

# Multitier Specification for NSEP Enhancement of Fiber Optic Long-Distance Telecommunication Networks

## Volume I: The Multitier Specification —An Executive Summary

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**NATIONAL COMMUNICATIONS SYSTEM**



**U.S. DEPARTMENT OF COMMERCE**  
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## 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 6-10038. Several other reports are submitted as part of this study to provide background information for the Multitier Specification described in this report. Those reports are listed below, and the reports by Ingram (1987) and Nesenbergs (1987) are referenced in this report.

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 No. 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 No. PB 87-230686 (report only), NTIS Order No. PB 87-230678 (report and flexible disk).

Nesenbergs, M. (1987), Fiber optic networks and their service survival, NTIA Report 87-214/NCS TIB 87-9, 121 pp., NTIS Order No. PB 87-186706/AS.

Englert, T. J. (1987), Effects of radiation damage in optical fibers--A tutorial, 55 pp., May, NTIA Contractor Report 87-38, NTIS Order No. PB 87-210308.

This report is issued in two volumes. Volume I contains a summary of a Multitier Specification for stress hardening long-haul fiber optic telecommunications systems. This volume is intended for those who wish an executive summary of the specification. Volume II provides a more detailed analysis of the levels of protection defined in the Multitier Specification.

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 author and should not be construed as an official NTIA or NCS position or decision unless designated by other official documentation.

The author wishes to express his appreciation to those industry representatives who offered information and ideas for inclusion in the report. He extends thanks to the following ITS colleagues: Mr. Joseph Hull, Program Manager, for his sharing of background knowledge; Dr. William Kissick and Mr. Robert Adair for their technical reviews; Mrs. Lenora Cahoon for her editorial review; and Ms. Karen Marvin for her word-processing assistance. Mr. David Blaylock, Federal Emergency Management Agency (FEMA) Regional VIII Engineering Office, and Dr. Thad Englert, University of Wyoming Department of Electrical Engineering, also contributed through their technical reviews.



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## LIST OF ACRONYMS

AT&T - American Telephone and Telegraph Company

CCITT - International Telephone and Telegraph Consultative Committee

CNS - commercial network survivability

EMP - electromagnetic pulse

FCC - Federal Communications Commission

FEMA - Federal Emergency Management Agency

GTE - General Telephone & Electronics Corp.

HEMP - high altitude electromagnetic pulse

ITS - Institute for Telecommunication Sciences

MCI - MCI Communications Corporation

MFJ - Modification of Final Judgement

MTBF - mean time between failures

NCS - National Communications System

NSDD - National Security Decision Directive

NSEP - National Security/Emergency Preparedness

NSTAC - National Security Telecommunications Advisory Committee

ROW - rights-of-way

TPD - transient protection device

## DEFINITION OF TERMS COMMONLY USED BY INDUSTRY

- closure -- A device that surrounds the fiber splices (the number of splices will be determined by the number of fibers contained within the fiber optic cable). The closure protects the splices by closing off exposure to the environment (i.e., air, moisture, dirt, chemicals, etc.)
- conduit -- A rigid tube, made of metal, fiberglass, or plastic, whose primary purpose is to protect the fiber optic cable. A conduit can also be constructed by encasing a duct in concrete.
- duct -- A rigid tube, usually made of plastic, that is used to support and protect a fiber optic cable installed above or below the Earth's surface. The duct is used primarily to allow lineal movement of the cable (i.e., for cable replacement and for temperature or earthquake stress relief) and provide limited protection from the physical environment.
- enclosure -- A structure that surrounds the regenerator electronics and associated hardware, along the fiber optic path placed at, approximately, 25-mile (40-kilometer) intervals. The primary purpose of the enclosure is to control the environment and to protect the enclosed hardware from external stress.
- enhancement -- A modification or improvement feature applied to a system that will increase its hardness.
- hardness -- The ability of a component, element, or system to withstand nuclear effects or natural disaster.
- hardness levels -- The extent to which protection factors have been applied to enhance the capability of a system to withstand stress.
- innerduct -- A duct that is placed within a conduit primarily for organization (i.e., to provide separation of adjacent cables within the same conduit).
- mode -- A way (path) that light energy is propagated along the optical fiber. The field distribution that is associated with the propagation must satisfy Maxwell's equations.
- multimode -- Denotes the capability of an optical fiber to propagation more than one mode of light.
- Multitier Specification -- A ranking of hardness levels which provide a progressively higher level of protection.
- protection level -- The amount of physical resistance (enhancements) installed to reduce the effects of stress.



DEFINITION OF TERMS COMMONLY USED BY INDUSTRY (cont.)

- single-mode -- Denotes the capability of an optical fiber to propagate a single mode of light.
- stress -- The result of an event or situation that modifies the normal environment of a component or physically damages a part of the system.

**MULTITIER SPECIFICATION FOR NSEP ENHANCEMENT OF FIBER OPTIC  
LONG-DISTANCE TELECOMMUNICATION NETWORKS**

Volume I: The Multitier Specification--An Executive Summary

David F. Peach\*

Fiber optic telecommunication systems are susceptible to both natural and man-made stress. National Security/Emergency Preparedness (NSEP) is a function of how durable these systems are in light of projected levels of stress. Emergency Preparedness in 1987 is not just a matter of--can we deliver food, water, energy, and other essentials?--but can we deliver the vital information necessary to maintain corporate function of our country? "Communication stamina" is a function of "probability of survival" when faced with stress. This report provides an overview of the enhancements to a fiber optic communication system/installation that will increase durability. These enhancements are grouped, based on their value in protecting the system, such that a Multitier Specification is created that presents multiple levels of hardness. Mitigation of effects due to high altitude electromagnetic pulse (HEMP) and gamma radiation, and protection from vandalism and weather events are discussed in this report. This study concludes that the probability of survival can be significantly increased with expeditious use of design and installation enhancements. The report is presented in two volumes entitled as follows:

Volume I : The Multitier Specification--An Executive Summary

Volume II: Multitier Specification Background and Technical Support Information

Volume I presents the Multitier Specification in a format that is usable for management review. The attributes of specified physical parameters, and the levels of protection stated in Volume I, are discussed in more detail in Volume II. This study is intended to be a guideline to aid in design and implementation, when the intent is to create a more durable, long-haul, fiber optic telecommunication system.

Key words: electromagnetic pulse (EMP); EMP hardening; fiber optics; fiber optic cable; fiber optic systems; gamma-radiation hardening; high altitude electromagnetic pulse (HEMP); long-distance telecommunication systems; National Security/Emergency Preparedness (NSEP); single-mode fiber optic cable; stress hardening; telecommunications; telecommunication survivability; telecommunication system hardening enhancements

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## 1. INTRODUCTION

This volume provides an introduction to the Multitier Specification and discusses the technical background needed to understand the rationale behind the specification. It is submitted by the Institute for Telecommunication Sciences (ITS) to the National Communications System (NCS), Office of Technology and Standards, in partial fulfillment of Reimbursable Order Number 6-10038. The primary output of this study is a Multitier Specification for NSEP-enhancing features required of commercial fiber optic transmission systems using rights-of-way (ROW) owned or controlled by the Federal Government, and included in this report.

### 1.1 NCS Mission

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 telecommunications 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 telecommunications planning; and establish a joint industry-Government National Coordinating Center (NCC). This study supports the national security telecommunications policy as enunciated in National Security Decision Directive (NSDD-97)... "the national telecommunications 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."

### 1.2 Purpose of Study

The primary purpose of the study is to prepare a Multitier Specification identifying prudent measures that could be incorporated in the design of commercial intercity fiber optic transmission systems to make them more responsive to NSEP requirements in exchange for right-of-way concessions by the Government. The specification will be structured in such a way that it also can be used as a "report card type" instrument for assessing the degree to

which present and future intercity fiber optic systems not using Federally controlled rights-of-way measure up from an NSEP standpoint. The spectrum of situations the fiber optic systems must cope with from an NSEP standpoint include natural disasters (e.g., floods, earthquakes, fire), local acts of sabotage, nuclear attacks [i.e., nuclear radiation effects and high altitude electromagnetic pulse (HEMP) effects]. The design parameters addressed by the specification will be those that tend to minimize interruptions of service in the face of these hazards by proper attention to features that facilitate quick restoral of operation or bridging around damaged terminals or repeaters.

### 1.3 Historical Perspective

In 1934, the Communications Act created the Federal Communications Commission. Part of the purpose of the Commission was to regulate telecommunications "in the public interest"--a phrase that apparently has no legal definition that can be cited as a yardstick (Bell, 1985). One of the FCC's missions was, in the words of the 1934 act, "to make available, so far as is possible, to all the people of the United States, a rapid, efficient, nationwide, and worldwide wire and radio communication service with adequate facilities at reasonable charges. AT&T was established as a monopoly to provide this "universal service at a reasonable rate." As a monopoly, AT&T was able to cross subsidize between long-distance and local rates to minimize the cost of less utilized portions of the network. Because the company could rely on its manufacturing expertise provided by Western Electric, it could assure uniform quality in all equipment.

In 1949, the Justice Department filed a major antitrust suit against both AT&T and Western Electric. The accusation dealt with the restraint of trade in the manufacture, distribution, sale, and installation of all forms of telephone apparatus in violation of the Sherman Antitrust Act. The result of this suit was a 1956 out-of-court consent decree that allowed the Bell System to remain intact on condition that it restrict its business to common carrier communication services subject to regulation. Western Electric was barred from manufacturing equipment other than the type used by the Bell System. AT&T, Western Electric, and Bell Laboratories were required to license their patents to all applicants--both domestic and foreign--upon payment of reasonable royalties. During the 1970s the Bell System and its allies pressed Congress for a new telecommunications policy bill that would update the 1934

Communications Act. The company wanted affirmation of the premise of universal service as a natural monopoly and the Bell System as the regulated quasi-utility to fulfill that service. During this period, several competitors (notably MCI) sued the Bell System for unfair anticompetitive practices under the Sherman Antitrust Act.

The advance of technology during the 1960 and 1970 decades made the 1956 consent decree highly constraining to the world's largest company. AT&T recognized the coming of an Information Age brought about by the marriage of computers and telecommunications. Consequently there was much effort to remove the restrictions of this decree to permit competition in the evolution of the information explosion.

In 1980, the FCC handed down a ruling, called the Second Computer Inquiry Decision. It did three things:

- It distinguished between basic transmission services, traditionally provided by common carriers, and enhanced network services such as those incorporating data processing.
- It found that enhanced services and customer-premises equipment would not be regulated as common-carrier offerings, whereas basic services should be so regulated.
- It concluded that AT&T should be allowed to sell equipment and enhanced services, but only through a separate subsidiary.

This Computer II decision opened the way for an explosion of new telecommunications products and services both by new suppliers and AT&T.

In 1974 the Justice Department brought an antitrust suit against AT&T, Western Electric, Bell Telephone Laboratories, and the 22 Bell Operating Companies again under the Sherman Antitrust Act. The Justice Department alleged that AT&T monopolized the long-distance telephone business by exploiting its control of the local telephone companies to restrict competition from other telecommunication systems and carriers by denying interconnection with the local phone service and that AT&T restricted competition from other manufacturers and suppliers of customer-premise equipment. The relief sought was not punishment for past deeds, but a cure that would prevent continued future violations. This suit was settled in 1982 through what is known as the Modification of Final Judgment (of the 1956 Consent Decree). This MFJ brought about the divestiture of the 22 Bell Operating Companies and a major

reorganization of the remaining Bell System and the removal of the restrictions of the 1956 Consent Decree. The divestiture took place on January 1, 1984.

One major result of the divestiture is the competitive installation of long-haul, fiber optic, common carrier systems. The technology for these systems has matured extremely rapidly under the competitive environment.

By April 1985, 12 companies had announced (Galuszka, 1985) plans for long-distance lightwave communication systems in the United States (see Table 1). In many cases, these common carrier or carrier's carrier systems will utilize ROWs of a few main trunk railways. There are more than 7 billion circuit miles of transmission capacity indicated here over a distance of 65,650 route miles. By the year 2000, it is forecast (By F. Dixon, of Electronicast Corporation, Redwood City, CA, in a paper presented at the Conference entitled "Fiber Optics of the Year 2000," held in Monterey, CA, June 16, 1985) that worldwide fiber optic transmission capacity will be about 200 billion circuit miles. All other transmission media combined will provide an additional 50 billion circuit miles. These trends indicate that fiber optic transmission media will be the dominant means of connecting nodes of the public switched telephone and data networks in the United States. The opportunity exists to plan for lightwave systems that assure the availability of emergency communications capacity through engineering design and implementation practices.

#### 1.4 Scope and Purpose of Report

The Multitier Specification concentrates on the engineering and installation aspects of optical communication, common-carrier-type systems and recommends those additional practices or alternatives that result in higher probability of survival or restoral in a broad range of NSEP environments. The rating approach is a multitier, rank-ordered specification.

This report is intended to provide background information and references needed to understand the rationale and basis for the NSEP enhancements. The specification is intended to be a living instrument that will grow and improve as feedback from the common-carrier industry is obtained and as more complete assessment of the NSEP environments and enhancements is reached. This report is not intended to be comprehensive or definitive, but rather a record of the literature, references, and considerations that were found useful in guiding

Table 1. Planned Lighwave Installations for the United States  
(after Galuszka, 1985)

LIGHTWAVE PLANS

COMPANY	INVESTMENT	AREAS	CIRCUIT MILES	ROUTE MILES/ DATE
United Telecommunications	\$2.0 B	National	1.2 B	23 K/1988
AT&T Communications	1.3 B	National	1.7 B	10 K/1988
Fibertrak (Sante Fe, Southern Pacific, Norfolk Southern)	1.2 B	National	2.4 B	8.1 K/1988
MCI Communications	450 M	National	550 M	8.0 K/1988
GTE Sprint	130 M	National	110 M	4.0 K/1989
Lightnet (CSX and SNET)	500 M	Regional (East of Miss. River)	650 M	4.0 K/1986
LDX Net (Kansas City South Industries)	110 M	Regional (South, Midwest)	165 M	1.7 K/1986
SOUTHERNET (E.F. Hutton et al.)	90 M	Regional (Southeast)	50 M	1.6 K/1986
RCI	90 M	Regional (Northeast, Midwest)	87 M	0.9 K/1986
Microtel (Alltel, E.F. Hutton, Centel, Norfolk Southern)	60 M	Regional (Florida, Georgia)	45 M	1.5 K/1986
Litel Telecommunications (Centel, Alltel, and Pirelli)	57 M	Regional (Midwest)	85 M	1.3 K/1986
Electra Communications	40 M	Texas	72 M	0.55K/1986

(Source: The Hudson Institute)

the work. The work has been based entirely on unclassified literature and information.

### 1.5 Organization of Report

The intent of this report will be to provide guidance in designing a durable fiber optic telecommunication system. The guidance will be provided by a "Multitier Specification" that is outlined in this Volume (I) of the report. Enhancements that improve the survivability, when the system (or component) is stressed, are discussed and their benefit to making the system more durable is presented. Data made available in this report will aid in predicting the stamina of a particular fiber optic, long-haul path.

Background information is presented in order that the scope of the study is understood. A discussion of the components that make up the fiber optic path is provided to allow a more structured approach to studying the problem.

Stresses that affect a fiber optic telecommunication system, or its components, are discussed next. An attempt has been made to define the type of damage that can be expected from each type of stress and whether the damage is gradual (due to deterioration) or catastrophic (causing immediate interruption of service). A presentation of the stress categories, based on whether they are occurrences of nature or caused by humans, is also included. This breakdown is useful for discussion in later portions of this report.

The next section presents a technical discussion concerning the fiber optic system components, their design options, and the design enhancements that provide resistance to stress. This section concentrates on physical parameters of the system.

Environmental enhancements that can be incorporated when installing or "placing in service" the cable and the regenerator station are discussed next. At this point one must realize that the design and the environment are integral in some cases, and separation is difficult. The discussion of enhancements will reflect these circumstances.

The main objective of this study is to provide protection from stress--countering the effects of stress is the defined problem. "Solutions" to the problems that are of concern to the fiber optic system and components designer are presented in Volume II. An attempt has been made to define the extent of protection that can be provided--since total protection is not always possible as pointed out in this portion of the report. For each major



classification of stress, an analysis is provided that defines the level or extent of protection that can be expected for each level of the Multitier Specification.

### 1.6 NSEP Implications for Fiber Optic Systems

In terms of hardness, fiber optic system survivability can be significantly extended by following the recommendations of the current study.

In terms of restorability, fiber optic systems offer unique capabilities for automatic restoration when configured in networks (Nesenbergs, 1987).

In terms of security, fiber optic services are inherently well suited to deny access to transmission content by an enemy and are free from the effects of jamming.

In terms of connectivity, present fiber optic, long-haul systems are concentrated along railway right-of-ways. The rapid introduction of IntraLATA (within a single LATA calling area) fiber optic systems along with judicious planning of interconnecting links could add significantly to this capability. The concept of this program is to make judicious choices of needed linkages and to utilize interstate highway rights-of-way as means of interconnecting population centers. These rights-of-way provide highly redundant paths between these population centers.

Redundancy is an attribute conveying the duplicity of routes, paths, or even equipment types that may be employed in a network or system. As a result, redundancy measures tend to be highly dependent on network topologies and site-specific installation procedures and more reflective of system rather than component attributes.

## 2. TYPES OF STRESS

A telecommunication system is subject to interruption from numerous causes. Some of these causes are predictable, but most are a result of random events. Many of these events occur as a result of the "forces of nature" and are virtually unpredictable--especially the events of a severe level. The severe events are of most concern to the survivability of a telecommunication system since they will do the most damage. Nature-caused events will be discussed later in this report. In addition to the stress caused by nature, there are many events that are caused by humans. Like the events of nature, many of the man-caused events are unpredictable because they are a result of

random occurrences (e.g., accidents, construction work, environmental pollution). These events are easiest to protect against because the magnitude of the stress is predictable; thus measures can be taken to avoid the interruption of operation. These measures will be discussed later in the report. Premeditated man-made damage is also a very real concern (e.g., damage caused by vandalism, sabotage, and nuclear weapons). The magnitude of stress associated with these events is not only unpredictable, but the ingenuity of humans comes into play. Protection by design or physical means is impossible because there are no limits on the extent of the stress. Hardening of a system against this type of stress will be dealt with, in concept, later in this report.

## 2.1 Key Elements

This report will assume that a fiber optic telecommunication system is made up of three major functional components: the fiber optic cable, the system regenerator electronics, and the people that may be necessary for continued operation. Each of these vital components can be enhanced to yield a more survivable telecommunication path or network. Obviously, if manual intervention is not necessary for day-to-day operation, the effect on people can be eliminated. However, if restoration of the system is of importance, the effect on human life/health must still be included. For purposes of this report, the assumption will be made that protection of humans is important.

## 2.2 Controllable Parameters

Physical protection for the key elements of the fiber optic system is necessary if positive protection from stress is desired. In addition to the physical protection, design parameters that will enhance the durability of components will be included in the discussion. Many of the enhancement ideas are brute-force techniques, however, and implementation is of essence. The implementation may be simple, or may seem so, but may not be easy. Expertise in doing a quality installation, with implementation of enhancements, is a necessity.

The controllable parameters, as shown in Table 2, are a function of the design and of the environment.

Table 2. Controllable Parameters

Key Element	Parameter
1. Fiber optic cable	<ul style="list-style-type: none"> <li>• Component design</li> <li>• Configuration design</li> <li>• Cable environment</li> </ul>
2. Fiber optic regenerator	<ul style="list-style-type: none"> <li>• Electronics design</li> <li>• Enclosure design</li> <li>• Enclosure environment</li> </ul>
3. Personnel	<ul style="list-style-type: none"> <li>• Environment</li> </ul>

### 2.3 Fiber Optic System Stress Sources

The sources of stress that are a threat to the fiber optic telecommunication system can be classified into two categories:

- events of nature
- man-made events

The source of stress on fiber optic telecommunication systems results from events of nature--such as wind, rain, ice, snow, flood, temperature extremes, sun, lightning, earthquakes, rodents--or from man-made events, such as vandalism, sabotage, construction work, agricultural works, accidents, chemical spills, nuclear explosions. The list of stress initiators increases daily as our culture becomes more active and complex, and the activity related to development of lands becomes more widespread.

Events that emanate from nature are usually not controllable; therefore, mitigation must be a result of hardening the system. The logical solution is to design harden the components, thus increasing the system stamina when subjected to stresses of nature. It is frequently more feasible, economically and technically, to modify the environment surrounding the components of the system. In order that we can devise methods to mitigate the effects of events originating from nature, generic categories of events that cause similar effects (damage) have been created. The common stress categories and stress sources that originate from nature are listed in Table 3 along with the damaging effect that can be expected from each category.

Table 3. Naturally Occurring Stress Types/Effects (CCITT, 1985)

Stress Type	Effects on Fiber Optic System
Temperature	Cable compression in duct by freezing Breakage and shrinkage due to temperature change
Winds (sea winds)	Damage to cable sheaths and joints due to vibration
Rain water (hot springs)	Corrosion, water penetration
Snow and Ice	Cuts, breaks, sagging, lines down
Moisture	Corrosion, dielectric breakdown
Lightning	Puncture of cable sheath, fusing metallic pairs
Earthquakes	Breaking
Geography, soil	Cuts, personnel falls due to sinking
Sun	Fading, degradation
Rodents, birds, insects	Sheath damage, fiber separation

Man-made stress results from either premeditated or accidental events that cause damage. The damage can be either permanent or temporary depending on the stress type. The mitigation options for man-made stress are: to somehow stop the man-made event from happening, to harden the design of the components, or to harden the environment in an attempt to build a barrier between the fiber optic components and the stress source. Table 4 lists some of the results of man-made events that cause either short-term or long-term effects on a fiber optic system.

### 3. SYSTEM DURABILITY ENHANCEMENT

The cable construction generally determines the durability of the cable. However, the material makeup of the cable can be shown to have an effect on the functional durability of the cable under certain stress conditions. The characteristics of some materials change when exposed to certain stress types. If these characteristics are crucial to the function of the optical fiber, a degradation in performance will occur, or in some cases the system will become inoperable.

The objective of the Multitier Specification is to identify enhancements that will harden the fiber optic cable installation against various types of stress. Using available parametric data, the level of stress resistance can be predicted. Since fiber optic technology is relatively new, and only limited in-place (field installed) testing has taken place, some of the parametric data will be somewhat sketchy. The areas where data are incomplete can be used as areas for future testing or topics for further study.

The factors that affect the durability of the fiber optic installation can be divided into two categories:

- physical properties of the hardware,
- environmental parameters surrounding the hardware

Physical properties can make a system resistant to some types of stress conditions to which the hardware will be subjected. In some cases "brute force" design will be sufficient to protect the hardware, while more subtle design features will be required to provide the required resistance. Design changes as simple as using a different material will, in some cases, add resistance to a stress condition. Shielding the fiber optic hardware from

Table 4. Man-made Stress Types/Effects (CCITT, 1985)

Stress Type	Effects on Fiber Optic System
Factory smoke	Corrosion
Cars, trucks	Damage to cable sheaths and joints due to vibration/accidents
Construction work	Cutting or breaking the cable
Communications systems power supply	Damage to cables and hazards to personnel
dc currents	Electrolytic corrosion
ac traction systems	Damage to cables and hazards to personnel
Power lines	Damage to cables and hazards to personnel
Petroleum gas leakage	Damage to cable sheath
Steam and hot water systems	Damage to cable sheath
Vandalism	Sheath damage, cutting
Gamma radiation	Darkening of the fiber/increased loss
Electromagnetic pulse	Damage to cable components and/or fiber

stress is necessary when it is not practical or, in some cases, not possible to provide stress resistance by changes of design parameters.

#### 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

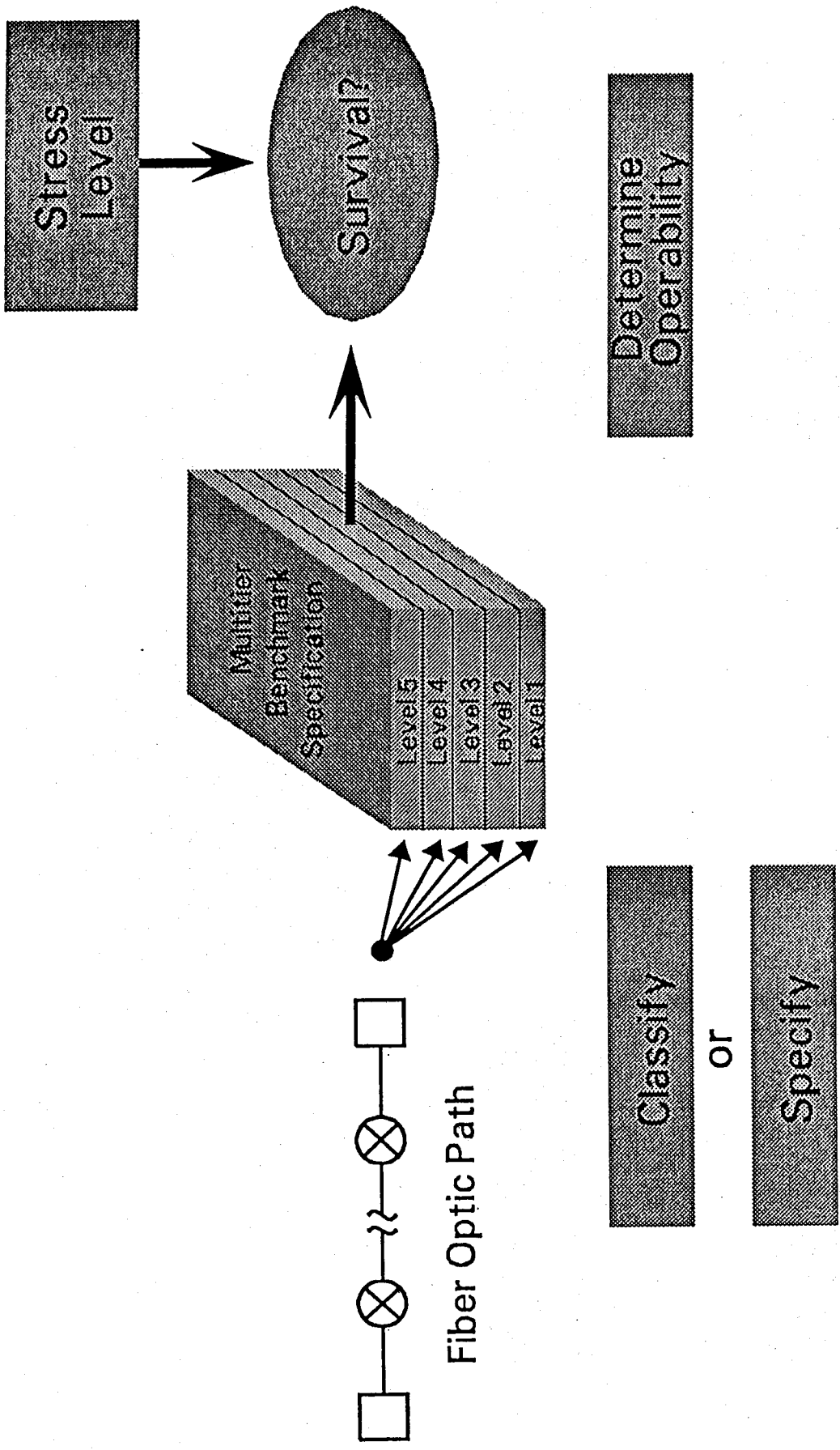


Figure 1. Multitier specification as a tool to classify or specify.



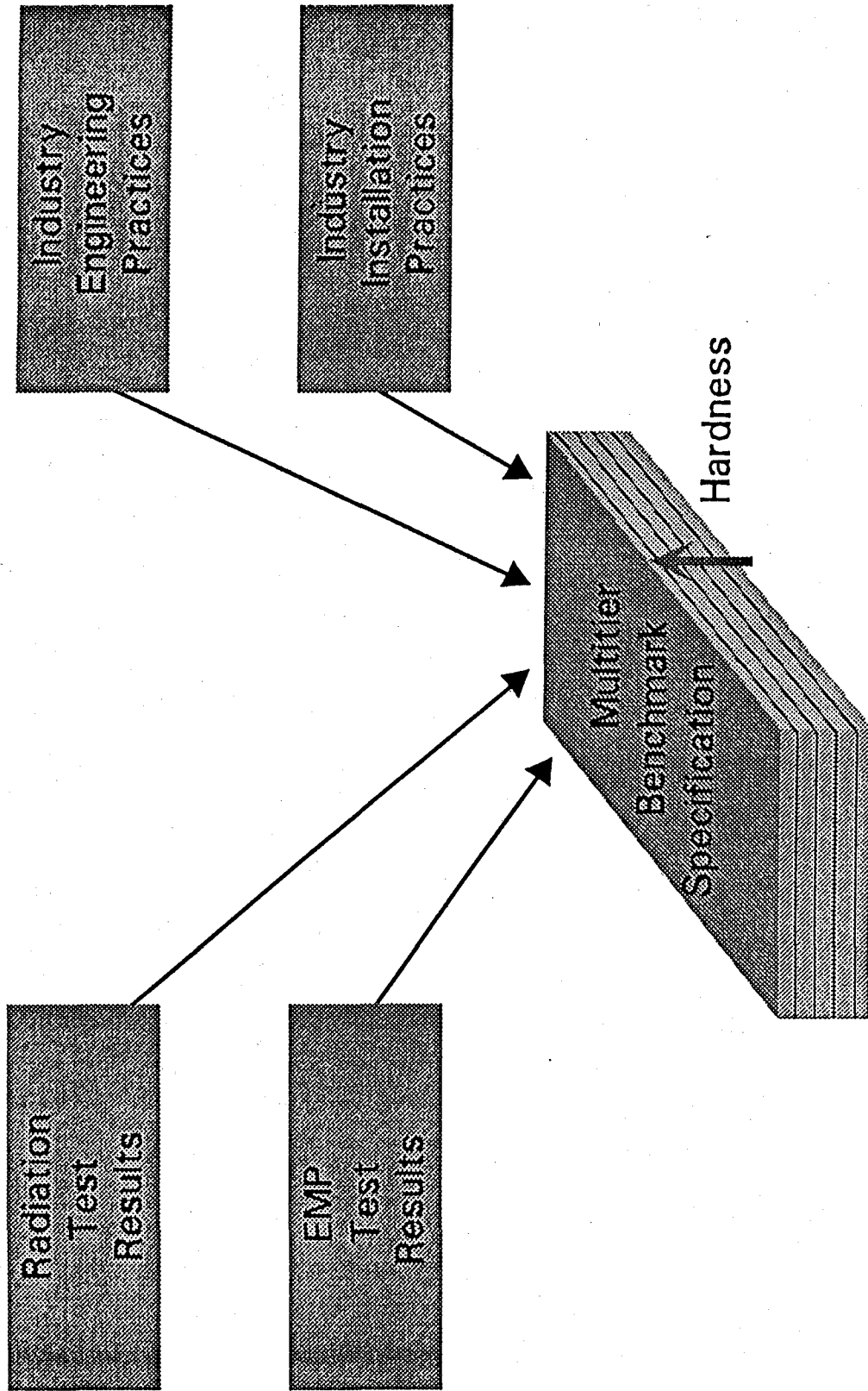


Figure 2. Inputs to the multitier specification.

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). 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

Table 5. Incremental Stress Improvement Areas/Risk Areas

HARDNESS LEVEL	IMPROVEMENTS	RISK AREAS
Level 1 (Minimum) • Surface/Aerial	---	---
Level 2 (Moderate) • Surface (with Duct) or Underground (12-24 in/0.3-0.6 m) • With or without EMP Shield • Surface Enclosure	Events of Nature Gamma Radiation EMP  Blast Extreme Temperature	Rodents Earthquake
Level 3 (Significant) • Underground (36 in/0.9 m) • With or without EMP Shield	Gamma Radiation EMP  Extreme Temperature Accidents Vandalism	Earthquake
Level 4 (Maximum) • Underground (48 in/1.2 m) • With or without EMP Shield	Gamma Radiation EMP  Extreme Temperature Rodents Lightning	Earthquake
Level 5 (Virtual) • Parallel Paths	All	HEMP

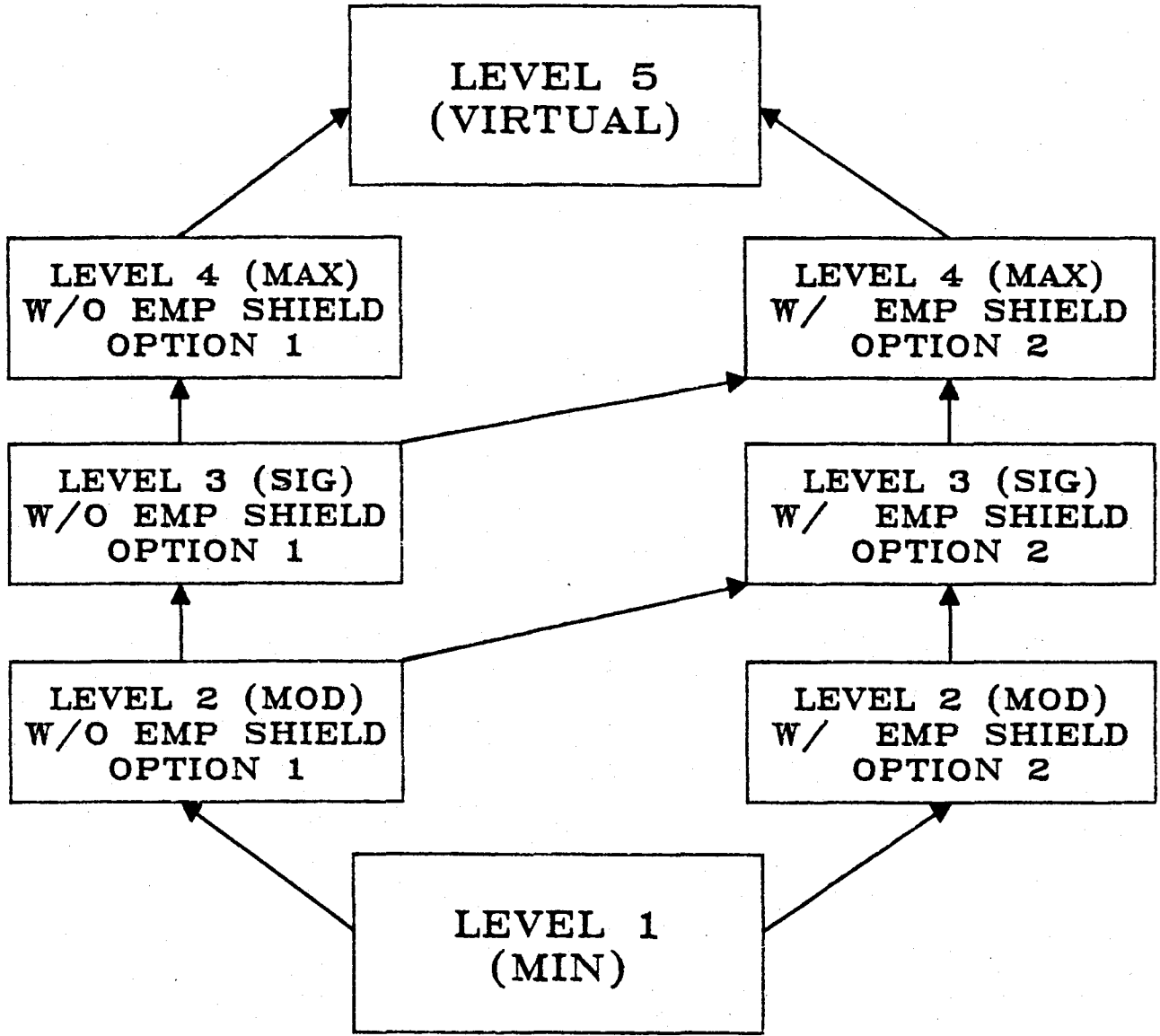


Figure 3. Multitier specification upgrade options.

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 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

Table 6. Multitier Specification--Relative Level of Protection

1 - LEAST PROTECTION  
10 - MOST PROTECTION

HARDNESS LEVEL	EMP OPTION		RADIATION		EXTREME TEMP.	BURST /WIND	RODENTS	EVENTS OF NATURE
	1	2	@1MeV	@6MeV				
Level 1 (Minimum)	4	-	1	-	3	2	3	2
Level 2 (Moderate)	6	10	3	1	6	5	10	7
Level 3 (Significant)	7	10	10	4	10	9	10	8
Level 4 (Maximum)	8	10	10	7	10	9	10	9
Level 5 (Virtual)	10	10	10	10	10	10	10	10

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 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.

#### 4.2 Level 1 (Minimum) Hardness

Level 1 (Minimum) hardness (stress resistance) is used for paths where continuous operations are not a necessity and time-critical traffic is not expected to be transmitted. Protection is afforded for day-to-day natural events such as weather, minor accidents, and deterioration due to common elements of nature (e.g., sunlight, moisture, wind, ice, snow).

A system with this level of hardness may not survive an atypical event of man or nature. These events include 10-, 25-, 50-, and 100-year floods or storms, severe earthquakes, and major accidents in the vicinity of the installation.

The survivability of this system will be marginal, at best, characterized by frequent outages of service, extended downtime, and laborious repair. Emergency communication circuits should not be placed on an installation of this type without some type of backup communication service (e.g., parallel route, microwave link, or satellite).

##### 4.2.1 Physical Parameters

Recognizable physical characteristics of this level system are noted below.

- The system is an aerial installation with the cable exposed to the environmental conditions--such as a pole-to-pole installation where the cable is not protected or surrounded with conduit or duct.
- A significant (i.e., 25 percent or more) portion of cable is installed or supported along or near the surface of the Earth or is supported by some type of rigid structure (e.g., a bridge or viaduct) near ground level. The cable is unprotected (i.e., it may be installed without protection of a conduit, duct, or metallic sheath).
- The cable design does not possess those attributes that make it resistant to stress such as gamma radiation or physical stresses due

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

<u>Physical Properties</u>	<u>Minimal Hardness (Level 1)</u>	<u>Moderate Hardness (Level 2)</u>	<u>Significant Hardness (Level 3)</u>	<u>Maximum Hardness (Level 4)</u>
<ul style="list-style-type: none"> <li>o <u>Cable</u> <ul style="list-style-type: none"> <li>Installation Type</li> <li>Installed without duct</li> </ul> </li> <li>o <u>Regenerator Enclosure</u> <ul style="list-style-type: none"> <li>Installation Type</li> </ul> </li> </ul>	<p>Aerial</p> <p>&gt; 25% of length</p> <p>Surface - wood frame reinforced</p>	<p>Underground 12-24 in. (0.3-0.6 m)</p> <p>None</p> <p>Surface - concrete reinforced with earth berm, but no earth cover. Bonded-rebar reinforced cage.</p>	<p>Underground &gt; 36 in. (0.9 m)</p> <p>None</p> <p>Underground &gt; 36 in. (0.9 m)</p>	<p>Underground &gt; 48 in. (1.2 m)</p> <p>None</p> <p>Underground &gt; 48 in. (1.2 m)</p>
<p><u>Stress Protection Parameters</u></p> <ul style="list-style-type: none"> <li>o <u>Heat (Fire Resistance)</u></li> <li>o <u>Blast (Wind) Resistance</u></li> <li>o <u>Wind Resistance</u></li> <li>o <u>Lightning</u></li> <li>o <u>EMP</u></li> <li>o <u>Gamma Radiation</u> <ul style="list-style-type: none"> <li>Cable</li> <li>Regenerator</li> </ul> </li> <li>o <u>Earthquake</u> <ul style="list-style-type: none"> <li>Cable</li> <li>Regenerator</li> </ul> </li> <li>o <u>Back-up Power Source</u></li> <li>o <u>Rodent Protection</u></li> <li>o <u>Electrical Grounding</u></li> </ul>	<p>Limited protection</p> <p>1-2 psi (&lt;70 mph)</p> <p>&lt; 70 mph (1, 2, &amp; 5-year events)</p> <p>Minor lightning-frequent interruption</p> <p>Structure Only: 10 dB atten.</p> <p>None</p> <p>Limited protection</p> <p>Limited protection</p> <p>Survives 1, 2, &amp; 5-year events</p> <p>None</p> <p>Limited protection</p> <p>Standard electrical ground</p>	<p>Good protection</p> <p>2 psi (70 mph)</p> <p>&lt; 100 mph (1, 2, 5, 10, &amp; 25-year events)</p> <p>Moderate lightning-very little interruption</p> <p>Structure Only: 25 dB atten. Structure &amp; Shield: 80 dB atten.</p> <p>Absorption factor = 35 dB at 1 Mev particle energy level</p> <p>Absorption factor = 2 dB at 1 Mev particle energy level</p> <p>Ground separation &lt; 1 in. (2.5 cm)</p> <p>Survives 1, 2, 5, &amp; 10-year events</p> <p>8-hour rechargeable battery</p> <p>Good protection (service interruption minimal)</p> <p>Meaningful electrical ground (penetration to water table)</p>	<p>Excellent protection</p> <p>5 psi (150 mph)</p> <p>&lt; 110 mph (1, 2, 5, 10, 25, &amp; 50-year events)</p> <p>Heavy lightning-very little interruption</p> <p>Structure Only: 40 dB atten. Structure &amp; Shield: 80 dB atten. 2-stage TPD protection</p> <p>Absorption factor &gt; 50,000 at 1 MeV particle energy level</p> <p>Absorption factor &gt; 50,000 at 1 MeV particle energy level</p> <p>Ground separation &lt; 4 in. (10 cm) 2% slack in slack pits cable in PVC innerduct</p> <p>Survives 1, 2, 5, 10, 25, &amp; 50-year events</p> <p>Sustains power for 7 days</p> <p>Excellent protection (service interruption rare)</p> <p>Meaningful electrical ground 2-stage TPD protection</p>	<p>Full protection</p> <p>10 psi (1,400 mph)</p> <p>&gt; 130 mph (1, 2, 5, 10, 25, 50, &amp; 100-year events)</p> <p>Multiple lightning strikes-very rare interruption</p> <p>Structure Only: 50 dB atten. Structure &amp; Shield: 80 dB atten. 3-stage TPD protection</p> <p>Absorption factor &gt; 2,000,000 at 1 Mev particle energy level</p> <p>Absorption factor &gt; 2,000,000 at 1 Mev particle energy level</p> <p>Ground separation &lt; 12 in. (0.3 m) 6% slack in slack pits cable in PVC innerduct</p> <p>Survives 1, 2, 5, 10, 25, 50, 100, &amp; 250-year events</p> <p>Sustains power for 14 days</p> <p>Full protection (service interruption very rare)</p> <p>Meaningful electrical ground 3-stage TPD protection</p>



to weathering or natural abrasion (e.g., sand or ice storms). The positive attributes will be defined later as enhancements that prevent or reduce the effects from the stresses referred to above.

- The system regenerator facility does not include enhancements that would protect the electronics from the effects of EMP, gamma radiation, or easy physical access (i.e., exposure to vandalism or sabotage). The physical enclosure is typically above ground, with only minimal protection against blast or similar types of extreme physical force.
- The system regenerator electronics (including the laser or light-emitting diode transmitting device and the light-sensing device) design is "standard commercial" (i.e., it does not typically offer more than a token attempt to mitigate the effects of gamma radiation, HEMP, or lightning).
- The installation does not typically include an alternate power source back-up that will keep the system operating when the primary power source is interrupted due to a stress event.

#### 4.2.2 Environmental Parameters

A system with Level 1 hardness receives very little protection from the surrounding environment. The primary resistance to stress comes from the component and system design.

This hardness level is generally characterized by an "open air" installation with little attempt made to physically protect any of the components. A typical system is parasitic [i.e., it is attached to an existing installation (e.g., a high power line pole route or a copper cable telecommunication route) or a dedicated fiber optic telecommunication route].

The environmental parameters associated with a Level 1 system are summarized, simply, as

- an aerial installation of the cable with protection provided by the cable sheath only,
- a surface installation of the regenerator enclosure with protection for the electronics by the enclosure structure only, and
- installation of the system along public rights-of-way with little attempt to conceal the location of regenerator stations or the fiber optic cable.

#### 4.2.3 Target Stress Level

The system installation (includes the cable and regenerator), with minimum hardness, will withstand typical day-to-day recurring natural and man-made

events. Severe weather events, such as 10-, 25-, 50-, or 100-year "return period" events will cause outages and extended downtime. "Return period" severe weather levels are discussed in Volume II. It is expected that numerous interruptions of service will occur throughout each year due to relatively minor natural events. Deterioration of the installation will be quite rapid if the system and/or environment lacks durability.

The probability of survival of an installation with a Level 1 hardness will be a function of its age, the skill of the installer, the physical durability of the components used, and the system designer's selection of components. A fiber optic path with a minimum hardness level can be expected to withstand the following general types of natural stress events:

- typical seasonal rainstorms accompanied by moderate wind
- typical seasonal windstorms with moderate velocity and sustained winds to 70 mph (113 kph)
- typical seasonal snow and sleet storms except extreme ice accumulation
- typical seasonal temperature fluctuations (-40 to 120 °F) [-40 to 49 °C]
- minor earthquakes
- minor lightning strikes--installations that are of the minimal level of protection will be interrupted frequently when subjected to typical lightning storms in the high risk lightning areas of the United States
- deterioration due to sun, moisture and naturally occurring chemical
- only limited protection from attacks by rodents, birds, and insects
- slight shifts of earth due to sinking, settling, compaction, or soil expansion and contraction (e.g., due to freezing and thawing)

The effects on the "outside plant" (components of the communication system that are installed remote from the switch point) due to natural stress events are listed in Table 3 (CCITT, 1985). The result of the stress can be immediate (e.g., punctures, cutting, breaks) or can develop over a period of time (degradation).

### 4.3 Level 2 (Moderate) Hardness

Level 2 (Moderate) hardness (stress resistance) will provide a small amount of stress protection. A typical commercial fiber optic telecommunication system would meet the standards for a moderately hardened system. This level of protection would be adequate for normal day-to-day commercial traffic.

A system with moderate hardening may not survive severe 25-, 50-, or 100-year "return period" events of nature. "Return period" weather events are discussed in Volume II. Since this level system is usually not an aerial installed system, the sensitivity to surface disturbances is less than for a Level 1-hardened system.

The survivability of a system with Level 2 hardness will be good, but frequent interruption of service can be expected during severe weather, (e.g., strong wind, lightning, flooding, surface erosion, cold temperatures), a surface or high altitude nuclear detonation, or a deliberate attempt by someone to damage a component of the system. Alternate circuits, such as parallel links, microwave links, or satellite links should be available if emergency circuits are served by this system.

#### 4.3.1 Physical Parameters

Recognizable physical characteristics of this level system are noted below.

##### Cable

- When compared to a Level 1-hardened system, the Level 2-hardened system is recognized by its predominantly surface or shallow underground installation. The outside plant may include up to 5 percent of the cable exposed as aerial installation or surface installed (e.g., attached to bridges, viaducts, or trestles) without protection other than the cable sheath.
- Underground installed cable is at depths greater than 12 inches (0.3 m) except where obstacles preclude burial. Placing cable in a rigid duct at less than a 12-inch (0.3-m) depth in the vicinity of obstacles or in lieu of the 12-inch (0.3-m) depth target may be used as an alternate installation guideline.
- The cable design does possess those attributes that make it resistant to physical stresses due to extreme nature events (e.g., sand storms, ice and snow conditions, temperature extremes).

- The cable sheath design provides blockage to moisture and average-to-good resistance to chemicals that may be present in the environment.
- A metallic central strength is not included in the cable design--a nonmetallic tensile support is substituted in the design providing adequate tensile strength during and after installation.
- The cable design includes a "rodent proof" sheath that will provide resistance to rodents and insects. An alternate method of protection that places the cable in a rigid rodent-proof duct may be used.

The attributes of various cable designs and configurations are discussed in Volume II of this report.

#### Regenerator

- Standard regenerator electronics are utilized at each regenerator station. The grounding system is designed using recommended procedures and transient protection devices (TPDs) installed for protection from lightning-caused ground transients. The amount of protection may vary with the lightning threat, which varies with the location and the frequency of lightning strikes. Refer to Volume II for specific criteria for installing TPDs.
- The installation includes a backup power source (batteries) that will sustain operation for at least 8 hours in the event of interruption of local power to the regenerator. Recovery (recharge) of the battery bank should be effected within 96 hours after the power grid recovery.

#### 4.3.2 Environmental Parameters

A system with Moderate hardening receives most of its protection from the environment--in particular, the protection afforded to the cable when placed underground.

A system with Level 2 hardening is generally an all-surface or subsurface installed facility. Less than 5 percent of the cable will be aeri ally installed or installed on the surface of the Earth without protection.

The distinct environmental parameters that characterize a Level 2 system are included below.

#### Cable

- At least 95 percent of the cable is placed either underground or with conduit, rigid duct, or poured concrete barrier.

### Regenerator

- The regenerator enclosure durability level will ensure capability to withstand moderate natural conditions including most annual occurring events, except those classified as 25-, 50-, and 100-year "return period" events.
- The regenerator enclosure is surface installed with protection for the electronics resulting from the enclosure structure alone.
- The enclosure used for the moderate level of hardness is designed to prevent penetration of gunshot bullets, is entry secure, and is watertight.
- The cable entry/exit into the enclosure is through an underground ingress/egress port.
- The structural strength must be sufficient to endure high winds, blast force from nuclear detonations up to 2 psi overpressure, vandalism, gun shots, severe weathering, and earthquakes.
- The enclosure may be constructed with an integral shielded room for EMP protection. A typical enclosure would not have this feature.

#### 4.3.3 Target Stress Level

A system installation (including the cable and regenerator) that has Level 2 hardness will withstand typical day-to-day recurring natural and man-made events. Severe weather events, such as 25-, 50-, and 100-year "return period" events may cause outages and extended downtime. The magnitude of severe weather conditions for "return periods" is given in Volume II for those weather events that have been analyzed. A moderately hardened system will resist degradation due to weathering.

The probability of survival for a Level 2-hardened system is improved over that of a Level 1-hardened system with addition of several physical and environmental improvements. Requirements are included to provide more protection against the threat of rodents, lightning, and other events of nature. Only limited protection for gamma radiation and HEMP is provided since they are not considered a threat to commercial installations. Additional protection against vandalism can be expected because of the reduced exposure of the cable and the strengthened regenerator enclosure. Battery backup power is also provided in the event of power grid failure.

A fiber optic path with moderate hardness can be expected to withstand all of the stress levels described for a minimally hardened system plus the following natural stress events. See Volume II for more information.

- Typical seasonal weather and storms involving rain, ice, snow, and temperature variations.
- Nontypical seasonal weather and storms with winds to 100 mph (161 kph), ice and snow accumulation, localized flooding, and other conditions accompanying a 25-year "return period" event.
- Seasonal temperature fluctuations from -40 to 130 °F (-40 to 54 °C).
- Minor earthquakes. Ground separations of < 1 in (2.5 cm) will not cause downtime.
- Lightning activity--very little downtime will result from common lightning storms; however, heavy lightning activity with multiple strikes to the same point will cause system interruption.
- Service interruption due to rodent attacks (intermittent nibbling and chewing) will be minimal.
- Protection against EMP will be dependent on the option selected.  
Option 1: Very little protection (equivalent to Level 1) or approximately 40 dB field attenuation.  
Option 2: EMP field attenuation protection is greater than 80 dB.
- The protection provided for the cable, between regenerators and where cable is buried [at least 12-inch (0.3-meter) depth] underground, will result in an absorption factor of at least 35 for particles with energy levels of 1 MeV. The safe dose of gamma radiation at 1 MeV, for a cable that is buried, will be approximately 3,500 rads. Exposed cable will not receive this protection. See Volume II, Section 4, for specific protection parameters.
- The regenerator protection factor will be at least 2 (for particles with energy of 1 MeV) resulting from the approximate half-thickness shield of the concrete enclosure construction. Cable and fiber exposed within the enclosure will receive the same amount of protection (factor of 2) as a result of being inside the concrete enclosure. See Table 21, of Volume II, for information on shielding effects of concrete.

#### 4.4 Level 3 (Significant) Hardness

Level 3 (Significant) hardness (stress resistance) will yield a very survivable fiber optic system. It is intended that commonly-used hardware and installation techniques should be used for the significantly hardened system. Because of the relative durability (full protection for most stress

categories), a fiber optic link with significant hardness could be used for time-critical and sequential traffic (e.g., when continuous service is necessary).

A system with Level 3 hardness would be expected to survive severe events of nature, except a 100-year, or greater, "return period" event. See Volume II for more definitive severe weather detail for "return periods." There is approximately a 15 percent risk of occurrence of a 100-year event during the 20-year lifetime of a system (Hollister, 1970). An example of this data is provided in Volume II.

The survivability of a significantly hardened system will be excellent with very few occurrences of service interruption. Deliberate, man-made events (e.g., sabotage with an intent to disrupt service) will not be prevented. However, the physical environment will make it difficult to damage the system without preplanning and use of implements.

#### 4.4.1 Physical Parameters

Recognizable physical characteristics of a Level 3-hardened fiber optic system are noted below.

##### Cable

- The cable will be installed totally underground with at least 36 inches (0.9 meters) of soil or material with equivalent density covering the cable. A minimum depth of 36 inches (0.9 meters) will be maintained through or around all obstacles along a planned route.
- The cable design will include a watertight sheath that is also resistant to chemicals that may be present in the soil or material surrounding the cable. This resistance to chemicals must be maintained for the lifetime of the cable--20 years is the projected lifetime quoted by most manufacturers.
- A metallic central strength member is not used in the design, but a metallic sheath may be used to provide rodent protection. The metallic sheath must be grounded by a separate path such that the sheath ground will not cause a ground shift transient on the regenerator ground system. Separation of the sheath ground and the enclosure ground is described by Sims (1987).
- The cable includes a "rodent proof" sheath that will prevent damage by rodents and insects. An alternate method of protection that places the cable in a rigid rodent-proof duct may be used. See Volume II for specific parameters.

### Regenerator

- Standard regenerator electronics are utilized at each regenerator station.
- The grounding system for the enclosure and installed system must meet the requirements for a "meaningful ground" (see Volume II, Section 4, for an explanation). The cable sheath ground and the regenerator ground must be separated with separate connections to the Earth (Sims, 1987).
- A two-stage design for transient protection will be included in the installation--transient protection devices (TPDs) will be installed at the primary power input to the building and also on the ac input to the power supply for the regenerator electronics. Guidelines are provided in the Federal Emergency Management Agency (FEMA) Civil Preparedness Guide (FEMA, 1986) and in Volume II, Section 4, of this report.
- Emergency (backup) power system shall be included that will sustain power to the regenerator electronics for at least 7 days.
- The enclosure may be constructed with an integral shielded room for EMP protection.

#### 4.4.2 Environmental Parameters

A significant amount of Level 3 hardening (protection) comes from the environment. All components of the system are installed underground, with a covering of at least 36 inches (0.9 meters) of earth or a material with equivalent protection factors and physical protection.

The distinct environmental parameters that are unique to Level 3 hardness are discussed below.

### Cable

- The cable network (link) is a totally underground installation.
- The cable depth of placement is at least 36 inches (0.9 meters), placed in a rigid duct. Underground placement must be continuous, which may require tunneling or drilling under or through obstacles.
- A 2 percent cable slack, by length, must be included in the installation where severe earthquakes are likely. The slack cable can be distributed, and bunched, in underground cavities or pits. The slack must be free to pay out if ground separation should occur. Charts of earthquake intensity for the United States are included in Section 4, of Volume II, of this report. More detailed information on the exact fault location may be necessary to determine where protection is required.



- The cable is placed in a rigid duct through areas where earthquakes or ground shifts are common.

#### Regenerator

- The regenerator enclosure will be underground and covered with at least 36 inches (0.9 meters) of soil or material with equivalent density and physical protection factors. See Volume II, Section 4, for equivalents in shielding effectiveness.
- The enclosure must be watertight and able to sustain local flooding for up to 5 days at average intervals of occurrence of 1 year. The structure (including ingress/egress ports) must withstand continuous wet conditions and withstand flood conditions as described above.
- The ground system must meet the conditions of a "meaningful ground" as specified in guidelines such as MIL-HDBK-419 (DOD, 1982), or another guideline that describes how to implement a ground that penetrates the water table.
- The protection, from gamma radiation, provided for the cable between regenerators, will result in an absorption factor of at least 50,000 for particles with energy levels of 1 MeV. The safe dose of gamma radiation at 1 MeV will be greater than 30,000 rads.
- The regenerator protection absorption factor will also be 50,000 for particles with energy of 1 MeV or less resulting from the 36 inch (0.9 meter) soil covering. For particles with energy level of 1 MeV or less, the safe dose will be greater than 30,000 rads. Therefore any electronics component, fiber optic cable, or person inside the enclosure will be protected. Benefits will result from the projected increasing Mean Time Before Failure (MTBF) and the significantly reduced maintenance requirement.

#### 4.4.3 Target Stress Level

The system installation, which includes the cable and regenerator, with significant hardness will withstand all events of nature and nondeliberate man-made events. The system can be expected to survive all severe weather events except 100-year "return period" events. A 100-year event may cause service interruption. A Level 3 system will resist degradation due to weathering and chemicals in the environment.

The stress tolerance level of a significantly hardened system is outlined below. Emphasis has been placed on the Level 3 requirements that are not also required for Level 2 compliance.

- Underground placement of the cable and the regenerator have made the significantly hardened system resistant to all events of nature.
- System will survive all events of nature except those classified as 100-year occurrence events.
- Environmental temperature fluctuations from -40 to 130 °F (-40 to 54 °C).
- Major earthquakes that cause separation of ground up to 4 inches (10.2 centimeters).
- Service interruption due to rodent damage will be rare.
- The underground placement (Option 1) will provide excellent protection from HEMP. Although 36 inches (0.9 meters) of soil will provide substantial attenuation of the EMP field, some low frequency energy will penetrate to the cable and the regenerator electronics. Additional EMP protection can be added with the addition of an integral shielded room. Full EMP protection (greater than 80 dB attenuation) can be attained with the added shielding (Option 2). Detailed information illustrating the levels of protection is provided in Volume II, Section 4, of this report.
- The protection from gamma radiation provided for the cable between regenerators will result in an absorption factor of at least 50,000 for particles with energy of 1 MeV. The safe dose of gamma radiation at 1 MeV will be greater than 30,000 rads.
- The regenerator protection absorption factor will also be 50,000 for particles with energy of 1 MeV or less resulting from the 36-inch (0.9-meter) soil covering. For particles with energy of 1 MeV or less, the safe dose will be greater than 30,000 rads. Therefore, any electronics component, fiber optic cable, or person inside the enclosure will be protected from gamma radiation if the dose does not exceed 30,000 rads.

#### 4.5 Level 4 (Maximum) Hardness

Level 4 (Maximum) hardness (stress resistance) provides the most protection possible with the technology available. A maximum level system will cost significantly more, initially, than a typical commercial installation. However, the owner of the installation will benefit from the projected Mean Time Before Failure (MTBF) that will result and a significantly reduced maintenance requirement.

The intended use for a Level 4 system is for all time-critical traffic, secure traffic, sequential traffic, and for crucial commercial traffic. The level of protection provided would be ideal for traffic concerned with National Security and Emergency Preparedness.

A system with Level 4 hardness would be expected to survive very severe natural events, including 100-year, or greater, "return period" events. See Volume II, Section 4, for severity of weather for "return periods." There is about a 15 percent chance of a 100-year event occurring during the 20-year lifetime of the fiber optic cable (Hollister, 1970). Examples of these data are provided in Volume II.

Interruption of service due to deliberate or accidental man-made events is still possible. Major damage to the physical environment surrounding the system from a nondeliberate event (e.g., a major accident) is not feasibly preventable. Deliberate damage due to sabotage or extreme vandalism presents a difficult situation--probably not possible to prevent by reasonable physical means.

If deliberate events are discounted, the survival probability will be near 100 percent assuming that backup power would automatically take over in the event of a power grid failure. In summary, a maximally protected system will survive all types and levels of stress except those events that are akin to a direct hit, either from a surface nuclear detonation (with the system near "ground zero") or locally inflicted damage to the system (damage intended to render the system inoperative).

#### 4.5.1 Physical Parameters

Recognizable physical characteristics of a Level 4-hardened fiber optic system are noted below.

##### Cable

- The cable will be installed totally underground with at least 48 inches (1.2 meters) of soil or material with equivalent density covering the cable. A minimum depth of 48 inches (1.2 meters) will be maintained through or around all obstacles along a planned route.
- The cable design will include a watertight sheath that is also resistant to chemicals that may be present in the soil or material surrounding the cable. This resistance to chemicals must be maintained beyond the functional lifetime of the cable--20 years is the projected lifetime quoted for most manufacturer's products.
- The cable design does not include a metallic central strength member or any other metallic component.
- The cable must be installed with a "rodent proof" conduit or rigid duct. Another type of equivalent rodent protection is acceptable if tests or history show that the installation is rodent protected. As

an added protection, through areas where extreme rodent problems exist, a backup cable should be installed to provide rapid recovery if an inoperable situation should occur. Recovery must be possible within the allowed 10 minute window.

- The enclosure may be constructed with an integral shielded room for EMP protection (Option 2). See Figure 3.

#### Regenerator

- Standard regenerator electronics are utilized at each regenerator station.
- The grounding system used for the regenerator station must be consistent with guidelines for EMP suppression. A "meaningful ground" connection to Earth ground must be provided to minimize the effects of a ground shift from stress such as lightning or HEMP.
- A three-stage (level) design for transient protection will be included in the installation--transient protection devices (TPDs) will be installed at the primary power input to the building, on the power phase lines at the ac input to the power supply, and on the dc power distribution system. Guidelines for TPD installation and placement are provided in the FEMA Civil Preparedness Guide (FEMA, 1986) and in Volume II, Section 4 of this report.
- Emergency (backup) power system shall be included that will sustain power for the regenerator electronics for 14 days. The emergency system should include battery bank for short-term power.

#### 4.5.2 Environmental Parameters

All components of the system are placed underground with at least 48 inches (1.2 meters) of soil or material with equivalent density covering the components. A large part of the protection results from the underground placement; however, the design requirements of the components of the system also provide protection.

The distinct environmental parameters that are unique to the maximum level of hardness are discussed in detail below.

#### Cable

- The cable network (link) is a totally underground installation.
- The cable depth of placement is at least 48 inches (1.2 meters), placed in a rigid duct or conduit for protection from rodents and damage from the soil surrounding the cable.

- A 6 percent cable slack, by length, must be included in the installation when the installation is to be located in an area of high earthquake risk (i.e., when crossing or laying parallel to a fault line). Charts of earthquake intensity for the United States are included in Volume II, Section 4, of this report. More detailed information on fault locations may be necessary to determine the exact areas where earthquake protection is required. The slack cable can be distributed, and bunched, in underground cavities or pits. The slack must be free to pay out if ground separation should occur.
- The cable is placed in a rigid duct through areas where earthquakes, ground shifts, or frequent digging occurs. A more durable type of protection that will prevent damage to the cable may be necessary to ensure no compromises of operability--particularly through urban areas where underground activity (e.g., construction digging) is greatest.

#### Regenerator

- The regenerator enclosure will be underground and covered with at least 48 inches (1.2 meters) of soil or material with equivalent density and protection factors.
- The enclosure must be watertight and able to sustain local flooding for up to 5 days occurring at least once per year. The structure (including ingress/egress ports) must withstand continuous wet conditions and withstand flood conditions as described above.
- The ground system must meet the conditions of a "meaningful ground" as specified in guidelines such as MIL-HDBK-419 (DOD, 1982), or another guideline that describes how to implement a ground that penetrates the water table.
- The surface entrance to the enclosure must provide physical security for the facility while maintaining watertight integrity of the enclosure. A second level of security will be provided by either a perimeter fence or a preentry vestibule. An intrusion alarm may be necessary to signal unauthorized entry.

#### 4.5.3 Target Stress Level

The intent of Level 4 hardness is to provide a system that is totally protected against any type of stress--to include events of nature or man-made stress. This goal is only unconditionally possible for events of nature, however, because the creative elements of man-made stress will always make it possible to compromise the system if desired. These situations will be isolated, however. Man-made events that result in random, nondeliberate events (e.g., accidents along rights-of-way, agricultural works, construction diggings) will be of little threat to a Level 4 system installation.

The stress tolerance levels for a Level 4-hardened system are outlined below. Emphasis has been placed on the Level 4 requirements that are not required for Level 3 compliance.

- The underground placement of the cable and regenerator have made the maximum enhanced system insensitive to all events of nature.
- The system will survive all events of nature including those classified as 100-year, "return period" events.
- The system will survive environmental temperature fluctuations from -40 to 140 °F (-40 to 60 °C). Note: The temperature will be tempered by the underground placement, thus temperature extremes at the surface will not reflect the system environment.
- Major earthquakes that cause separation of ground up to 12 inches (0.3 meters).
- Service interruption due to rodents and insects will be eliminated.
- The underground placement (Option 1) will provide excellent protection from HEMP, however not total protection. Although 48 inches (1.2 meters) of soil will provide substantial attenuation of the EMP field, some low-frequency energy will penetrate to the cable and the regenerator electronics. In addition a shielded room may be added to the enclosure for full (greater than 80 dB attenuation) EMP protection (Option 2). Detailed information illustrating the levels of protection is provided in Volume II, Section 4, of this report.
- The protection from gamma radiation provided for the cable, between regenerators, will result in a projected absorption factor of at least 2 million for particles with energy of 1 MeV. The safe dose of gamma radiation at 1 MeV will be greater than 30,000 rads.
- The regenerator protection absorption factor will also be at least 2 million for particles with energy of 1 MeV or less resulting from the 48-inch (1.2 meters) soil covering. For particles with energy of 1 MeV or less, the safe dose will be greater than 30,000 rads. Therefore any electronics component, fiber optic cable, or person inside the enclosure will be protected adequately from gamma radiation if the dose does not exceed 30,000 rads.

#### 4.6 Level 5 (Virtual) Hardness

Level 5 (Virtual) hardness (stress resistance) enlists the use of parallel routing to circumvent communications circuits that have been damaged and subsequently rendered inoperative. Alternate routes must be chosen by consulting a data base that catalogs all available facilities and selecting the most likely candidate for backup. This idea was suggested and outlined by the

Commercial Network Survivability (CNS) Task Force of the National Security Telecommunications Advisory Committee (NSTAC) report completed in October 1984.

#### 4.6.1 Physical Parameters

The network that is used to provide parallel paths and to continue providing service may not have the same physical parameters as the original path. This could result in the new paths having a different level of hardness than the original path. The goal, however, is to maintain service--assuming that the traffic carried does not stipulate an equal or higher hardness level.

#### 4.6.2 Target Stress Level

The goal is to continue service when the path normally used has been disabled by severe stress. Rerouting of service (traffic) over another path assumes that the stress that has disabled the first path is not so widespread that it has disabled all parallel paths. Determination of paths that remain operable is of essence. A discussion of methods that will accomplish this determination, systematically, is provided by Nesenbergs (1987).

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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.) Fiber optic telecommunication systems are susceptible to both natural and man-made stress. National Security/Emergency Preparedness (NSEP) is a function of how durable these systems are in light of projected levels of stress. Emergency Preparedness in 1987 is not just a matter of--can we deliver food, water, energy, and other essentials?--but can we deliver the vital information necessary to maintain corporate function of our country? "Communication stamina" is a function of "probability of survival" when faced with stress. This report provides an overview of the enhancements to a fiber optic communication system/installation that will increase durability. These enhancements are grouped, based on their value in protecting the system, such that a Multitier Specification is created that presents multiple levels of hardness. Mitigation of effects due to electromagnetic pulse (EMP) and gamma radiation, and protection from vandalism and weather events are discussed in this report. This study concludes that the probability of survival can be significantly increased with expeditious use of design and installation (cont.)			
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enhancements. The report is presented in two volumes entitled as follows:

Volume I : The Multitier Specification--An Executive Summary

Volume II: Multitier Specification Background and Technical Support Information

Volume I presents the Multitier Specification in a format that is usable for management review. The attributes of specified physical parameters, and the levels of protection stated in Volume I, are discussed in more detail in Volume II. This study is intended to be a guideline to aid the design and implementation, when the intent is to create a more durable, long-haul, fiber optic telecommunication system.



