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Rev. 2

Generic Cost Estimates

Abstracts From Generic Studies for Use in Preparing Regulatory Impact Analyses

Prepared by
F. Sciacca

Science and Engineering Associates, Inc.

Prepared for
U.S. Nuclear Regulatory Commission

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PAGE CHANGE INFORMATION SHEET
REVISION 2

The attached pages are the latest revision to NUREG/CR-4627. Revision 1 completely superseded the original Generic Cost Estimates catalog. This revision updates the catalog to reflect the new methodology for estimating radiation-related impacts for nuclear plant physical modifications.

This revision should be incorporated to your existing NUREG/CR-4627, Revision 1, catalog as follows:

	Insert New Pages	Remove Superseded Pages
Front Matter	Cover, Title Page, Page Change Information Sheet, Abstract, Contents, List of Tables, Acknowledgments dated Aug. 1989	Cover, Title Page, Abstract, Acknowledgements, Table of Contents, List of Tables from Revision 1
Abstract 2.1.6, Health Physics Services	Abstract 2.1.6 dated Aug. 1989	Abstract 2.1.6 dated Dec. 1988
Abstract 2.1.7, Labor Costs for the Installation of Hardware, Materials, and Structures	Abstract 2.1.7 dated Aug. 1989	Abstract 2.1.7 dated Dec. 1988
Abstract 2.1.8, Labor Costs for the Removal of Hardware, Materials, and Structures	Abstract 2.1.8 dated Aug. 1989	Abstract 2.1.8 dated Dec. 1988
Abstract 4.3, Occupational Radiation Exposure for Physical Modification Activities	Insert New Abstract After Abstract 4.2	Not Applicable

ABSTRACT

The Nuclear Regulatory Commission has sponsored a number of generic cost estimating studies. These studies were prepared to aid analysts in preparing Regulatory Impact Analyses. These generic studies provide cost estimates that would have wide application to a large number of Regulatory Analyses being performed throughout the NRC and deal primarily with repair and modification activities that may be imposed on nuclear power plants as a result of regulatory actions.

Abstracts of each of the generic cost estimating studies have been prepared and assembled in this catalog. These abstracts present the results of the more detailed studies in a compact, easily understood and readily usable format. Individual abstracts have been developed to treat the main-line topics of the generic studies. In addition, abstracts have been prepared covering important sub-topics or "stand-alones" which are of broad interest in RIA preparation.

Revision 2 of this catalog incorporates a new methodology for estimating radiation-related impacts for nuclear plant physical modifications.

PREVIOUS REPORTS IN SERIES

NUREG/CR-4546	Labor Productivity Adjustment Factors	March 1986
NUREG/CR-5035	Data Base of System-Average Dose Rates	October 1987
NUREG/CR-5138	Validation of Generic Cost Estimates for Construction-Related Activities at Nuclear Power Plants	May 1988
NUREG/CR-5160	Guidelines for the Use of the EEDB at the Subcomponent and Subsystem Level	May 1988
NUREG/CR-4555, Revision 1	Generic Cost Estimates for the Disposal of Radioactive Wastes	September 1988
NUREG/CR-4627, Revision 1	Generic Cost Estimates: Abstracts From Generic Studies for Use in Preparing Regulatory Impact Analyses	February 1989
NUREG/CR-5236	Radiation-Related Impacts for Nuclear Plant Physical Modifications	October 1989

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ACKNOWLEDGEMENTS

A special thanks is extended to Dr. Sidney Feld, Program Manager, of the NRC Regulation Development Branch and other members of the NRC staff for their guidance, assistance, and comments.

ABSTRACT 2.1.6

HEALTH PHYSICS SERVICES

1.0 PRIMARY DATA SOURCE

The data in this abstract was derived from the following documents: "Generic Cost Analysis for Steam Generator Repairs and Replacements," W.L. Miller and L.C. Brown, EGG-PE-6670, August 1984; "Generic Cost Estimates for Reactor Shutdown and Startup, "F.W. Sciacca, et al., SEA 79-02-A:1, June 1984; and "Radiation-Related Impacts for Nuclear Plant Physical Modifications," F.W. Sciacca, et al., NUREG/CR-5236, October 1989.

2.0 PURPOSE

During any modification or repair to a nuclear power plant that involves potential radiation exposure to personnel, the utility is responsible for the health and safety of the repair crews in the working environment and for conducting training required to familiarize repair crews with plant layout and health physics requirements and procedures. The plant radiological controls department carries out this responsibility on behalf of the utility. Health Physics (HP) personnel perform the radiological surveys that are conducted throughout the time required to perform the repair task, staff radiological checkpoints, erect radiological barriers to prevent intrusion by repair crews, prepare work plans and activities for minimizing radiological exposure, and set up anti-contamination (anti-c) clothing removal areas. They also determine the protective clothing and badging requirements for the task, review work packages to assure that anticipated exposures are maintained "As Low As Reasonably Achievable" (ALARA), and brief the repair crews on the HP requirements for the job.

The purpose of this abstract is to provide guidelines for estimating the costs of providing comprehensive health physics support services during plant modifications or repairs.

3.0 APPLICABILITY AND BASES

The cost estimates for HP services presented herein are applicable to modifications and repairs at current-generation PWRs and BWRs. The costs presented are in 1989 dollars.

Two levels of costs are defined. The first provides an overall measure of the costs of comprehensive HP services. The second deals with labor costs only.

The comprehensive cost measure represents the cost of providing complete health physics services at a nuclear plant. The costs are intended to cover expenditures for both labor and materials associated with providing such services. As such, they include all labor and materials costs associated with ALARA radiation exposure, worker qualification, training, protective clothing, dosimetry, bio-assay, respiratory protection, radiation instrumentation, anti-Cs, radiation surveys, job coverage, maintenance of health physics records, radiation work permits (RWPs), etc. This cost represents all the expenditures normally incurred by a Radiological Controls Department in carrying out its functions. The cost index was derived from the total operations and maintenance (O&M) budgets of the Radiological Controls Departments from several nuclear utilities. As such, capital costs for major equipment or facilities associated with the conduct of HP support activities are not included. The cost index presented is applicable to nuclear plants which have operated for several years and in which radiation levels have stabilized.

Certain analyses may require that HP labor costs be separately identified. Guidance is provided herein to allow analysts to estimate the costs of HP labor.

4.0 RESULTS AND HOW TO USE THEM

4.1 Comprehensive HP Services Costs

The costs of comprehensive health physics services can be estimated using the following factor:

Costs of HP Services = \$8350/person-rem (1989 \$)

To estimate the costs of HP related services for a particular activity, the analyst first must estimate the total radiation exposure associated with the activity. The HP services costs are then determined by simply multiplying the exposure (in person-rem) by the cost factor of \$8350 per person-rem, i.e.

HP Support Costs (1989 \$) = (\$8350/person-rem) x Job exposure (person-rem).

4.2 HP Labor Costs

The labor cost of providing HP services depends on whether the HP personnel are employees of the utility or contract personnel and the number of personnel required.

The cost for HP personnel who are employees of the utility are estimated at \$43.00 per hour. This estimate includes base pay, benefits and overhead (100%). No allowance is made for shift differentials.

The cost of contract HP personnel is estimated at \$54.50 per hour for the day shift, \$55.50 per hour for the evening shift, and \$57.50 per hour for the night shift. A composite rate of \$56.00 per hour is estimated for large jobs that will be worked on a three-shift basis. These estimates assume a basic hourly rate of \$22.00 per hour and shift differentials of 2 and 7 percent of the basic hourly rate for evening and night shifts, respectively. A multiplier of 2 is applied to the direct hourly rate, and a per diem charge of \$10.00 per hour (\$80.00 per day) is added. The estimates have been rounded to the nearest dollar for normal day shifts and to the nearest fifty cents for evening and night shifts.

The number of HP personnel required to provide HP services depends on several factors including: the size of the repair crew (craft persons plus supervisors), the magnitude of the radiation fields encountered by the repair crew, and the degree to which remote and/or automated equipment is used.

The following ratios of HP personnel to repair/modification crew size are recommended. The recommended ratios are based on radiation levels at the work-site:

Radiation Level, mr/hr	Ratio of HP, to Crew Personnel
0 to 2.5	1:20
2.6 to 100	1:8 (overall avg.)
>100	1:2

If the work site radiation levels are not known the average ratio of one HP per eight crew members is recommended.

5.0 EXAMPLES

As an example of the use of HP services cost estimates, assume that inspection and repairs are to be made to the steam generators in a PWR. It is postulated that the job included full eddy current testing of three steam generators and plugging of 75 tubes. The eddy current testing is estimated to take 30 days using a repair crew of 36 working a single eight-hour shift per day HP services for the eddy current testing will be provided by utility HP personnel. The tube plugging is estimated to take 6 days with 8 persons per 8-hour shift and three shifts per day. HP services for the tube plugging will be provided by contract HP personnel.

5.1 Calculations of HP Labor Costs

The estimated cost of HP labor for eddy current testing is constructed as follows:

1. Rate for HP personnel = utility rate = $43.00 per hour;
2. Size of repair crew/shift = 36;
3. Number of HP personnel/repair persons = 1:8
4. Number of HP personnel needed/shift = 36/8 = 4.5; Assume 4 HP personnel are adequate.

Therefore, the HP labor cost for eddy current testing = 4 Health Physicists/shift x 8 hours/shift x 1 shift/day x 30 days x $43.00/hour = $41,280.

The estimated cost for HP labor for tube plugging is constructed as follows:

1. Rate for HP personnel = composite contract rate = $56.00 per hour;
2. Size of repair crew/shift = 8
3. Number of HP personnel/repair persons = 1:8
4. Number of HP personnel needed per shift = 8/8 = 1.

Therefore the HP labor cost for tube plugging = 1 HP/shift x 8 hours/shift x 3 shifts/day x 6 days x $56.00/hour = $8,064.

The estimated cost of HP labor for the entire job is therefore $49,300 (rounded off), derived by summing the estimated costs for eddy current testing and tube plugging.

5.2 Calculations of HP Services Cost

The estimate of costs for comprehensive HP services is based on the total radiation exposure associated with a particular activity. Abstract 4.2 can be used to estimate exposures associated with steam generator tube inspection and tube plugging.

Abstract 4.2, Section 4.2, indicates that 25 person-rem of exposure is typical of a full inspection of steam generator tubes. The association costs of comprehensive HP services is:

HP Services Costs = 25 person-rem x $8350/person-rem = $208,750.

The exposure associated with steam generator tube plugging can be estimated using the guidelines presented in Section 4.3 of Abstract 4.2. The case on interest here assumes 75 tubes must be plugged. Linear interpolation of the data presented in Abstract 4.3 yields an estimate of 57 person-rem of exposure to accomplish the tube plugging operation. The associated HP services costs are:

HP Services Costs = 57 person-rem x $8350/person-rem = $475,950.

The combined costs of inspection and tube plugging are $684,700.

A comparison of these costs with the estimates of HP labor costs from Section 5.1 indicates that the costs of directly-applied HP labor are only a small part of the total costs of providing comprehensive health physics and radiological protection services.

6.0 CAUTIONS AND LIMITATIONS

The estimated costs per person-rem for providing comprehensive health physics and radiological protection services is based on average conditions experienced at several nuclear plants during 1988. The estimated ratios of HP personnel to craft persons presented in Section 4.2 are based on a limited number of jobs, most related to steam generator testing and repair. Specific factors, as noted, can cause a significant variation in the ratio. The estimates cover only the cost of HP services covering the work as it is actually performed. They do not include the costs of training or ALARA reviews.

7.0 RELATED ABSTRACTS

Abstract 2.1.5	"Anti-Contamination Clothing."
Abstract 2.2.3	"Industry Costs for Training or Retraining Staff and Writing or Rewriting Training Manuals."
Abstract 2.3.1	"Steam Generator Replacement."
Abstract 2.3.2	"Steam Generator Tube Inspection."
Abstract 2.3.3	"Steam Generator Tube Repair."
Abstract 2.3.4	"Centrifugal Pump Shaft Seal Replacement."
Abstract 4.2	"Occupational Radiation Exposure for Specific Repair/Modification Activities."
Abstract 4.3	"Occupational Radiation Exposure for Physical Modification Activities."

ABSTRACT 2.1.7

LABOR COSTS FOR THE INSTALLATION OF HARDWARE, MATERIALS, AND STRUCTURES

1.0 PRIMARY DATA SOURCES

The data in this abstract was derived from the documents: "Labor Productivity Adjustment Factors," B. J. Riordan, NUREG/CR-4546, March 1986; "Validation of Generic Cost Estimates for Construction-Related Activities at Nuclear Power Plants," G. Simion, et al., NUREG/CR-5138, May 1988; and "Radiation-Related Impacts for Nuclear Plant Physical Modifications," F. Sciacca, et al., NUREG/CR-5236, October 1989.

2.0 PURPOSE

The purpose of this abstract is to assist NRC analysts in the estimation of craft labor construction costs resulting from regulatory requirements. The information presented here attempts to illuminate labor tasks involving construction and equipment changes at operating reactors as opposed to new construction sites, and at new construction sites in those instances when required modifications involve levels of difficulty different from those associated with conventional "greenfield" construction.

3.0 APPLICABILITY AND BASES

The methodology and results presented here will allow an NRC analyst to develop reasonably accurate estimates for the installation labor cost associated with new physical modifications to operating and, in some instances, to partially complete nuclear power reactors. In general, the approach relies on the Energy Economic Data Base (EEDB) for baseline estimates of the direct labor hours and/or costs required to perform specific tasks. While the EEDB estimates reflect actual experience with labor productivity within a new construction environment, the adjustments developed here allow for such additional factors as working in a radiation environment, poor access, congestion and interference, etc., which typically occur on construction tasks at operating reactors and can occur under certain circumstances at reactors under construction.

Two general qualifications are necessary in order to have a better understanding of the completeness and accuracy of the estimates that can be derived in this fashion. First, there are labor activities beyond the composite crew involved in supporting the construction/installation activity. The most common support personnel would include the engineering staff, and health physics and quality control specialists. In addition, hours spent on such items as oil, air, and water line connections, instrumentation and electrical control and power connections and respective peripheral devices can be significant.

Second, the reasonableness of these cost estimates hinges on the comparability of the task at hand to the EEDB reference task. To the extent that a modification entails removal or dismantling of systems already in place (tasks that typically would not take place in a new construction environment), these types of activities must be estimated directly (see Abstract 2.1.8).

Because they are based on actual experience the EEDB labor-hour and labor cost estimates include implicit labor productivity factors. Thus, adjustment factors incorporate only deviations from the average productivity experience at new construction sites. In instances where the EEDB is not applicable or where the analyst must work from an estimate obtained from a a source other than the EEDB, all estimates must be placed on a basis consistent with nuclear plant "greenfield" construction labor productivity in order to apply the adjustment factor formulation.

4.0 RESULTS AND HOW TO USE THEM

4.1 Formulution and Use of Productivity Factors

The following form has been chosen for representation of labor productivity factors:

$$F(LP) = 1 + F_L$$

where F_L = sum of labor productivity factors, and F(LP) is the composite adjustment factor which is the sum of factors dependent on workplace conditions. Total estimated man-hours or labor cost are a function of F(LP) and baseline hours or labor costs derived from the Energy Economic Data Base.

The EEDB labor values represent two different labor elements: (1) the time spent actually performing work and, (2) the time spent preparing for (or peripheral to) the actual work but which is not directly productive. This latter aspect can include time spent in work briefings, job planning, studying drawings and blueprints, worker qualification activities, rework, rest breaks, etc. It also allows for time spent waiting for instructions, waiting periods while quality checks and inspections are performed, and other necessary but not directly productive time that contribute to total job costs.

The labor productivity factors associated with work in operating nuclear facilities generally further reduce greenfield productive work time. These factors act on the direct work portion of the EEDB labor hours or costs. This greenfield productive work time is estimated to be about 37.5% of the total time. Thus the total adjusted labor hours or labor cost associated with equipment installation activities can be represented by the following equation:

$$C'_L = C_L\ [0.625 + 0.375\ (1 + F_L)] \quad (1)$$

where:

C'_L = adjusted installation labor hours or labor cost

C_L = EEDB labor costs or labor hours representing greenfield (new construction) conditions

The labor as defined here accounts for direct craft labor and direct support (supervisors, helpers, etc.). It does not account for health physics staff requirements or the engineering and quality assurance labor associated with modifications to nuclear plants. Health physics costs can be estimated using Abstract 2.1.6. Abstract 6.4 gives guidance for estimating engineering and Q/A costs.

If the modifications of concern are large and complex, the amount of labor required is often dependent on the extent of prior experience for similar or closely related jobs. This effect is accounted for with a learning curve factor (see Abstract 6.5). Including this effect, the installation labor estimate formulation takes the form:

$$C_L' = CL[0.625 + 0.375\ (1 + F_L)(1 + F_{LC})] \quad (2)$$

where

C_L' = Adjusted installation labor
C_L = EEDB installation labor (costs or hours)
F_L = Sum of labor productivity factors
F_{LC} = Learning Curve Factor (see Abstract 6.5)

The greenfield labor, C_L, used in the above equations and as given in the EEDB can be either labor hours or labor costs. The labor costs given in the EEDB include direct wages plus an allowance for fringe benefits. To arrive at loaded costs, the total amount derived from Equation (2) is multiplied by a factor which accounts for overheads and indirect costs (see Abstract 6.2). Since the labor costs given in the EEDB are in 1986 dollars (for BWRs) or in 1987 dollars (for PWRs) they have to be adjusted to reflect present-day dollars (1988 or later). Abstract 6.3 presents guidelines for such time-related cost escalations.

If labor hours are used in the above relationships, the hours are multiplied by appropriate craft labor wage rates with overheads. Typical wage rates and overhead factors for industry are presented in Abstract 6.2.

The following list outlines the major steps which should be taken to effectively utilize the above formulation. Table 4.1 gives values of the labor productivity factors for use in these relationships.

- Identify specific construction/installation task(s) associated with NRC requirements;
- Locate similar or comparable task(s) in the EEDB and extract base-line labor cost estimate;
- Based on knowledge of the modification and the environment in which work is to be performed, select appropriate values for relevant labor productivity factors from Table 4.1. Note that values for specific labor productivity factors will vary by reactor depending on reactor status and work environment at time of modification. Similar reactors among the impacted population should be grouped and assigned equivalent productivity factor values;
- If the repair/modification activity of concern is considered to be a major undertaking (i.e., in the class of steam generator, reactor coolant pump, or recirculation piping replacement) determine the appropriate learning curve factors (see Abstract 6.5). If these activities or others which are quite similar have been performed several times in the past by industry, then the learning curve factor (i.e., $1 + F_{LC}$) is 1.0;
- Compute the adjusted labor costs using Equation (2).
- To include indirect labor costs and overheads, multiply the result from Equation (2) by the "adder" factor (see Abstract 6.2);
- Escalate labor costs to present-day dollars (see Abstract 6.3); and
- Sum result above over all impacted reactors to obtain total industry direct labor cost associated with installation/construction effort.

TABLE 4.1

LABOR PRODUCTIVITY FACTORS

Activity Characteristic	Factor Value					
1. i. Access and Handling (operating plants)	a. Operating plant, security procedures, easy access, 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, 4, 5]	Radiation Factor F_r = 1.0 x ALARA adjusted Dose Rate for Dose Rates $\leq$ 5 mrem/hr; 0.191 x ALARA adjusted Dose Rate for Dose Rates > 5 mrem/hr					
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 radiation labor productivity factors

(5) Assumes ALARA practices are implemented and dose rates are reduced, on average, by 20%

*RWP: Radiation Work Permit required

The labor hours specified in the EEDB for a certain activity already take account of rework hours that typically occur during construction, up to about the 70 percent construction-complete stage. Therefore, when dealing with plants at or before this stage the EEDB labor hour estimates generally need not be adjusted for modification of hardware or systems, unless the NRC requirement involves a major structural modification. For plants under construction beyond the 70 percent stage, the labor productivity factors should be used with caution. As construction nears completion, the cost of a design change is very dependent on the equipment already installed in an area, its configuration, and resulting congestion. Whenever possible, under such circumstances, labor should be estimated on a case-by-case basis.

In instances when the EEDB is not applicable, alternative estimates might be formulated using such sources as Richardson Engineering Estimating Standards and R.S. Means Construction Standards. Use of these familiar data bases will entail initial adjustment to place estimates on a nuclear new construction basis. For instance, the Richardson system includes allowance for a number of incidental work tasks affecting productivity, such as coffee breaks, materials handling, tool adjustment, etc. These non-operational items range from 15 to 30 percent of a normal work day. However, labor productivity during construction of nuclear power plants is further hindered by extreme quality assurance controls, security measures, and other features that are likely to impede labor. Thus, labor hours calculated by the Richardson and Means systems must be multiplied by a factor of 2.5 - 2.7 to properly reflect the nuclear plant level of effort and equipment/material specifications. Only at that point can the incremental adjustment factors described here be applied.

4.2 Directions for Using Productivity Factors

4.2.1 Access and Handling

This factor incorporates site restrictions and security procedures, but more importantly, material and equipment transportation and handling complications. Transportation complications include distance from storage sites, additional handling due to pathway encumbrances such as hatchways, and possible difficulties in moving to elevated locations.

The access component 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 labor-hour savings normally credited to on-ground prefabrication of components are lost.

The maximum value of 0.4 is approached in incremental steps, and is applicable to both operating plants and plants 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. Internal areas to which such factors would apply might include:

- primary auxiliary building;
- waste process building;
- fuel storage building;
- control room; and
- diesel generator building.

The extreme value of 0.4 is reserved for activities to be carried out within the main reactor containment building itself.

4.2.2 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.

Congestion also refers to interferences from already installed permanent materials and equipment that limit accessibility to work areas or physically block new work planned. Such conditions slow the rate of production, or add labor-hours because new work must be reconfigured or previous work redone.

Height of the workplace above floor level can also be considered an element of interference. This is often a psychological element as well as a physical one. Workplace positions several stories above floor level can be considered the same as a congested area in terms of labor productivity.

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, and/or electrical systems, and/or mechanical systems in the same area. Available literature and expert opinion suggest that an adjustment factor of 0.4 would describe 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.

Judging where to apply factors for moderate and severe congestion can be quite difficult without site-specific knowledge. However, some a priori guidance is possible: any work in tunnels or vaults is likely to take place under conditions of severe congestion, as is most work within the containment and primary auxiliary buildings. Plumbing or electrical work in other internal plant areas is likely to take place under moderately congested conditions. The EEDB provides guidance in many instances as to the dimensions of various areas (e.g., the diesel generator building measures 90 by 93 feet externally) and to the equipment installed there (e.g., two diesel generator sets, fuel storage tanks). This information can assist in an assessment of available working space and maneuverability.

4.2.3 Radiation

Work in a radiological environment presents a particularly difficult problem with regard to operating reactors. There are two separable causes for productivity reductions: (1) the encumbrances of protective equipment, particularly under conditions of elevated temperature, and (2) strict limitations on permissible radiation dosages that limit the time any 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. In addition, use of such equipment in a high temperature environment is even more debilitating.

1

IMAGE EVALUATION TEST TARGET (MT-3)

1.0 1.1 1.25 1.4 1.6 1.8 2.0 2.2 2.5 2.8 3.2

150mm

6"

1

IMAGE EVALUATION
TEST TARGET (MT-3)

1.0 1.1 1.25 1.4 1.6 1.8 2.0 2.2 2.5 2.8 3.2

150mm

6"

1

IMAGE EVALUATION TEST TARGET (MT-3)

150mm

6"

1

IMAGE EVALUATION TEST TARGET (MT-3)

1.0 1.1 1.25 1.4 1.6 1.8 2.0 2.2 2.5 2.8 3.2 3.6 4.0

150mm

6"

The key element which determines the radiation productivity factor is the in-field work time. Limitations on in-field work time, in turn, are determined primarily by the radiation dose rate for a given work environment. The radiation productivity factor must be able to quantitatively reflect the degree by which radiation levels and stay time reduce normal direct work time relative to greenfield construction.

As noted previously, the normal direct work time for new nuclear construction is about of 37.5% of the total time allotted for a particular activity. This corresponds to three hours of in-field productive work time of a normal eight hour shift. For greenfield construction the average worker would provide a total of 191 hours of direct work time in a three month period or calendar quarter (i.e., total direct work hours = 170 hours/month x 3 months/quarter x 0.375 = 191 hours/quarter).

Typical U.S. nuclear utility practice is to impose an administrative upper limit of 1 rem per calendar quarter for each radiation worker. This limit, together with the 191 hours/quarter estimate of useful work typical of nuclear plant construction, provides a basis for defining a radiation labor productivity factor.

The radiation labor productivity factor (F_r) can be expressed mathematically by the following equation:

$$F_r = \frac{\text{Maximum possible quarterly direct work hours}}{\text{Quarterly direct work hours based on radiation exposure limits}}$$

$$= \frac{\text{Greenfield normal direct work} \left[\frac{\text{hours}}{\text{quarter}}\right]}{\left\{\frac{\text{Quarterly Whole Body Exposure Limit}}{\text{ALARA adjusted area dose rate}}\right\}}$$

Where:

$$\text{Greenfield normal direct work} \left[\frac{\text{hours}}{\text{quarter}}\right] = \left(3\ \frac{\text{months}}{\text{quarter}}\right)\left(170\ \frac{\text{hours}}{\text{month}}\right)(0.375)$$

$$= 191\ \frac{\text{hours}}{\text{quarter}}$$

$$\text{Quarterly whole body exposure limit} = 1000\ \frac{\text{mrem}}{\text{quarter}}$$

ALARA adjusted area dose rate =

(system average dose rate or area dose rate as defined in Abstract 4.1)

· (ALARA dose reduction factor)

Therefore:

$$F_r = \frac{191\ \frac{\text{hours}}{\text{quarter}}}{\left\{\frac{1000\ \frac{\text{mrem}}{\text{quarter}}}{\text{ALARA adjusted dose rate} \left[\frac{\text{mrem}}{\text{hour}}\right]}\right\}}$$

$$F_r = \left(0.191\ \frac{\text{hours}}{\text{mrem}}\right) \cdot \text{Adjusted Dose Rate}\left[\frac{\text{mrem}}{\text{hour}}\right]$$

Application of ALARA techniques is estimated to reduce worker radiation exposures on average by about 20%. This is an average reduction cited by a number of utilities. ALARA practices are typically implemented for a particular job or activity whenever the cumulative radiation exposure for that activity is expected to exceed one person rem. Since most physical modifications of interest to NRC analysts will likely entail exposures which exceed one person rem, the ALARA dose reduction factor of 0.8 should be used in most cases.

In the foregoing formulation, F_r can vary from zero to very large values, depending on the area dose rates prevalent at the work location. However, a comparison of estimated labor hours versus actual labor for a number of specific physical modification tasks at operating nuclear plants indicates that the estimated values better match actual labor if a minimum value of 1.0 is assigned to F_r. The recommended approach, therefore, for quantifying the radiation labor productivity factor is as follows:

For Dose Rates >5 mrem/hr (3)
F_r = 0.191 x ALARA adjusted dose rate (mrem/hr);

For Dose Rates ≤5 mrem/hr,
F_r = 1.0

4.2.4 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 work force onsite. 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. An adjustment factor of 0.3 is recommended for work performed during plant outages and 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.

4.3 Special Considerations for Piping

The evaluation of case studies of piping installation/replacement labor costs indicates that certain special considerations are in order. When compared to the actual plant costs, piping cost estimates produced using the generic methodology required that the "greenfield" EEDB man-hours be reduced by 90% (or formulated differently, EEDB man-hours x 0.1) 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 base data derived from the EEDB. The "large pipe" factor, 0.1, is recommended for all cost estimates involving pipe with a diameter of over 18 inches. The estimated cost installation equation for this case has the form:

$$C'_L = 0.1 \times C_L \; [0.625 + 0.375 \times (1 + F_L)(1 + F_{LC})]$$

Smaller piping installation estimates do not require this special treatment.

5.0 EXAMPLE

The following example illustrates the application of the labor productivity adjustment factors quantified above.

A cost estimate is necessary for a regulatory action requiring the potential replacement of the control rod drive missile shield (CRDMS) at a number of pressurized water reactors. Twelve are in operation, ten are under construction. Of those under construction, eight are at advanced stages, typically 80 percent complete. An estimate is needed of the labor costs associated with these activities.

From the EEDB, Phase IX (Account Number 221.213), installation requires 2,400 labor-hours at a cost of $55,440 (in 1987 dollars). Table 5.1 shows the appropriate EEDB printout referring to CRDMS. It is assumed that removal of the existing CRDMS will be calculated separately.

For the operating reactors, factors are chosen as follows:

- Access and handling: since CRDMS is installed inside containment, the factor 0.4 is chosen from Table 4.1;

- Congestion and interference: the containment location will almost always imply severe congestion, thus 0.4 is chosen;

- Radiation: to establish a numerical value for the radiation factor the work-site radiation level must first be estimated. Abstract 4.1 does not give a dose rate for the CRDMS. However, since it is in the vicinity of the reactor vessel head, we assume that the radiation levels should be lower than or equal to the 140 mrem/hr cited for the reactor vessel studs, fasteners, etc. Note, that the combination of this radiation dose rate and even the unadjusted EEDB labor hours confirms that the worker radiation exposure for this task will be in excess of one person-rem. ALARA practices would, therefore, be put into effect. We estimate the radiation factor from equation (3) as follows:

  $$F_r = 0.191 \text{ (hr/mrem)} \times \text{ALARA adjusted dose rate (mrem/hr)}$$
  $$= 0.191 \times (0.8 \times 140) = 21.4$$

- Manageability: Since this activity will by necessity take place during an outage, this factor is assigned a value of 0.4.

From equation (1) the total labor productivity factor, $1 + F_L$, is

$$1 + (0.4 + 0.4 + 21.4 + 0.4) = 23.6$$

TABLE 5.1 EEDB PRINTOUT

PLANT CODE 148 COST BASIS 01/87 1144 MWE PRESSURIZED WATER REACTOR 11/02/87

ACCT NO.	ACCOUNT DESCRIPTION	FACTORY QUANTITY	FACTORY COSTS	SITE QUANTITY	SITE LABOR HRS	SITE LABOR COST	SITE MATERIAL COST	TOTAL COSTS
221.21	CONTROL ROD SYSTEM							
221.211	CONTROL RODS							
221.212	CONTROL ROD DRIVES (CRD)	57 EA		1 LT	18240 MH	431,094	43,109	
221.213	CRD MISSILE SHIELD	1 LT		1 LT	2400 MH	55,440	5,544	
221.214	CRDM SEISMIC SUPPORTS	1 LT	25,175	1 LT	700 MH	16,170	1,617	
221.215	CRDMS + RODS- PU RECYCLE							
	221.21 CONTROL ROD SYSTEM		25,175		21340 MH	502,704	50,270	578,149
	221.2 REACTOR CONTROL DEVICES		25,175		21340 MH	502,704	50,270	578,149
	221. REACTOR EQUIPMENT		838,428		181940 MH	4,284,831	6,068,482	11,191,741
222.	MAIN HEAT X/ER XPORT SYS.							
222.1	REACTOR CORE COOLANT SYS.							
222.11	FLUID CIRCULATION DR. SYS.							
222.111	ROTATING MACHINERY							
222.1111	MAIN COOLANT PUMPS&DRIVES	4 EA		1 LT	30400 MH	763,800	76,380	
222.11111	MAIN COOLANT PUMPS							
222.11112	MAIN COOLANT PUMP DRIVES							
	222.1111 MAIN COOLANT PUMPS&DRIVES				30400 MH	763,800	76,380	840,180
	222.111 ROTATING MACHINERY				30400 MH	763,800	76,380	840,180
222.118	INSTRUMENTATION + CONTROL							

This activity is not judged to be extremely large o[illegible]x. Therefore, the learning curve factor F_{LC} is set to 0.0.

To calculate adjusted installation labor, C_L', Equation (2) is used in labor-hours,

$$C'_L = 2{,}400\ [0.625 + 0.375 \times 23.6 \times 1.0] = 22{,}740 \text{ labor hours}$$

or in 1987 dollars,

$$C'_L = \$55{,}440 \times [0.625 + 0.375 \times 23.6 \times 1.0] = \$525{,}294 \text{ per reactor}$$

These cost represent direct labor costs plus fringe benefits. Other labor overheads can be accounted for by applying an additional factor of 1.59 (see Abstract 6.2).

Loaded labor costs = 1.59 x $525,294 = $835,217 (in 1987 dollars).

Now escalating the loaded labor costs to reflect present-day (1989) dollars (see Abstract 6.3):

$$\$835{,}217 \times \frac{109.9}{108.0} \times (1 + 0.048 - 0.004)^{(1989-1988)} = \$887{,}307 \text{ per reactor}$$

or

$887,307 x twelve operating reactors = $10,647,700 (rounded).

Escalation using the cost indices shown assumes that the work will be performed by contract personnel.

For the reactors under construction (80 percent complete), factors are chosen as follows:

- Access and handling: containment area = 0.4
- Congestion and interference: severe conditions = 0.4
- Radiation: clean environment, use min. value of 1.0
- Manageability: reactor under construction, not applicable - 0.0

Total factor = 1 + (0.4 + 1.0 + 0.4) = 2.8

$C_L' = 2{,}400\ [0.625 + 0.375\ (2.8)\ (1.0)] = 4{,}020$ labor-hours or

$C_L' = (\$55{,}440)[0.625 + 0.375 \times 2.8] = \$92{,}862$ (1987 dollars)

Loaded labor costs = 1.59 x $92,862 = $147,651 (1987 dollars)

Adjusting to reflect 1989 costs (assuming the work is performed by contract construction workers)

$$\$147{,}651 \times \frac{109.9}{108.0} \times 1.044 = \$156{,}860 \text{ per reactor,}$$

or

$156,860 x eight reactors = $1,254,900 (rounded).

The two reactors at early stages of construction have not yet installed the CRDMS, thus their incremental labor cost is zero.

Total loaded installation labor cost of the regulation (in 1988 dollars) =

$10,647,700 + $1,254,900 = $11,902,600.

6.0 CAUTIONS AND LIMITATIONS

Despite the appearance of quantitative precision, analysts should be mindful that labor productivity adjustment factors have been derived on a subjective basis. These factors should not be applied mechanically. They should be utilized as necessary, but not in a manner precluding sound judgement.

All results involving application of labor productivity factors should be carefully reviewed for realism. Sensitivity of results to the choice of a factor should be analyzed and ranges of values should be applied as necessary.

Most physical modification activities at nuclear plants will involve both removal of old equipment and the installation of the new replacement items. To estimate the labor costs for removal activities or costs for combined removal and installation, consult Abstract 2.1.8.

Comprehensive cost estimates should include costs of health physics services and engineering and quality assurance. These must be separately accounted for using Abstracts 2.1.6 and 6.4, respectively.

7.0 RELATED ABSTRACTS

Abstract 2.1.6	"Health Physics Services."
Abstract 2.1.8	"Labor Costs for the Removal of Hardware, Materials, and Structures."
Abstract 2.1.9	"Greenfield Costs for Piping and Piping-Related Commodities."
Abstract 4.1	"Typical System-Average Dose Rates."
Abstract 4.2	"Occupational Radiation Exposure for Specific Repair/Modification Activities."
Abstract 4.3	"Occupational Radiation Exposure for Physical Modification Activities."
Abstract 6.2	"Industry Labor Rates."
Abstract 6.3	"Time-Related Cost Adjustments."
Abstract 6.4	"Engineering and Quality Control Cost Factors."
Abstract 6.5	"Labor Adjustments for Learning Curve Effects."

ABSTRACT 2.1.8

LABOR COSTS FOR THE REMOVAL OF HARDWARE, MATERIALS, AND STRUCTURES

1.0 PRIMARY DATA SOURCE

The data in this abstract was derived from the documents: "Validation of Generic Cost Estimates for Construction-Related Activities at Nuclear Power Plants," G. Simion, et al., NUREG/CR-5138, May 1988; and "Radiation-Related Impacts for Nuclear Plant Physical Modifications," F. Sciacca, et al., NUREG/CR-5236, October 1989.

2.0 PURPOSE

Many proposed regulatory requirements involve physical modifications to nuclear power plants that require the removal of existing hardware, materials, and structures. This need can arise, for example, if the NRC determines that a specific component needs to be replaced with one that is environmentally qualified or more reliable. In instances such as these, the affected component will have to be removed before the installation of the new component can occur.

The purpose of this abstract is to assist NRC analysts in the estimation of total labor costs resulting from regulatory requirements. In particular, this abstract presents guidelines for estimating the labor cost associated with the removal of hardware, materials, and structures from nuclear power plants.

3.0 APPLICABILITY AND BASES

The methodology and results presented in this abstract allow NRC analysts to develop reasonably accurate estimates for the removal costs associated with physical modifications to operating and substantially completed nuclear power plants. The approach relies on the Energy Economic Data Base (EEDB) to provide baseline installation labor costs for specific components, systems, and materials. In addition, the approach presented here draws on the labor productivity factors (See Abstract 2.1.7) to help define the conditions and environment under which the removal activities must be conducted.

This methodology will yield estimates of both the total labor (i.e., removal and installation combined) and the removal effort labor associated with physical modifications. The estimates account for craft labor and craft supervision. An analyst should recognize that many other costs may occur in connection with a specific removal activity (i.e., engineering/QA costs, health physics costs, etc). Guidance on estimating other likely impacts is addressed elsewhere in this compilation of abstracts, and analysts preparing total cost estimates must separately account for these excluded costs. Section 7.0 provides a listing of the abstracts.

4.0 RESULTS AND HOW TO USE THEM

4.1 Formulation and Use of Removal Factors

The methodology employed in deriving removal factors is generally patterned after the approach presented in "A Handbook for Cost Estimating," (NUREG/CR-3971). This approach uses as a baseline the system, component, and material costs given in the EEDB. Since the baseline costs reflect new construction or "greenfield" conditions, a set of factors is used to adjust these costs for labor productivity changes associated with conditions at operating and nearly-completed nuclear plants. The specific formulation used here, which includes factors to account for removal labor as well as installation labor, is as follows:

$$C_L^{*} = C_L[0.625 + 0.375 \times (1 + F_L)(1 + F_{LC})](1 + F_{R1})(1 + F_{R2}) = \qquad (1)$$

$$= C_L'(1 + F_{R1})(1 + F_{R2})$$

where

C_L^{*} = Adjusted direct total labor cost or labor hours

C_L = EEDB installation labor (cost or hours)

C_L' = Adjusted installation labor

F_L = Sum of labor productivity factors (see Abstract 2.1.7)

F_{LC} = Factor based on learning curve effects (see Abstract 6.5)

F_{R1} = Removal factor related to the nature of the target items

F_{R2} = Removal factor related to impacts on non-target or ancillary systems

The formulation as presented by Equation (1) recognizes that, of the base greenfield labor, about 37.5% of the labor is directly productive. The remaining 62.5% of the time is spent in activities such as work briefings, job planning, worker qualification, rework, rest breaks, and other such activities which are necessary but which are not directly productive. Equation (1) indicates that certain labor productivity factors account for influences which impact only the directly productive work time, whereas other considerations impact both the productive and non-productive components of the total labor.

The relationship indicated in Equation (1) produces an estimate of total labor, i.e. removal and installation combined. If estimates of removal costs alone are needed, they are calculated using the following relationship:

$$C_{RL} = C_L[0.625 + 0.375 \times (1 + F_L)(1 + F_{LC})][(1 + F_{R1})(1 + F_{R2}) - 1] \qquad (2)$$

$$= C_L'[(1 + F_{R1})(1 + F_{R2}) - 1]$$

where C_{RL} is the removal labor cost

The removal factors F_{R1} and F_{R2}, depending on the circumstances of the physical modification of interest, can both be zero-valued. In such cases Equations (1) and (2) cannot be used to predict the costs and labor hours associated with the combined removal/installation or just removal of hardware, equipment, or structures. The limited amount of data available on actual nuclear plant physical modification activities indicates that removal labor is generally about 1/3 of installation labor. Therefore, for those cases where $F_{R1} + F_{R2} = 0$, the following relationship can be used to estimate removal labor:

$$C_{RL} = 0.33\, C_L' \qquad (3)$$

$$= 0.33 \times C_L[0.625 + 0.375 \times (1 + F_L)(1 + F_{LC})]$$

where C_L' is the adjusted installation labor (Abstract 2.1.7).

Similarly, for calculating total labor (both removal and installation) the following expression can be used:

$$C_L'' = 1.33 \, C_L'. \qquad (4)$$

The "greenfield" installation labor, C_L, used in the above equations and as given in the EEDB can be either labor hours or labor costs. The labor costs given in the EEDB include direct wages plus an allowance for fringe benefits. To arrive at loaded costs, the total amount derived from Equations (1) through (4) is multiplied by a factor which accounts for overheads and indirect costs (see Abstract 6.2). Since the labor costs given in the EEDB are in 1986 dollars (for BWRs) or in 1987 dollars (for PWRs) they have to be adjusted to reflect present-day dollars (1988 or later). Abstract 6.3 presents guidelines for such time-related cost adjustments.

If labor hours are used in the above relationships, the hours are multiplied by appropriate craft labor wage rates with overheads. Typical wage rates and overhead factors for industry are presented in Abstract 6.2.

Equations (1), (2), (3), and (4) 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 (from utilities or other industry sources) but it is known that it does not include removal labor costs. 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 Equations (2) or (3), with C_L' as the independent installation labor cost. The relationships, when used in this manner, assume the independently-obtained installation labor cost (C_L') adequately reflects labor productivity and learning curve effects.

Table 4.1 presents the removal labor factors.

TABLE 4.1

REMOVAL FACTORS

Activity Characteristic	Factor Value				
1. Targeted Systems and Structures					
Structural (F_{R1})	b.	Congested Work Area	.5	b. Severely Congested Work Area	.8
2. Ancillary Systems and Structures					
Access and handling (F_{R2})	a.	Complex activity impingement on surrounding systems and structures	.40-.60		

The following steps outline the procedures to follow to obtain estimates of labor costs for hardware, material, and structure replacement activities at nuclear power plants.

For cases where the EEDB is used to define the baseline installation labor costs:

- Identify the specific removal/replacement activities associated with the NRC requirement;
- Locate the corresponding system, equipment, and/or material items in the EEDB and extract the baseline labor cost (or man-hours) estimates;
- Based on knowledge of the modification and the environment in which the work must be performed, select appropriate labor productivity factors (refer to Abstract 2.1.7);
- If the removal/replacement activity of concern is considered to be a major undertaking (i.e., in the class of steam generator, reactor coolant pump, or recirculation piping replacement) determine the appropriate learning curve factors (see Abstract 6.5). If these activities or others which are quite similar have been performed several times in the past by industry, then the learning curve factor (i.e., $1 + F_{LC}$) is 1.0;
- Select appropriate removal factors from Table 4.1. Follow the guidelines in Section 4.2 to select factors pertinent to the work envisioned and to the specific reactors affected by the NRC requirement;
- Compute total labor costs using Equations (1) or (4). If removal costs need to be identified separately, calculate these using Equations (2) or (3).
- To include indirect labor costs and overheads, multiply the results from Equations (1), (2), (3), or (4) by the indirect costs factor (see Abstract 6.2);
- Escalate labor costs to present-day dollars (see Abstract 6.3);
- Sum the above result over all impacted reactors to obtain an estimate of industry-wide labor costs for the subject NRC requirement.

Note that values for specific factors will vary by reactor, depending on the reactor status and work environment at the time the modifications will be carried out. Similar reactors among the impacted population should be grouped and assigned similar factors.

For cases where an independent estimate of installation labor is available, removal costs can reasonably be estimated by using Equation (2) or (3). The independent estimate of installation labor must adequately reflect labor productivity and learning curve effects.

4.2 Directions for Selecting Removal Factors

4.2.1 Targeted System Removal Factors: 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 factor approximates the gradations of congestion described in the installation labor costs (Abstract 2.1.7). 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.

In summary, it is estimated that the target system 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 work space. If these conditions do not apply the structural factor F_{R1} is assigned a value of 0.

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. The data available suggest a range of 0.40 to 0.60 for this factor; however, it should be stressed that these values are based on a very small number of observations. A larger data base would likely show that the range for this factor should be broadened.

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 of 0.4 for F_{R2}. If a labor productivity 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.

The ancillary structures and systems factor can correctly adjust the cost estimates to a closer match of the actual cost data. Industry data show that large and bulky components, such as steam generators, reactor coolant pumps, and feedwater heaters demand that adjustment factor. Another type of component that needs correction for its impingement on auxiliary systems is small to medium pipe (less than 12 inches in diameter). In order to remove small pipe (which is generally 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 man-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 described herein, 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 analysts. 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 Special Considerations for Piping

The evaluation of case studies of piping removal/replacement labor costs indicates that certain special considerations are in order. When compared to the actual plant costs, piping cost estimates produced using the generic methodology required that the "greenfield" EEDB man-hours be reduced by 90% (or formulated differently, EEDB man-hours x 0.1) 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 base data derived from the EEDB. The "large pipe" factor, 0.1, is recommended for all cost estimates involving pipe with a diameter over 18 inches. The total estimated cost equation for this case has the form:

$$C_L^* = C_L \times 0.1[0.625 + 0.375\ (1 + F_L)\ (1 + F_{LC})]\ (1 + F_{R1})\ (1 + F_{R2})$$

$$\text{or } C_L^* = 1.33 \times 0.1 \times C_L[0.625 + 0.375\ (1 + F_L)\ (1 + F_{LC})]$$

for cases where $F_{R1} + F_{R2} = 0$.

Similarly, the removal labor cost equation takes the form:

$$C_{RL} = C_L \times 0.1[0.625 + 0.375\ (1 + F_L)\ (1 + F_{LC})]\ [(1 + F_{R1})\ (1 + F_{R2}) - 1] \text{ or}$$

$$C_{RL} = 0.33 \times 0.1 \times C_L\ [0.625 + 0.375\ (1 + F_L)\ (1 + F_{LC})]$$

for the case where $F_{R1} + F_{R2} = 0$.

5.0 EXAMPLE

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

For purposes of this example, we assume that an NRC regulation calls for the upgrading of the containment spray pumps and motors on certain plants. This system removes 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, the pumps and motors are located within the reactor containment building.

The EEDB PWR reference plant indicates that there are two of these pumping units in the base design. They are described in account No. 223.411 of the EEDB. The cost data from the EEDB are shown in Table 5.1 (in 1987 dollars).

To determine the removal and replacement labor costs, it is necessary to first assess the environment under which these activities must be carried out. Since the pumps are located inside containment the work can only be performed while the reactor is shut down. The pumps are located in the reactor building annulus between the secondary shield wall and the outer wall of the building. Therefore, the work must be performed in a radiation environment. Based on

TABLE 5.1 EEDB PRINTOUT

PLANT CODE 146   COST BASIS 01/87

UNITED ENGINEERS & CONSTRUCTORS INC.
EEDB-IX BASE COSTS (MEDIAN EXPERIENCE BASIS)
1144 MWE PRESSURIZED WATER REACTOR

11/02/87

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	147,255	1 LT	378 MH	9,106	455	
	223.3 SAFETY INJECTION SYSTEM		1,506,236		181115 MH	4,418,102	599,953	6,524,291
223.4	CONTAINMENT SPRAY SYSTEM							
223.41	ROTATING MACHINERY							
223.411	CONTAINMNT SPRAY PUMP + MTR	2 EA	254,295	1 LT	3300 MH	82,912	8,291	
223.4111	CONTAINMENT SPRAY PUMP							
223.4112	CONTAINMENT SPRAY PUMP MTR							
	223.411 CONTAINMNT SPRAY PUMP + MTR		254,295		3300 MH	82,912	8,291	345,498
	223.41 ROTATING MACHINERY		254,295		3300 MH	82,912	8,291	345,498
223.42	HEAT TRANFER EQUIPMENT							
223.421	CONTAIN SPRAY HEAT XCHNGER	2 EA	258,039	1 LT	1001 MH	23, 0	2,365	
	223.42 HEAT TRANFER EQUIPMENT		258,039		1001 MH	23,650	2,365	284,054
223.43	TANKS AND PRESSURE VESSELS							
223.431	SPRAY ADDITIVE TANK	1 EA	159,256	1 LT	1200 MH	28,361	2,836	
	223.43 TANKS AND PRESSURE VESSELS		159,256		1200 MH	28,361	2,836	190,453
223.45	PIPING							
223.451	2IN + SMALLER							
223.4511	SS/NNS			730 LB	2190 MH	53,481	4,460	
223.4512	SS/SC2			820 LB	3690 MH	90,112	10,398	

the information presented in Abstract 4.1, we ascertain that the average dose in the area of these pumps is about 15 mrem/hr.

The containment spray pumps 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 Abstract 2.1.7.

- Access and handling

  Operating plant, inside the RCB — 0.4
- Congestion and interference

  Congested work area — 0.4
- Radiation (15 mr/hr)

  Fr = 0.191 x 15 x 0.8 = — 2.3
- Manageability

  Outage activity, inside containment — 0.4

The total labor productivity adjustment factor is:

$$1 + 0.4 + 0.4 + 2.3 + 0.4 = 4.5$$

The replacement of these pumping units is not 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 (see Abstract 6.5).

The removal factors are assessed based on the information given in Table 4.1. Since the containment spray pumps are hardware, which is not structural, the F_{R1} factor has a value of 0. However, these pumps and motors are expected to impinge to some extent on surrounding equipment and systems when they are removed and replaced. A value of 0.4 is assigned to the factor F_{R2}. The overall removal factor is:

$$(1.0 + 0)\ (1.0 + 0.4) = 1.4.$$

Summarizing, the three adjustment factors to be applied to the EEDB are:

Labor Productivity	4.5
Learning Curve	1.00
Removal	1.4

The total estimated labor hours to remove and replace the containment spray pumps and motors, on a per plant basis, is:

$$C_L" = C_L\ [0.625 + 0.375(1 + F_L)\ (1 + F_{LC})]\ (1 + F_R)$$

$$= 3{,}300\ [0.625 + 0.375 \times 4.5 \times 1.0]\ 1.4 = 10{,}684 \text{ hours}$$

Assume that the work will be performed by utility personnel. For the type of crafts needed, assume an average wage rate of $16.00/hr. Other labor overheads can be accounted for by applying an additional factor of 2.0 (see Abstract 6.2). Loaded total labor costs are (in 1988 dollars):

10,684 hrs x $16.00/hr x 2.0 = $341,880.

Now escalate the loaded labor costs to reflect present-day (1989) dollars (see Abstract 6.3):

$341,880 x (1.0 + 0.048 + 0.008) = $361,000 per reactor (rounded).

6.0 CAUTIONS AND LIMITATIONS

Analysts using this abstract to estimate labor costs should do so with considerable caution. Any results should be considered to be very approximate, and in some cases results could be far removed from reality. As with any generic procedure, the methods presented here must be applied prudently and with sound engineering judgement as to their applicability and the reasonableness of the results they produce.

The user should be aware of the following:

- The factors presented here were derived based on a limited set of data, and considerable subjective judgement was used.
- These results are intended for application to cases involving operating nuclear plants or plants which are at least at the 70% construction-complete stage. They are not applicable to plants in earlier stages of construction.
- The cost data in the EEDB are based on generic plant designs which are reasonably close to modern BWR and PWR designs. The design in the EEDB 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.
- Proper application of these methods requires considerable familiarity with the specific plants involved and with 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 will take place.
- Comprehensive cost estimates should include costs of health physics services and engineering and quality assurance. These must be separately accounted for using Abstracts 2.1.6 and 6.4, respectively.

7.0 RELATED ABSTRACTS

Abstract 2.1.4 "Radioactive Waste Disposal."

Abstract 2.1.6 "Health Physics Services."

Abstract 2.1.7 "Labor Costs for the Installation of Hardware, Materials, and Structures."

Abstract 2.1.9 "Greenfield Costs for Piping and Piping-Related Commodities."

Abstract 4.1 "Typical System-Average Dose Rates."

Abstract 4.2	"Occupational Radiation Exposure for Specific Repair/Modifications Activities."
Abstract 4.3	"Occupational Radiation Exposure for Physical Modification Activities."
Abstract 6.2	"Industry Labor Ratios."
Abstract 6.3	"Time-Related Cost Adjustments."
Abstract 6.4	"Engineering and Quality Assurance Cost Factors."
Abstract 6.5	"Labor Adjustments For Learning Curve Effects."

ABSTRACT 4.3

OCCUPATIONAL RADIATION EXPOSURE FOR PHYSICAL MODIFICATION ACTIVITIES

1.0 PRIMARY DATA SOURCE

The data in this abstract was derived from the report "Radiation-Related Impacts for Nuclear Plant Physical Modifications," F.W. Sciacca, et al., NUREG/CR-5236, October 1989.

2.0 PURPOSE

The purpose of this abstract is to assist NRC analysts in the estimation of occupational radiation exposure associated with physical modifications at operating nuclear plants. Guidelines are also presented for accounting for the impacts of ALARA on reducing exposures.

3.0 APPLICABILITY AND BASES

The guidelines for estimating occupational radiation exposure presented herein are applicable to current generation U.S. light water cooled reactors (BWRs and PWRs). The exposure estimates are presented in person-rem.

The guidelines presented here give estimates of the total exposure associated with the conduct of physical modification activities at LWRs. It includes exposures both to those directly involved in carrying out the modifications and to health physics personnel. The resulting estimates should be considered to be very approximate. The relationships presented are semi-empirical in nature, and they are based on a limited number of data points.

The approach presented is similar to other elements of the NRC's generic cost estimating methodology in that it utilizes as a starting point greenfield construction labor. This baseline labor is then adjusted with labor productivity factors to provide an estimate of the labor hours actually spent in a radiation environment. The labor productivity factors attempt to characterize the actual work site conditions.

4.0 RESULTS AND HOW TO USE THEM

The radiation exposure incurred in the conduct of nuclear plant physical modification activities can be estimated if the in-field labor hours and the average radiation dose rate at the work site are known. The dose rate for a particular job should be determined based on actual conditions if such data are available. Barring this, the dose rate data presented in Abstract 4.1 can be used.

Current industry practice is to apply ALARA procedures and techniques whenever the cumulative dose for a particular job or activity is expected to equal or exceed one person-rem. When ALARA practices are applied, the average dose reduction achieved, based on a recent industry survey, is about 20%. That is, the typical radiation dose rate at a work site is reduced by about 20% as a result of ALARA practices such as system flushing and decontamination, application of shielding, etc.

The estimation of radiation exposure requires that an estimate be made of the in-field labor hours as well as of the prevalent dose rate at the work site. The in-field hours can be estimated using greenfield labor and the labor productivity factors which directly effect the time spent in the radiation field. These are factors such as access, congestion, manageability, the nature of the target item, and possible impingement on ancillary systems and structures.

The estimation of occupational radiation exposure requires the use of several different relationships, depending on the particular work activity of interest. The following relationships are recommended:

Exposure associated with installation activities:

$$E_I = AD \times 0.375 \times C_L \times (1 + F_a + F_c + F_m)$$

where

E_I = installation radiation exposure, person-rem,

AD = ALARA adjusted dose rate, rem/hr,

C_L = greenfield installation labor (hours)

F_a = access labor productivity factor (Abstract 2.1.7)

F_c = congestion labor productivity factor (Abstract 2.1.7)

F_m = management labor productivity factor (Abstract 2.1.7)

The ALARA adjusted dose rate is simply 80% of the prevalent dose rate at the work site (i.e., of the dose rate prior to the application of ALARA dose reduction techniques).

For removal activities:

If $F_{R1} + F_{R2} > 0$,

$$E_R = AD \times 0.375 \times C_L \times (1 + F_a + F_c + F_m)\,[(1 + F_{R1})(1 + F_{R2}) - 1]$$

If $F_{R1} + F_{R2} = 0$,

$$E_R = AD \times 0.33 \times 0.375 \times C_L \times (1 + F_a + F_c + F_m)$$

where E_R = removal radiation exposure, person-rem,

F_{R1} = structural removal factor (Abstract 2.1.8)

F_{R2} = ancillary systems and structures removal (impingement) factor (Abstract 2.1.8)

For combined removal plus installation (total):

If $F_{R1} + F_{R2} > 0$,

$$E_T = AD \times 0.375 \times C_L \times (1 + F_a + F_c + F_m)(1 + F_{R1})(1 + F_{R2})$$

If $F_{R1} + F_{R2} = 0$,

$$E_T = AD \times 1.33 \times 0.375 \times C_L \times (1 + F_a + F_c + F_m)$$

where E_T = combined installation and removal radiation exposure, pers[illegible]em.

In Equations (1) through (5) C_L, the EEDB labor or greenfield labor obtained from other sources must be given in hours. Similarly, AD, the ALARA adjusted dose rate, has the units of rem/hr (not mrem/hr).

The following list outlines the major steps which should be taken to effectively utilize the above formulations.

- Identify specific physical modification task(s) associated with NRC requirements;
- Locate similar or comparable task(s) in the EEDB and extract the base-line labor hour estimate;
- Based on knowledge of the modification and the environment in which work is to be performed, select appropriate values for relevant labor productivity factors from Abstracts 2.1.7 and 2.1.8. Note that values for specific labor productivity factors will vary by reactor depending on reactor status and work environment at time of modification. Similar reactors among the impacted population should be grouped and assigned equivalent productivity factor values;
- Determine the prevalent dose rate at the work location. Use plant-specific and system-specific information if this is available. Otherwise, use the system-average dose rates presented in Abstract 4.1;
- Roughly estimate the total exposure expected for the job by multiplying the greenfield or EEDB hours by the average dose rate (in rem). If this estimate is one person-rem or greater, assume that ALARA practices will be applied. When ALARA practices are in effect, reduce the prevalent dose rate by 20%, i.e., assume

  ALARA adjusted dose rate = dose rate x 0.8;
- Calculate the radiation exposure using equations (1) through (5) as appropriate to the activity of interest;
- Perform the exposure calculations for as many different plant classes or types as necessary to characterize the exposure for each;
- Sum the exposures for each plant type to arrive at the total exposure for all plants.

Special Considerations for Piping

The evaluation of case studies of piping installation/replacement labor cost and exposures indicates that certain special considerations are in order. When compared to the actual plant exposures, piping exposure estimates produced using the generic methodology required that the "greenfield" EEDB labor-hours be reduced by 90% (or formulated differently, EEDB labor-hours x 0.1) in order to reasonably agree with actual exposures reported by utilities. This correction is purely empirical in nature and is perhaps a result of abnormalities in the base data derived from the EEDB. The "large pipe" factor, 0.1, is recommended for all exposure estimates involving pipe with a diameter of over 18 inches, that is, for large piping the exposure estimates from equations (1) through (5) are multiplied by 0.1.

5.0 EXAMPLE

Assume that a regulatory action requiring the potential replacement of the control rod drive missile shield (CRDMS) at a number of pressurized water reactors is being evaluated. Twelve reactors would be impacted. An estimate is needed to the radiation exposure associated with the CRDM replacement.

From the EEDB Phase IX (Account Number 221.213), installation requires 2,400 labor-hours. Table 5.1 shows the appropriate EEDB printout referring to CRDMS. It is assumed that both removal and replacement of the existing CRDMS will be necessary.

For the operating reactors, factors are chosen as follows:

- Access and handling: Since CRDMS is installed inside containment, the factor 0.4 is chosen from Table 4.1, Abstract 2.1.7;
- Congestion and interference: The containment location will almost always imply severe congestion, thus 0.4 is chosen (Table 4.1, Abstract 2.1.7);
- Manageability: Since this activity will by necessity take place during outage, this factor = 0.4. Since removal will also be required, the removal factor must be evaluated;
- Structural removal factor: Since the CRDMS is not structural (i.e., concrete, etc.) this factor does not apply. Its value is zero;
- Impingement removal factor: The removal of the CRD missile shield will require that some of the nearby equipment be removed to gain access. Assume a value of 0.4 for this factor;
- Radiation levels: The work-site radiation level must first be estimated. Abstract 4.1 does not give a dose rate for the CRD missile shield. However, since it is in the vicinity of the reactor vessel head, we assume that the radiation levels should be lower than or equal to the 140 mrem/hr cited for the reactor vessel studs, fasteners, etc. Note, that the combination of this radiation dose rate and even the unadjusted EEDB labor hours confirms that the worker radiation exposure for this task will be in excess of one person-rem. ALARA practices would, therefore, be put into effect. We estimate the ALARA adjusted dose rate to be:

$$\frac{140\ (\text{mrem/hr}) \times 0.8}{1000\ \frac{\text{mrem}}{\text{rem}}} = 0.112\ \text{rem/hr.}$$

At this point we can calculate the expected exposure per reactor. Since both removal and installation are involved, and since $F_{R1} + F_{R2} > 0$, we will use equation (4).

$$E_T = AD \times 0.375 \times C_L \times (1 + F_a + F_c + F_m)(1 + F_{R1})(1 + F_{R2})$$

$$= 0.112\ (\text{rem/hr}) \times 0.375 \times 2{,}400\ (\text{hrs}) \times (1 + 0.4 + 0.4 + 0.4)(1.0)(1.4)$$

$$= 310\ \text{person-rem per plant.}$$

The total exposure for the twelve impacted plants would be:

$12 \times 310 = 3{,}720$ person-rem.

TABLE 5.1 EEDB PRINTOUT

PLANT CODE 148	COST BASIS 01/87	UNITED ENGINEERS & CONSTRUCTORS INC. EEDB-IX BASE COSTS (MEDIAN EXPERIENCE BASIS) 1144 MWE PRESSURIZED WATER REACTOR						PAGE 107 11/02/87
		******* FACTORY *******		******************** SITE ********************				TOTAL
ACCT NO.	ACCOUNT DESCRIPTION	QUANTITY	COSTS	QUANTITY	LABOR HRS	LABOR COST	MATERIAL COST	COSTS
221.21	CONTROL ROD SYSTEM							
221.211	CONTROL RODS							
221.212	CONTROL ROD DRIVES (CRD)	57 EA		1 LT	18240 MH	431,091	43,109	
221.213	CRD MISSILE SHIELD	1 LT		1 LT	2400 MH	55,440	5,544	
221.214	CRDM SEISMIC SUPPORTS	1 LT	25,175	1 LT	700 MH	16,170	1,617	
221.215	CRDMS + RODS- PU RECYCLE							
	221.21 CONTROL ROD SYSTEM		25,175		21340 MH	502,704	50,270	578,149
	221.2 REACTOR CONTROL DEVICES		25,175		21340 MH	502,704	50,270	578,149
	221. REACTOR EQUIPMENT		838,428		181940 MH	4,284,831	6,068,482	11,191,741
222.	MAIN HEAT XFER XPORT SYS.							
222.1	REACTOR CORE COOLANT SYS.							
222.11	FLUID CIRCULATION DR. SYS.							
222.111	ROTATING MACHINERY							
222.1111	MAIN COOLANT PUMPS&DRIVES	4 EA		1 LT	30400 MH	763,800	76,380	
222.11111	MAIN COOLANT PUMPS							
222.11112	MAIN COOLANT PUMP DRIVES							
	222.1111 MAIN COOLANT PUMPS&DRIVES				30400 MH	763,800	76,380	840,180
	222.111 ROTATING MACHINERY				30400 MH	763,800	76,380	840,180
222.118	INSTRUMENTATION + CONTROL							

5

6.0 CAUTIONS AND LIMITATIONS

The methods suggested here rely on labor productivity factors to estimate in-field labor hours. Despite the appearance of quantitative precision, analysts should be mindful that labor productivity adjustment factors have been derived on a subjective basis. These factors should not be applied mechanically. They should be utilized as necessary, but not in a manner precluding sound judgement.

All results produced using this approach must be considered to be only rough estimates of occupational radiation exposures. Actual exposures are highly dependent on specific work-site conditions and the effectiveness of the ALARA practices employed.

Similarly, the ALARA dose reduction activities can vary considerably in their effectiveness from job to job and plant to plant. The 20% reduction recommended herein should be considered as an average benefit when considering a wide range of activities. On very large repair/modification activities where large doses might be expected, ALARA measures may be considerably more effective than simply reducing doses by 20%.

7.0 RELATED ABSTRACTS

Abstract 2.1.6	"Health Physics Services."
Abstract 2.1.8	"Labor Costs for the Removal of Hardware, Materials, and Structures."
Abstract 2.1.9	"Greenfield Costs for Piping and Piping-Related Commodities."
Abstract 4.1	"Typical System-Average Dose Rates."
Abstract 4.2	"Occupational Radiation Exposure for Specific Repair/Modification Activities."

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10. SUPPLEMENTARY NOTES

11. ABSTRACT (200 words or less)

The Nuclear Regulatory Commission has sponsored a number of generic cost estimating studies. These studies were prepared to aid NRC analysts in preparing Regulatory Impact Analyses (RIA's). These generic studies provide cost estimates that would have wide application to a large number of Regulatory Analyses being performed throughout the NRC and deal primarily with repair and modification activities that may be imposed on nuclear plants as a result of regulatory actions.

Abstracts of each of the generic cost estimating studies have been prepared and assembled in this catalog. These abstracts present the results of the more detailed studies in a compact, easily understood and readily useable format. Individual abstracts have been developed to treat the main-line topics of the generic studies. In addition, abstracts have been prepared covering important sub-topics or "stand-alones" which are of broad interest in RIA preparation.

This abstract catalog updates and revises information presented in NUREG/CR-4627, Rev.1. The catalog will be expanded and modified as additional generic cost studies are completed and as abstracts are modified to reflect updated conditions.

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