COSTING DATA FOR FIRE PROTECTION IN COMPLEX INDUSTRIAL OCCUPANCIES

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COSTING DATA FOR FIRE PROTECTION
IN COMPLEX INDUSTRIAL OCCUPANCIES

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Introduction

This study covers two primary objectives related to fire protection in nuclear power plants:

1. The development of realistic cost estimates for the installation of halon and water suppression systems.

2. The development of cost estimates for installation of passive fire barriers including barrier penetration seals.

To obtain information for these objectives, contact was made with representatives of 21 operating nuclear power facilities and 21 vendors of equipment. Valid responses were received from 11 nuclear facilities and from 13 of the vendor sources.

The nuclear plant representatives were willing to share whatever information they could. Unfortunately, many nuclear utilities' accounting methods prevent the retrieval of any detailed information. For example, many large contracts have been awarded to provide "fire detection throughout the plant" for a total cost of $5 to $10,000,000. In many cases, however, no breakdown is available for specific areas protected. In addition, many costs are fragmented such as engineering fees, material costs, and labor and installation costs. Because of these factors, specific data is limited.

The data presented herein cover equipment and systems installed during 1980 or 1981 only. All cost information has been adjusted to reflect a July, 1981 installation date in Chicago, IL to minimize the effects of inflation and regional factors.

The conclusions do not represent a statistical analysis of reviewed data. Rather, the "cost estimates" proposed are heavily influenced by the subjective interpretation of the authors and are tempered by significant field experience. The figures quoted do, however, reflect sound engineering judgement and can be used to estimate (or in some cases bound) actual costs.

ABSTRACT

This study indicates that the cost of providing active and passive fire protection systems for nuclear power generating facilities is much higher than the corresponding cost in general industry. In addition, there appears to be a substantial variance between "cost estimates" obtained from manufacturers and installers and actual "cost summaries" obtained from operating nuclear facilities.
Active Fire Suppression System Cost Estimates

Data were obtained for halon and water suppression systems only. Most of these systems were designed for automatic actuation. A summary of the estimated cost of providing halon and water suppression systems in specific plant areas is provided in Table 1.

Halon Suppression Systems

A figure of $4.25 per cu. ft. of volume protected may be used to estimate the cost of installing a halon suppression system in a nuclear power plant. This value includes the total cost of engineering, materials and labor, automatic detection and alarm equipment, main and reserve charges of halon, and acceptance testing for a single five to six percent concentration total flooding system. It should be noted that where several protected rooms are located in close proximity to one another, the use of a common rack of cylinders with discrete selector valves could significantly reduce the cost per unit volume of each system.

System costs are influenced by many variables. Our analysis of the data combined with our previous experience in this area indicates several factors which can be classified as significantly affecting or not affecting system cost.

Factors significantly impacting system cost include:

1. Quality Assurance/Quality Control (QA/QC) Requirements - This feature accounts for much of the difference in cost between system installation in nuclear power plants and the cost in general industry.

2. Compression of Time Schedules - Time constraints can raise system costs dramatically. Typically, nuclear projects are installed under demanding schedules. This directly impacts labor costs and indirectly reduces efficiency of both engineering and labor.

3. Area Congestion and Room Geometry - This feature increases costs in two ways. First, the congestion encountered in many cable spreading and switchgear rooms increases the difficulty of system installation because of obstructions and physical limitations of access. Secondly, obstructions tend to limit the natural distribution of the halon gas, resulting in "pockets" of both high and low concentrations. This may require installation of fans to increase circulation or even modification of the agent distribution piping.

4. Use of Selector Valves - Obviously use of selector valves to protect several rooms using a single rack of agent cylinders can significantly reduce system costs.

Factors which do not appear to significantly affect system costs include:

1. Seismic Qualification - This impact is minimized since most piping can be attached directly to the ceiling or wall although some additional cost could be incurred for provision of seismically qualified equipment (solenoid valves, detectors, control panels, etc.).

2. Initial vs. Retrofit Installation - This appears to provide no significant impact.

3. Room Size - From the data reviewed, room size appears to have little impact on halon system cost.

One clear result of this portion of the study is the difference between vendor estimates and actual plant cost. This may be partially explained by the fairly limited experience most vendors have in nuclear power plants. Also, much of the vendor data does not include materials or
## TABLE ONE

Cost of Protecting Specific Areas in a Typical Nuclear Power Plant

<table>
<thead>
<tr>
<th>Area designation</th>
<th>Area ($\text{ft}^2$)</th>
<th>Volume ($\text{ft}^3$)</th>
<th>Suppression System Cost Estimates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Water ($)</td>
</tr>
<tr>
<td>Relatively &quot;Open&quot; Areas:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Auxiliary Feedwater Pumps</td>
<td>409</td>
<td>9,100</td>
<td>4,213$^a$</td>
</tr>
<tr>
<td>Component Cooling Water Pumps</td>
<td>10,550</td>
<td>200,400</td>
<td>108,665</td>
</tr>
<tr>
<td>Feedwater Valve Rooms</td>
<td>1,852</td>
<td>105,588</td>
<td>19,076</td>
</tr>
<tr>
<td>Tump Valve Compartment</td>
<td>653</td>
<td>8,493</td>
<td>6,726</td>
</tr>
<tr>
<td>Diesel Generator Cells</td>
<td>3,030</td>
<td>136,500</td>
<td>31,209</td>
</tr>
<tr>
<td>Control Room</td>
<td>4,760</td>
<td>119,000</td>
<td>49,028</td>
</tr>
<tr>
<td>Emergency Exhaust Equipment Room</td>
<td>685</td>
<td>10,900</td>
<td>7,056</td>
</tr>
<tr>
<td>Reactor Building (general areas)</td>
<td>15,393</td>
<td>1,539,300</td>
<td>158,584</td>
</tr>
<tr>
<td>Auxiliary Building (general areas)</td>
<td>18,180</td>
<td>255,320</td>
<td>187,254</td>
</tr>
<tr>
<td>Relatively &quot;Congested&quot; Areas</td>
<td></td>
<td></td>
<td>Non-Seismic $^b$</td>
</tr>
<tr>
<td>Auxiliary Shutdown Panel Room</td>
<td>94</td>
<td>1,780</td>
<td>4,606</td>
</tr>
<tr>
<td>Auxiliary Building Cable Chase</td>
<td>73</td>
<td>1,700</td>
<td>3,673</td>
</tr>
<tr>
<td>Electrical Penetration Rooms</td>
<td>1,816</td>
<td>34,500</td>
<td>88,984</td>
</tr>
<tr>
<td>Switchgear Room</td>
<td>2,843</td>
<td>39,800</td>
<td>139,307</td>
</tr>
<tr>
<td>Battery and Switchgear Room</td>
<td>1,466</td>
<td>20,550</td>
<td>71,932</td>
</tr>
</tbody>
</table>

Notes:

a. Based upon a cost estimate of $10.30/\text{ft}^2$ for "open" areas.
b. Based upon a cost estimate of $49.00/\text{ft}^2$ for "congested" areas without seismic design requirements.
c. Based upon a cost estimate of $101.00/\text{ft}^2$ for "congested" areas with seismic design requirements.
d. Based upon a cost estimate of $4.25/\text{ft}^3$ of volume protected.
labor for installation of wiring and conduit associated with the suppression system since this typically is provided by the plant.

Water Suppression Systems

The discussion of water suppression systems is divided into the two broad headings of "open" and "congested" areas. This distinction is decidedly subjective and dependent on a combination of several factors including structural geometry of ceiling and walls; quantity and arrangement of equipment, piping, cables, conduit and other obstructions; impediments to access and freedom of movement; and radiological contamination potential. Typical examples of "open" and "congested" areas are diesel generator cells and cable spreading rooms, respectively.

Water Suppression Systems in "Open" Areas

A figure of $10.30 per sq. ft. of protected area may be used to estimate the cost of installing a water suppression system in a relatively "open" area within a nuclear power plant. This figure can vary + 50 percent but represents our best judgement of the reasonably expected cost of all engineering, materials and labor for the detection and suppression equipment on the system side of the supply valve. This estimates does not include the cost of providing the water supply, pumps, distribution piping, or manually operable hose standpipes. Most systems reviewed were of the automatic, preaction type with closed-head, water spray nozzles, although some, as noted, were ordinary wet pipe sprinkler systems.

Five factors that significantly impact the cost of installing fire suppression systems in "open" areas are:

1. Compression of Time Schedules - A compressed time schedule can dramatically increase costs as discussed previously.

2. Quality Assurance/Quality Control Requirements - This factor accounts for much of the difference in cost between water suppression systems in nuclear power plants and those in general industry. (Costs for water systems in industry are between $0.95 and $1.10 per sq. ft., not including detection systems.)

3. Regulatory Requirements - This factor is difficult to quantify but is cited by plant representatives as significant and is undoubtedly involved to some degree.

4. Radiological Contamination - Although this is not a factor in many open areas, it can play a significant role. Cost increases can be expected where laborers must wear protective clothing and where they must conform to radiation work permit (RWP) procedures.

5. Special Design Objectives - Costs can increase where "special" designs are employed such as installation of sprinklers to protect all cable trays as opposed to ceiling installation only.

Surprisingly, several factors do not seem to significantly influence the cost of installing water suppression systems in open areas. These factors include:

1. Seismic Qualification - The cost of system control valves increases where seismic qualification is required. However, overall system costs (including pipe support) seem to be governed by the factors listed above.

2. Room Size - There seems to be no identifiable relationship between system cost and room size or area protected. It is reasonable to assume that some economy of scale does exist, but the five factors above appear to override any impact of this.
3. Initial Installation vs. Retrofit — Little comparative data is available on this. However, based on discussions with plant personnel and vendors, this factor is considered insignificant.

4. Design — Items of decisions regarding system density and choice of materials (e.g., sprinklers vs. water spray nozzles, schedule 40 vs. schedule 80 pipe, type of detection) are usually not significant. However, they could become important (e.g., use of linear thermistor heat detection vs. ordinary heat-sensitive wire).

Graph One indicates the variance between actual plant data, vendor supplied data, and estimates of general industry costs obtained from insurance sources.

Water Suppression Systems in "Congested" Areas

Two figures are required to estimate the cost of installing a water suppression system in a relatively "congested" area within a nuclear power plant. A figure of $49.00 per sq. ft. of protected area may be used for systems not requiring seismic qualification. A figure of $101.00 per sq. ft. may be used where seismic analysis is required. These figures include all engineering, materials, and labor for the detection and suppression equipment on the system side of the supply valve. These estimates do not include the cost of providing and adequate water supply, pumps, distribution piping, or manually operable hose standpipes. Most systems reviewed were automatic preaction systems with closed-head water spray nozzles, although one system did employ open nozzles.

Several factors have been identified as being significant in the development of these cost estimates. Factors such as time schedule, QA/QC requirements, regulatory paperwork and radiological contamination all affect costs. However, the driving force for the cost increase in congested areas is, in fact, the congestion of the area. Many of these so-called "congested" areas are contained in irregularly shaped rooms or are provided with ceilings criss-crossed with 24 to 30 in. deep "beam pockets." These construction features require large increases in engineering time to adequately address specific location of water spray nozzles to ensure adequate coverage and compliance with applicable standards. Additionally, the congestion of various equipment, piping, conduit, cable trays, components, grated flooring, etc., provides innumerable obstructions to the distribution pattern of standard water spray nozzles.

All of these factors tend to increase the importance of the time schedule factor and dramatically increase the paperwork associated with QA/QC functions. The resulting piping design is much more complicated than in "open" areas and this results in a substantial increase in labor costs for installation. In congested areas, each factor appears to build on the next with a multiplier effect.

Graph Two provides a direct comparison of the impact of seismic qualification on water suppression system costs in congested areas. It is worth noting that in "open" areas seismic analysis was determined not be a significant factor whereas in "congested" areas it is found to be very significant. Complications in the pipe routing (number of turns, cantilevered lines, etc.) and the location of piping suspended some distance below the ceiling (rather than attached directly to the ceiling) require additional engineering time for seismic design of pipe supports. This, in turn, requires considerably more time for labor and installation. In some cases the design is impacted by the fact that there simply is not sufficient space to install a seismically qualified hanger at a given location. The factors of room size and initial design versus retrofit installation are not significant as they are overshadowed by the factor of congestion. Obviously, congestion is a subjective term.
GRAPH ONE: WATER SUPPRESSION SYSTEM COST COMPARISON: PLANT DATA VS. VENDOR DATA IN "OPEN" AREAS

NOTE: THESE FIGURES DO NOT INCLUDE THE COSTS OF ASSOCIATED SMOKE DETECTION SYSTEMS OR THE COST OF SEISMIC ANALYSIS.
GRAPH TWO
EFFECT OF SEISMIC ANALYSIS ON COST OF WATER SUPPRESSION SYSTEMS IN "CONGESTED" AREAS

NOTES
☐ ACTUAL PLANT DATA
☒ ACTUAL VENDOR DATA

COST PER UNIT AREA
($/FT^2)

WITH NO SEISMIC ANALYSIS REQUIRED

WITH SEISMIC ANALYSIS REQUIRED
which must be evaluated on a case by case basis.

Passive Fire Barrier Cost Estimates

The cost analysis for fire barriers, including protection of penetrations, first requires identifying the components to be evaluated. The fire barrier is defined for this report as a wall, floor, or ceiling assembly installed with the intent of providing a pre-determined resistance to a standard fire exposure. Fire barrier penetrations are defined as breaks in the fire barrier created by openings for personnel access, ventilation ducts, cables (cable trays or conduit) and other mechanical services.

This report considered the cost of providing the fire barrier itself as well as the cost of providing protection for the penetrations. For an existing barrier, the cost of creating the opening is not normally part of the fire protection cost but has not necessarily been excluded in the project cost. All actual project data involve barriers that were added after initial construction. Therefore, all are non-bearing partitions and the report does not reflect differences between bearing and non-bearing partitions.

Because of the relatively limited project data and the wide range of costs, no average values can be developed with credibility. There is also no certainty that specific installations meet the required listing criteria in all details. The fire resistance ratings reported may, in some cases, have been a solution to a regulatory requirement based on engineering judgement rather than an assembly subjected to and passing a standardized test.

The cost associated with enlarging an opening to accommodate a fire damper installed in a wall is not addressed. The actual installation data for fire dampers included dampers installed at the walls only (not in the wall). Such and installation would not provide the required barrier integrity unless the damper housing and supports were protected to the desired fire resistance rating. This was done in only one case and produces a significantly higher cost.

Fire Barriers

For fire barriers the cost of $189 per sq. ft. is an upper boundary within the scope of this report. Although this figure cannot have the same certainty as the figure for the lower boundary, it is probable that this cost does represent a reasonable upper boundary. The average of all costs reported is $74 per sq. ft. with the average of the highest five projects being $138 per sq. ft. The higher average would appear to be a reasonable estimate for installations involving strict QA/QC requirements, restricted personnel access, and restrictive design criteria.

Table Two shows the lack of correlation between actual costs and barrier location within the plant (e.g., the cost for one project is as much as six times that of another in a similar area).

A review of construction cost data for fire barriers provided a range of from $2.99 to $4.10 per sq. ft. These costs included material, labor and overhead as taken from Means Construction Cost Data, 28th Edition. Actual project costs reflected a minimum of $4.51 per sq. ft. Adjusting to a common date reference, the maximum estimated construction cost of $4.10 per sq. ft. is 9 percent less than the minimum actual project cost of $4.51 per sq. ft. The construction cost estimates vary by 37 percent. The highest actual project cost is 42 times greater than the lowest.

In actual projects reviewed there is no correlation between cost per square foot and the overall size of the project. There is also no correlation between the material used and the cost per square foot. The lowest cost per square foot was for 8-in. hollow block wall while the highest was for a 6-in. hollow block wall.
<table>
<thead>
<tr>
<th>Barrier Location within the Plant</th>
<th>Actual Cost per Unit Area ($/ft²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Switchgear Room</td>
<td>133.00</td>
</tr>
<tr>
<td>Switchgear Room</td>
<td>87.24</td>
</tr>
<tr>
<td>Fire Pump House</td>
<td>4.51</td>
</tr>
<tr>
<td>Fire Pump House</td>
<td>12.14</td>
</tr>
<tr>
<td>Diesel Generator Cell</td>
<td>25.49</td>
</tr>
<tr>
<td>Diesel Generator Cell</td>
<td>14.73</td>
</tr>
<tr>
<td>Cable Spread Room</td>
<td>118.81</td>
</tr>
<tr>
<td>Cable Spread Room</td>
<td>27.20</td>
</tr>
<tr>
<td>Cable Spread Room</td>
<td>164.25</td>
</tr>
<tr>
<td>Control Room</td>
<td>36.40</td>
</tr>
<tr>
<td>Health Physics Area and Cable Tunnel</td>
<td>190.00</td>
</tr>
</tbody>
</table>

There appear to be no specific trends to be drawn or "rules of thumb" to be used. It is apparent from the information developed that the material used for the barrier and the fire resistance rating desired did not directly impact the cost per square foot for projects reported.

Data from three actual "fire barrier" projects included a fire door in the total project cost. Two of the three were almost identical installations at the same plant (Plant C) with reported costs for one barrier 50 percent greater than the other. These installations did not involve radiation controlled areas but did include seismic design and quality control reviews. The cost difference in the two projects cannot be adequately explained based on the information available. If the average cost per door (developed from other door installations at the same plant) is subtracted from the total projected costs, the average price per square foot drops only 3 percent in one case and 13 percent in the other.

The third project which included a door involved three layers of 5/8 in. gypsum board on steel studs to achieve a required 1-1/2 hour fire resistance rating. The project at Plant H utilized 5/8 in. gypsum board installed 3 in. thick designed to achieve a 3-hour fire resistance rating. If the cost of the average door from Plant C is subtracted, the cost differential for these two walls still remains about the same.

Fire Barrier Penetrations

Protection of penetrations in fire barriers has been divided into three categories: fire doors, fire dampers, and penetration seals. Various manufacturers
were contacted to develop a base price for material and installation. Most of the projects reviewed did not significantly address costs related to special requirements such as seismic design, security criteria for doors, watertight design and other similar features. Often the protection of a fire barrier penetration is included as a part of the project that created the penetration and, therefore, is not retrievable as a separate item. As a result, actual information is limited.

**TABLE THREE**

<table>
<thead>
<tr>
<th>Location</th>
<th>Door Type</th>
<th>Actual Cost ($)</th>
<th>Per Door</th>
<th>Per Unit Area of Opening (ft²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fire Pump House</td>
<td>Swinging</td>
<td>408</td>
<td></td>
<td>16.66</td>
</tr>
<tr>
<td>Diesel Generator Building</td>
<td>Swinging</td>
<td>1427</td>
<td></td>
<td>68.00</td>
</tr>
<tr>
<td>Auxiliary Building</td>
<td>Swinging</td>
<td>5305</td>
<td></td>
<td>126.00</td>
</tr>
<tr>
<td>Cable Spreading Room</td>
<td>Swinging</td>
<td>3487</td>
<td></td>
<td>83.00</td>
</tr>
<tr>
<td>Cable Spreading Room</td>
<td>Swinging</td>
<td>1522</td>
<td></td>
<td>68.00</td>
</tr>
<tr>
<td>Pan Rooms</td>
<td>Roll Down</td>
<td>2080</td>
<td></td>
<td>35.00</td>
</tr>
</tbody>
</table>

**TABLE FOUR**

<table>
<thead>
<tr>
<th>Location (Quantity)</th>
<th>Special Design Requirements</th>
<th>Actual Cost Per Damper ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel Generator Room (2)</td>
<td>No</td>
<td>303</td>
</tr>
<tr>
<td>Diesel Generator Room (23)</td>
<td>Yes</td>
<td>11,699</td>
</tr>
<tr>
<td>Control Building (24)</td>
<td>Yes</td>
<td>4,641</td>
</tr>
<tr>
<td>Control Building (5)</td>
<td>No</td>
<td>7,936</td>
</tr>
<tr>
<td>Various (15)</td>
<td>No</td>
<td>699</td>
</tr>
<tr>
<td>Various (15)</td>
<td>No</td>
<td>3,634</td>
</tr>
<tr>
<td>Various (31)</td>
<td>Yes</td>
<td>21,390</td>
</tr>
</tbody>
</table>
GRAPH THREE:
EFFECT OF FIRE BARRIER SIZE ON COST OF INSTALLATION (ACTUAL PROJECT COSTS)
Fire Doors

Actual project cost information reflects installation of self-closing swing-type doors in most cases, with the installation of roll-down type doors reported in two projects. Table Three shows the representative costs of specific installations at various locations within the plant.

As would be anticipated, the manufacturer's estimate of cost per sq. ft. for fire doors decreased as the door size increased, but the plant's actual cost per sq. ft. for fire doors increased dramatically with an increase in door size. The costs are only project limits and not boundaries due to the small number of projects reviewed and the limited information available for each project.

Fire Dampers

The lowest reported cost of $303 per damper reflected only the reinforcement of existing fire dampers. Since no equipment cost was involved, this would reflect the minimum labor cost for a simple installation. Adding 10 percent to 20 percent to this cost (manufacturers' prices ranged from $27 to $63 per damper) should provide a reasonable estimate of total project cost for 3-hour rated fire dampers.

The project reflecting the highest cost per damper (above $21,000 per damper) also involved the largest number of dampers for any project in the study. The project included additional considerations including seismic design, wall modifications, electrical interlocks, QA/QC control, and radiation chemistry control. Although this is the only project reporting extensive design considerations, it is reasonable that the order of magnitude of this cost is an upper boundary.

Table Four shows the wide range of costs for fire damper installations in specific plant areas with and without special design requirements. The special design requirements may include some or all of those mentioned above.

Penetration Seals

For penetration seals, three of the five projects reflect lump sum costs with no indication of the total number of penetrations sealed. One project included penetration seals with the cost of barrier construction.

Graph Three compares manufacturer's cost estimates for two types of penetration seals with three actual plant installations. The high cost reported for Plant J may be due to the size of the project. For this plant the cost of material only was $228 per cu. ft. which is 2.3 time the manufacturers' estimate for material cost. The cost included the sealing of only eight openings whereas most manufacturers' estimates reflect installations involving a large number of such penetration. By eliminating the cost at Plant J, the average of manufacturers' estimates and actual plant costs of $390 per cu. ft.
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