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Validation of Generic Cost Estimates for Construction-Related Activities at Nuclear Power Plants

Final Report

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Prepared for
U.S. Nuclear Regulatory
Commission

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ABSTRACT

This report represents a validation study of the cost methodologies and quantitative factors derived in Labor Productivity Adjustment Factors (NUREG/CR-4546) and Generic Methodology for Estimating the Labor Cost Associated with the Removal of Hardware, Materials, and Structures From Nuclear Power Plants (SEA Report 84-116-05-A:1). This cost methodology was developed to support NRC analysts in determining generic estimates of removal, installation, and total labor costs for construction-related activities at nuclear generating stations. In addition to the validation discussion, this report reviews the generic cost analysis methodology employed. It also discusses each of the individual cost factors used in estimating the costs of physical modifications at nuclear power plants. The generic estimating approach presented uses the "greenfield" or new plant construction installation costs compiled in the Energy Economic Data Base (EEDB) as a baseline. These baseline costs are then adjusted to account for labor productivity, radiation fields, learning curve effects, and impacts on ancillary systems or components.

For comparisons of estimated vs actual labor costs, approximately four dozen actual cost data points (as reported by 14 nuclear utilities) were obtained. Detailed background information was collected on each individual data point to give the best understanding possible so that the labor productivity factors, removal factors, etc., could judiciously be chosen.

This study concludes that cost estimates that are typically within 40% of the actual values can be generated by prudently using the methodologies and cost factors investigated herein.

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ACKNOWLEDGEMENTS

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VALIDATION OF GENERIC COST ESTIMATES FOR CONSTRUCTION-RELATED ACTIVITY AT NUCLEAR POWER PLANTS

1.0 BACKGROUND

The U.S. Nuclear Regulatory Commission's (NRC) Regulation Development Branch has sponsored several studies on generic costs associated with construction activity at nuclear power plants. These generic studies are intended to provide tools and methods to assist analysts in the estimation of costs resulting from new and revised regulatory requirements.

Three studies have recently been completed for the Regulation Development Branch which deal specifically with construction costs at nuclear power plants. These studies are documented in Labor Productivity Adjustment Factors (NUREG/CR-4546), Generic Methodology for Estimating the Labor Cost Associated with the Removal of Hardware, Materials, and Structures From Nuclear Power Plants (SEA Report 84-116-05-A:1), and Engineering and Quality Assurance Cost Factors Associated with Nuclear Plant Modification (NUREG/CR-4921). A number of other studies have also been sponsored by the Regulation Development Branch which draw on these generic cost studies to help form a comprehensive and consistent cost estimating approach for NRC analysts. In particular the NRC has issued analytical guides which draw on and build on this cost information. These include Generic Cost Estimates (NUREG/CR-4627), A Handbook for Cost Estimating (NUREG/CR-3971), and A Handbook for Quick Cost Estimates (NUREG/CR-4568). Another study, Data Base of System-Average Dose Rates at Nuclear Power Plants (NUREG/CR-5035), provides guidance in estimating worker radiation doses associated with nuclear plant modifications.

The overall approach taken in these studies is to build on information developed previously. The approach generally utilizes the Energy Economic Data Base (EEDB) to provide baseline costs for labor, equipment, and materials associated with new plant construction. These baseline costs are then adjusted to reflect actual conditions existing at operating or nearly completed nuclear plants. Successive sets of factors are used to estimate the total resource requirement, as well as aspects such as worker radiation exposure. This "building block" approach is efficient and practical. However, the sequential structure of the methodology increases the need to assure that each "block" or set of cost factors is accurate and adequately reflects reality. One inaccurate factor or set of factors can have its errors multiplied and throw off the entire estimate by a substantial amount.

Section 2 of this report presents some of the points which justified the need for this validation study. It also summarizes what the analysis focused on throughout this report and cautions the cost estimator on the limitations of this methodology. A review of the general approach taken in this study and the applicability of the cost methodology confirmed herein are presented in Section 3. The adjustment factors and their characteristics are discussed and tabulated in Section 4. Special guidelines for pipe replacement activities are also included in this Section. Comparisons of actual cost data with estimated labor costs are presented in Section 5 together with a statistical analysis of the results. An example of applying the generic methodology and factors to derive an estimate of the labor costs is given in Section 6. Section 7 presents several cautions and limitations that users of this methodology should be aware of. The conclusions are given in Section 8.

2.0 PURPOSE AND SCOPE

The primary purpose of the generic cost estimating approach is to assist NRC analysts in preparing approximate estimates of cost impacts associated with the implementation of generic regulatory requirements. This report reviews methods, rules-of-thumb, quantitative cost factors, etc., (derived in NUREG/CR-4546 and SEA 84-116-05-A:1) which will allow the user to develop realistic and consistent estimates for total labor cost as well as for removal and/or installation labor costs associated with physical modifications to operating or nearly completed nuclear power reactors. The study was necessary because only a partial verification of the entire set of factors has been conducted in previous work.

The objective of this task was to assess the validity of the methodologies derived in NUREG/CR-4546 and SEA 84-116-05-A:1. Therefore, this report will focus on the costing approach as well as the adjustment factors and their relationship to the overall generic model. The analysis focused on the overall results of the estimated labor costs as compared to actual cost data and not on the individual adjustment factors. Although the labor productivity factors, removal factors, and learning curve factors were investigated in great detail, the value of the engineering and QA/QC factor was not examined.

It should be noted that although the cost adjustment factors were developed or refined based on actual cost data, they are by no means "cast in concrete." The user has to recognize that each requirement is unique and has its own specific problems. The more detailed and realistic estimates will require a sound knowledge of technical details as well as implementation cost data.

3.0 TECHNICAL APPROACH

3.1 GENERIC METHODS

NRC analysts must often produce industry-wide cost estimates for modifications done on a large number of reactors of varying designs and site characteristics. The generic cost estimating approach requires the analyst to perform the following activities in order to perform a cost analysis:

- Identify the type and number of plants that are impacted by the requirement. Group the plants according to those features that will allow a technically sound common resolution of the regulatory requirement. For each grouping, a reference plant can be chosen for which the cost estimates will be prepared.

- Define the technical detail of the generic action.

- Locate within the EEDB those systems and structures that best match those affected by the proposed regulatory requirement.

- Evaluate the relevant cost categories, i.e., removal, installation, and quality assurance and engineering costs. Use the cost data presented in the EEDB together with the appropriate generic cost factors, rules-of-thumb, and any other information supplied by the sources mentioned in the background section of this report.

- Distribute the reference plant costs to the entire population of impacted nuclear reactors in the same group.

Other major costs (not included in our discussion) associated with the implementation of a generic regulatory requirement have to be considered in addition to the removal and installation labor costs. Figure 3.1 illustrates these costs. They are:

- Replacement energy costs for the time period while the plant is shutdown to accomplish the modifications (see Generic Cost Estimates, Ref. 1, and Replacement Energy Costs for Nuclear Electricity-Generating Units in the United States, Ref. 6).

- Labor and other costs associated with ALARA activities, such as radiation dose estimation, dose reduction through application of temporary shielding, decontamination, or use of remote tools and robots.

- Costs of shutting down the reactor, making general preparations so the work activities can commence, and restarting the plant when the repairs are complete (see Generic Cost Estimates for Reactor Shutdown and Startup, Ref. 5, and Generic Cost Estimates, Ref. 1).

- Costs and impacts associated with worker radiation exposure (Ref. 1, Generic Cost Estimates, presents exposure costs for a number of discrete repair/modification activities at nuclear plants, and Ref. 11, Data Base of System-Average Dose Rates at Nuclear Power Plants, provides tables on radiation dose rates typical for most PWR and BWR systems and components accounts).

- Costs of disposing of radioactive materials generated as a result of repair/replacement activities (see Generic Cost Estimates for the Disposal of Radioactive Materials, Ref. 8, and Generic Cost Estimates, Ref. 1).

- Costs of equipment and materials needed to accomplish the repair/replacement activities.

- Utility licensing and administration costs.

- NRC costs.

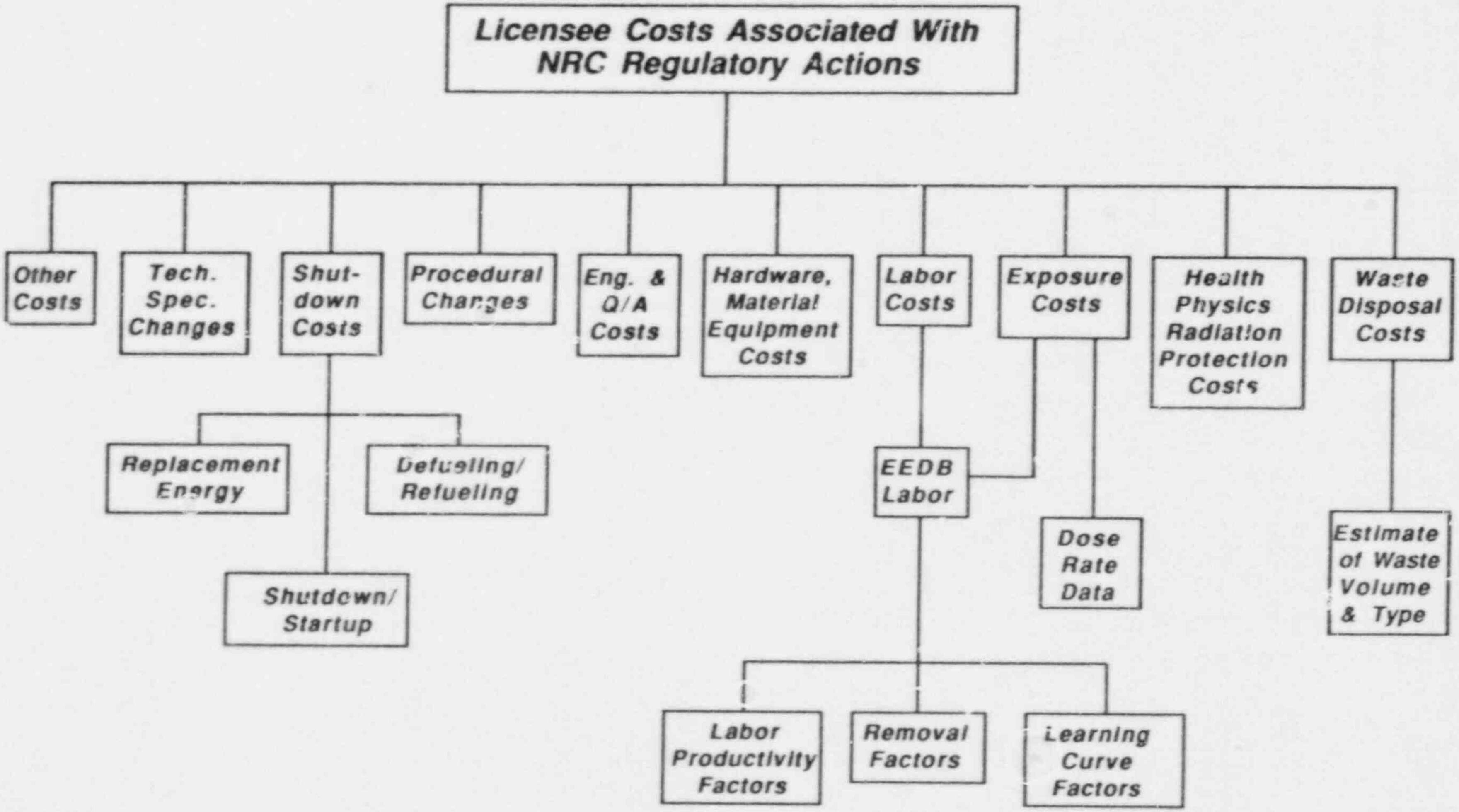

FIGURE 3.1. REGULATORY EFFECTS COST ANALYSIS

3.2 CONCEPTUAL FRAMEWORK

The costing methodology presented in this report utilizes the data base derived in the EEDB for baseline estimates of the direct installation labor hours and for estimates of new plant equipment and material costs. Since the EEDB expresses costs only for a new construction environment, adjustments are necessary to properly account for work performed at operating or nearly completed nuclear plants. These methods must account for aspects such as radiation environment, poor access, congestion and interference, and other conditions which are typically present at operating or near completed reactor sites. Figure 3.2 illustrates this overall cost adjustment approach. To estimate installation labor requirements, the general form of the adjustment is:

$$C_L' = C_L\ (1+F_L)\ (1+F_Y) \tag{1}$$

where

C_L' = adjusted installation labor cost
C_L = EEDB installation labor cost
F_L = sum of labor productivity factors
F_Y = quality assurance and engineering factor

Adhering to this general methodology, a total cost that incorporates both removal and installation is defined as:

$$C_L'' = C_L\ (1+F_L)\ (1+F_Y)\ (1+F_R) = C_L'\ (1+F_R) \tag{2}$$

where

C_L'' = adjusted installation and removal labor cost
F_R = sum of removal factors.

Also, the presence of a learning curve in many large and unusual replacement activities (e.g., steam generator replacement) has an important bearing on industry-wide efforts. That is, experience has shown that removal and replacement activities generally become more efficient after they have been performed several times, especially for large and complex jobs. Applying this learning curve effect, the relationship for the combined costs for removal and installation labor becomes:

$$C_L'' = C_L\ (1 + F_L)(1 + F_Y)(1 + F_R)(1 + F_{LC}) \tag{3}$$

where F_{LC} is the learning curve factor.

If estimates of removal costs alone are needed, they can be calculated using the formula:

$$C_{RL} = C_L\ (1 + F_L)(1 + F_Y)(1 + F_{LC})[(1 + F_{R1})(1 + F_{R2}) - 1] \tag{4}$$

where

C_{RL} = the removal labor cost
F_{R1} and F_{R2} account for removal activities.

F_{R1} is a factor which accounts for environmental conditions and target item characteristics (structural or hardware), and F_{R2} is a factor which corrects for impingement on ancillary systems.

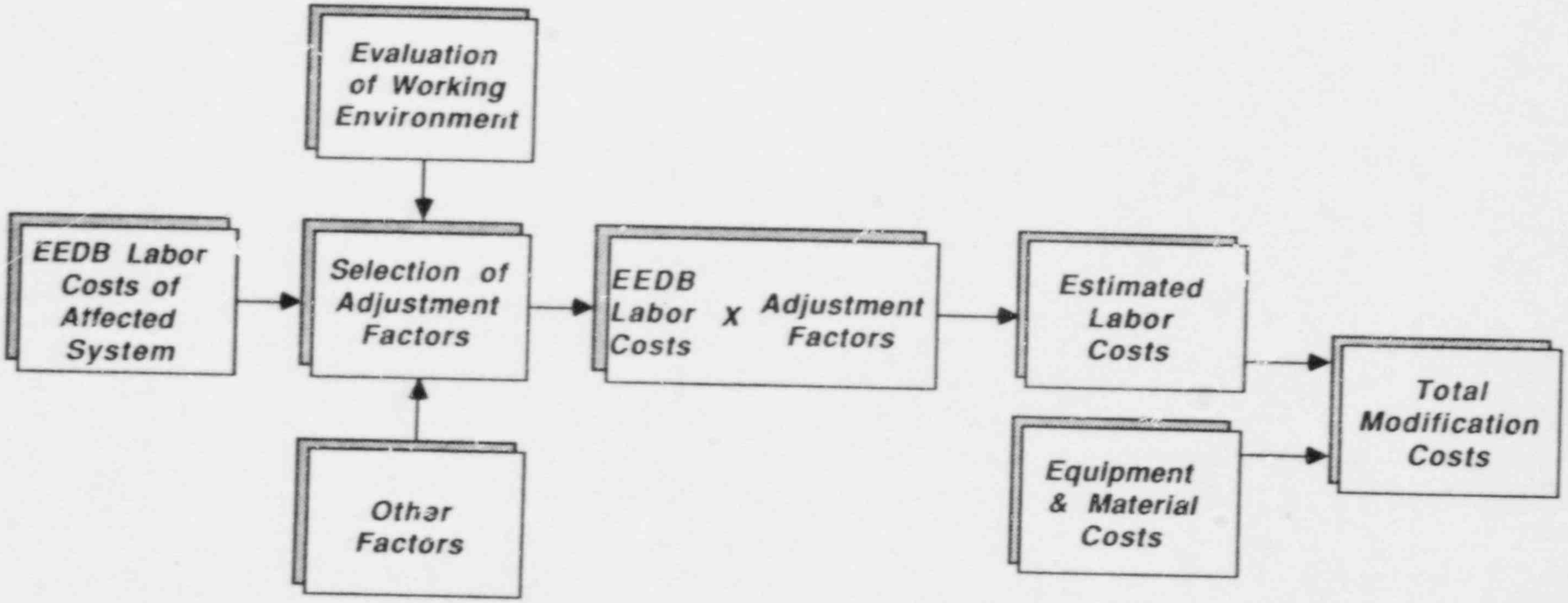

FIGURE 3.2. COSTS ADJUSTMENT METHODLOGY

3.3 APPLICABILITY LEVEL

Although the EEDB presents cost and labor information down to the system and component level of detail, most modification activities at nuclear plants seldom involve entire systems but rather affect individual sub-components and/or portions of systems. As a result, guidelines are now being developed to obtain costs and installation hours for individual items such as piping, valves, pumps and motors, electrical instrumentation and control devices, etc., from the aggregated values in the EEDB (Ref. 12). The cost methodology and factors discussed herein could be applied to estimate generic modification costs down to an even finer level of detail than currently possible with the EEDB.

4.0 FACTOR QUANTIFICATION

NRC analysts using the information presented here will generally use it in the context of estimating costs for a complete modification, i.e., the final estimate should include costs of both removal and installation activities. However, separate factors have been defined for estimating installation labor costs and removal labor costs. These factors must be defined in a consistent and complimentary manner. The factors for hardware and material removal should not overlap with those applicable to installation, and vice versa. Section 4.1 presents guidelines for selecting labor productivity factors, and Section 4.2 gives guidelines for removal factors.

4.1 LABOR PRODUCTIVITY FACTORS

The NRC publication Labor Productivity Adjustment Factors (NUREG/CR-4546)(Ref. 9) discusses factor quantification in detail. Four different workplace characteristics have been identified as (1) possessing significant impact, and (2) fitting approximately with information available to NRC analysts. These characteristics are Access and Handling, Congestion and Interference, Radiation, and Manageability. Their recommended factor values are reproduced in Table 4.1. Each workplace characteristic is discussed briefly below. The following form is chosen for representation of labor productivity factors:

$$F_{total} = 1 + F_L$$

where

F_L = sum of labor productivity factors.

4.1.1 Access and Handling

This factor is concerned with the adequacy of space for spotting materials immediately adjacent to work areas, for permitting shakeout of materials (layout in sequence of need) in laydown areas, and for on-ground prefabrication of components. If such space is limited, additional non-productive time is required for identifying and picking up materials and the man-hour savings normally credited to on-ground prefabrication of components are lost.

TABLE 4.1.

LABOR PRODUCTIVITY FACTORS

Activity Characteristic	Factor Value						
1. i. Access and Handling (operating plants)	a. Operating plant, security procedures, easy acces, adequate laydown	0.1	b. Operating plant, non-containment RWP* restrictions, extra handling, limited laydown	0.3	c. Operating plant, containment area, extra handling; restricted laydown prefabrication, and shakeout potential	0.4	
ii. Access and Handling (plants under construction)[1]	a. Under construction, easy access, adequate laydown	0.0	b. Under construction, internal area, extra handling, limited laydown	0.2	c. Under construction, containment area, extra handling; restricted laydown prefabrication, and shakeout potential	0.4	
2. Congestion and Interference[2]	a. Uncongested work area	0.0	b. Congested work area	0.2	c. Severely congested work area	0.4	
3. Radiation[3]	a. No radiation	0.0	b. Minimal equipment requirements (respirator)	0.2	c. Full protective equipment required	0.5	d.[4] High radiation, high temperature; Stay Time — Rad. Factor 2 hr — 1.1 1 hr — 2.6 .5 hr — 5.6
4. Manageability[3]	a. Non-outage related	(0.2)	b. Outage activity	0.3	c. Outage activity, within containment	0.4	

$$F_{total} = 1 + \text{Sum of Labor Productivity Factors}$$

Notes:

(1) Under construction generally denotes plants more than 70 percent complete

(2) Applies to both operating plants and plants under construction

(3) Normally applies to operating plants only

(4) See text for basis of stay time factors

*RWP: Radiation Work Permit required

As necessary personnel movement to and from the work site becomes more time-consuming and as material handling becomes more difficult, direct work time falls relative to total time. The factor associated with such conditions ranges up to 0.25 for general construction. Expert opinion, however, is unanimous that such difficulties increase in the case of operating reactors, and that a maximum factor of 0.4 is appropriate for nuclear plant containment areas.

This maximum value is approached in incremental steps, depending upon whether one is concerned with an operating plant, or a plant under construction. The first 0.1 increment is due almost entirely to security precautions at operating reactors. Another 0.2 increment is estimated to be imposed by problems at operating plants associated with internal area activities and the typical constraints placed upon personnel and material movement in such areas. This same 0.2 factor becomes the first increment associated with plants under construction. The extreme value of 0.4 is reserved for activities carried out within the main reactor containment building itself.

In this validation study, the following values were selected and are recommended for most future cost estimating analyses:

0.1 - For work conducted in open areas, involving only security restrictions

0.3 - For work conducted in primary auxiliary building, waste process building, fuel storage building, diesel generator building

0.4 - For work conducted in reactor building, drywell.

4.1.2 Congestion and Interference

This factor refers to the physical condition of the actual work site. Congestion can be interpreted as limitations on the ability to maneuver equipment and materials freely and of individuals to perform their tasks unhindered. Severe congestion suggests the inability to function except in extremely restricted positions. Congestion of workers and construction equipment adds to non-productive (waiting) time in addition to reducing production rates during direct time as workers and equipment get in each others way. It also refers to interferences from already-installed permanent materials and equipment that limit accessibility to work areas or physically block new work planned.

The standard situation (labor productivity adjustment factor = 0) incorporates adequate crew activity space and no significant potential for interference with the systems being addressed. A severely congested work area is defined as one with one-third or less of the adequate crew work space plus interferences such as a dense mix of piping, electrical systems, and/or mechanical systems in the same area. Available literature and data suggest that an adjustment factor of 0.4 describes the maximum end of this range, and it applies to most work activities performed inside the reactor building or drywell. For work areas that are congested enough to interfere with worker effectiveness, but are not extremely congested, a factor of 0.2 is recommended.

4.1.3 Radiation

Work in a radiological environment presents a particularly difficult problem for operating reactors. There are two reasons for productivity reductions: (1) the encumbrances of protective equipment, particularly under conditions of elevated temperature, and (2) strict limits on permissible radiation exposure that constrain the time that a given worker can remain in a particular environment.

Even minimal equipment, such as a face mask respirator, can reduce productivity significantly. Full protective equipment, including air units and a double set of protective clothing, are much more cumbersome. The use of such equipment in a high temperature environment is even more debilitating. Information supplied by industry sources assigns maximum factor values of 0.5 for full protective equipment and an additional 0.1 for high temperature operation, e.g., above 95-100° F. The same value of 0.1 is recommended for all activities performed in a non-radiation but high temperature work environment.

The consideration of limited "stay time" is somewhat more complex arithmetically. "Stay time" is defined as the maximum time a worker is permitted to remain in a particular radiological environment. A stay time limitation would increase necessary work hours by a factor equal to the ratio of the difference between stay time and normal direct work time per shift to the stay time.

$$F_{\text{stay time}} = \frac{\text{normal direct work time} - \text{stay time}}{\text{stay time}}$$

If normal direct work time is, say, three hours per shift (37.5 percent of total shift time) for new nuclear construction, and stay time is limited to one hour, the factor is (3-1)/1 = 2. If stay time is 30 minutes, the factor is (3-0.5)/0.5 = 5; etc.

This time must also be adjusted for protective equipment and high temperature activity -- represented by the combined factor of 0.6. Continuing the examples above, for a one hour stay time the factor is 2.0 + 0.6 = 2.6. If stay time is 30 minutes, the total radiation adjustment factor is 5.6.

Stay time becomes an important productivity element only for activities performed within the containment. Any containment activities taking place while the reactor core is producing power will be limited in time duration. Under outage conditions, activities in proximity to reactor coolant system and within the drywell of a boiling water reactor almost certainly involve stay time limitations of less than an hour.

This study assigned point values for the radiation adjustment factor for specific radiation dose rate level ranges. The values, which were based on detailed background information known on most of the actual modification data points, produced the best fit when incorporated in the cost equations. They are:

Radiation Dose Rate (mr/hr)	Radiation Adjustment Factor
0	0
0<Dose Rate≤10	0.2
10<Dose Rate≤30	0.5
30<Dose Rate≤50 & high temperature	1.1
50<Dose Rate≤100 & high temperature	2.6
>100 & high temperature	5.6

The cost analyst is cautioned that the generated point values are highly empirical in nature and very specific to the conditions present at those particular nuclear units. They should be used with great care since, in many cases, they may prove invalid or produce meaningless results. The cost estimator is encouraged to employ the radiation dose rate tables developed in Ref. 11. Careful consideration should be given to all cautions and limitations associated with those tables.

4.1.4 Manageability

This concept refers not only to the individual task, but the overall management environment within which it is performed. Generally speaking, evidence suggests that productivity tends to decline as management complexity increases, and that management complexity can be approximated by the size of the workforce on site. For operating reactors, this leads to the conclusion that productivity falls for work undertaken during plant outages.

Given the usual cost of replacement power, there is enormous incentive to return a plant to service as soon as possible; thus round-the-clock schedules and heavy overtime are routine. Most studies have concluded that longer-than-normal workdays and weeks cause workers to slow down throughout the workday so that production during any hour is less than would be expected under normal five day per week, eight hours per day conditions. The adjustment factor used (0.3) reflects productivity losses associated with managing a crash project involving high levels of overtime. When the activity occurs within containment, an additional 0.1 is added to adjust for difficulties associated with preplanning work without adequate prior physical access.

However, relative to new construction, normal maintenance performed while a plant is on-line is probably more productive. This is due to relatively small crew sizes, ability to focus close management attention, and a lack of stringent time pressure. A productivity credit of 0.2 is applied in this case.

4. REMOVAL FACTORS

The removal adjustment factors were first presented in the study Generic Methodology for Estimating the Labor Cost Associated with the Removal of Hardware, Materials, and Structures from Nuclear Power Plants (SEA Report 84-116-05-A:1, Ref.13). Since no single specific methodology existed to adequately estimate labor removal costs, the problem was addressed in an eclectic fashion, using actual industry data when possible, employing industry rules-of-thumb when necessary, and referring to standard cost estimating sources when appropriate.

The analysis of original removal cost data indicated that two separate sets of removal factors were needed to adequately reflect actual cost variations. That is, removal costs can better be estimated using factors in the form $(1 + F_{R1})\ (1 + F_{R2})$ rather than simply $(1 + F_R)$. The factors F_{R1} and F_{R2} can each be the sum of appropriate sub-factors. F_{R1} is a factor that accounts for the environmental conditions under which the removal operations take place. It also takes into account whether the target item is hardware or is structural in nature. Industry practice favors differential treatment of structures and systems/hardware. Because the data collected during that study covered hardware and equipment removal almost exclusively, the factors for removal of structures were estimated using guidelines given in standard cost estimating references.

F_{R2} is a cost adjustment factor based on whether or not the removal operations have significant impacts on adjacent or ancillary systems. It accounts for time spent removing "non-target" or ancillary systems and structures.

Using the above factors, estimates of total labor costs, including both removal and installation, are produced using the formula:

$$C_L'' = C_L\ (1 + F_L)(1 + F_Y)(1 + F_{LC})(1 + F_{R1})(1 + F_{R2}) \qquad (5)$$

In order to facilitate use of these factors by NRC analysts, removal factors have been categorized to the extent possible by the same characteristics that must be evaluated in order to apply the labor productivity factors. This does not necessarily imply causative relationships as are present in the labor productivity formulation. However, it does imply that certain characteristics, like site access, are associated positively with other factors that affect removal efforts.

Equations (4) and (5) are suitable when the EEDB is being used to estimate either the total or removal labor cost requirement for the modification in question. However, there may be circumstances where the analyst has an independent installation labor cost. In these circumstances just the removal labor cost would be needed in order to see the total labor cost picture. Removal labor costs can be estimated using the following expression:

$$\text{Labor Removal Cost} = C_L'\ [(1 + F_{R1})(1 + F_{R2}) - 1] \qquad (6)$$

This assumes the independently-obtained installation labor cost (CL') adequately reflects labor productivity, engineering/QA considerations, and learning curve effects.

Removal labor costs as a percentage of the labor installation costs can vary dramatically, depending on the number and complexity of removal activities associated with a given modification, as well as learning curve considerations. Data from a number of actual cases indicate that removal labor generally accounts for about 30% of the total labor costs, or is about 55% of the installation labor costs. Therefore, where independent labor installation costs are available, removal costs can reasonably be estimated to be about 55% of the installation value.

The original data set assembled in SEA 84-116-05-A:1 contained about two dozen actual cases of equipment replacement that occurred at both BWRs and PWRs during recent years. Those cases provided data on 11 distinct areas of the plant and were extremely important in estimating the range of values of the adjustment factors needed to derive replacement labor costs from the EEDB data. However, it should be recognized that data collected from industry were not necessarily internally consistent and could not be checked for quality. Thus, results derived from the data varied widely and were applied selectively rather than comprehensively. This also led to a presentation of the removal factors in terms of value ranges rather than point estimates.

For this validation study, an updated set of data points (almost double the original size) was gathered. The data include actual cases of equipment and structure replacement performed by 14 nuclear utilities and conducted in 26 discrete areas of the plant. Based on analysis of the improved data set and detail background information about each work activity, a new range of values was derived for the radiation component of the removal factor F_{R11}.

Removal factors are summarized in Table 4.2 and are discussed separately below.

4.2.1 <u>Targeted System Removal Factors</u>

4.2.1.1 Radiation Environment

It is clear that the radiation environment at an operating reactor greatly affects removal efforts as compared to greenfield (EEDB) installation. However, once EEDB data are adjusted for radiological effects on labor productivity, the ratio of removal to installation approaches more conventional levels (0.3 to 0.8 for hardware and equipment).

Industry data show a clear inverse relationship between the radiation component of the labor productivity adjustment and the removal factor. Although not intuitively obvious this is a logical relationship since the base the removal factor operates against becomes very large under high radiation conditions. Although removal effort becomes relatively smaller (as measured by the removal factor) under radiological conditions, absolute values of labor hours and costs increase as the radiological conditions become more restrictive.

High radiation conditions appear to favor a removal factor range of 0.05 to 0.20, with low radiation (non-containment) conditions associated with a 0.35 to 0.40 range. Generally, within the ranges, the more severe the radiation, the lower the factor and vice versa. For work within containment areas, the lower end of the lower range (i.e., 0.05 to 0.10) would be appropriate for any removal work undertaken while the plant is in operation. Under outage conditions activities in proximity to the reactor coolant systems or within the dry well of a BWR will also imply the lower end of the range. Outside the containment any activity mandating the use of air units and/or protective clothing will imply the lower end of the upper range (e.g., ~0.35).

This study assigned point values for the radiation adjustment factor for specific radiation dose rate level ranges (and consequently productivity

TABLE 4.2

REMOVAL FACTORS

Activity Characteristic		Factor Value		
Stage 1: Targeted Systems and Structures				
1. Radiation (F_{R11})	a. Low Radiation, outside containment	0.35 - 0.40	b. High Radiation, inside containment	0.05 - 0.20
2. Structural (F_{R12})	a. Congested work area	.5	b. Severely congested work area	.8
Stage 2: Ancillary Systems and Structures				
1. Access and handling (F_{R2})	a. Complex activity, impingement on surrounding systems and structures	.40 - .60		

$$\text{Total Removal Factor} = (1 + F_{R11} + F_{R12})(1 + F_{R2})$$

factors for radiation). They are recommended for future cost analyses and are presented below:

Productivity Factor for Radiation	Removal Factor for Radiation
0	0.40
0.2	0.35
0.5	0.20
1.1	0.15
2.6	0.10
5.6	0.05

Caution should be used when applying these radiation removal factors to generate cost estimates.

4.2.1.2 Structure Removal

Removal of structures in many cases requires a disproportionately large labor effort as compared to the effort associated with the removal of hardware and equipment. For instance, the removal of an internal concrete floor is much more labor intensive than its installation. This effect, however, is also dependent upon the work environment. The ability to apply wrecking equipment to a free-standing concrete structure, for example, would greatly alter the relationship.

The structural removal factor should only be applied when the use of specialized equipment is hindered. In addition, it should be applied only when the structural material of concern is bulky, such as concrete, brick, or concrete blocks. It should not be applied to the removal of steel structures.

This removal factor approximates the gradations of congestion described in the labor productivity section. The choice of the factor value is dependent on the degree of congestion at the work site. For example, if the work place is rated "severely congested" for productivity purposes, the 0.8 factor should be used.

Since in the original document, SEA 84-05-A:1, no data were obtained for removal of structures, the adjustment factor was approximated using Richardson's Process Plant Construction Estimating Standards (Ref. 10). Richardson allows derivation of various removal to installation ratios, of which the following are representative:

Equipment	Removal/Installation
Suspended Gas Heater	.725
Electrical Cooling Unit	.772
Structural	
4 in. Interior Concrete Floor	1.194
6 in. Interior Concrete Floor	1.305

Based on these data, it is estimated that the removal factor is increased by a factor of 0.5 or 0.8 if the target is structural in nature, is bulky, and is located in a congested or severely congested workspace. If these conditions do not apply the structural factor F_{R12}

is assigned a value of 0. The factor for radiation, F_{R11}, still applies, however.

4.2.2 Ancillary Structures and Systems Factor

The factor F_{R2} is to be applied whenever the removal of the target item also requires the removal of non-target or ancillary components and systems in order to accomplish the tasks. As mentioned above, a separate multiplicative factor was derived based on residual data from very large and complex removal tasks. The original data suggested a range of 0.40 to 0.60 for this factor.

This factor has been defined in terms of site access, which must also be evaluated in order to choose the appropriate labor productivity factors. It should be applied only in extreme access cases for both operating plants and plants whose construction is more than 70 percent complete. If a labor productivity access factor of 0.2 or 0.3 has been used, then the analyst should use a value for F_{R2} of 0.4. If an access factor of 0.4 has been used, then $F_{R2} = 0.6$ should be chosen. Since the access factor attempts to correct for inability to enter the work area easily, it is in essence used as a proxy for the interrelationship of the target system with other systems and structures.

This study confirmed that the ancillary structures and systems factor can correctly adjust the cost estimates to closer match the actual cost data. Industry data show that large and bulky components, such as steam generators, reactor coolant pumps, feedwater heaters, demand that adjustment factor but small hardware items do not. Another type of component that needed correction for its impingement on auxiliary systems is the small to medium pipe (less than 12 inches in diameter). This finding, although empirical, is logical: in order to remove small pipe (which is given secondary priority in the layout of overall plant piping systems and is generally more difficult to gain access to than major piping and large components) non-target components likely will have to be removed. That is, in order to clear the work area additional labor-hours are spent to remove surrounding equipment which otherwise would not be affected by the modification.

Due to heavy congestion conditions present within principal buildings at nuclear reactor sites and limited laydown space available for future modifications, it is recommended that the impingement factor be used on all activities similar to those investigated in this study, i.e., heavy, bulky items such as steam generators, large pumps, etc., as well as small piping.

An alternative approach to estimating labor removal costs for ancillary systems and structures is available to the analyst. When such an item is identified, it can be estimated directly by treating the ancillary item as the primary activity, finding its installation cost in the EEDB, and making all factor adjustments directly on that EEDB installation labor cost. This approach is preferable and should produce more accurate results than using the 0.4 to 0.6 adjustment factor discussed here. However, the 0.4 to 0.6 factor is useful for quick estimates or when gross approximations are viewed as adequate.

4.3 LEARNING CURVE FACTORS

Two sets of data were collected which clearly demonstrate that learning from prior efforts significantly improves the efficiency of subsequent physical modification activities. This learning curve effect applies to large and unusual repair and removal activities. These are the types of removal activities requiring extensive preparation, and which involve significant disturbances to major systems or components within a nuclear power plant.

Figure 4.1 illustrates the quantitative effect of learning from prior activities. The values shown are normalized to the fourth time a given activity has taken place. Data for efforts beyond the fourth time are not available, so it is recommended that no benefits be taken beyond this point.

The data used in generating Figure 4.1 were derived from two different major removal/replacement efforts at several different nuclear power plants. These activities were:

- Steam generator removal and installation at PWRs
- Reactor coolant pump removal and installation at a PWR

These were major replacement operations involving thousands of labor-hours to accomplish. The normalized data from these different types of removal activities were averaged to produce the values displayed in Figure 4.1. The average values for first through fourth-of-a-kind factors are as follows:

Event Number	Labor Required Relative to Fourth-of-a-Kind Event
1	3.6
2	2.5
3	1.4
4	1.0

Any application of these learning curve effects to regulatory impact analyses must be used with caution. The reduction in labor from the first to the fourth-of-a-kind effort assumes that these efforts are conducted sequentially and that the information from the first effort is available to those conducting the second effort. Similarly, the information from the second effort must be available in time to benefit the third, and the third be available to benefit the fourth. The effects illustrated in Figure 4.1 are also based on the assumption that information is shared fairly freely among utilities and plant crews performing similar replacement operations at different plants. The data available suggest that this is typically the case. If this sequential ordering is not possible and the replacement efforts at different plants must take place essentially simultaneously, then first-of-a-kind factors should be applied to each of these efforts. That is, the total labor costs to accomplish the required plant modifications, as derived according to the discussions in Sections 4.1 and 4.2, should be multiplied by a factor of about 3.6.

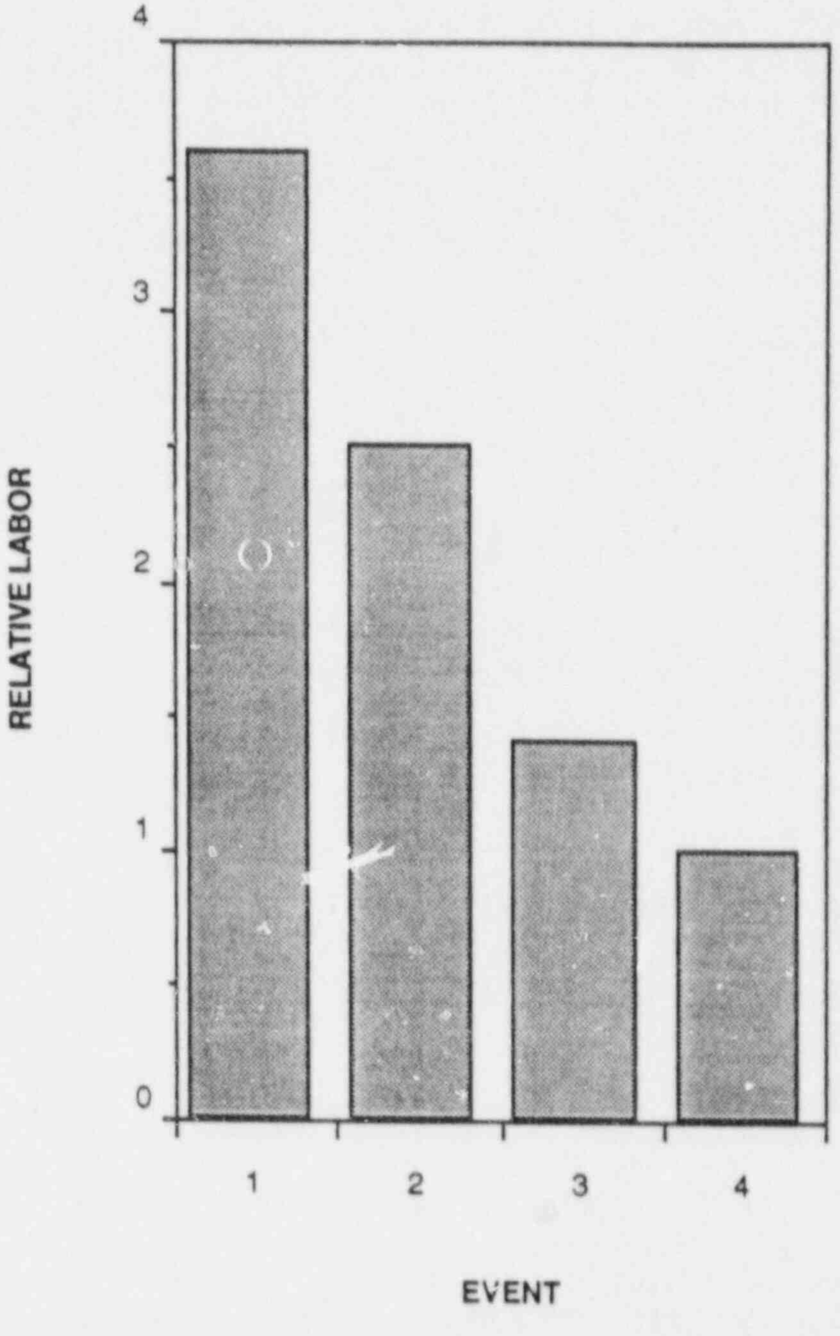

FIGURE 4.1. LEARNING CURVE EFFECTS

The preceding discussion noted that these learning curve effects have been quantified based on data from two major replacement activities at nuclear power plants. These are efforts that required thousands of labor hours to complete. Data were not available to determine whether such first- to fourth-of-a-kind improvements would also hold true for lesser replacement activities. Therefore, it is recommended that the learning curve factors be applied only in the context of major activities. For smaller jobs analysts should use a learning curve factor of 1.0 (i.e., $1 + F_{LC} = 1.0$).

The learning curve trends presented here were derived from both removal and installation data. The trends for removal are fairly similar to those for installation. Therefore, the learning curve factors presented here can be applied to both estimates of installation labor and to those of removal labor.

Table 4.3 summarizes the learning curve factors and gives brief guidelines for selecting the appropriate factor.

TABLE 4.3
LEARNING CURVE FACTORS[1,2]

Activity Characteristic	Factor Value, F_{LC}
Previous experience or knowledge of removal or installation activity	
1. Work has already been performed by industry at least three times	0.0
2. Work has already been performed twice by industry	0.4
3. Work has been performed once before by industry	1.5
4. This is the first time work has been been performed by industry	2.6

learning curve factor = $1 + F_{LC}$

[1] Applicable only to major replacement activities

[2] Applicable to both removal and installation activities

4.4 ENGINEERING AND QUALITY ASSURANCE/CONTROL COST FACTOR

This factor accounts for the cost of engineering and design, as well as quality assurance (QA) and quality control (QC) activities, associated with implementing a requirement. A study of the relationship of these costs with the total direct cost of material, equipment, and labor has been conducted under contract to NRC. This study concluded that a reasonable approximation of the combined cost for engineering, design, QA, and QC can be obtained by using factors of 25% for changes to plants well along in construction (typically more than 70% complete) and operating plants, and 30% for new plants. The basis for these values and a more detailed breakdown of engineering and quality control costs by EEDB code of accounts is available in the document Engineering and Quality Assurance Cost Associated With Nuclear Plant Modification (NUREG/CR-4921, Ref. 7). Although Engineering/QA/QC factors are presented as point values rather than ranges, the cost estimator is cautioned that there are cases where Engineering/QA/QC costs are greater than normally anticipated (i.e., minimal structure/system modifications but major engineering analysis effort) or are lower than anticipated (i.e., installation of off-the-shelf items requiring a minor amount of engineering).

As defined in NUREG/CR-4921, the Engineering and QA/QC factor should be applied to total direct cost, i.e., material/equipment and labor costs. However, since this validation study dealt with labor costs only, the Engineering and QA/QC factor was used here to adjust the "greenfield" labor costs alone. For all future cost estimating analyses it is recommended that both material and labor costs be multiplied by the same factor in order to generate Engineering/QA/QC costs and to include these costs in the overall analysis.

4.5 SPECIAL CONSIDERATIONS FOR PIPING

4.5.1 Large Pipe

Estimates of piping replacement costs were generated using the methodology and factors currently being developed by SEA as part of an EEDB Disaggregation Task (Ref. 12). Table 4.4 presents factors that help determine labor, factory, and site material costs. The "greenfield" EEDB installation labor for a particular safety class and material type pipe was calculated by multiplying the installation cost factor (in labor-hours/lb of material) with the pipe weight (in lb/linear foot).

Six of the ten pipe data points considered in this study were large pipe replacements. When compared to the actual plant costs, all six cost estimates produced using the generic methodology required that the "greenfield" EEDB labor-hours be adjusted by a factor of 0.2 in order to reasonably agree with actual costs reported by utilities. This correction is purely empirical in nature and is perhaps a result of abnormalities in the disaggregated EEDB installation cost factor itself. The "large pipe" factor, PF, is recommended for all cost estimates involving pipe with a diameter of over 18 inches. The total estimated cost equation for piping replacement activities has the form:

$$C_L" = C_L \times PF(1+F_L)(1+F_Y)(1+F_{LC})(1+F_R) \qquad (7)$$

TABLE 4.4

PIPING INSTALLATION COSTS, FACTORY COSTS, AND SITE MATERIAL COSTS FOR PWRs AND BWRs

Diameter Size	Material Type / Safety Class	Installation Costs MHs/lb	Factory Costs $/lb	Site Material Costs $/lb
2" and Smaller	CS/NNS	1.62	-	1.572
	CS/SC1, 2, or 3	2.52	-	2.568
	SS/NNS	3.6	-	7.296
	SS/SC1, 2, or 3	5.4	-	15.144
2.5" and Larger	CS/NNS	0.42	3.636	0.9953
	CS/SC 1, 2, or 3	0.78	4.512	1.8484
	SS/NNS	1.32	17.76	3.1284
	SS/SC 1, 2, or 3	2.16	18.492	5.1185

CS - CARBON STEEL SS - STAINLESS STEEL

NNS - NON NUCLEAR SAFETY : Piping system that does not interface with safety class systems.

SC1 - SAFETY CLASS 1 : Piping system that is part of the primary coolant boundary.

SC2 & SC3 - SAFETY CLASSES 2 & 3 : Piping systems that are not part of the primary coolant boundary, i.e., Emergency Core Cooling and Auxiliary Cooling Systems.

where

for large pipe PF = 0.2
for small pipe PF = 1.0

4.5.2 Small Pipe

The other four of the pipe data points considered involve small to medium size pipe replacements. A factor reflecting the impingement on ancillary components is recommended for most of these removal and replacement activities. The guidelines and values described in Section 4.2.3 of this report have to be followed closely.

5.0 COMPARISONS OF ACTUAL DATA WITH ESTIMATED LABOR

5.1 DATA COMPARISONS

Table 5.1 presents a comparison of actual labor data obtained from nuclear plants with estimated labor based on the generic estimating procedures presented in Section 4. The table gives the values assigned to the factors used in estimating the total, installation, and removal labor. The resulting values for the estimated costs are given in terms of ratios relative to actual labor costs as reported by the utilities.

The table contains data on a wide variety of hardware removal and replacement activities. The equipment was located both inside and outside of containment. The data included both very large jobs, such as steam generator replacement, and very small jobs, such as replacement of a make-up pump.

The following equations were utilized to calculate estimates of the installation, removal, and total labor costs:

$$\text{Installation:}\quad C_L' = C_L\ (1+F_L)(1+F_Y)(1+F_{LC}) \tag{8}$$

$$\text{Removal:}\quad C_{RL} = C_L\ (1+F_L)(1+F_Y)(1+F_{LC})[(1+F_{R1})(1+F_{R2}) - 1] \tag{4}$$

$$\text{Total:}\quad C_L'' = C_L\ (1+F_L)(1+F_Y)(1+F_{LC})(1+F_{R1})(1+F_{R2}) \tag{5}$$

The first column of numbers in Table 5.1 shows the values of the overall labor productivity factor chosen for each case. This is the $(1 + F_L)$ term in the cost equations (8), (4), and (5). The factor F_L is the sum of the sub-factors presented in Table 4.1. The values for the labor productivity sub-factors used in this study to estimate costs for comparisons with actual cost data are shown in Table 5.2. They were chosen based on an assessment of the environment and working conditions under which each operation was conducted. Each factor selected was in complete agreement with the guidance provided for choosing each factor.

Column 2 in Table 5.1 shows the Engineering and Quality Assurance/Control factor, $(1 + F_Y)$ in the cost equations. The factor F_Y was not applied to all cases, but only to those which included Engineering/QA/QC costs in the actual labor to accomplish the modification. That is, since some utilities providing cost information for this study had grouped Engineering/QA/QC costs together with actual labor costs, the generated estimates for the labor costs had to be adjusted by $(1 + F_Y)$.

TABLE 5.1

COMPARISONS OF ACTUAL VS ESTIMATED COSTS

ITEM NUMBER	ITEM	LABOR PRODUCTIVITY FACTOR 1+FL	ENGR & QA/QC FACTOR 1+ FY	LEARNING CURVE FACTOR 1+ FLC	TOTAL REMOVAL FACTOR (1+FR11+FR12)x (1+FR2)	ACTUAL / ESTIMATED REMOVAL COSTS	ACTUAL / ESTIMATED INSTALL COSTS	ACTUAL / ESTIMATED TOTAL COSTS
1	#1 SPENT FUEL POOL RERACK	7.6	1.00	1.0	1.05	–	–	1.32
2	#2 SPENT FUEL POOL RERACK	2.9	1.00	1.0	1.15	–	–	0.80
3	#3 SPENT FUEL POOL RERACK	0.9	1.00	1.0	1.40	–	–	1.05
4	#4 SPENT FUEL POOL RERACK	0.9	1.00	1.0	1.40	0.93	1.26	1.16
5	#5 SPENT FUEL POOL RERACK	0.9	1.00	1.0	1.40	1.02	–	–
6	LOW POWER RANGE MONITOR	7.8	1.25	1.0	1.05	–	–	2.39
7	FIRE DOORS - containmt.	2.7	1.00	1.0	1.70	–	–	1.02
8	FIRE DOORS - open	0.9	1.00	1.0	1.90	–	–	2.74
9	SRM/IRM(dry tubes)	2.7	1.00	2.5	1.20	–	–	0.94
10	CLASS 1E STATION BATTERY	1.4	1.00	1.0	1.40	–	–	1.18
11	AUX. CONDENSATE PUMP	.0	1.00	1.0	1.35	–	–	0.48
12	INTAKE COOLING WATER PUMP	1.8	1.00	1.0	1.40	–	–	1.73
13	MAKE-UP PUMP	2.3	1.00	1.0	1.20	4.46	1.00	1.58
14	2 LOW PRESSURE FW HEATERS	2.2	1.00	1.0	1.89	–	–	0.93
15	2 HIGH PRESSURE FW HEATERS	2.2	1.25	1.0	1.89	0.97	1.34	1.16
16	2 HIGH & 4 LOW PRESS. FW HEATERS	2.2	1.25	1.0	1.89	0.76	1.06	0.92
17	CONDENSER RE-TUBING	2.0	1.25	1.0	1.35	1.76	0.76	1.02
18	CHILLERS	2.7	1.00	1.0	1.20	1.04	0.41	0.51
19	RTDs & PRESSURE TRANSMITTERS	3.3	1.25	1.0	1.15	1.04	1.00	1.00
20	RADIATION MONITORING SYSTEM	2.0	1.25	1.0	1.35	0.30	1.16	0.94
21	REACTOR PROTECTION SYSTEM	1.4	1.00	1.0	1.40	0.07	0.16	0.14
22	HYDROGEN RECOMBINER	2.4	1.00	1.0	1.35	0.22	0.61	0.51
23	CORE SPRAY PIPING	4.8	1.25	1.0	1.76	0.58	2.72	1.80
24	EMERGENCY CONDENSER PIPING	2.7	1.00	1.0	1.92	0.37	0.78	0.59
25	# 1 FEEDWATER PIPING	3.3	1.00	1.4	1.84	0.88	1.77	1.36
26	# 2 FEEDWATER PIPING	3.3	1.00	1.0	1.84	1.77	0.42	1.03
27	#1 MAIN STEAM PIPING	3.3	1.00	1.4	1.15	2.11	1.60	1.66
28	#2 MAIN STEAM PIPING	3.3	1.00	1.0	1.15	2.38	0.88	1.08
29	#1 RECIRCULATION PIPING	2.7	1.00	1.0	1.20	1.16	0.44	0.56
30	#2 RECIRCULATION PIPING	2.7	1.00	1.0	1.20	1.37	1.29	1.30
31	#3 RECIRCULATION PIPING	2.7	1.00	1.0	1.20	0.90	0.99	0.98
32	#4 RECIRCULATION PIPING	2.7	1.00	1.0	1.20	0.98	0.69	0.74
33	#1 REACTOR COOLANT PUMP	3.3	1.00	3.6	1.84	0.90	0.85	0.87
34	#2 REACTOR COOLANT PUMP	3.3	1.00	2.5	1.84	0.70	[illegible]	0.68
35	#3 REACTOR COOLANT PUMP	3.3	1.00	1.4	1.84	1.10	1.04	1.06
36	#4 REACTOR COOLANT PUMP	3.3	1.00	1.0	1.84	0.98	0.93	0.96
37	#1 STEAM GENERATOR	4.8	1.25	3.6	1.76	0.58	1.34	1.01
38	#2 STEAM GENERATOR	4.8	1.25	2.5	1.76	0.64	1.59	1.18
39	#3 STEAM GENERATOR	4.8	1.25	1.4	1.76	0.57	0.97	0.80
40	#4 STEAM GENERATOR	4.8	1.25	1.0	1.76	0.61	1.14	0.91
41	#1 STEAM GENERATOR SUPPORT	2.7	1.25	3.6	1.92	0.38	–	–
42	#2 STEAM GENERATOR SUPPORT	2.7	1.25	2.5	1.92	0.33	–	–
43	#1 MANIPULATOR CRANE	2.7	1.25	3.6	1.20	0.62	–	–
44	#2 MANIPULATOR CRANE	2.7	1.25	2.5	1.20	0.35	–	–
45	#3 MANIPULATOR CRANE	2.7	1.25	1.0	1.20	0.19	–	–
46	CONDENSATE STORAGE TANK-install. only	1.6	1.25	1.0	–	–	1.84	–
					AVERAGE	0.97	1.06	1.12

TABLE 5.2

ASSIGNED LABOR PRODUCTIVITY FACTORS

ITEM NUMBER	ITEM	ACCESS AND HANDLING	CONGESTION AND INTERFERENCE	RADIATION	MANAGEMENT	NET LABOR PRODUCTIVITY FACTOR
1	#1 SPENT FUEL POOL RERACK	0.3	0.4	5.6	0.3	7.6
2	#2 SPENT FUEL POOL RERACK	0.3	0.2	1.1	0.3	2.9
3	#3 SPENT FUEL POOL RERACK	0.1	0.0	0.0	-0.2	0.9
4	#4 SPENT FUEL POOL RERACK	0.1	0.0	0.0	-0.2	0.9
5	#5 SPENT FUEL POOL RERACK	0.1	0.0	0.0	-0.2	0.9
6	LOW POWER RANGE MONITOR	0.4	0.4	5.6	0.4	7.8
7	FIRE DOORS - containmt.	0.4	0.4	0.5	0.4	2.7
8	FIRE DOORS - open	0.1	0.0	0.0	-0.2	0.9
9	SRM/IRM(dry tubes)	0.4	0.4	0.5	0.4	2.7
10	CLASS 1E STATION BATTERY	0.1	0.0	0.0	0.3	1.4
11	AUX. CONDENSATE PUMP	0.3	0.2	0.2	0.3	2.0
12	INTAKE COOLING WATER PUMP	0.3	0.2	0.0	0.3	1.8
13	MAKE-UP PUMP	0.3	0.2	0.5	0.3	2.3
14	2 LOW PRESSURE FW HEATERS	0.3	0.4	0.2	0.3	2.2
15	2 HIGH PRESSURE FW HEATERS	0.3	0.4	0.2	0.3	2.2
16	2 HIGH & 4 LOW PRESSURE FW HEATERS	0.3	0.4	0.2	0.3	2.2
17	CONDENSER RE-TUBING	0.3	0.2	0.2	0.3	2.0
18	CHILLERS	0.4	0.4	0.5	0.4	2.7
19	RTDs & PRESSURE TRANSMITTERS	0.4	0.4	1.1	0.4	3.3
20	RADIATION MONITORING SYSTEM	0.3	0.2	0.2	0.3	2.0
21	REACTOR PROTECTION SYSTEM	0.1	0.0	0.0	0.3	1.4
22	HYDROGEN RECOMBINER	0.4	0.4	0.2	0.4	2.4
23	CORE SPRAY PIPING	0.4	0.4	2.6	0.4	4.8
24	EMERGENCY CONDENSER PIPING	0.4	0.4	0.5	0.4	2.7
25	#1 FEEDWATER PIPING	0.4	0.4	1.1	0.4	3.3
26	#2 FEEDWATER PIPING	0.4	0.4	1.1	0.4	3.3
27	#1 MAIN STEAM PIPING	0.4	0.4	1.1	0.4	3.3
28	#2 MAIN STEAM PIPING	0.4	0.4	1.1	0.4	3.3
29	#1 RECIRCULATION PIPING	0.4	0.4	0.5	0.4	2.7
30	#2 RECIRCULATION PIPING	0.4	0.4	0.5	0.4	2.7
31	#3 RECIRCULATION PIPING	0.4	0.4	0.5	0.4	2.7
32	#4 RECIRCULATION PIPING	0.4	0.4	0.5	0.4	2.7
33	#1 REACTOR COOLANT PUMP	0.4	0.4	1.1	[illegible]	3.3
34	#2 REACTOR COOLANT PUMP	0.4	0.4	1.1	0.4	3.3
35	#3 REACTOR COOLANT PUMP	0.4	0.4	1.1	0.4	3.3
36	#4 REACTOR COOLANT PUMP	0.4	0.4	1.1	0.4	3.[illegible]
37	#1 STEAM GENERATOR	0.4	0.4	2.6	0.4	4.8
38	#2 STEAM GENERATOR	0.4	0.4	2.6	0.4	4.8
39	#3 STEAM GENERATOR	0.4	0.4	2.6	0.4	4.8
40	#4 STEAM GENERATOR	0.4	0.4	2.6	0.4	4.8
41	#1 STEAM GENERATOR SUPPORT	0.4	0.4	0.5	0.4	2.7
42	#2 STEAM GENERATOR SUPPORT	0.4	0.4	0.5	0.4	2.7
43	#1 MANIPULATOR CRANE	0.4	0.4	0.5	0.4	2.7
44	#2 MANIPULATOR CRANE	0.4	0.4	0.5	0.4	2.7
45	#3 MANIPULATOR CRANE	0.4	0.4	0.5	0.4	2.7
46	CONDENSATE STORAGE TANK - install. only	0.1	0.2	0.0	0.3	1.6

Because all modifications were done to operating plants, a value of 0.25 was chosen for the F_Y where Engineering/QA/QC was included.

Column 3 in Table 5.1 presents the learning curve factors used, i.e., the $(1+F_{LC})$ term in the cost equations. Values other than 1.0 were used only for major replacement tasks or subtasks which were performed as part of major activities.

Column 4 in Table 5.1 shows the values chosen for the total removal factors, $(1+F_{R1}) \times (1+F_{R2})$. They were taken from the descriptions and value ranges of Table 4.2. A detailed breakdown for the individual removal factors is presented in Table 5.3. Since there exists an inverse relationship between the radiation component of the labor productivity adjustment and the removal factor, the following values were used:

Radiation Productivity Factor	Radiation Removal Factor
0.0	0.4
0.2	0.35
0.5	0.2
1.1	0.15
2.6	0.1
5.6	0.05

Although the above factors represent point values rather than ranges, the use of these values resulted in estimates which reflected and matched the actual cost data most accurately.

The factor which accounts for impacts on ancillary systems, F_{R2}, was chosen based on the relative degree of impact on non-target systems/components. Table 5.3 shows the specific values used.

The last three columns in Table 5.1 show how the actual cost as incurred by the utilities compared to the estimated costs. Since some utilities supplied total costs rather than separate removal and installation costs, no actual-over-estimate ratios for those individual activities could be calculated. The generic methods presented in this study produced labor cost estimates which, on the average, were within 15% of the actual cost reported by the utilities.

5.2 ERROR ANALYSIS

Ideally, the values in the last three columns of Table 5.1 should be unity. In most cases the estimated costs are within ± 40 percent of the actual values. In some cases, however, the estimated labor is more than double or less than half the actual labor as reported by utilities. Some of the misfit is undoubtedly due to an incomplete understanding of the work environment. This would result in choosing the wrong values of the factors from Tables 4.1, 4.2, and 4.3. Errors may also result because the designs of some of the plants providing the data do not coincide with the designs upon which the EEDB data base is derived. Differences could also arise because some of the actual data may include significant and unusual amounts of rework labor costs which, unless specifically reported, can not be accounted for by the generic cost estimating model.

TABLE 5.3

ASSIGNED REMOVAL FACTORS

ITEM NUMBER	ITEM	RADIATION REMOVAL FACTOR FR11	STRUCTURAL REMOVAL FACTOR FR12	ANCILLARY REMOVAL FACTOR FR2	TOTAL REMOVAL FACTOR (1+FR11+FR12)x (1+FR2)
1	#1 SPENT FUEL POOL RERACK	0.05	0.0	0.0	1.05
2	#2 SPENT FUEL POOL RERACK	0.15	0.0	0.0	1.15
3	#3 SPENT FUEL POOL RERACK	0.40	0.0	0.0	1.40
4	#4 SPENT FUEL POOL RERACK	0.40	0.0	0.0	1.40
5	#5 SPENT FUEL POOL RERACK	0.40	0.0	0.0	1.40
6	LOW POWER RANGE MONITOR	0.05	0.0	0.0	1.05
7	FIRE DOORS - containmt	0.20	0.5	0.0	1.70
8	FIRE DOORS - open	0.40	0.5	0.0	1.90
9	SRM/IRM(dry tubes)	0.20	0.0	0.0	1.20
10	CLASS 1E STATION BATTERY	0.40	0.0	0.0	1.40
11	AUX. CONDENSATE PUMP	0.35	0.0	0.0	1.35
12	INTAKE COOLING WATER PUMP	0.40	0.0	0.0	1.40
13	MAKE-UP PUMP	0.20	0.0	0.0	1.20
14	2 LOW PRESSURE FW HEATERS	0.35	0.0	0.4	1.89
15	2 HIGH PRESSURE FW HEATERS	0.35	0.0	0.4	1.89
16	2 HIGH & 4 LOW PRESS. FW HEATERS	0.35	0.0	0.4	1.89
17	CONDENSER RE-TUBING	0.35	0.0	0.0	1.35
18	CHILLERS	0.20	0.0	0.0	1.20
19	RTDs & PRESSURE TRANSMITTERS	0.15	0.0	0.0	1.15
20	RADIATION MONITORING SYSTEM	0.35	0.0	0.0	1.35
21	REACTOR PROTECTION SYSTEM	0.40	0.0	0.0	1.40
22	HYDROGEN RECOMBINER	0.35	0.0	0.0	1.35
23	CORE SPRAY PIPING	0.10	0.0	0.6	1.76
24	EMERGENCY CONDENSER PIPING	0.20	0.0	0.6	1.92
25	# 1 FEEDWATER PIPING	0.15	0.0	0.6	1.84
26	# 2 FEEDWATER PIPING	0.15	0.0	0.6	1.84
27	#1 MAIN STEAM PIPING	0.15	0.0	0.0	1.15
28	#2 MAIN STEAM PIPING	0.15	0.0	0.0	1.15
29	#1 RECIRCULATION PIPING	0.20	0.0	0.0	1.20
30	#2 RECIRCULATION PIPING	0.20	0.0	0.0	1.20
31	#3 RECIRCULATION PIPING	0.20	0.0	0.0	1.20
32	#4 RECIRCULATION PIPING	0.20	0.0	0.0	1.20
33	#1 REACTOR COOLANT PUMP	0.15	0.0	0.6	1.84
34	#2 REACTOR COOLANT PUMP	0.15	0.0	0.6	1.84
35	#3 REACTOR COOLANT PUMP	0.15	0.0	0.6	1.84
36	#4 REACTOR COOLANT PUMP	0.15	0.0	0.6	1.84
37	#1 STEAM GENERATOR	0.10	0.0	0.6	1.76
38	#2 STEAM GENERATOR	0.10	0.0	0.6	1.76
39	#3 STEAM GENERATOR	0.10	0.0	0.6	1.76
40	#4 STEAM GENERATOR	0.10	0.0	0.6	1.76
41	#1 STEAM GENERATOR SUPPORT	0.20	0.0	0.6	1.92
42	#2 STEAM GENERATOR SUPPORT	0.20	0.0	0.6	1.92
43	#1 MANIPULATOR CRANE	0.20	0.0	0.0	1.20
44	#2 MANIPULATOR CRANE	0.20	0.0	0.0	1.20
45	#3 MANIPULATOR CRANE	0.20	0.0	0.0	1.20
46	CONDENSATE STORAGE TANK-install. only	–	–	–	–

The degree of confidence assigned to each data point is presented in Table 5.4. It was based on the amount of background information known about the data point, the technical level of detail given by the EEDB as compared to the plant component/system, and also on the consistency and simplicity of the actual data with respect to cost figures. A value of 1 for the confidence level corresponds to data which was well characterized in terms of the work environment and scope, so that the choice of cost factors was straightforward, with minimal uncertainty.

The breakdown of the data is as follows:

Confidence Level	Number of Data Points
#1	25
#2	12
#3	9

Figure 5.1 shows how well the actual costs compared to the estimated costs. As expected, data having the highest degree of confidence produced the best estimates for the total and removal costs. The generic cost estimating methods produced estimates which, on the average, were about 2% lower than the actual costs as reported by nuclear utilities.

As indicated in Figure 5.1, better estimates of removal labor costs were produced for data of confidence level #3 than for level #2 data. One reason for this is that since most of the level #3 data points involved pipe replacement activities, the generated cost estimates were adjusted according to the guidelines presented in Section 4.5 (i.e., applying a "large pipe" factor or a small pipe impingement factor). Confidence level #2 data did not benefit from this correction or any other empirical rectifications and thus, their estimates of the removal labor cost are higher than the actual costs by a factor of three. However, both total cost and installation cost estimates for the confidence level #2 group were typically within 15% of the actual costs reported.

5.3 STATISTICAL ANALYSIS OF NUCLEAR MODEL ACCURACY

The nuclear model predicts the cost of power station refurbishment and repair by estimating the repair costs of generic equipment in a theoretical power plant. The parameters and mathematical structure of the model were not determined through examination of historical data and the testing of statistical hypotheses (regression). Instead, experts have brought experiential and technical knowledge to bear upon the problem, and have constructed a model that is highly accurate.

Although regression techniques were not used to generate the nuclear model, it is useful to assume that it has and then search for adherence to the standard regression criteria for residuals.

To test the nuclear cost analysis model's accuracy, we have for the moment assumed that the model was constructed using regression analysis. Regression analysis, among other things, determines how closely data fits some hypothesized mathematical framework. For instance, the speed with which water flows through a pipe is related to the pipe's diameter. If we increase the pipe's diameter, the water flow rate changes. By varying the diameter of the pipe a number of times and recording the

TABLE 5.4

ACTUAL DATA CONFIDENCE LEVEL

ITEM NUMBER	ITEM	CONFIDENCE LEVEL
1	#1 SPENT FUEL POOL RERACK	1
2	#2 SPENT FUEL POOL RERACK	1
3	#3 SPENT FUEL POOL RERACK	1
4	#4 SPENT FUEL POOL RERACK	1
5	#5 SPENT FUEL POOL RERACK	1
6	LOW POWER RANGE MONITOR	3
7	FIRE DOORS - containmt.	2
8	FIRE DOORS - open	2
9	SRM/IRM(dry tubes)	1
10	CLASS 1E STATION BATTERY	1
11	AUX. CONDENSATE PUMP	2
12	INTAKE COOLING WATER PUMP	2
13	MAKE-UP PUMP	1
14	2 LOW PRESSURE FW HEATERS	1
15	2 HIGH PRESSURE FW HEATERS	1
16	2 HIGH & 4 LOW PRESS. FW HEATERS	1
17	CONDENSER RE-TUBING	1
18	CHILLERS	3
19	RTDs & PRESSURE TRANSMITTERS	1
20	RADIATION MONITORING SYSTEM	1
21	REACTOR PROTECTION SYSTEM	2
22	HYDROGEN RECOMBINER	2
23	CORE SPRAY PIPING	1
24	EMERGENCY CONDENSER PIPING	1
25	# 1 FEEDWATER PIPING	3
26	# 2 FEEDWATER PIPING	3
27	#1 MAIN STEAM PIPING	3
28	#2 MAIN STEAM PIPING	3
29	#1 RECIRCULATION PIPING	1
30	#2 RECIRCULATION PIPING	3
31	#3 RECIRCULATION PIPING	3
32	#4 RECIRCULATION PIPING	3
33	#1 REACTOR COOLANT PUMP	1
34	#2 REACTOR COOLANT PUMP	1
35	#3 REACTOR COOLANT PUMP	1
36	#4 REACTOR COOLANT PUMP	1
37	#1 STEAM GENERATOR	1
38	#2 STEAM GENERATOR	1
39	#3 STEAM GENERATOR	1
40	#4 STEAM GENERATOR	1
41	#1 STEAM GENERATOR SUPPORT	2
42	#2 STEAM GENERATOR SUPPORT	2
43	#1 MANIPULATOR CRANE	2
44	#2 MANIPULATOR CRANE	2
45	#3 MANIPULATOR CRANE	2
46	CONDENSATE STORAGE TANK-install. only	2

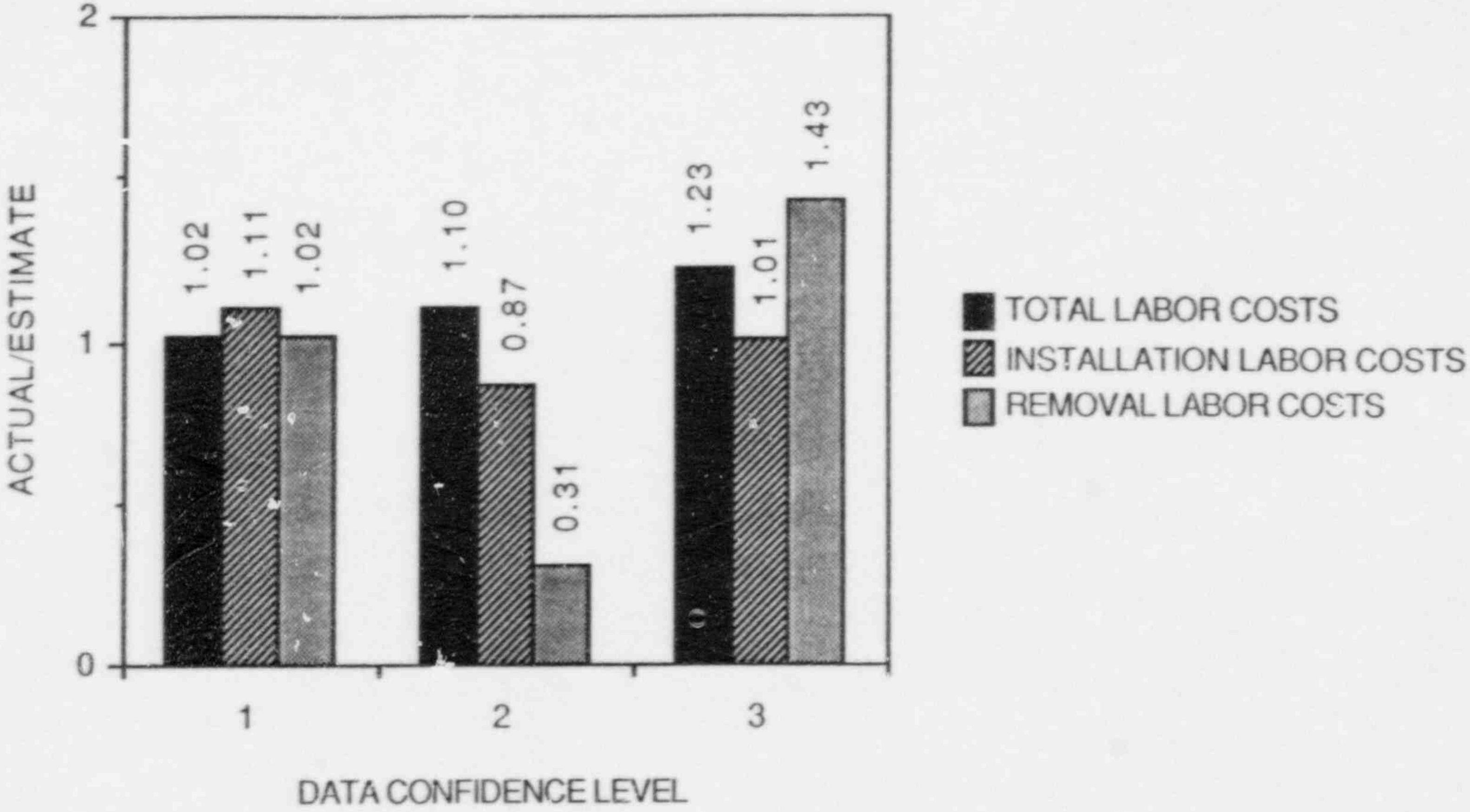

FIGURE 5.1. ACTUAL VS ESTIMATED COSTS ARRANGED BY DEGREE OF CONFIDENCE

data, regression analysis can be used to fit the data to the proper mathematical function that relates water flow to pipe diameter. The error in the data makes itself apparent when we compare the water flow predicted by the equation to the actual water flow. This residual represents random deviations from the model that are attributable to data anomalies and variables that have been omitted.

Similarly, in the nuclear model, an equation has been constructed to depict the relationship between repair cost and physical attributes/work environment of machinery to be repaired or replaced. As in the water flow/pipe diameter example, deviations or residuals can be measured and represent data uncertainties or randomness and variables that have been omitted.

From the residuals, a statistic called R^2, $0<R^2<1$, can be calculated. This statistic measures how closely the model predicts costs. Figures 5.2 and 5.3 display two hypothetical situations, one in which the R-square is relatively low and one in which it is high. The latter case is most representative of the nuclear model. The nuclear model has an R-square between .85 and .96.

The second consideration is the shape of the distribution of the residuals. If the nuclear model has accounted for most of the variables affecting cost, the parameter "estimates" are based upon a sufficiently large random sample, then it would be reasonable to expect that the residuals would be distributed as a "bell-curve" or normal distribution. This in fact seems to be the case although rigorous statistical testing for normality was not performed on the data. In regression analysis, the residual distribution takes this shape, in part, because the regression technique maximizes the likelihood that an observed value falls upon the regression line. This is why the distribution comes to a peak over the residual value of zero (0). Also, there is an equal probability that an actual value falls below the regression line as rises above it. The mean of the residuals in the nuclear model is insignificantly different from zero. Figures 5.4.a, 5.4.b, 5.5, and 5.6 present these findings graphically.

In conclusion, it is apparent that: 1) the mean of the nuclear model residuals is effectively zero, 2) that visual inspection of the residual distribution indicates a bell-curve, and 3) the accuracy of the model is on the order of .96 on a scale of 0 to 1. Because the model is not based upon rigorous statistical techniques, we find this result surprisingly good because these attributes would be expected had we, in fact, used rigorous estimation methods.

6.0 EXAMPLE APPLICATION

The following example illustrates the use of the factors presented in Section 4 to estimate removal and replacement costs.

For purposes of this example, we assume that an NRC regulation calls for the upgrading of the containment spray heat exchangers on certain plants. These heat exchangers remove heat from water which collects in the reactor containment building sumps following a loss-of-coolant accident and activation of the containment spray system. For the affected plants, these heat exchangers are located within the reactor containment building.

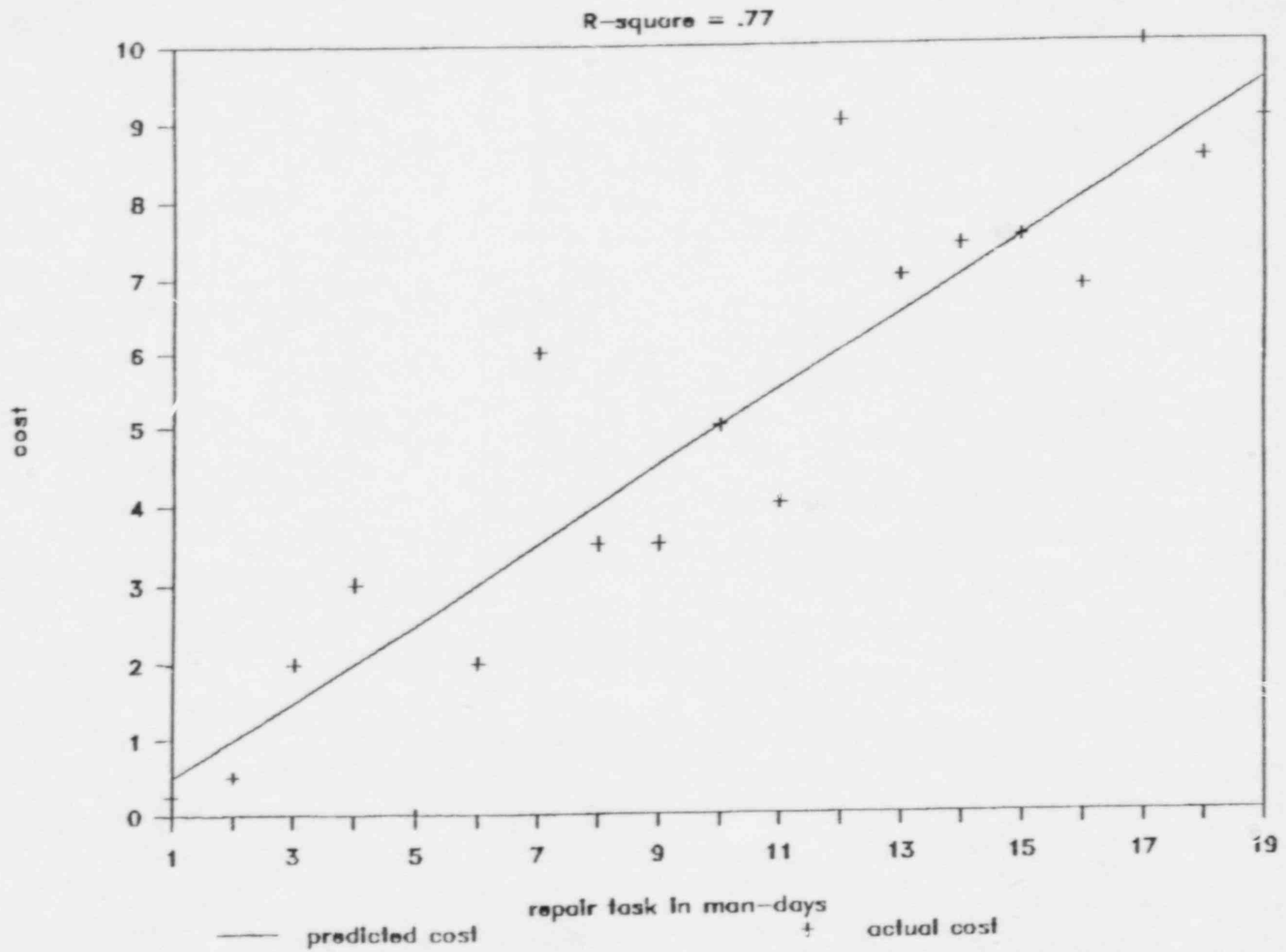

FIGURE 5.2. A LESS ACCURATE MODEL

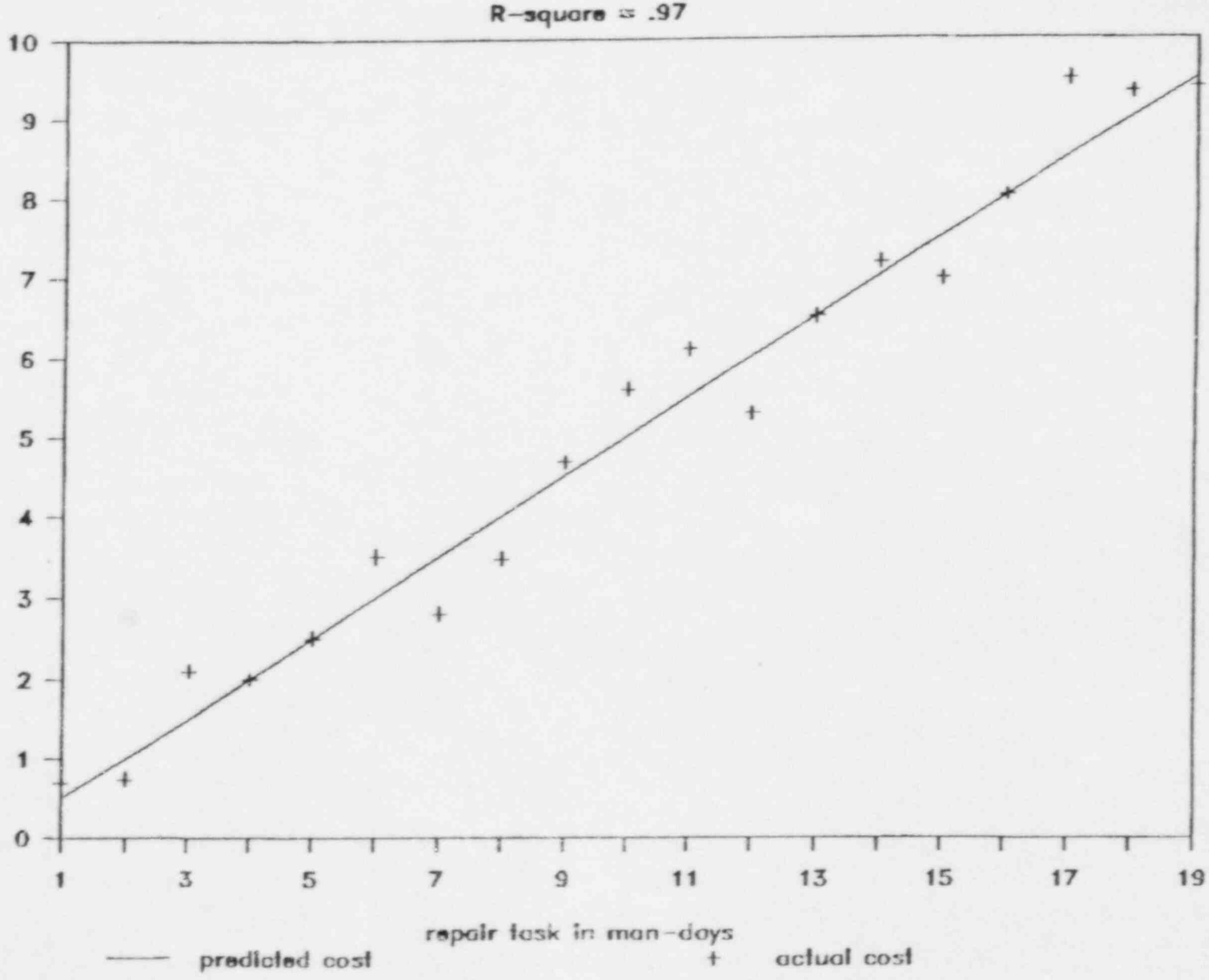

FIGURE 5.3. A MORE ACCURATE MODEL

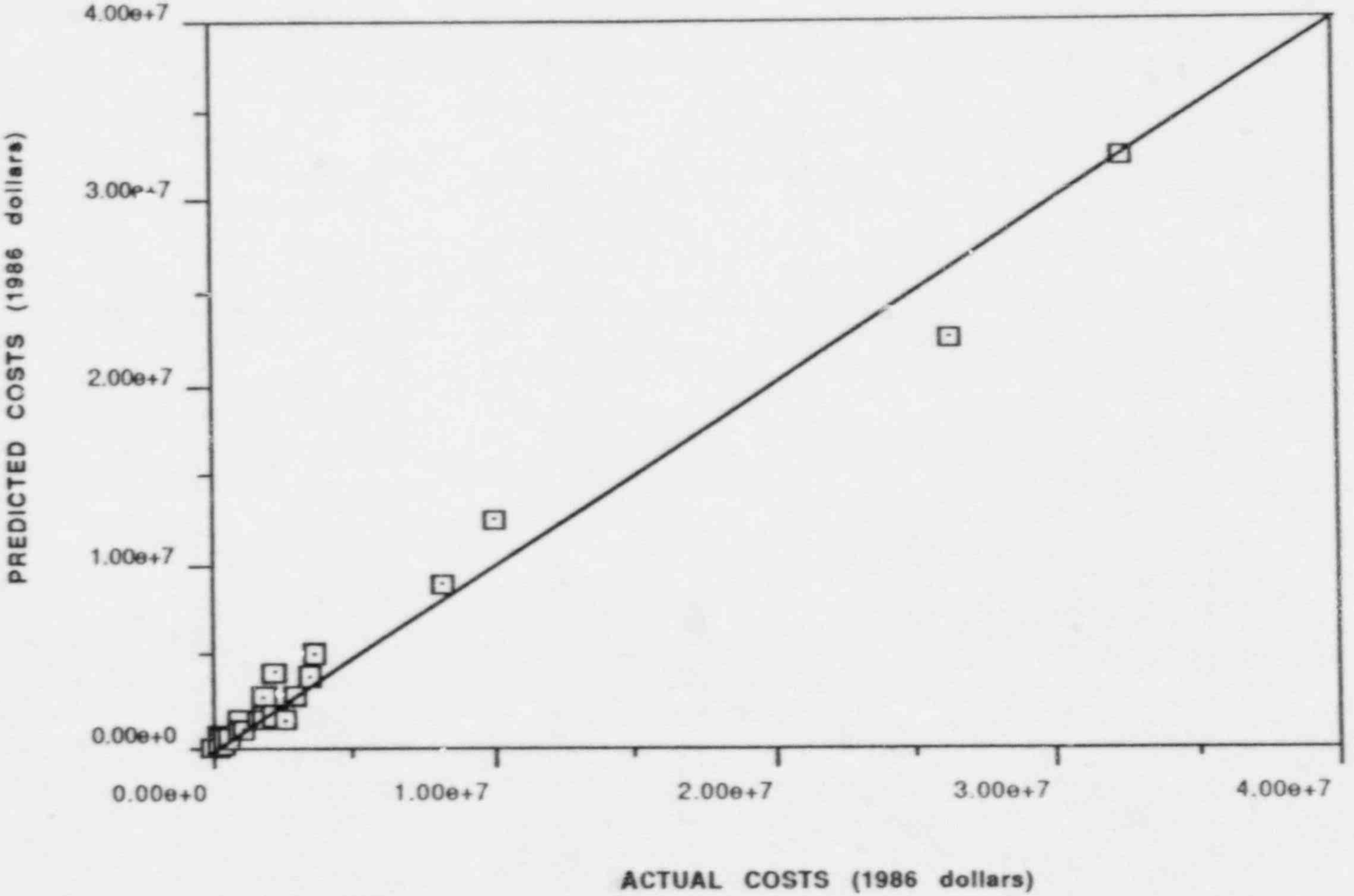

FIGURE 5.4.a. R-SQUARE FIT (all data points)

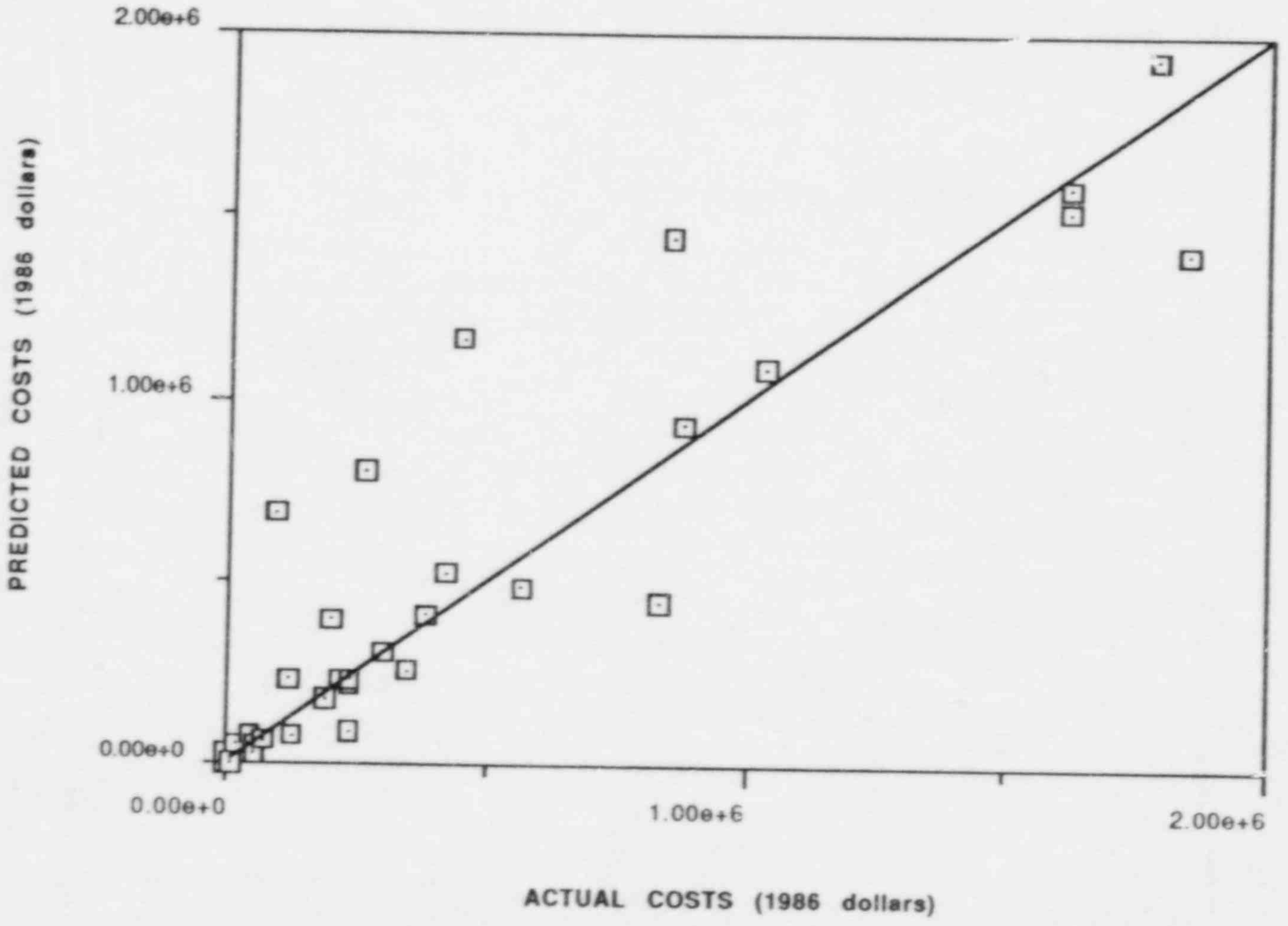

FIGURE 5.4.b. R-SQUARE FIT (costs less than $2 million only)

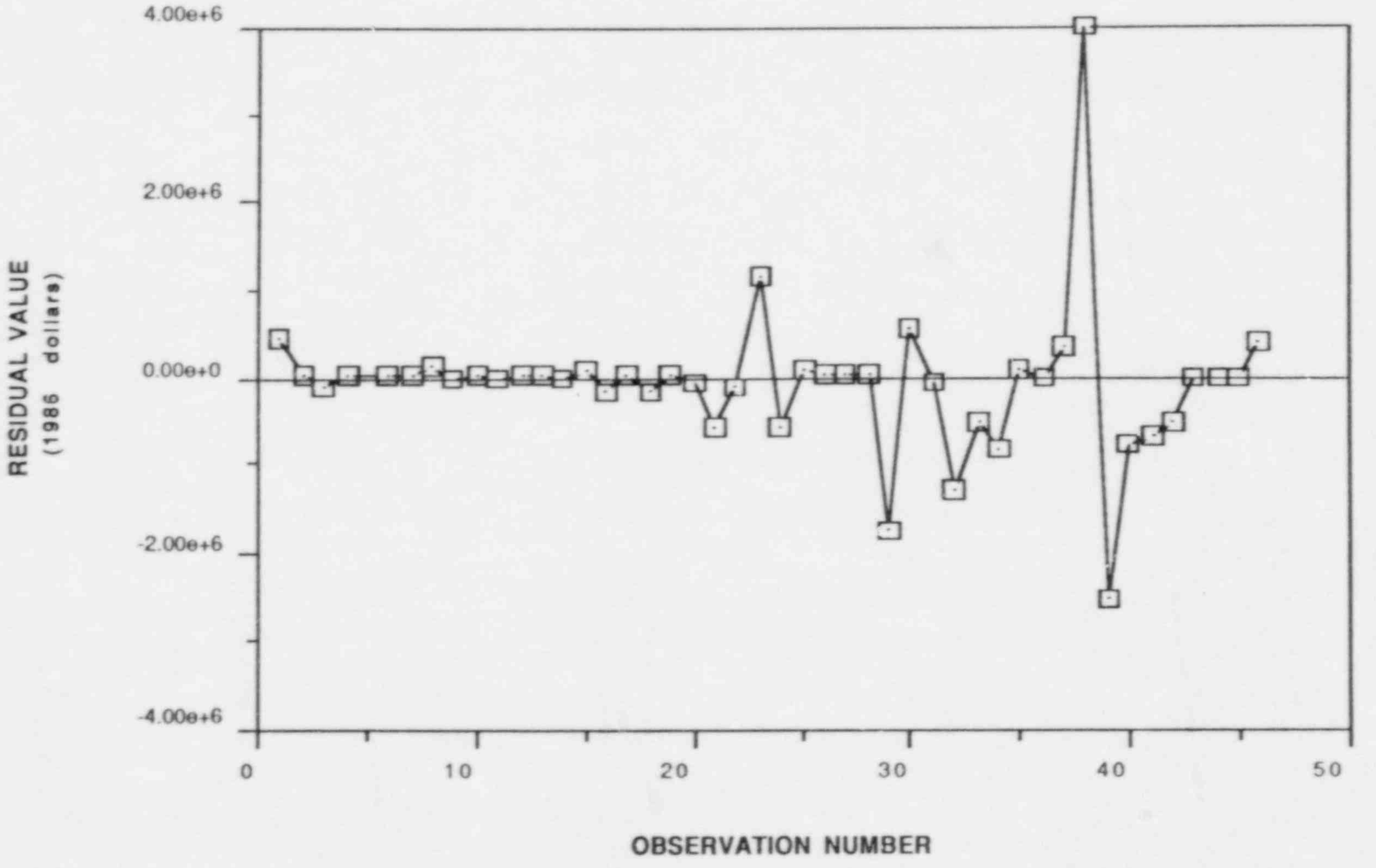

FIGURE 5.5. MEAN OF THE RESIDUALS

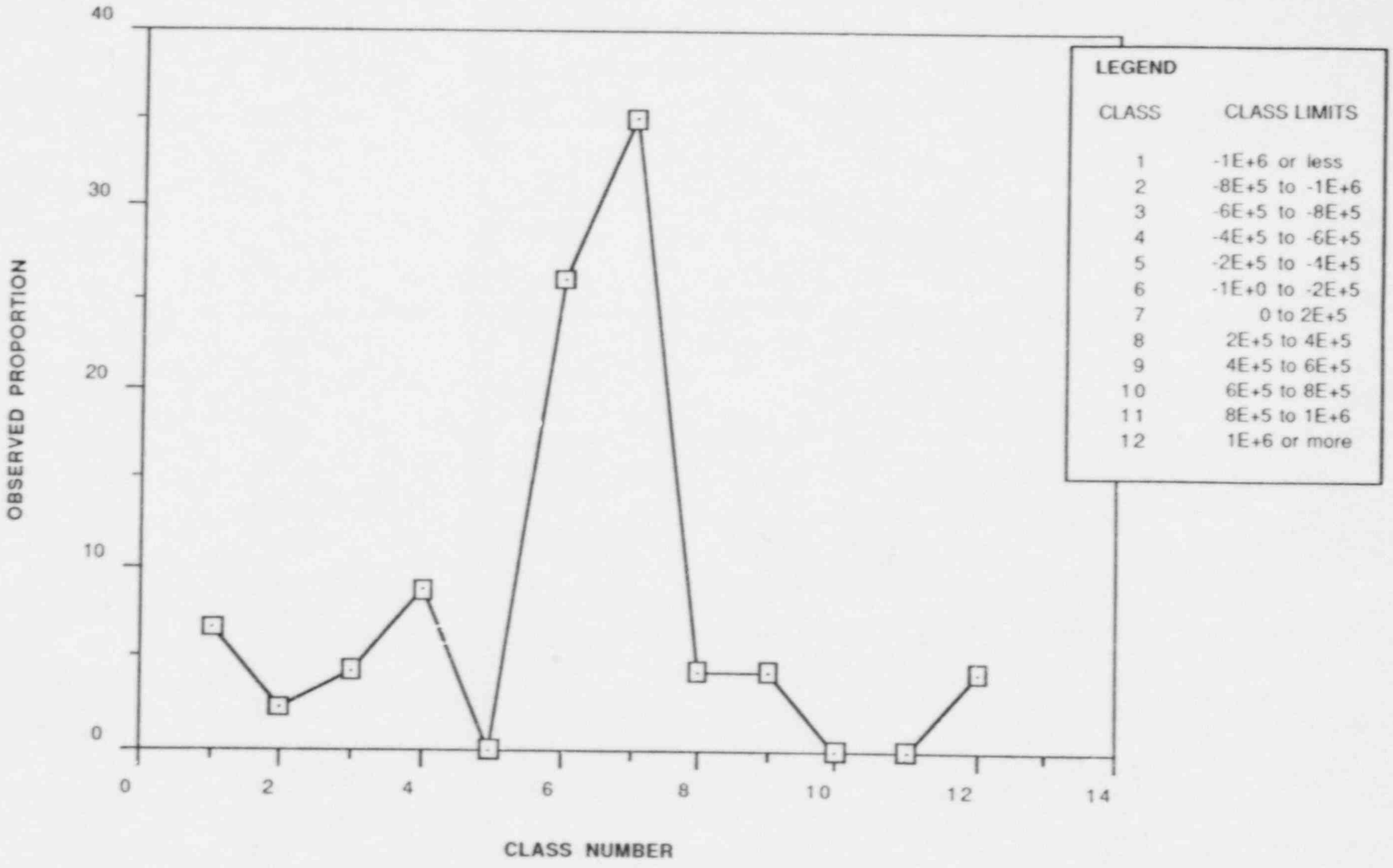

FIGURE 5.6. FREQUENCY DISTRIBUTION OF THE RESIDUALS

The EEDB PWR reference plant indicates that there are two of these cooling units in the base design. They are described in account No. 223.421 of the EEDB. The cost and technical data from the EEDB are shown in Tables 6.1 and 6.2. From Table 6.1 the labor costs for installing these heat exchangers under a new construction environment is $23,209.

To determine the removal and replacement labor costs for plants already in operation, it is necessary to first assess the environment under which these activities must be carried out. Since the heat exchangers are located inside containment the work can only be performed while the reactor is shut down. The coolers or heat exchangers are located in the reactor building annulus between the secondary shieldwall and the outer wall of the building. Therefore, the work must be performed in a radiation environment. Based on the working conditions and radiation environment, we estimate a worker stay time of about two hours.

The containment spray heat exchangers are located in an area with considerable piping, electrical conduit and cable trays, and other hardware. Therefore, the area is considered to be very congested.

This assessment of the work environment yields the following labor productivity factors from Table 4.1.

o	Access and handling Operating plant, inside the RCB	0.4
o	Congestion and interference Congested work area	0.4
o	Radiation Stay time of 2 hours	1.1
o	Manageability Outage activity, inside containment	0.4

The total labor productivity adjustment factor is:

$$1 + 0.4 + 0.4 + 1.1 + 0.4 = 3.3$$

A factor must also be included for engineering and quality assurance. The factor for operating plants is 0.25. Note that this adjustment will be done to both labor costs and material costs.

The replacement of these cooling units is not a considered a major undertaking. Industry has removed equipment similar to this many times in the past. Therefore, the learning curve factor applicable is 1.0.

The removal factors are assessed based on the information given in Table 4.2. The first factor, F_{R11}, is assessed based on the radiation environment. The value is selected from the 0.05 to 0.20 range since the work is conducted inside containment. The radiation environment is anticipated to be on the lower end of the in-containment radiation range, so the value selected is 0.15 (using guidelines presented in Section 4.2.1.1).

EEDB COST DETAIL

PLANT CODE 148 COST BASIS 01/86
UNITED ENGINEERS & CONSTRUCTORS INC.
EEDB-VIII BASE COSTS (MEDIAN EXPERIENCE BASIS)
1144 MWE PRESSURIZED WATER REACTOR
PAGE 122
08/05/86

ACCT NO.	ACCOUNT DESCRIPTION	FACTORY QUANTITY	FACTORY COSTS	SITE QUANTITY	SITE LABOR HRS	SITE LABOR COST	SITE MATERIAL COST	TOTAL COSTS
223.38	INSTRUMENTATION + CONTROL	1 LT	144,085	1 LT	378 MH	8,749	437	
	223.3 SAFETY INJECTION SYSTEM		1,493,377		181115 MH	4,289,187	590,544	6,373,108
223.4	CONTAINMENT SPRAY SYSTEM							
223.41	ROTATING MACHINERY							
223.411	CONTAINMT SPRAY PUMP + MTR	2 EA	249,309	1 LT	3300 MH	80,294	8,029	
223.4111	CONTAINMENT SPRAY PUMP							
223.4112	CONTAINMENT SPRAY PUMP MTR							
	223.411 CONTAINMT SPRAY PUMP + MTR		249,309		3300 MH	80,294	8,029	337,632
	223.41 ROTATING MACHINERY		249,309		3300 MH	80,294	8,029	337,632
223.42	HEAT TRANFER EQUIPMENT							
223.421	CONTAIN SPRAY HEAT XCHNGER	2 EA	256,245	1 LT	1001 MH	23,209	2,321	
	223.42 HEAT TRANFER EQUIPMENT		256,245		1001 MH	23,209	2,321	281,775
223.43	TANKS AND PRESSURE VESSELS							
223.431	SPRAY ADDITIVE TANK	1 EA	159,256	1 LT	1200 MH	27,833	2,783	
	223.43 TANKS AND PRESSURE VESSELS		159,256		1200 MH	27,833	2,783	189,872
223.45	PIPING							
223.451	2IN. + SMALLER							
223.4511	SS/NNS			730 LB	2190 MH	51,896	4,438	
223.4512	SS/SC2			820 LB	3690 MH	87,441	10,348	

TABLE 6.2

EEDB EQUIPMENT DESCRIPTiON

```
PROG. CM-711 *PEG030*                     UNITED ENGINEERS & CONSTRUCTORS INC.                                PAGE  166 - 1

EQUIPMENT LIST - REPORT 1                 ENERGY ECONOMIC DATA BASE                                                08/01/86

        MODEL 148 - 1144 MWE/3431 MWT  PWR  - EEDB EQUIPMENT LIST                          - COST BASIS  01/86

         ACCOUNT                                                                              DESCRIPTION
          NUMBER               ITEM

        222.421      CONTAIN.SPRAY HEAT XCHNGER                            QUANTITY -          2 X 100 PCT
                                                                           TYPE -              SHELL AND U-TUBE
                                                                           ORIENTATION -       VERTICAL
                                                                           HEAT LOAD -          96.7 E06 BTU/HR
                                                                           SURFACE AREA -
                                                                           SHELL CONDITION:
                                                                             DES.PRESS/TEMP -  150 PSIG/200 F
                                                                             TEMP IN/OUT -     120 F/161 F
                                                                             FLOW RATE -         2.36E+06 LB/HR
                                                                             FLUID -          BORATED RX COOLANT
                                                                             MATERIAL -
                                                                             SAFETY CLASS -    3
                                                                             DESIGN CODE -     ASME III, CLASS 3
                                                                           TUBE CONDITION:
                                                                             QUANTITY -
                                                                             SIZE -
                                                                             DES.PRESS/TEMP -  300 PSIG/300 F
                                                                             TEMP IN/OUT -     245 F/181 F
                                                                             FLOW RATE -         1.5E+06 LB/HR
                                                                             MATERIAL -
                                                                             SAFETY CLASS -    2
                                                                             FLUID -          CCW
                                                                             DESIGN CODE -    ASME III, CLASS 2
                                                                           SEISMIC CAT. -     I

        223.43       TANKS AND PRESSURE VESSELS

        223.431      SPRAY ADDITIVE TANK                                   QUANTITY -        1
                                                                           ORIENTATION -   VERTICAL
                                                                           DIMENSIONS -
                                                                           VOLUME -        8396 GAL
                                                                           DESIGN PRESS -  ATMOS
                                                                           DESIGN TEMP -    100 F
                                                                           MATERIAL -      STAINLESS STEEL
                                                                           SAFETY CLASS -  3
                                                                           SEISMIC CAT. -  I
                                                                           DESIGN CODE -   ASME III, CLASS 3

        223.45       PIPING

        223.451      2IN. + SMALLER
```

Since the containment spray heat exchangers are hardware which is not structural, the F_{R12} factor is not used. Similarly, these heat exchangers are not expected to impinge extensively on surrounding equipment and systems when they are removed and replaced. Therefore, the F_{R2} removal factor is not used. The overall removal factor is:

$$(1.0 + 0.15 + 0)(1.0 + 0) = 1.15$$

Summarizing, the four adjustment factors to be applied to the EEDB labor costs are:

Labor Productivity	3.3
Engineering and QA	1.25
Learning Curve	1.00
Removal	1.15

The estimated labor cost to remove and replace the containment spray heat exchangers, on a per plant basis is:

$$C_L" = C_L\ (1 + F_L)(1 + F_y)(1 + F_{LC})\ (1 + F_R)$$

$$= \$23,209 \times 3.3 \times 1.25 \times 1.0 \times 1.15 = \$110,098$$

Additional Engineering/QA/QC costs are determined when material costs are adjusted by the Engineering/QA/QC factor, F_Y, of 0.25. From Table 6.1 the combined factory and site material costs are \$258,566. The additional Engineering/QA/QC costs are:

$$\$258,566 \times 0.25 = \$64,642.$$

Finally, the total estimated labor cost to removal and replace the containment spray heat exchangers, on a per plant basis is:

$$C_L" = \$110,098 + \$64,642 = \$174,740$$

7.0 CAUTIONS AND LIMITATIONS

This activity has attempted to verify the adequacy of generic cost analysis methods for estimating the labor requirements of repair/modification activities at nuclear power plants. The results obtained from the actual-versus-estimated cost comparisons indicate that the generic methods are reasonably good predictors of these costs. Analysts using these generic methods should be aware of the following cautions and limitations.

- Even though, as a whole, the generic cost estimating model appears to predict actual costs reasonably well, the cost predictions for specific cases can be significantly in error. All cost estimates must be reviewed carefully for reasonableness.

- The comparisons made here involved a limited number of actual data points (46 points were used). This is not a large sampling population from a statistical standpoint. A larger data base might indicate a poorer fit of the generic models compared to actual data than was shown for the comparisons made here.

- Analysts using the generic methodology must use caution and care in selecting each individual cost factor applicable to a specific analysis. Proper application of this method requires considerable familiarity with the specific plants involved and with the design features of the systems and components to be removed. The analysts must have a good grasp on the working environment under which the removal/replacement activities will take place.

- The factors related to radiation can have a particularly large effect on the estimated labor costs. The relationship between the radiation dose rate and the radiation adjustment factors discussed in Sections 4.1.3 and 4.2.1.1 should be used with caution and tempered with sound engineering judgment. For example, if the working environment for a large physical modification effort is expected to be greater than 100 mr/hr, the corresponding labor productivity factor for radiation is given as 5.6. If the work required the expenditure of thousands of labor-hours to accomplish, the utilities involved may well take measures to reduce the dose rates. The application of shielding, decontamination, or the use of remote tools might well be employed. For cases such as this, or cases where the dose rates involved fall on the border of adjacent dose rate ranges (see Section 4.1.3), analysts are encouraged to investigate the sensitivity of the results to the particular radiation cost factors selected.

  Note also that the generic methods do not explicitly account for ALARA procedures or the labor expended in reducing worker exposure.

- The cost data in the EEDB are based on generic plant designs which are reasonably close to modern BWR and PWR designs. The EEDB designs may be significantly different from those impacted by specific NRC requirements. Therefore, considerable care must be exercised in assuring that the EEDB data are indeed applicable to the plants of interest to a particular cost analysis.

- Since the generic cost methodology typically relies on the information in the EEDB for baseline costs, any incorrect costs in the EEDB could well result in erroneous cost estimates. Some checks of the EEDB system and component costs were made. Actual plant greenfield construction cost data was collected from several utilities. Costs of systems and components (both labor and material costs) from these actual cases were compared against comparable items in the EEDB. The results of this comparison were inconclusive. The EEDB costs were higher than actual costs for some plants and lower for other plants. A large part of the problem was disparities in the designs and scopes of the systems and components compared. In addition, the cost data collected showed considerable difference in costs from one plant to the next for the same item or system. This was even true from one unit to the next on a multiple-plant site operated by a single utility. Thus, while this effort did not serve to verify the costs in the EEDB, neither did it identify any substantial errors in the EEDB.

8.0 CONCLUSIONS

In this study we have:

- Re-assessed removal, installation, and total cost factors.
- Found that the general methodology appears sound, and no major revisions are necessary.
- Determined that certain components, such as piping, appear to warrant special considerations. Based on a limited number of actual data points, special adjustment factors are identified.
- Shown through statistical analysis that the nuclear model behaves well in a statistical sense and is a good cost predictor.

Overall, the generic methodology appears sound and, when properly used, should result in reasonably accurate estimates of physical modifications at nuclear power plants.

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(2-84)
NRCM 1102,
3201, 3202

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12. SUPPLEMENTARY NOTES

13. ABSTRACT (200

This report represents a validation study of the cost methodologies and quanritative factors derived in Labor Productivity Adjustment Factors (NUREG/CR-4546) and Generic Methodology for Estimating the Labor Cost Associated with the Removal of Hardware, Materials, and Structures From Nuclear Power Plants (SEA Report 84-116-05-A:1). This cost methodology was developed to support NRC analysts in determining generic estimates of removal, installation, and total labor costs for construction-related activities at nuclear generating stations. In addition to the validation discussion, this report reviews the generic cost analysis methodology employed. It also discusses each of the individual cost factors used in estimating the costs of physical modifications at nuclear power plants. The generic estimating approach presented uses the "greenfield" or new plant construction installation costs compiled in the Energy Economic Data Base (EEDB) as a baseline. These baseline costs are then adjusted to account for labor productivity, radiation fields, learning curve effects, and impacts on ancillary systems or components.
For comparisons of estimated vs actual labor costs, approximately four dozen actual cost data points (as reported by 14 nuclear utilities) were obtained. Detailed background information was collected on each individual data point to give the best understanding possible so that the labor productivity factors, removal factors, etc., could judiciously be chosen. This study concludes that cost estimates that are typically within 40% of the actual values can be generated by prudently using the methodologies and cost factors investigated herein.

14. DOCUMENT ANALYSIS - a. KEYWORDS/DESCRIPTORS

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Value-Impact Analysis
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Licensee Costs

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VALIDATION OF GENERIC COST ESTIMATES FOR CONSTRUCTION-RELATED ACTIVITIES AT NUCLEAR POWER PLANTS

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