multimode Fiber, 5000 rads



139

Figure G-5. "BER versus Time" graph for AT&T multimode fiber operating at a wavelength of 1.3 microns in response to various levels of fallout radiation.

protection is far better than no protection, but a large amount of protection is only somewhat better than a moderate amount.

FIBRAM can similarly be used to vary the radiation dosage rates, change the intrinsic losses, or substitute a different fiber type for each section. These results could then be compared and appropriate cabling selections could then be made.

Table G-2. Data Used for FT3C Northeast Corridor Model Using Multimode Cable

Section Number	Protection Factor	Fiber Type	Length (meters)	Intrins. Loss (db/km)
1	4	MM, 1.3 μ m	30	2.0
2	7000	MM, 1.3 μ m	14902	2.0
3	*	MM, 1.3 μ m	68	2.0
4	10	n/a	photodiode	n/a
<u>Other Data</u>				
Total Transmit Power			110 μ watts	
Total Exposed Gamma			5000 rads	
Max. Gamma for Photodiode			1500 rads	
Regenerator Type			11D/11E/11F	
Fiber Manufacturer			AT&T	
* indicates the PF is varied from 1 to 1000				

G.3.2 Station Damage

The best way to repair regenerator station damage is to prevent the damage in the first place. One way to do this is to bury the regenerator station in an underground shelter. The shelter would be best buried several feet (several meters) deep in soil. To protect the integrity of the structure, all entrances and exits should be covered with adequate protection. The entrance to the shelter could be sealed and buried along with the shelter itself. The shelter should have no ventilation shafts open to the atmosphere.

Because the shelter is completely sealed and buried several feet (several meters) underground, the station must be self-contained. The optical fibers and the incoming power supply cables will enter the station through sealed underground conduits. Sealed batteries must be used in the station because there would be no ventilation. The backup battery life must be able to run the station for a minimum of several weeks. This would be enough time for workers

to discover that a power supply problem exists, dig down to the entrance, and repair the damage.

By burying the shelter underground, such hazards as vandalism, weather damage, and HEMP damage can be drastically reduced. Although damage from earthquakes, sabotage, and war can never be completely eliminated, underground shelters can somewhat reduce the severeness of these events.

Should the shelter be damaged somehow, contingency plans must be made for the repair or replacement of the facility. The simplest method would be to design the shelter so that it could quickly be exhumed and replaced with an undamaged shelter. This shelter could be brought in by truck for stations near roadways or by helicopters to remote areas. A crane or helicopter could be used to lift the damaged station out of its crater and replace it with the replacement station. Once the replacement shelter is put in place, a team of workers could quickly resplice the cable connections and bring the station on line again.

Of course such a scheme would be very expensive to implement. Spare regenerator stations would depreciate and deteriorate while not in use. Helicopters can cost hundreds of dollars per hour to operate. A team of workers to resplice the cable can also cost hundreds of dollars per hour. In addition, helicopters and workers may be difficult to find in the aftermath of whatever caused the destruction of the regenerator station.

G.3.3 Power Loss

"Where were you when the lights went out?" "In the dark!", goes the old one-liner. But when a fiber optics regenerator station loses power, it's unlikely anyone would find it very humorous.

When power is lost, hundreds or even thousands of communication links will be broken. If the regenerator station is along a critical path between two major communication centers, the broken link might not be able to be reestablished.

To make matters worse, whatever event that caused the power loss will likely increase the volume of attempted calls over those and other telecommunication lines. For example, if an earthquake struck an area and knocked out power to a regenerator station, it will probably have caused damage to nearby towns also. The town's phone lines will subsequently be tied up with

outgoing emergency calls as well as incoming calls to find out if friends and relatives have survived.

Another example might be in the event of a war. Communications between the armed forces would be most critical during and after an attack by hostile forces. Unfortunately during and after an attack would be the most likely times of a power outage.

The installation of an integrated power system utilizing a continuous UPS, public utilities, automatic diesel generators, and PV cells can ensure that a regenerator station can survive and function in almost any environment short of total station destruction.

G.4 References

- Ingram, W.J. (1987), A program description of FIBRAM: a radiation attenuation model for optical fibers, NTIA Report 87-216/NCS Technical Information Bulletin 87-22, June. (NTIS Order number PB87-230686, report only; PB87-230678, report and data disk).
- Kindschuh, D. (1987), Cell grading improves communications batteries, Mobile Radio Tech. 5, Number 6, pp. 22-28, June.
- Knurek, D. (1987), Invertor evolution in UPS applications, Telephone Engineer & Management 91, Number 11, pp. 80-87, June 1.
- Maycock, P.D., and Stirewalt, E.N. (1981), Photovoltaics, Sunlight to Electricity in One Step (Brick House Publishing Co., 34 Essex St., Andover, MA).
- McVeigh, J.C. (1977), Sun Power. An Introduction to the Application of Solar Energy, (Pergamon Press, Maxwell House, Fairview Park, Elmsford, NY 10523).
- Murr, L.E. (ed.) (1980), Introduction to Solar Materials Science (Academic Press Inc., 111 Fifth Ave., New York City, NY 10003), p.7.
- NCS (1985), Assessment of nuclear fallout radiation on FT3C lightwave digital transmission system, National Communications System Technical Information Bulletin 85-11, November.
- Pontin, G. W-W. (1975), The bland economics of windpower, Wind Energy Supply Company, Redhill.
- Wilson, G.A. (1987), Batteries modernize for TELCO backup, Telephone Engineer & Management 91, Number 11, pp. 64-67, June 1.

BIBLIOGRAPHIC DATA SHEET

1. PUBLICATION NO. NTIA Report 88-231/ NCS TIB 88-02		2. Gov't Accession No.	3. Recipient's Accession No.
4. TITLE AND SUBTITLE Multitier Specification Applied to Modify the Hardness of an Essential NSEP Fiber Optic Link			5. Publication Date March 1988
7. AUTHOR(S) David F. Peach and Robert T. Adair			6. Performing Organization Code NTIA/ITS.N1
8. PERFORMING ORGANIZATION NAME AND ADDRESS National Telecommunications and Information Admin. Institute for Telecommunication Sciences 325 Broadway Boulder, CO 80303			9. Project/Task/Work Unit No.
11. Sponsoring Organization Name and Address National Communications System Office of Technology and Standards Washington, DC 20305-2010			10. Contract/Grant No.
			12. Type of Report and Period Covered
14. SUPPLEMENTARY NOTES			13.
15. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.) The Multitier Specification was developed to provide guidelines and recommendations for improving the durability of the communication installations necessary for National Security/Emergency Preparedness (NSEP). The application of the Multitier Specification is considered beyond the installation and engineering requirements of typical commercial fiber optic systems. Five levels of hardness are defined in the specification. A link that could be important (may be asked to provide service) to the operation of the U.S. Space Command/NORAD was chosen as a candidate for this analysis. Based on the time-critical nature of the telecommunication traffic carried on this link and the stress expected, the Level 4 (Maximum) hardness was chosen as the target level for upgrade of this link. The elements of the existing system are classified into levels using the Multitier Specification. This report describes the enhancements necessary to mitigate the stress threat within the guidelines of the Multitier Specification and to raise the level of hardness to Level 4 (Maximum). The cost associated with the installation of these enhancements is included. Solutions to problems peculiar to the path specified for the link are described in terms of <u>one</u> suggested alternative. Also, an estimate of the additional initial investment required to harden the system to Level 4 (Maximum) is included. Key Words: cost projections; durability; enhancements; fiber optic link; guidelines; hardness level; Multitier Specification; National Security/Emergency Preparedness (NSEP); stress threat; telecommunication systems; U.S. Space Command/NORAD			
17. AVAILABILITY STATEMENT <input checked="" type="checkbox"/> UNLIMITED. <input type="checkbox"/> FOR OFFICIAL DISTRIBUTION.		18. Security Class. (This report) Unclassified	20. Number of pages 152
		19. Security Class. (This page) Unclassified	21. Price:

