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U.S. DEPARTMENT OF COMMERCE
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# A LIFE-CYCLE COST ANALYSIS METHODOLOGY FOR FIRE PROTECTION SYSTEMS IN NEW HEALTH CARE FACILITIES

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TABLE OF CONTENTS

## PREFACE

This report was prepared solely to demonstrate a methodology for comparing alternative provisions for code compliance in new health care facilities using life-cycle cost analysis. The examples presented herein are illustrative only, and cannot be applied to health care facilities other than the sample facility used in this report, or to health care facilities in general. To apply the methodology illustrated here, calculations must be done for the specific facility under consideration, using the information relevant to that specific facility.

LIST OF TABLES

# A LIFE-CYCLE COST ANALYSIS METHODOLOGY FOR FIRE PROTECTION SYSTEMS IN NEW HEALTH CARE FACILITIES

Louis P. Clark

Abstract

An analytical procedure is presented for conducting life-cycle cost (LCC) analyses of fire safety systems in new health care facilities. Comparative LCC evaluations of alternative fire safety systems can be obtained based on their initial costs, useful life times, operation and maintenance costs, salvage values, and corresponding fire insurance costs for the building and its contents.

The case study used to demonstrate the procedure compares the life-cycle costs of two fire safety systems in compliance with the NFPA Life Safety Code in a particular hospital:

(1) fire resistive construction with no sprinklers, and

(2) protected noncombustible construction fully equipped with automatic sprinklers.

Five different examples are provided with varying assumptions regarding initial construction costs, the choice of a discount rate, the tax status of the facility, and the life expectancy of the sprinkler equipment.

# 1. INTRODUCTION

## 1.1 Purpose and Scope

Compliance with the National Fire Protection Association (NFPA) Life Safety Code (1973) [1][1] is now a requirement for the certification of a health care facility for participation in Federal Medicare and Medicaid programs[2]. Many jurisdictions require compliance with later editions of the Code, such as the 1976 edition [2]. Modifying existing health care facilities to attain full compliance with the Life Safety Code can be very expensive [3,4]. However, in new health care facilities, full compliance can usually be achieved at considerably less cost than in existing facilities. Not only can fire safety provisions be incorporated into the new building design at less cost than in retrofit, but certain design substitutions are permitted by the Code which are not practical in a retrofit situation.

The designer, faced with a number of system alternatives for fire safety, as permitted by the Life Safety Code, must be able to determine which adds the least cost to the new health care facility. This determination is better made on a life-cycle cost (LCC) basis than a first cost basis, because the LCC concept includes all costs incurred or avoided over the life of the building attributable to the fire safety system. These costs include not only the additional first cost of the system, but changes in building operating, maintenance and repair costs; insurance costs; resale value; and possibly property taxes as well, all evaluated on a time-equivalent basis.

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1 Numbers in brackets refer to the literature references listed at the end of this report.

2 Federal regulations published by the Health Care Finance Administration.

The primary purpose of this report is to provide a methodology for computing and comparing the LCC of alternative fire safety systems for new health care facilities that comply with the Life Safety Code. Its scope is limited in that differences in fire safety performance attributable to these alternative systems are not directly considered. However, some measure of those differences may be indirectly considered in the LCC analysis through the inclusion of reductions (or increases) in fire insurance costs over the life of the building.

This same LCC methodology can also be applied to alternative fire safety systems in existing health care facilities. However, since the greatest opportunities for savings are in the design of new facilities, the example used here, that of a sprinklered vs. non-sprinklered system approach, focuses on code compliance in a new facility. The LCC methodology used in this report can be applied to government-owned, non-profit, and privately-owned health care facilities, although the choice of an appropriate discount rate and tax calculation procedures will vary in each case.

## 1.2 Background

One of the basic requirements of the 1976 edition of the NFPA Life Safety Code is adherence to the total concept that:

> "All health care facilities shall be designed, constructed, maintained, and operated in such a manner as to minimize the possibility of a fire emergency requiring the evacuation of occupants. Because the safety of occupants of health care facilities cannot be assured adequately by dependence on evacuation of the building, their protection from fire shall be provided by appropriate arrangement of facilities, adequate staffing, and careful development of operating and maintenance procedures composed of the following:

(a) Proper design, construction, and compartmentation;

(b) provision for detection, alarm, and extinguishment; and

(c) fire prevention and the planning, training and drilling in programs for the isolation of fire, transfer of occupants to areas of refuge or evacuation of the building."

Chapter 10-2 of the 1976 Life Safety Code presents details of the principal life safety requirements in new health care facilities. The construction code requirements for new health care facilities, together with the requisite fire safety components, comprise a basic fire safety system for health care occupancies. Chapter 10-2 also delineates certain "exceptions" in the code requirements which allow alternative fire safety systems to be substituted for the basic building-fire safety system.

For example, the basic fire safety system described by the Life Safety Code for a new hospital has fire resistive construction features throughout, but no sprinkler equipment. An acceptable alternative in the Life Safety Code is the use of protected, noncombustible construction materials (which offer less resistance to a fire when used alone) along with automatic sprinkler equipment throughout the building[3]. Since the cost of protected, noncombustible construction is usually less than that of fire-resistive construction, its use might offset some of the first cost of sprinkler equipment in a new facility. Lower fire insurance premiums might also reduce the effective cost of the sprinkler alternative.

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[3] Characteristics of fire resistive construction and protected non-combustible construction are detailed in section 3.1.

These two alternative fire safety systems are used in this report to demonstrate the LCC approach to design decision making in a new health care facility. Other acceptable alternatives for health care facilities that might be considered in future studies include a smoke detector system, an engineered smoke control system, and an automatic door closer system.

## 1.3 Approach

A methodology for conducting LCC analyses of alternative building fire safety systems in a health care facility is outlined in section 2. This outline includes the elements of a LCC analysis, the discounting procedures needed to adjust costs occurring in different time periods to a common point in time, the selection of a time horizon and discount rate, and the distinction between constant dollar and current dollar analyses.

In section 3 performance requirements for the fire resistive construction and the protected noncombustible construction alternatives are provided. Five examples of a comparative LCC analysis of the two alternatives in a specific hospital building are worked out. These examples vary with regard to first cost, discount rate, life expectancy of the sprinkler equipment, and tax status of the facility. A summary and some conclusions are presented in section 4. A glossary of terminology frequently used in LCC studies is provided in Appendix A. Appendix B includes single present worth factors and modified uniform present worth factors for selected discount rates and years.

# 2. LIFE-CYCLE COST ANALYSIS METHODS

## 2.1 General Requirements

The comparison of two (or more) competing fire safety systems, based on their life-cycle cost, requires that only those cost elements that change from one system to the other be directly considered. However, all cost elements must each be evaluated over the same study period (i.e., lifetime or investors time horizon), and all costs must be discounted to a common point in time. If any of the components of either system have a different expected life than the study period used in the LCC analysis, replacement costs and/or salvage (or resale) value factors must be used to adjust the life of each component to the study period used. Discounting procedures, used to reflect the time-value of money in its best alternative use, are detailed in section 2.2 below.

Selection of the appropriate study period for a LCC study depends both on the nature of the investment and the requirements of the investor. New health care facilities are generally designed for a long physical life and may be expected to be in operation for many years. P.A. Stone [5] suggests that most building structures have a physical life of 50 to 100 years if they are properly constructed and maintained. The physical life of the building structure is generally much longer than the useful lives of many of the building elements or components which have more discrete and predictable lives, and are therefore subject to periodic replacement or renewal. Typical estimated useful lives of some health care building components were obtained from reference [6] and are shown in table 2.1.

Table 2.1 Estimated useful life of land improvements, buildings, and fixed equipment

From Reference (6)

| LAND IMPROVEMENTS | Years |
|---|---|
| Fencing | |
| Brick or stone | 25 |
| Chain link | 15 |
| Wire | 5 |
| Wood | 8 |
| Flagpole | 20 |
| Paving (including roadways, walks and parking) | |
| Asphalt | 15 |
| Concrete | 20 |
| Gravel | 5 |
| Retaining wall | 20 |
| Shrubs, lawns, and trees | 10 |
| Sign | 12 |
| Turf, artificial | 5 |
| Underground sewer and water lines | 30 |
| Yard lighting | 15 |
| **BUILDINGS** | |
| Boiler house | 25 |
| Garage | |
| Masonry | 25 |
| Wood frame | 15 |
| Masonry, reinforced concrete frame | 40 |
| Masonry, steel frame, fireproofed | 40 |
| Masonry, steel frame, not fireproofed | 30 |
| Masonry, wood frame | 25 |
| Multilevel parking structure, masonry | 25 |
| Residence | |
| Masonry | 25 |
| Wood frame | 25 |
| Storage building | 20 |
| **FIXED EQUIPMENT** | |
| Building Services Equipment | |
| Electric lighting and power feed wiring | 20 |
| Conduit and wiring | 20 |
| Fixtures | 10 |
| Transformer | 20 |
| Switch gear | 20 |
| Elevator | |
| Dumbwaiter | 20 |
| Freight | 20 |
| Passenger, high-speed automatic | 20 |
| Passenger, other | 20 |
| Central television antenna system | 15 |
| Central clock system | 20 |
| Heating, ventilating, and air conditioning system | 20 |

| Building Services Equipment (continued) | Years |
|---|---|
| Air conditioning system, all equipment and units | |
| Large--over 20 tons | 15 |
| Medium--5 to 15 tons | 10 |
| Small--under 5 tons | 8 |
| Boiler | 20 |
| Compressor, air | 15 |
| Condensate tank | 20 |
| Condenser | 15 |
| Controls | 20 |
| Cooler and dehumidifier | 10 |
| Cooling tower | |
| Wood | 15 |
| Metal | 15 |
| Duct work | 20 |
| Fan, air handling and ventilating | 15 |
| Filter | 15 |
| Furnace, domestic type | 15 |
| Incinerator, indoor | 20 |
| Oil storage tank | 20 |
| Piping | 25 |
| Precipitator | 15 |
| Pump | 15 |
| Radiator, cast iron | 30 |
| Radiator, finned tube | 20 |
| Unit heater | 10 |
| Nurse call system | 15 |
| Oxygen, gas, air piping | 25 |
| Paging system | 15 |
| Plumbing, composite | 25 |
| Fixtures | 20 |
| Piping | 25 |
| Pump | 15 |
| Water heater, commercial | 15 |
| Water storage tank | 20 |
| Sprinkler and fire protection system | 25 |
| Fire alarm system | 20 |
| Fire pump | 20 |
| Sprinkler system | 25 |
| Tank and tower | 25 |
| Sewerage, composite | 30 |
| Piping | 25 |
| Sump pump and sewerage ejector | 10 |
| Telephone system | 20 |
| Vacuum cleaning system | 15 |
| **Other Fixed Equipment** | |
| Built-in bench, bin, cabinet, counter, shelving | 20 |
| Conveying system | 15 |
| Generator set | 20 |
| Hood, fume | 20 |
| Sink and drainboard | 20 |
| Sterilizer, built-in | 20 |

However, the study period selected as appropriate by an individual investor may be considerably shorter than the physical life of the building or its longer-lived components. In general, a longer study period, approaching the physical life of the facility, is more appropriate from a societal standpoint and is therefore more likely to be used for public sector facilities. For example, the General Services Administration uses a 40 year life for public service buildings [7]. From the individual investor's standpoint, especially one in the private sector, a considerably shorter study period is usually selected, based on the intended holding period, the financing period, depreciation period, or specific company guidelines [8].

The shorter the study period used in evaluating the LCC of a building system, the more important it is to assess the remaining value of that system at the end of the study period, especially if the building and the system will in fact continue in use. Simple proration factors can be used to determine this remaining value. However, a more accurate measure of remaining value, and one more acceptable to investors in the private sector, is the increase in selling price that the building could command that can be attributed to the system at the end of the study period. (This premium should be adjusted downwards by any potential increase in capital gains and/or depreciation recapture tax liabilities at that same time.)

The present value, life-cycle cost (LCC) for a given building system can be computed directly as follows:

$$LCC = I + R + A + M + T - S - X, \qquad (2\text{-}1)$$

where $I$ = initial investment cost,

$R$ = capital replacement costs,

$A$ = annually recurring costs (including operating, maintenance, energy, security, and insurance costs),

$M$ = non-annually recurring costs,

$T$ = property taxes (where applicable),

$S$ = resale value at the end of the study period, and

$X$ = tax savings and tax credits (where applicable),

all in present value terms, summed over the study period selected for the analysis.

If the system costs are to be financed in part (or in whole) rather than paid for immediately, the initial investment cost (I) can be adjusted to reflect the present value consequences of principal and interest payments over time. In such a case:

$$I = D + F - X', \qquad (2\text{-}2)$$

where $D$ = down payment,

$F$ = present value principal and interest payments, and

$X'$ = additional present value tax savings (if any) from interest payments.

In the following section, discounting procedures will be provided which can be used to adjust all future costs to present value.

## 2.2 Discounting Procedures

"Discounting" is the procedure by which costs (or savings) incurred in different time periods are adjusted to a common point in time (the "base time"), in order to reflect the time value of money. The discount rate used for this adjustment should be based on the best alternative risk-free investment opportunity(ies) available to the investor over the study period. (If capital must be borrowed for the additional investment, then the interest rate should be used for the discount rate during the life of the loan if the interest rate is higher than the opportunity rate.) The discount rate can be adjusted upward to account for risk if a risk adjustment is not incorportated into the costs (or savings) themselves.

If tax savings are included in the LCC analysis, then an "after-tax" discount rate should be used, based on the best alternative after-tax rate of return (or on the after-tax cost of borrowing). If tax savings are not included, then a "before-tax" discount rate should be used. Because of the different nature of taxable and non-taxable investments and the many different ways that costs are treated in determining tax liabilities, it is impossible to formulate a general relationship between a before-tax and after-tax rate of return, except that the latter is generally smaller than the former for the same investor.

If the LCC analysis is performed in current dollars, the discount rate must be specified in nominal terms, i.e., including inflation. If the LCC analysis is performed in constant dollars, the discount rate must be specified in constant dollar terms, based on the best alternative real rate of return (or real cost of borrowing) i.e., net of inflation. The real discount rate (d′) in any given year is equivalent to

$$d' = \frac{1 + d}{1 + E} - 1 \qquad (2\text{-}3)$$

where d = the nominal discount rate, and

E = the general rate of inflation.

Generally, all future costs related to a new building and its systems are discounted to the date of initial occupancy. All initial investment costs are assumed to be incurred on that day, so that no discounting of these costs is required. However, if the planning, design and construction process is lengthy and the investor must put up substantial sums of money prior to occupancy, these payments should be discounted forward to the occupancy date. (Alternatively, all initial and future costs can be discounted back to the beginning of the construction period or any other common point in time. This will not change the comparative outcome of the analysis if all costs are discounted by the same factor over the same time period.)

In this report, the date of building occupancy is used as the base time for discounting purposes, and all initial investment costs are assumed to be incurred at that time. A uniform discount rate and general inflation rate are used over the entire study period. Actual discounting procedures used are as follows:

(1) Single Present Value (SPV) Formula

This single present value formula is used to discount a single cost in year n to present value:

$$P = F_n \left[ \frac{1}{(1+d)^n} \right], \qquad (2\text{-}4)$$

where P = the present value of the future cost ($F_n$),

$F_n$ = the future cost in year n, and

d = the discount rate.

Table B-1 in Appendix B provides single present value factors for discount rates of 5, 10, and 15 percent over 50 years.

(2) Uniform Present Value (UPV) Formula

When equal costs are incurred each year over n years, the present value of those costs can be found as:

$$P = A \left[ \frac{(1+d)^n - 1}{d(1+d)^n} \right], \qquad (2\text{-}5)$$

where A = the uniform annual cost

In tables B-2 and B-3, UPV factors for discount rates of 10 and 15 percent, respectively, can be found in the first column (inflation rate = 0%).

(3) Modified Uniform Present Value (UPV*) Formula

When a LCC analysis is conducted in current dollars and an annually recurring cost increases at some constant rate each year over n years, the present value of those costs can be found as

$$P = A_o \left[ \frac{1+p}{d-p} \cdot \left( 1 - \left( \frac{1+p}{1+d} \right)^n \right) \right] , \tag{2-6}$$

where $A_o$ = the initial annual cost, and

$p$ = the annual rate of price or cost increase.

When the LCC analysis is conducted in constant dollars, annually recurring costs which increase at the general rate of inflation can be evaluated using eq. (2-5) and a real discount rate. However, some annually recurring costs may increase at a rate significantly different than the general rate of inflation. In this case, eq. (2-6) should be used with a differential inflation rate $p'$, instead of $p$, where

$$p' = \frac{p-E}{1+E} , \tag{2-7}$$

and where $E$ = the general rate of inflation.

Table B-2 and B-3 provide UPV* factors for inflation rates of 0 to 10% and for discount rates of 10 and 15%, respectively, over 30 years. If a real discount rate is used, the inflation rates in tables B-2 and B-3 are differential inflation rates; if a nominal discount rate is used, these are actual inflation rates.

# 3. APPLICATION OF METHODS TO FIRE SAFETY SYSTEMS

## 3.1 Physical Description of Alternatives

In order to demonstrate the application of the LCC methods outlined in section 2, two potentially competing fire safety systems that are in compliance with the 1976 Life Safety Code are examined in a new health care facility. The base system is one of fire resistive construction with no sprinkler equipment requirements. The alternative system is designed of protected noncombustible construction and has automatic sprinkler equipment throughout the facility.

Table 3.1 shows the construction requirements for new health care facilities based on the fire resistance ratings of structural members. These fire resistance ratings are shown in hours. The ratings were obtained from reference [9] and are shown for fire resistive construction and protected noncombustible construction, with the fire resistive construction being further subdivided into a 3 hour classification and a 4 hour classification.

Table 3.2 shows the characteristics of corridor walls in new health care facilities as obtained from reference [2]. The table presents a comparison of principal characteristics for health care facilities of fire resistive construction and protected noncombustible construction. Table 3.3 shows the characteristics of safety features in new health care facilities of the two construction types as obtained from reference [2].

Table 3.1 Construction requirements - New health care facilities (NFPA 220-1975)

| Building Component | Fire Resistance Ratings of Structural Members in Hours — Fire Resistive Construction: 4-hour classification | 3-hour classification | Protected Noncombustible |
|---|---|---|---|
| Bearing walls | 4 | 3 | 2 |
| Non-bearing walls | NC * | NC* | NC* |
| Principal support members (for 1 floor or roof only) | 3 | 2 | 1 |
| Principal support members (for more than 1 floor or roof) | 4 | 3 | 1 |
| Secondary floor supporting members | 3 | 2 | 1 |
| Secondary roof supporting members | 2 | 1-1/2 | 1 |
| Interior partitions enclosing stairways and other openings through floors | 2 | 2 | 1 |

* NC = noncombustible

Table 3.2 Characteristics of corridor walls in new health care facilities (NFPA Life Safety Code - 1976)

| Fire Resistive Construction | Protected Noncombustible Construction with Sprinklers |
|---|---|
| Corridor Wall Requirements | Corridor Wall Requirements |
| Fire resistance rating $\geq$ 1 hour | Non-fire rated partitions are permissible |
| Partitions shall be continuous from the floor slab to the underside of roof or floor slab above | Partitions may be terminated at suspended ceilings |
| Doors to corridors should have at least 20 minutes fire protection rating | Doors and frames to corridors are not required to have a fire protection rating, but shall be constructed to resist the passage of smoke |

Table 3.3 Characteristics of safety features in health care facilities (NFPA Life Safety Code - 1976)

| Parameters | Fire Resistive Construction | Protected Noncombustible Construction with Sprinklers |
|---|---|---|
| Protection of vertical openings | 2 hour rating | 1 hour rating |
| Interior finish - corridors and exits | Class "A" | Class "B" |
| Interior finish - rooms | Class "B" | Class "C" |
| Capacity of means of egress | Stairs--22 per exit unit<br>Horizontal--30 per exit unit | Stairs--35 per exit unit<br>Horizontal--45 per exit unit |
| Maximum travel distance to exit | Room door to exit ≤ 100 ft<br>Any point in room to exit ≤ 150 ft | Room door to exit ≤ 150 ft<br>Any point in room to exit ≤ 200 ft |
| Hazardous areas | | |
| Not severe | 1 hour fire resistant construction | Non-rated partitions and sprinklers |
| Severe | 1 hour fire resistant construction and sprinklers | 1 hour fire resistant construction and sprinkler |
| Doors to corridors | ≥ 20 minute fire protection rating | Non-rated doors and frames with sprinklers<br>Doors to resist passage of smoke |
| Wired glass vision panels | Panels ≤ 1,296 sq. in. mounted in steel frames | No restriction in area of vision panels<br>Vision panels do not need to be wired glass |

The particular health care facility used as an example is the new Mary Immaculate Hospital in Newport News, Virginia. This is a three-story hospital with a gross area of 117,050 square feet, having 120 beds and 25 bassinets. It was built of fire resistive construction, without a sprinkler system, at a base cost of $6,917,900 in 1980 dollars.

## 3.2 Life Cycle Cost Analysis of Alternatives

A demonstration of the LCC method of comparing fire safety system costs requires specific cost data and estimated life expectancies for the major components of each system, along with a common study period and discount rate. Five examples of the LCC method applied to the basic fire safety system and the sprinkler alternative are provided in this section. These examples are based on the particular hospital facility described in section 3.1, although the study period and discount rates used here were selected for demonstration purposes only and do not necessarily represent the actual financial analysis assumptions used in that project. These comparisons are not intended to provide a definitive assessment of sprinkler systems in health care facilities, nor is it possible to do so except on a case by case basis.

The initial cost of the base case hospital building of fire resistive construction was approximately $6,918,000 in 1980 dollars. In the first example, it is assumed that the reduction in the initial cost due to the substitution of protected noncombustible construction for fire resistive construction is five percent, or approximately $346,000. In this same example, the installed cost of an automatic sprinkler system is assumed to be approximately $2.00 per square foot, or $234,000 for the entire facility[4].

A 30 year study period is used in all of the examples. Except as noted, both the building and the sprinkler equipment are assumed to have 50 year lives, so that no capital replacement costs are anticipated. In order to simplify the analyses, the property tax assessment (if any) and resale value of the building at the end of 30 years are assumed to be the same for both alternatives. In addition, all other future costs (e.g., energy, general building maintenance, and building security) are assumed to be the same in both cases except for the sprinkler equipment maintenance and fire insurance costs.

Sprinkler equipment maintenance is assumed to cost $500 per year in base time dollars, and to increase each year in proportion to the general rate of inflation. Fire insurance rates vary from one state to another, for different types of buildings, for different types of building constructions, and for the type of coverage provided. Typical insurance rates for health care facilities are shown in table 3.4 and will be used in all of the following examples.

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[4] This square foot cost is based on a 1976 Congressional Report [10], updated to 1980 dollars. The actual cost per square foot can vary significantly depending on the type of equipment, whether piping is concealed or exposed, and requirements for sprinkler head placement.

Table 3.4 Insurance rates for new health care facilities (annual)*

| Building Construction Type | Building Insurance Rate | Contents Insurance Rate |
|---|---|---|
| Fire Resistive Building Construction | 12 cents/hundred | 20 cents/hundred |
| Protected Noncombustible Building Construction (sprinklered) | 6 cents/hundred | 15 cents/hundred |

* Based on rate information from Industrial Risk Insurance and the Insurance Services Office of Maryland.

The initial amount of insurance coverage for the hospital building itself is based on its construction cost, including the sprinkler equipment. In addition, insurance on its contents is initially based on a value of $2,000,000. It is assumed that the insurance rates themselves will remain stable over time, but that the total amount of coverage required will increase by five percent per year over and above the general inflation rate.

The comparative analysis of life-cycle costs for the base case and the sprinkler alternative is worked out in table 3.5 for the first example, a tax-exempt facility. The analysis is conducted in constant dollars using a real discount rate of 10 percent. Since only the difference in life-cycle costs is sought, only those cost elements which change from one alternative to the other are considered. Columns (1) and (2) display intermediate calculations needed to arrive at the difference; however, neither of these columns provides a meaningful LCC analysis of the individual alternatives. Column (3) displays the actual difference in life cycle costs between the two systems. The negative cost difference here means that the sprinklered alternative costs less than the fire resistive construction alternative. In the first example, the sprinklered alternative has a clear first cost and future cost advantage relative to the base system.

Table 3.5 Example #1

Non-profit Hospital
Constant Dollar Analysis
Real Discount Rate: 10%
Time Horizon: 30 years
PNC Cost: ~95% of FRC Cost
Sprinkler Equipment Cost: $2.00/ft$^2$
Building Value Differential at End of Time Horizon: 0

| | (1) Fire Resistive Construction (No Sprinklers) | (2) Protected Noncomb. Const. (With Sprinklers) | (3) (2) - (1) |
|---|---|---|---|
| Initial Costs | | | |
| Building | $6,918,000 | $6,572,000 | -$346,000 |
| Sprinklers | 0 | 234,000 | 234,000 |
| TOTAL INITIAL COSTS | $6,918,000 | $6,806,000 | -$112,000 |
| Future Costs | | | |
| Sprinkler Maintenance (UPW = 9.43) | $ 0 | $ 4,715 | $ 4,715 |
| Insurance Cost (UPW* = 15.80) | | | |
| Building | $ 131,165 | $ 64,521 | -$ 66,644 |
| Contents | 63,200 | 47,400 | - 15,800 |
| TOTAL INSURANCE COST | $ 194,365 | $ 111,921 | -$ 82,444 |
| TOTAL FUTURE COST | $ 194,365 | $ 116,636 | -$ 77,729 |
| TOTAL LIFE-CYCLE COST | $7,112,365 | $6,922,636 | -$189,729 |

In the second example, shown in table 3.6, the reduction in the construction cost attributable to the use of protected noncombustible construction is assumed to be only 2.5 percent rather than 5 percent. As a result, the initial cost of the alternative building fire safety system increases the total initial building cost, including sprinkler equipment, by $61,000 relative to the base case. However, because of the substantial reduction in insurance costs, the sprinkler alternative has a LCC advantage of $15,089. In this second example, the LCC method of comparison results in a choice opposite that made using first cost considerations alone.

The third example, shown in table 3.7, is identical to the second, except for the use of a real discount rate of 15 percent, in order to show the potential sensitivity of the results to the discount rate. In this example, the LCC advantage of the sprinkler alternative is lost because the present value of the future reductions in insurance costs is significantly reduced. Thus the selection of the discount rate can be critical to the outcome when investment costs are increased and future costs reduced as the result of a given design change.

The fourth example, shown in table 3.8, is similar to the second in terms of actual costs. However, the fourth example is based on a for-profit (i.e., tax paying) facility rather than a non-profit facility. As a result, a nominal, after-tax discount rate (10 percent) is used and the study is conducted in current, rather than constant dollars. A general inflation rate of 5 percent per year is also assumed.

Table 3.6 Example #2

Non-profit Hospital
Constant Dollar Analysis
Real Discount Rate: 10%
Time Horizon: 30 years
PNC Cost: ~97.5% of FRC Cost
Sprinkler Equipment Cost: $2.00/ft$^2$
Building Value Differential at End of Time Horizon: 0

| | (1) Fire Resistive Construction (No Sprinklers) | (2) Protected Noncomb. Const. (With Sprinklers) | (3) (2) - (1) |
|---|---|---|---|
| Initial Costs | | | |
| Building | $6,918,000 | $6,745,000 | -$173,000 |
| Sprinklers | 0 | 234,000 | 234,000 |
| TOTAL INITIAL COSTS | $6,918,000 | $6,979,000 | $ 61,000 |
| Future Costs | | | |
| Sprinkler Maintenance (UPW = 9.43) | $ 0 | $ 4,715 | $ 4,715 |
| Insurance Cost (UPW* = 15.80) | | | |
| Building | $ 131,165 | $ 66,161 | -$ 65,004 |
| Contents | 63,200 | 47,400 | - 15,800 |
| TOTAL INSURANCE COST | $ 194,365 | $ 113,561 | -$ 80,804 |
| TOTAL FUTURE COST | $ 194,365 | $ 118,276 | -$ 76,089 |
| TOTAL LIFE-CYCLE COST | $7,112,365 | $7,097,276 | -$ 15,089 |

Table 3.7 Example #3

Non-profit Hospital
Constant Dollar Analysis
Real Discount Rate: 15%
Time Horizon: 30 years
PNC Cost: ~97.5% of FRC Cost
Sprinkler Equipment Cost: $2.00/ft$^2$
Building Value Differential at End of Time Horizon: 0

| | (1) Fire Resistive Construction (No Sprinklers) | (2) Protected Noncomb. Const. (With Sprinklers) | (3) (2) - (1) |
|---|---|---|---|
| Initial Costs | | | |
| Building | $6,918,000 | $6,745,000 | -$173,000 |
| Sprinklers | 0 | 234,000 | 234,000 |
| TOTAL INITIAL COSTS | $6,918,000 | $6,979,000 | $ 61,000 |
| Future Costs | | | |
| Sprinkler Maintenance (UPW = 6.57) | $ 0 | $ 3,285 | $ 3,285 |
| Insurance Cost (UPW* = 9.81) | | | |
| Building | $ 81,438 | $ 41,078 | -$ 40,360 |
| Contents | 39,240 | 29,430 | - 9,810 |
| TOTAL INSURANCE COST | $ 120,678 | $ 70,508 | -$ 50,170 |
| TOTAL FUTURE COST | $ 120,678 | $ 73,793 | -$ 46,885 |
| TOTAL LIFE-CYCLE COST | $7,038,678 | $7,052,793 | $ 14,115 |

Table 3.8 Example #4

Tax-Paying Hospital (50% Combined Income Tax Rate)
Current Dollar Analysis: Inflation Rate = 5%
Nominal Discount Rate: 10% (after tax)
Time Horizon: 30 years
PNC Cost: ~97.5% of FRC Cost
Sprinkler Equipment Cost: $2.00/ft$^2$
Building Value Differential at End of Time Horizon: 0

| | (1) Fire Resistive Construction (No Sprinklers) | (2) Protected Noncomb. Const. (With Sprinklers) | (3) (2) - (1) |
|---|---|---|---|
| Initial Costs | | | |
| Building | $6,918,000 | $6,745,000 | -$173,000 |
| Sprinklers | 0 | 234,000 | 234,000 |
| TOTAL INITIAL COSTS | $6,918,000 | $6,979,000 | $ 61,000 |
| Future Costs | | | |
| Sprinkler Maintenance (UPW* = 15.80) | $ 0 | $ 7,900 | $ 7,900 |
| Insurance Cost (UPW* = 31.08)[1] | | | |
| Building | $ 258,014 | $ 130,144 | -$127,870 |
| Contents | 124,320 | 93,240 | - 31,080 |
| TOTAL INSURANCE COST | $ 382,334 | $ 223,384 | -$158,950 |
| Tax Savings from Depreciation (UPW = 9.43) | -$2,174,558 | -$2,193,732 | -$ 19,174 |
| Tax Savings from Maintenance and Insurance Costs | -$ 191,167 | -$ 111,692 | -$ 79,475 |
| TOTAL LIFE-CYCLE COST | $4,934,609 | $4,904,860 | -$ 29,749 |

[1] Insurance cost assumed to rise 5% faster than 5% inflation rate. This yields a compound rate of increase of (1.05)(1.05) = 1.1025.

In this for-profit example, initial costs are subject to recovery through depreciation over a specified number of years, while all operating-relating costs can be recovered in the year they are incurred. The Economic Recovery Tax Act of 1981 now permits full depreciation of new buildings in 15 years with no salvage consideration and no separate depreciation schedules for major building components. Straight-line depreciation is used in the fourth example to compute the annual depreciation allowance.

The present value of the cumulative depreciation taken over the 15 years is considerably less than the initial cost upon which it is based. Present value tax savings from depreciation are computed by multiplying the combined federal and state income tax rate[5] by the present value of the cumulative depreciation. Similarly, present value tax savings from maintenance and insurance costs are computed by multiplying the combined tax rate by the present value of those two cost elements. In this example, the sprinkler alternative has a lower LCC than the base system. Increasing the discount rate will reduce the present value of these tax saving items, eventually making the base system the more cost effective of the two.

A fifth and final example of the LCC method is shown in table 3.9. This example is identical to the second except that the sprinkler equipment must be replaced after 25 years rather than having a 50 year expected life. The

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5 The combined federal and state income tax rate (CTR) is computed as:

$$CTR = FTR + STR\ (1 - FTR)$$

where FTR = Federal Income Tax Rate, and
STR = State Income Tax Rate,

because state income taxes are deductible from income in computing federal tax liabilities.

Table 3.9 Example #5

Non-profit Hospital
Constant Dollar Analysis
Real Discount Rate: 10%
Time Horizon: 30 years
PNC Cost: ~97.5% of FRC Cost
Sprinkler Equipment Cost: $2.00/ft$^2$
Sprinkler Replacement Cost in Year 25: $3.00/ft$^2$
Building Value Differential at End of Time Horizon: 50% of sprinkler replacement cost.

| | (1) Fire Resistive Construction (No Sprinklers) | (2) Protected Noncomb. Const. (With Sprinklers) | (3) (2) - (1) |
|---|---|---|---|
| Initial Costs | | | |
| Building | $6,918,000 | $6,745,000 | -$173,000 |
| Sprinklers | 0 | 234,000 | 234,000 |
| TOTAL INITIAL COSTS | $6,918,000 | $6,979,000 | $ 61,000 |
| Future Costs (Present Value) | | | |
| Sprinkler Replacement (SPW = 0.092) | $ 0 | $ 32,292 | $ 32,292 |
| Sprinkler Maintenance (UPW = 9.43) | $ 0 | $ 4,715 | $ 4,715 |
| Insurance Cost (UPW* = 15.80) | | | |
| Building | $ 131,165 | $ 66,161 | -$ 65,004 |
| Contents | 63,200 | 47,400 | - 15,800 |
| TOTAL INSURANCE COST | $ 194,365 | $ 113,561 | -$ 80,804 |
| Resale Value (SPW = 0.057) | 0 | - 10,004 | - 10,004 |
| TOTAL FUTURE COST | $ 194,365 | $ 140,564 | -$ 53,801 |
| TOTAL LIFE-CYCLE COST | $7,112,365 | $7,119,564 | $ 7,199 |

sprinkler replacement cost is assumed to be 50 percent more than the original equipment cost ($3.00 per square foot or $351,000 in 1980 dollars) because of the need to work in finished spaces. In addition, it is assumed that at the end of the 30 year study period the new equipment will retain approximately 50 percent of its value if the building were to be resold ($175,500 in 1980 dollars). Using equation 2.4, and a real discount rate of 10%, the replacement cost after 25 years has a present value of $32,292 (SPW = 0.092 x $351,000). Similarly, the present value of the pro-rated resale value at the end of 30 years is $10,004 (SPW = 0.057 x $175,500). Because the sprinkler equipment must be replaced before the end of the study period, the sprinkler alternative has a higher LCC than the base system. However, the effect of discounting this future cost over 25 years, along with its anticipated resale value, greatly reduces the impact of the replacement on present-value costs.

It is important to note that these LCC comparisons are based on a variety of assumptions as to the present value cost impact of protected noncombustible construction with sprinklers relative to fire resistive construction without sprinklers, and in no way can be extrapolated to other health care facilities. Detailed analysis is required to determine the actual design changes and their related costs in any new facility. Appropriate financial analysis criteria, including the time horizon, discount rate, insurance costs, tax analysis, and assumptions about inflation should be determined by those actually responsible for the financial analysis of the overall facility and cannot be generalized. Other alternatives permitted by the Life Safety Code should also be considered in order to determine which results in the lowest overall cost of compliance.

# 4. SUMMARY AND CONCLUSIONS

This report provides a methodology for determining which of several alternative building fire safety systems in compliance with the Life Safety Code for new health care facilities has the lowest life-cycle cost in a particular application. It is suggested that the LCC criteria is a more valid means of comparing alternatives than initial costs alone because the LCC concept includes all costs incurred or avoided over the life of the building (or the time horizon of the investor) attributable to the design changes. The elements of the LCC equation are spelled out, and the discounting procedures needed to adjust future costs to their present values are shown.

The LCC methodology is applied to two alternative building fire safety systems in a new hospital: (1) fire resistive construction with no sprinklers, and (2) protected noncombustible construction with automatic sprinkler equipment. Five examples of a LCC comparison are presented, each with a somewhat different assumption about the initial cost of the sprinkler alternative, the discount rate, tax savings assumptions, or the life of the sprinkler system. The alternative with the lower life-cycle cost varies from example to example as these basic assumptions are changed. The results, however, are not meant to provide a definitive answer to the question of least cost, but rather to stand only as a demonstration of the methodology. They, therefore, should not be extrapolated to health care facilities (or other buildings) in general.

Life-cycle cost analysis can be a valuable decision-making tool at the design stage of a new health care facility when selecting among alternative technologies that satisfy the same design criteria (e.g., the Life Safety Code). However, the usefulness of LCC analysis can be expanded if the difference in benefits from the alternative technologies could be better measured and quantified in economic terms. While some quantification of this difference may be found in fire insurance rates for buildings, more information is needed by building designers in order to determine the most cost-effective fire safety systems overall for new health care facilities.

## 5. ACKNOWLEDGMENTS

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## Appendix A - Glossary of Economic Terms in Life Cycle Cost Studies[1]

Alternatives - The different approaches or methods by which objectives may be attained.

Base Time - The date to which all future and past benefits or costs are converted when a present value method is used.

Constant Dollars - Values expressed in terms of the purchasing power of the dollar in the baseline year. Constant dollars have not been adjusted for the effects of future inflation or deflation.

Current Dollars - Values expressed in terms of actual prices for each year.

Differential Cost - The difference in cost of two alternatives.

Differential Inflation Rate - The expected percent difference between the rate of increase assumed for a given item of cost (such as energy) and the general rate of inflation.

Discount Factor - A multiplicative number for converting costs and benefits occurring at different times to a common time.

Discount Rate - The rate of interest reflecting the investor's time value of money used to determine discount factors for converting benefits and costs occurring at different times to a common time.

Discounting - The technique for converting costs and benefits occurring over time to equivalent amounts at a common point in time.

Future Costs - Any costs during the study period which occur after the base time, or the initial occupancy date. Future costs may be of recurring or non-recurring types.

Initial Cost (First Cost) - The sum of costs associated with the planning, design, and construction of a facility.

Life Cycle - The period of time between the base time and the end of the study period over which the future costs relating to the alternative under study will be incurred.

Life Cycle Cost Analysis - A generic method of economic evaluation that considers all relevant costs associated with a project investment during its study period.

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[1] These definitions are consistent with the "Standard Definitions of Terms Relative to Building Economics" E883-81, in the Annual Book of ASTM Standards, American Society for Testing and Materials, 1982, when such a definition is provided.

Modified Uniform Present Worth Factor - A discount factor used to convert a series of annual costs or benefits, increasing in value at a uniform rate, to their present value, given a discount rate and a length of time.

Non-Recurring Cost - Cost which occurs, or is expected to occur, at any one time during the building life cycle.

Operation and Maintenance Costs - Costs incurred in the operation and maintenance of a building or a building system, component, or equipment.

Opportunity Rate of Return - The rate of return available in the next best available investment of comparable risk.

Present Value - The value of a benefit or cost found by discounting future cash flows to the base time.

Present Value Factor - The number by which a future value may be multiplied to find its value at the base time.

Recurring Costs - Costs which occur as regularly repeating single payments over two or more years of the analysis life cycle. They are uniform (or uniformly increasing or decreasing) amounts.

Repair and Replacement Costs - Costs associated with restoring a facility, or a component element, to approximately its original performance. Repair costs can be expensed for income tax purposes in the year they are incurred, while replacement costs are considered to be capital expenditures to be depreciated over time.

Resale Value - See Salvage Value.

Salvage Value - The residual costs or values of assets, or the net sum to be realized from disposal of an asset at the end of the study period, or whenever it is no longer to be used. Also Resale Value.

Sensitivity Analysis - A test of the outcome of an analysis by altering one or more system parameters from an initially assumed value(s).

Single Present Value Factor - A discount factor used to convert a future sum of money to its present value, given a discount rate and a length of time.

Study Period - The length of time over which an investment is analyzed (syn. life cycle, time horizon).

Uniform Present Worth Factor - A discount factor used to convert a series of uniform annual costs or benefits to their present value, given a discount rate and a length of time.

Table B-1. Single present worth (SPW) factor for discount rates (d) of 5%, 10%, and 15%[1]

| Year (n) | 5% | 10% | 15% |
|---|---|---|---|
| | Discount Rates | | |
| 1 | .9524 | .9091 | .8696 |
| 2 | .9070 | .8264 | .7561 |
| 3 | .8638 | .7513 | .6575 |
| 4 | .8227 | .6830 | .5718 |
| 5 | .7835 | .6209 | .4972 |
| 6 | .7462 | .5645 | .4323 |
| 7 | .7107 | .5132 | .3759 |
| 8 | .6768 | .4665 | .3269 |
| 9 | .6446 | .4241 | .2843 |
| 10 | .6139 | .3855 | .2472 |
| 11 | .5847 | .3505 | .2149 |
| 12 | .5568 | .3186 | .1869 |
| 13 | .5303 | .2897 | .1625 |
| 14 | .5051 | .2633 | .1413 |
| 15 | .4810 | .2394 | .1229 |
| 16 | .4581 | .2176 | .1069 |
| 17 | .4363 | .1978 | .0929 |
| 18 | .4155 | .1799 | .0808 |
| 19 | .3957 | .1635 | .0703 |
| 20 | .3769 | .1486 | .0611 |
| 21 | .3590 | .1351 | .0531 |
| 22 | .3419 | .1228 | .0462 |
| 23 | .3256 | .1117 | .0402 |
| 24 | .3101 | .1015 | .0349 |
| 25 | .2953 | .0923 | .0304 |
| 26 | .2812 | .0839 | .0264 |
| 27 | .2678 | .0763 | .0230 |
| 28 | .2551 | .0693 | .0200 |
| 29 | .2429 | .0630 | .0174 |
| 30 | .2314 | .0573 | .0151 |
| 35 | .1813 | .0356 | .0075 |
| 40 | .1420 | .0221 | .0037 |
| 45 | .1113 | .0137 | .0019 |
| 50 | .0872 | .0085 | .0009 |

[1] Single Present Value (SPV) factor is given by:

$$SPV = \frac{1}{(1+d)^n},$$

where d = discount rate, and
n = number of interest periods (years).

Table B-2 Modified uniform present worth factors for inflation rates from 0% to 10% (discount rate d = 10%)

| | Inflation Rates | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | 0% | 1% | 2% | 3% | 4% | 5% | 6% | 7% | 8% | 9% | 10% |
| 1 | 0.9091 | 0.9182 | 0.9273 | 0.9364 | 0.9455 | 0.9546 | 0.9636 | 0.9727 | 0.9818 | 0.9909 | 1.0000 |
| 2 | 1.7355 | 1.7612 | 1.7871 | 1.8131 | 1.8393 | 1.8657 | 1.8921 | 1.9188 | 1.9457 | 1.9727 | 2.0000 |
| 3 | 2.4868 | 2.5353 | 2.5844 | 2.6340 | 2.6844 | 2.7354 | 2.7869 | 2.8391 | 2.8921 | 2.9456 | 3.0000 |
| 4 | 3.1698 | 3.2460 | 3.3237 | 3.4027 | 3.4834 | 3.5656 | 3.6492 | 3.7344 | 3.8213 | 3.9097 | 4.0000 |
| 5 | 3.7907 | 3.8986 | 4.0092 | 4.1225 | 4.2388 | 4.3581 | 4.4801 | 4.6053 | 4.7336 | 4.8650 | 5.0000 |
| 6 | 4.3552 | 4.4978 | 4.6449 | 4.7966 | 4.9531 | 5.1146 | 5.2808 | 5.4524 | 5.6294 | 5.8117 | 6.0000 |
| 7 | 4.8684 | 5.0480 | 5.2344 | 5.4278 | 5.6284 | 5.8367 | 6.0524 | 6.2765 | 6.5089 | 6.7498 | 7.0000 |
| 8 | 5.3449 | 5.5521 | 5.7810 | 6.0188 | 6.2669 | 6.5260 | 6.7959 | 7.0780 | 7.3723 | 7.6793 | 8.0000 |
| 9 | 5.7590 | 6.0159 | 6.2878 | 6.5722 | 6.8705 | 7.1839 | 7.5124 | 7.8577 | 8.2201 | 8.6004 | 9.0000 |
| 10 | 6.1445 | 6.4417 | 6.7577 | 7.0903 | 7.4411 | 7.8118 | 8.2028 | 8.6161 | 9.0524 | 9.5130 | 10.0000 |
| 11 | 6.4930 | 6.8328 | 7.1935 | 7.5755 | 7.9807 | 8.4113 | 8.8682 | 9.3539 | 9.8696 | 10.4174 | 11.0000 |
| 12 | 6.8137 | 7.1919 | 7.5977 | 8.0299 | 8.4909 | 8.9837 | 9.5095 | 10.0717 | 10.6722 | 11.3138 | 12.0000 |
| 13 | 7.1034 | 7.5216 | 7.9725 | 8.4553 | 8.9733 | 9.5300 | 10.1274 | 10.7698 | 11.4601 | 12.2020 | 13.0000 |
| 14 | 7.3667 | 7.8243 | 8.3199 | 8.8536 | 9.4293 | 10.0513 | 10.7227 | 11.4487 | 12.2335 | 13.0819 | 14.0000 |
| 15 | 7.6061 | 8.1022 | 8.6421 | 9.2266 | 9.8604 | 10.5490 | 11.2964 | 12.1092 | 12.9929 | 13.9539 | 15.0000 |
| 16 | 7.8238 | 8.3574 | 8.9408 | 9.5758 | 10.2680 | 11.0240 | 11.8492 | 12.7516 | 13.7384 | 14.8178 | 16.0000 |
| 17 | 8.0216 | 8.5918 | 9.2179 | 9.9029 | 10.6535 | 11.4776 | 12.3821 | 13.3767 | 14.4706 | 15.6742 | 17.0000 |
| 18 | 8.2014 | 8.8069 | 9.4747 | 10.2090 | 11.0177 | 11.9103 | 12.8953 | 13.9844 | 15.1891 | 16.5223 | 18.0000 |
| 19 | 8.3649 | 9.0044 | 9.7129 | 10.4957 | 11.3622 | 12.3235 | 13.3900 | 14.5757 | 15.8947 | 17.3630 | 19.0000 |
| 20 | 8.5135 | 9.1857 | 9.9337 | 10.7641 | 11.6878 | 12.7178 | 13.8666 | 15.1507 | 16.5873 | 18.1958 | 20.0000 |
| 21 | 8.6486 | 9.3512 | 10.1385 | 11.0154 | 11.9957 | 13.0942 | 14.3259 | 15.7101 | 17.2674 | 19.0211 | 21.0000 |
| 22 | 8.7715 | 9.5042 | 10.3285 | 11.2509 | 12.2870 | 13.4537 | 14.7688 | 16.2546 | 17.9355 | 19.8394 | 22.0000 |
| 23 | 8.8832 | 9.6446 | 10.5046 | 11.4714 | 12.5623 | 13.7968 | 15.1955 | 16.7841 | 18.5913 | 20.6501 | 23.0000 |
| 24 | 8.9847 | 9.7735 | 10.6679 | 11.6777 | 12.8225 | 14.1241 | 15.6065 | 17.2989 | 19.2349 | 21.4531 | 24.0000 |
| 25 | 9.0770 | 9.8919 | 10.8193 | 11.8710 | 13.0886 | 14.4367 | 16.0026 | 17.7998 | 19.8670 | 22.2490 | 25.0000 |
| 26 | 9.1607 | 10.0047 | 10.9607 | 12.0585 | 13.3108 | 14.7333 | 16.3939 | 18.2776 | 20.5529 | 23.2070 | 26.0000 |
| 27 | 9.2376 | 10.1423 | 11.0905 | 12.2285 | 13.5315 | 15.0188 | 16.7602 | 18.7539 | 21.1664 | 23.9909 | 27.0000 |
| 28 | 9.3068 | 10.1958 | 11.2111 | 12.3864 | 13.7385 | 15.2897 | 17.1138 | 19.2115 | 21.7598 | 24.7397 | 28.0000 |
| 29 | 9.3698 | 10.7298 | 11.3231 | 12.5345 | 13.9342 | 15.5478 | 17.4546 | 19.6586 | 22.3409 | 25.5189 | 29.0000 |
| 30 | 9.4266 | 10.3571 | 11.4273 | 12.6740 | 14.1207 | 15.7981 | 17.7865 | 20.7008 | 22.9106 | 26.3261 | 30.0000 |

Table B-3 Modified uniform present worth factors for inflation rates from 0% to 10% (discount rate d = 15%)

| | Inflation Rates | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | 0% | 1% | 2% | 3% | 4% | 5% | 6% | 7% | 8% | 9% | 10% |
| 1 | .8696 | .8783 | .8870 | .8957 | .9043 | .9126 | .9218 | .9304 | .9391 | .9478 | .9565 |
| 2 | 1.6257 | 1.6496 | 1.6736 | 1.6978 | 1.7222 | 1.7467 | 1.7714 | 1.7961 | 1.8211 | 1.8462 | 1.8715 |
| 3 | 2.2832 | 2.3270 | 2.3714 | 2.4163 | 2.4618 | 2.5078 | 2.5545 | 2.6016 | 2.6494 | 2.6977 | 2.7466 |
| 4 | 2.8550 | 2.9220 | 2.9903 | 3.0598 | 3.1307 | 3.2028 | 3.2763 | 3.3511 | 3.4272 | 3.5048 | 3.5837 |
| 5 | 3.3522 | 3.4446 | 3.5392 | 3.6362 | 3.7356 | 3.8373 | 3.9417 | 4.0484 | 4.1578 | 4.2697 | 4.3845 |
| 6 | 3.7845 | 3.9035 | 4.0261 | 4.1524 | 4.2826 | 4.4167 | 4.5549 | 4.6972 | 4.8438 | 4.9948 | 5.1503 |
| 7 | 4.1604 | 4.3065 | 4.4579 | 4.6148 | 4.7773 | 4.9454 | 5.1202 | 5.3009 | 5.4881 | 5.6819 | 5.8829 |
| 8 | 4.4873 | 4.6605 | 4.8409 | 5.0289 | 5.2247 | 5.4286 | 5.6412 | 5.8626 | 6.0932 | 6.3334 | 6.5837 |
| 9 | 4.7716 | 4.9714 | 5.1807 | 5.3998 | 5.6293 | 5.8696 | 6.1215 | 6.3852 | 6.6614 | 6.9508 | 7.2540 |
| 10 | 5.0188 | 5.2445 | 5.4820 | 5.7320 | 5.9952 | 6.2723 | 6.5646 | 6.8714 | 7.1951 | 7.5360 | 7.8951 |
| 11 | 5.2337 | 5.4843 | 5.7492 | 6.0295 | 6.3261 | 6.6399 | 6.9722 | 7.3239 | 7.6962 | 8.0906 | 8.5075 |
| 12 | 5.4206 | 5.6948 | 5.9863 | 6.2960 | 6.6253 | 6.9755 | 7.3483 | 7.7448 | 8.1669 | 8.6163 | 9.0949 |
| 13 | 5.5831 | 5.8799 | 6.1965 | 6.5347 | 6.8960 | 7.2820 | 7.6949 | 8.1365 | 8.6089 | 9.1146 | 9.6560 |
| 14 | 5.7245 | 6.0423 | 6.3830 | 6.7484 | 7.1407 | 7.5618 | 8.0145 | 8.5009 | 9.0240 | 9.5869 | 10.1927 |
| 15 | 5.8474 | 6.1850 | 6.5484 | 6.9399 | 7.3620 | 7.8173 | 8.3090 | 8.8400 | 9.4139 | 10.0345 | 10.7061 |
| 16 | 5.9542 | 6.3103 | 6.6951 | 7.1114 | 7.5622 | 8.0506 | 8.5805 | 9.1554 | 9.7800 | 10.4588 | 11.1971 |
| 17 | 6.0472 | 6.4203 | 6.8252 | 7.2650 | 7.7432 | 8.2636 | 8.8307 | 9.4490 | 10.1238 | 10.8609 | 11.6669 |
| 18 | 6.1280 | 6.5170 | 6.9406 | 7.4026 | 7.9069 | 8.4580 | 9.0614 | 9.7221 | 10.4467 | 11.2421 | 12.1161 |
| 19 | 6.1982 | 6.6019 | 7.0430 | 7.5258 | 8.0549 | 8.6356 | 9.2740 | 9.9762 | 10.7500 | 11.6034 | 12.5458 |
| 20 | 6.2593 | 6.6764 | 7.1338 | 7.6361 | 8.1888 | 8.7977 | 9.4699 | 10.2126 | 11.0347 | 11.9458 | 12.9569 |
| 21 | 6.3125 | 6.7419 | 7.2143 | 7.7350 | 8.3099 | 8.9457 | 9.6505 | 10.4326 | 11.3022 | 12.2704 | 13.3501 |
| 22 | 6.3587 | 6.7994 | 7.2857 | 7.8235 | 8.4194 | 9.0809 | 9.8170 | 10.6373 | 11.5534 | 12.5780 | 13.7262 |
| 23 | 6.3988 | 6.8499 | 7.3491 | 7.9028 | 8.5184 | 9.2043 | 9.9705 | 10.8278 | 11.7893 | 12.8696 | 14.0859 |
| 24 | 6.4338 | 6.8943 | 7.4053 | 7.9738 | 8.6079 | 9.3169 | 10.1119 | 11.0050 | 12.0108 | 13.1460 | 14.4300 |
| 25 | 6.4641 | 6.9332 | 7.4551 | 8.0374 | 8.6889 | 9.4198 | 10.2423 | 11.1699 | 12.2188 | 13.4079 | 14.7592 |
| 26 | 6.4906 | 6.9675 | 7.4993 | 8.0944 | 8.7621 | 9.5137 | 10.3624 | 11.3233 | 12.4142 | 13.6562 | 15.0740 |
| 27 | 6.5135 | 6.9975 | 7.5385 | 8.1454 | 8.8284 | 9.5995 | 10.4732 | 11.4660 | 12.5977 | 13.8915 | 15.3751 |
| 28 | 6.5335 | 7.0239 | 7.5733 | 8.1911 | 8.8883 | 9.6778 | 10.5753 | 11.5988 | 12.7700 | 14.1146 | 15.6632 |
| 29 | 6.5509 | 7.0471 | 7.6041 | 8.2320 | 8.9424 | 9.7493 | 10.6694 | 11.7224 | 12.9318 | 14.3260 | 15.9387 |
| 30 | 6.5660 | 7.0674 | 7.6315 | 8.2687 | 8.9914 | 9.8145 | 10.7562 | 11.8373 | 13.0838 | 14.5264 | 16.2063 |

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5. AUTHOR(S)

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6. PERFORMING ORGANIZATION *(If joint or other than NBS, see instructions)*

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10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

An analytical procedure is presented for conducting life-cycle cost (LCC) analyses of fire safety in new health care facilities. Comparative LCC evaluations of alternative fire safety systems can be obtained based on their initial costs, useful life times, operation and maintenance costs, salvage values, and corresponding fire insurance costs for the building and its contents.

The case study used to demonstrate the procedure compares the life-cycle costs of two fire safety systems in compliance with the NFPA Life Safety Code in a particular hospital:

(1) fire resistive construction with no sprinklers, and

(2) protected noncombustible construction fully equipped with automatic sprinklers.

Five different examples are provided with varying assumptions regarding initial construction costs, the choice of a discount rate, the tax status of the facility, and the life expectancy of the sprinkler equipment.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

automatic sprinklers; building codes; building construction; health care facilities; life cycle cost; Life Safety Code

13. AVAILABILITY

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