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Labor Productivity Adjustment Factors

A Method for Estimating Labor Construction Costs Associated With Physical Modifications to Nuclear Power Plants

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Prepared for
U.S. Nuclear Regulatory
Commission

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ABSTRACT

This report develops quantitative labor productivity adjustment factors for the performance of regulatory impact analyses (RIAs). These factors will allow analysts to modify "new construction" labor costs to account for changes in labor productivity due to differing work environments at operating reactors and at reactors with construction in progress. The technique developed in this paper relies on the Energy Economic Data Base (EEDB) for baseline estimates of the direct labor hours and/or labor costs required to perform specific tasks in a new construction environment. The labor productivity cost factors adjust for constraining conditions such 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. While the results do not portray all aspects of labor productivity, they encompass the major work place conditions generally discernible by the NRC analysts and assign values that appear to be reasonable within the context of industry experience.

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LABOR PRODUCTIVITY ADJUSTMENT FACTORS

I. Introduction

The U.S. Nuclear Regulatory Commission's (NRC) Cost Analysis Group has sponsored this study on labor productivity adjustment factors in order to assist NRC analysts in the estimation of labor construction costs resulting from regulatory requirements.

The subject of labor productivity in the construction of nuclear power plants has been one of considerable concern for a number of years. The rapid escalation of labor costs as a component of total nuclear power plant costs has been addressed in numerous studies and papers.(2,3,10,14,15) Such studies for the most part have been "macro" in nature, in the sense that they have tended to focus on changes in the overall labor content of completed generating stations. They have also tended to be expository rather than predictive, concentrating on explanatory factors for labor differences over time or among plants of various types.

This study differs substantially in focus from such work. It is, first of all, an attempt to formulate ex ante predictors of labor productivity, rather than ex post explanations. Secondly, this study is concerned with "micro" labor tasks rather than the entire construction experience. Finally, but perhaps most importantly, the following discussion 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. These points will be developed more fully below.

II. Objectives and Constraints

The principal objective of this study is to provide a means to aid the U.S. Nuclear Regulatory Commission in estimating the costs of regulatory requirements prior to promulgation. More specifically, the objective is to develop quantitative factors that will allow NRC analysts to adjust "new construction" labor workhours to account for differing productivity due to various types of work environments at operating reactors and at reactors with construction in progress.

Such productivity adjustment factors have been described previously by various authors and analysts.(1,4,6,8,11) However, the particular constraints under which the NRC analyst will operate significantly limit the usefulness of such prior estimates. These constraints fall into two basic categories: (1) those related to the peculiarities of the nuclear industry, and (2) those related to limitations of information and resources.

Existing productivity estimates with few exceptions concentrate on construction work in general, under the assumption that the effects of various site and labor force characteristics will have similar impacts on labor productivity no matter what is being constructed -- office buildings, factories, oil refineries, etc. It is, however, a widely accepted fact that labor productivity related to nuclear power plant construction is different. This is due to the peculiarities of the technology, the scale of the project, the severe regulatory requirements imposed, and other factors. Thus, generalized construction estimates must be adjusted to fit the specifications of the nuclear reactor environment.

Also, those few nuclear-specific labor productivity estimates focus primarily on conventional new construction and shed little light on the peculiar problems frequently associated with modifications to operating reactors and in some cases associated with reactors already under construction. Here again, existing estimates must be adjusted to fit the constraints and requirements imposed by the regulatory environment.

The second category of constraints is particularly important to recognize. Cost estimators normally concentrate on one project at a time and have access to considerable quantitites of project-specific information. NRC analysts, on the other hand, must produce industry-wide cost estimates, potentially encompassing more than a hundred reactors at differing stages in their life-cycle, and of widely differing designs and site characteristics. NRC analysts also are limited in terms of information in their possession. For instance, while a typical industry cost estimator could be expected to know the demographic characteristics of the labor force to be employed on a project and the specific local union contracts, the NRC analyst would normally have no knowledge of such factors for any single plant, let alone for more than a hundred.

Even if analysts had such information in their possession, they would be unlikely to be able to utilize it, since they ordinarily work under severe time constraints and with few resources available to them. Thus, for labor productivity factors to be useful to the NRC analyst, they must (1) fit the type of information generally available, and (2) be applicable to potentially large classes of nuclear reactors.

These constraints tend to eliminate a number of traditional labor productivity predictors from further consideration. Cost estimators often try to incorporate such site specific factors as local construction activity trends, unemployment rates, education and training of labor force, quality of supervision, and expected weather conditions. Clearly, an NRC analyst faced with estimating aggregate costs at dozens of sites could not be expected to gather the necessary data, digest it, and incorporate it into the analysis.

On the other hand, the analyst should have relatively good information on important work-place related job attributes: whether operating reactors must be shut down to perform the specific task; whether work must be performed in radiological environments; whether work must be performed in congested areas of the plant; what quality assurance requirements are in effect; etc.

Thus, by necessity, NRC labor productivity adjustment factors must focus on workplace characteristics peculiar to power reactors. Other site specific characteristics must be assumed to average out or to be incorporated in the productivity factors imbedded in new construction labor estimates. Since NRC cost estimates are typically aggregated over a large number of impacted plants, it is doubtful that site specific characteristics will materially affect any decisions relying on this methodology.

III. General Approach

The methodology and results presented here will allow an NRC analyst to develop reasonable order-of-magnitude estimates for the installation 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) (17,18) 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 things 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.

Once the appropriate adjustments have been identified by the analyst, they can be applied to the EEDB baseline direct labor estimate to produce an installation cost estimate that is most appropriate for the environment in which the work will actually be performed. The direct labor estimates available in the EEDB are typically expressed in both labor hours and dollars. Since dollar quantification is the ultimate objective in NRC value-impact analyses, the factor adjustments can be applied directly to the dollar value in the EEDB.*

The EEDB labor estimate includes the labor cost for all workers and direct supervisors (typically to the foreman level) performing the specific construction or installation task. Adjustments to the EEDB estimate will therefore capture the labor costs of the composite crew most directly involved in the construction activity.

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. While these activities are beyond the scope of this study, the NRC Cost Analysis Group has developed cost factors elsewhere that would permit dollar quantification for the more dominant of these support activities.

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* If, for the activity of concern, the EEDB only specifies labor hours, the productivity factor adjustments can be applied to the labor hour estimate. Final dollar quantification would require multiplying the adjusted labor hours by an appropriate hourly wage rate.

In addition, care must be taken to ensure that the data base addresses all the detail components that compose the system being addressed. 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.

In summary, the following list outlines the major steps which should be taken to effectively utilize the cost information contained in this report. These steps are illustrated in Section VIII.

- Identify specific construction/installation task(s) associated with NRC requirement;
- Locate similar or comparable task(s) in 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. 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;
- Multiply the total productivity adjustment factor (see Section V) by the EEDB labor cost estimate; and

- Sum result above over all impacted reactors to obtain total industry direct labor cost associated with installation/construction effort.

IV. The Concept of Productivity

Before addressing the quantification of productivity adjustment factors, it is useful to discuss the concept of productivity itself and its relationship to the methodological approach being employed in this study.

Labor productivity is defined in economic theory as the change in total product (output) that results from a change in labor input. This theoretical concept has important analytical applications in the real world, principally in terms of capital investment decisons and cost control. Productivity itself can be viewed as a combination of several components.(11)

There are three variables that are determinants of final productivity rates on any given labor task:

- Number of direct work minutes applied during any paid labor hour;
- Rate of work during direct labor applications; and
- Appropriateness of labor task in relation to the overall project.

Given sixty minutes of the working hour of any laborer or craftsman, the minutes of that hour can be broken down into three general activity time categories -- direct work time, preparatory work time, and non-productive time.

Direct work time is that time spent in actual installation construction activity. Preparatory work includes all actions required to prepare for or otherwise permit the direct work to be accomplished -- picking up materials and tools, putting up work platforms, and comparable activities are examples. Non-productive time typically includes waiting for instructions, tools, materials, or support equipment, travel time, personal breaks, late starts, and early quits. The net result is that there are far fewer than 60 minutes available for direct work each working hour. In fact, research on nuclear power plant construction indicates that direct work time averages roughly 20 minutes per hour.(15)

Non-productive time is certain to occur and supporting work must be accomplished before direct work can take place. Thus, direct work essentially gets whatever time is left over. Assuming that 20 minutes per hour is a fair representation of average direct work time per hour, it will take only a two minute change in direct work time per hour to alter overall productivity by ten percent. Thus, any situation on a project which can eliminate even a few minutes of non-productive or preparatory work time has the potential for significantly affecting overall productivity on the project. This is why workplace impediments such as congestion, radiation, protective equipment, and other factors have a large potential impact.

Direct work time, however, can be used inefficiently. This efficiency depends on the rate at which a worker accomplishes a task. The rate of work is generally considered to be primarily a function of labor force characteristics -- experience, training, age, socio-economic background, etc. -- although workplace characteristics such as congestion and radiation can also make a difference.

Finally, unless the task undertaken contributes rationally to the accomplishment of the overall project, productivity as measured by direct labor time application and worker efficiency is meaningless. For instance, if electricians are installing the wrong motor-generator set, their work is by definition entirely unproductive. This last item is principally a function of management effectiveness.

When looking at productivity in terms of its components, it is clear that the constraints of this project as discussed earlier preclude a comprehensive analysis of labor productivity. The NRC analyst can be expected to have little or no insight into either direct, preparatory, and unproductive work time, or inherent labor efficiency or management skill. These are terms that are, on average, already embodied within the baseline EEDB construction labor estimate which reflects actual experience at new nuclear construction sites.

Consequently, the labor productivity reduction factors that are calculated here are specifically designed to predict the aggregate change in total paid hours without explicitly addressing the more severe components or contributions to labor productivity. The resulting labor cost estimates fully capture these micro considerations based on new construction experience and adjust only for additional impediments to worker productivity brought about by a more constrained work environment.

V. Formulation of Productivity Factors

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

(1) $$F_{total} = 1+ (F_1 + F_2 + \ldots + F_N)$$

where F_{total} is the composite adjustment factor and 1,2, ..n represent components dependent on workplace conditions

F_{total} will be applied as follows:

(2) Total estimated manhours = (F_{total}) (baseline hours), or

(3) Total estimated labor cost = (F_{total}) (baseline labor cost)

where baseline hours or labor costs are derived from the Energy Economic Data Base (EEDB). The EEDB is produced by United Engineers and Constructors based on their experience with nuclear reactor new construction and, as such, is a generally realistic and usable tool. The EEDB is a consistent, readily available, and flexible data base that contains annually updated, comparable-baseline capital, fuel cycle, and operating and maintenance costs for different types of nuclear and coal-fired electricity generating plants.(18)

Each plant in the data base consists of a technical model and a directly related cost estimate for that model. The cost estimates included in the data base are unencumbered by controversial factors such as the effects of future inflation, and by non-uniform factors such as costs arising from owners' options or utility system configurations. All assumptions and ground rules are clearly identified in the data base report and are applied uniformly to all cost estimates.

Each cost estimate in the EEDB is developed in accordance with an expanded AEC code of accounts (USAEC Report NUS-531) and is based on a detailed technical model -- described in the EEDB report -- that includes system design descriptions for over 400 plant systems; a detailed equipment list containing over 1250 minispecifications; and up to 10,000 subdivisions of commodity, materials, and equipment quantities, labor hours, and costs. The technical models are based on actual power plant designs and over 50 years of power plant design and construction experience. Site-related factors are normalized by locating each technical model on a common hypothetical "Middletown" site, for which there is a detailed, written geological and environmental description.

For each plant design the EEDB provides base capital costs composed of direct and indirect costs, reported in terms of factory equipment, site labor, and site materials costs. The results are internally consistent across each plant and are sufficiently detailed to identify why costs differ and whether they are credible.*

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* The Nuclear Regulatory Commission has adopted the EEDB as the basis for its cost estimating activities and is supporting its application and expansion along several lines. The reader is referred to NUREG/CR-3971, A Handbook for Cost Estimating(17) for a full explanation of the EEDB and discussion of its applicability to different types of estimating problems.

Because it is based on actual experience, the EEDB manhour and labor cost estimates include implicit labor productivity factors. Thus, the adjustment factors will incorporate only deviations from the average productivity experience at new construction sites. It should also be noted that following the design of the EEDB, only direct craft labor is being considered here, and only as it applies to work being performed in a new construction environment. Consequently, support activities such as engineering health physics, radiation work permit preparation, quality control, etc. are not lumped into the productivity reduction factors; they must be estimated separately as direct labor or as part of some overall indirect labor rate. Similarly, subtasks unique to a retrofit (removal or preparation activities such as the dismantling of systems already in place) must be estimated directly.

There will occur instances, such as the above, where the EEDB is not applicable, or where the analyst must work from an estimate supplied by a third party. In such instances, all estimates must be first placed on a basis consistent with "greenfield" construction labor productivity in order to apply the adjustment factor formulation. The basis of third-party estimates must be investigated and established, where feasible.

Other original estimates might be formulated using such sources as Richardson Engineering Estimating Standards(12) and G.S. Means Construction Standards.(13) 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. Thus, labor hours calculated by the Richardson system must be multiplied by a factor of 1.8 - 2.1 in order to bring them into line with a nuclear new construction baseline of, say, 60 percent nonproductive time. Only at that point can the incremental adjustment factors described here be applied.

VI. Factor Quantification

As discussed above, the overall labor productivity adjustment factors are based on a number of workplace characteristic components. Overall, adjustment factors have been derived to account for perceived differences in productivity across two classes of sites: primarily, operating reactors and, secondarily, reactors under construction and generally at advanced stages of construction. The latter class has been chosen for consideration because modifications at such sites can be subject to degraded labor productivity due to disruption of established construction schedules, as well as congestion and other factors common to operating plants.

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.(18) Therefore, when dealing with plants at or before this stage, the labor hours requirements generally need not be adjusted for modification of hardware or systems. If, however, the requirement involves a major structural modification even at or before the 70 percent complete stage, the hours should be estimated separately. Beyond the 70 percent stage, labor should be estimated on a case-by-case basis. As construction nears completion, the cost of a design change is very dependent on the equipment already installed in an area, and its configuration resulting congestion.

Four different workplace characteristics have been indentified as (1) possessing significant impact, and (2) fitting appropriately with the information available to NRC analysts. These components have been identified through the existing literature and with the assistance of several industry experts.(1,8,9,11) It should be noted that there is no unanimous view that the components cited here are the only set that could prove useful; other components are possible and the components shown are only significant under certain circumstances.

Since no body of primary data is currently accessible for direct analysis of labor productivity, a basically judgemental

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* 70 percent is a rule-of-thumb guide that should be viewed with appropriate skepticism, depending on the particular problem being addressed.

quantification methodology has been employed. This consists of a crude initial formulation using values published in the technical literature, with successive review iterations involving knowledgeable cost estimating professionals in the nuclear industry. These iterations have attempted to refine the initial values into quantities reflecting actual experience.

In those cases where firm data is unavailable, technical judgement has been utilized. Although in many cases the technical basis for specific values is not rigorous, the results should be viewed as reasonable representations, providing order of magnitude estimates appropriate for NRC regulatory impact analysis requirements. The bases for specific values are discussed below; the values themselves are summarized in Table 1.

A. 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 encumberances 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

TABLE 1

LABOR PRODUCTIVITY FACTORS

Activity Characteristic	Factor Value						
1.a. 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	
b. 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. High radiation, high temperature; stay time[4] of: 2 hrs 1.1 1hr 2.6 .5hr 5.6
4. Manageability[3]	a. Non-outage related	(0.2)	b. Outage activity	0.3	c. Outage activity, within containment	0.4	

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

required for identifying and picking up materials and the man-hour savings normally credited to on-ground prefabrication of components are lost.

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 containment areas.

This maximum value is approached in incremental steps, depending upon whether an operating plant is being examined, or one 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.

B. 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 manuever 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 man-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, although 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.

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

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 manueverability.

C. _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 encumberances of protective equipment, particularly under conditions of elevated temperature, and (2) strict limitations on permissable 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. 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.

The consideration of limited "stay time" is somewhat more complex arithmetically in terms of productivity factor formulation. "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.

Note that this calculation assumes that workers perform no work per shift other than that represented by stay time. Also note that this quantification procedure is invalid for stay time values greater than normal direct work time (e.g., three hours). Above this point, stay time limitations pose no additional limitations on productivity other than those associated with protective equipment and high temperature.

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

D. <u>Manageability</u>

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.(2,6,11) 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.

VII. Illustrative Example

The following are examples illustrating the application of the labor productivity adjustment factors quantified above.

A. RHR Gate Valves

For this example, it is assumed that NRC regulations require plant operators to upgrade stainless steel plumbing associated with the Residual Heat Removal (RHR) system of pressurized water reactors. Preliminary indications are that this requirement will mean that a typical operating PWR must replace the 12 inch gate valves associated with this system.

The EEDB (Table 2) lists four such gate valves (Account 223.161) contained in its reference PWR. The gate valves are contained in the residual heat removal vault of the primary auxiliary building, which is a Seismic Category I structure located adjacent to the containment. The vault is approximately 85 feet below grade and has overall dimensions of approximately 40 feet by 50 feet. This structure is subdivided into compartments and houses containment spray pumps, heat exchangers, and residual heat removal pumps, as well as valve stations. The EEDB implicitly calculates installation labor at 1.8 manhours per pound of stainless steel plumbing material over two inches in diameter. (See Account Number 223.1521 and 223.1522 in Table 2). From the Richardson Standards (12) it is determined that the lighter gauge valves currently in service weigh 790 lbs., while the new valves weigh 1400 lbs. It is assumed that removing valves is comparable in labor effort to installing them.

Baseline labor hours are calculated thus:

<u>Removal</u>: 4 valves x 790lbs x 1.8 manhours/lb =	5,688 m-hrs
<u>Installation</u>: 4 valves x 1400lbs x 1.8 manhours/lb =	<u>10,080 m-hrs</u>
	15,768 m-hrs

In order to adjust for labor productivity variation, it is necessary to assess the work environment. First, it is clear from the dimensions of the residual heat removal vault and its

TABLE 2

EEDB COST AND EQUIPMENT DETAIL

RESIDUAL HEAT REMOVAL SYSTEM (RHR)

PLANT CODE 149 | COST BASIS 01/83 | UNITED ENGINEERS & CONSTRUCTORS INC. ENERGY ECONOMIC DATA BASE (EEDB) PHASE VI 1139 MWE PRESSURIZED WATER REACTOR | PAGE 119 | 09/28/83

ACCT NO.	ACCOUNT DESCRIPTION	FACTORY QUANTITY	FACTORY COSTS	SITE QUANTITY	SITE LABOR HRS	SITE LABOR COST	SITE MATERIAL COST	TOTAL COSTS
223.	SAFEGUARDS SYSTEM							
223.1	RESIDUAL HEAT REMOVAL SYS							
223.11	ROTATING MACHINERY							
223.111	RHR PUMPS AND DRIVES	2 EA	3,613	1 LT	2600 MH	54,205	5,421	
223.1111	RHR PUMPS							
223.1112	RHR PUMP DRIVES							
	223.111 RHR PUMPS AND DRIVES		3,613		2600 MH	54,205	5,421	63,239
	223.11 ROTATING MACHINERY		3,613		2600 MH	54,205	5,421	63,239
223.12	HEAT TRANSFER EQUIPMENT							
223.121	RHR HEAT EXCHANGERS	2 EA	1,724	1 LT	1300 MH	26,012	2,601	
	223.12 HEAT TRANSFER EQUIPMENT		1,724		1300 MH	26,012	2,601	30,337
223.18	PIPING							
223.181	2IN + SMALLER							
223.1811	SS/SC2			3380 LB	10140 MH	205,526	38,870	
	223.181 2IN + SMALLER				10140 MH	205,526	38,870	244,396
223.182	2.5IN + LARGER							
223.1821	SS/SC1	14040 LB	196,880	1 LT	28272 MH	812,234	81,223	
223.1822	SS/SC2	55380 LB	345,000	1 LT	96684 MH	2,050,473	302,047	
	223.182 2.5IN + LARGER		541,880		124956 MH	2,862,707	383,270	3,787,857

TABLE 2 (Continued)

PLANT CODE 148 COST BASIS 01/83

UNITED ENGINEERS & CONSTRUCTORS INC.
ENERGY ECONOMIC DATA BASE (EEDB) PHASE VI
1139 MWE PRESSURIZED WATER REACTOR

08/28/83

ACCT NO.	ACCOUNT DESCRIPTION	FACTORY QUANTITY	FACTORY COSTS	SITE QUANTITY	SITE LABOR HRS	SITE LABOR COST	SITE MATERIAL COST	TOTAL COSTS
	223.15 PIPING		971,880		139096 MH	2,738,233	292,140	4,002,283
223.16	RHR VALVES	20 EA	11,703					
223.161	GATE							
223.162	CHECK							
223.163	GLOBE							
223.165	RELIEF							
223.166	BUTTERFLY							
	223.16 RHR VALVES		11,703					11,703
223.17	PIPING - MISC. ITEMS							
223.171	HANGERS + SUPPORTS	15000 LB	83,880					
223.172	INSULATION							
223.173	SPECIALTIES							
	223.17 PIPING - MISC. ITEMS		83,880					83,880
223.18	INSTRUMENTATION + CONTROL	1 LT	44,863	1 LT	528 MH	10,436	522	
	223.1 RESIDUAL HEAT REMOVAL SYS		1,107,283		139624 MH	2,826,889	300,084	4,238,836
223.3	SAFETY INJECTION SYSTEM							
223.31	ROTATING MACHINERY							
223.311	S.I. PUMPS AND DRIVES	2 EA	2,941	1 LT	3000 MH	42,844	6,294	
223.3111	S I PUMPS							
223.3112	S I PUMP DRIVES							

TABLE 2 (Continued)

PROG. CR-711 *PEG030* UNITED ENGINEERS & CONSTRUCTORS INC. PAGE 157 - 1

EQUIPMENT LIST - REPORT 1 ENERGY ECONOMIC DATA BASE 09/26/83

MODEL 148 - 1139 MWE/3425 MWT PWR - 2.5 IN HG AV - MIDDLETOWN,USA - COST BASIS 01/83

ACCOUNT NUMBER	ITEM	SIZE INCH	SCH/ WALL THICK	LBS/ FOOT	LIN. FEET	PIPE WEIGHT	FITTING WEIGHT
223.1521	SS/SC1						
		6	160	48.2	191	9,190	1,840
		8	160	76.2	33	2,510	500
					TOTAL -	11,700	2,340
223.1522	SS/SC2						
		3	40S	7.7	51	390	80
		4	40S	11.0	118	1,300	260
		6	40S	19.3	3	60	10
		6	160	48.2	49	2,260	450
		8	160	76.2	273	20,800	4,160
		8	40S	29.2	366	10,690	2,140
		12	140	143.	33	4,720	940
		12	40S	54.7	106	5,740	1,150
		14	40S	54.7	3	190	40
					TOTAL -	46,150	9,230

ACCOUNT NUMBER	ITEM	SIZE INCH	NO.	DESCRIPTION
223.18	RHR VALVES			
223.181	GATE			
		8	1	G-G198- EB2
		10	2	G-G198- EB2
		10	2	G-G198-ZMB2
		12	4	G-K198-ZMB1
223.182	CHECK			
		10	4	C-G198- ZB2

Reference (17)

contents, that handling heavy valves and installation equipment will be very cumbersome and that the work area can be considered to be severely congested. Since this structure is isolated from the containment, severe radiation is not a problem, however, since the RHR system handles primary coolant some radiation can be expected. In addition, a task of this type is assumed to be feasible during plant operations, rather than strictly under outage conditions.

From Table 1, the appropriate adjustment factors are:

o	Access and handling	0.3
o	Congestion and interference	0.4
o	Radiation	0.2
o	Manageability	(0.2)

The total adjustment factor is 1+ (0.3 + 0.4 + 0.2 - 0.2) = 1.7 Consequently, total adjusted manhours are 15,768 x 1.7 = 26,806. At an assumed rate of $22 per hour, this amounts to $589,723 for labor alone.

B. CRDMS Replacement

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.

From the EEDB, (Account Number 221.213), installation requires 2,400 man hours at a cost of $48,720. Table 3 shows the

TABLE 3

EEDB COST DETAIL

CONTROL ROD DRIVE MISSILE SHIELD (CRDMS)

PLANT CODE 148 | COST BASIS 01/83 | UNITED ENGINEERS & CONSTRUCTORS INC. ENERGY ECONOMIC DATA BASE (EEDB) PHASE VI 1139 MWE PRESSURIZED WATER REACTOR | PAGE 118 | 09/20/83

ACCT NO.	ACCOUNT DESCRIPTION	FACTORY QUANTITY	FACTORY COSTS	SITE QUANTITY	SITE LABOR HRS	SITE LABOR COST	SITE MATERIAL COST	TOTAL COSTS
221.212	CONTROL ROD DRIVES (CRD)			69 EA	20800 MH	418,198	28,386	
221.213	CRD MISSILE SHIELD			1 LT	2400 MH	48,720	3,230	
221.214	CRDM SEISMIC SUPPORTS			1 LT	700 MH	14,210	33,387	
221.216	CRDMS + RODS- PU RECYCLE							
	221.21 CONTROL ROD SYSTEM				23900 MH	479,128	63,008	542,133
	221.2 REACTOR CONTROL DEVICES				23900 MH	479,128	63,008	542,133
	221. REACTOR EQUIPMENT		770,984		184800 MH	3,700,034	3,298,381	7,768,379

Reference (17)

appropriate EEDB printout referring to CRDMS. It is assumed that removal of the existing CRDMS will be calculated separately. This calculation will probably involve a detailed analysis employing more conventional cost estimating methodologies.

For the operating reactor, factors are chosen as follows:

- o Access and handling: since CRDMS is installed inside containment, the factor 0.4 is chosen from Table 1;
- o Congestion and interference: the containment location will almost always imply severe congestion, thus 0.4 is chosen;
- o Radiation: CRDMS activities will take place under severe radiation conditions. Assuming stay time = 0.5 hrs, the appropriate factor is 5.6; and
- o Manageability: Since this activity will by necessity take place during outage, this factor = 0.4.

From equation (1) the total factor =

$$1 + (0.4 + 0.4 + 5.6 + 0.4) = 7.8$$

Total factor x EEDB hrs = (7.8) (2400) = 18,720 hrs, or

Total factor x EEDB dollars = (7.8) ($48,720) = $380,016 per reactor, or $380,016 x twelve operating reactors = $4,560,192

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

- o Access and handling : containment area = 0.4
- o Congestion and interference: severe conditions = 0.4

Total factor = 1 + (0.4 + 0.4) = 1.8

Total factor x EEDB hrs = (1.8) (2400) = 4320 hrs, or

Total factor x EEDB dollars = (1.8) ($48,720) = $87,696

$87,696 x eight reactors = $701,568

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

Total labor cost of the regulation = $4,560,192 + 701,568 = $5,261,760

VIII. Conclusions

This report has attempted to incorporate the full range of existing productivity information with the particular need of the Nuclear Regulatory Commission to provide a means of improving cost estimates for regulatory actions involving reactor modifications. While the results do not portray all aspects of labor productivity, they encompass the major work place conditions generally discernable by NRC analysts and assign values that appear to be reasonable within the context of industry experience.

The labor productivity adjustment factors derived, however, should be applied prudently and with independent judgement. They represent a continuum of values, and individual factors will certainly differ depending upon the particular application. There is no reason to believe that this report covers every possible situation or that the ranges in values are applicable in every case.

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13. ABSTRACT (200 words or less)

NRC regulatory impact analyses (RIA's) address the costs and benefits associated with proposed regulatory requirements. Many of these requirements will result in physical modification to existing structures and systems at nuclear power plants.

This report develops quantitative labor productivity adjustment factors for the performance of RIA's. These factors will allow analysts to modify "new construction" labor costs to account for changes in labor productivity due to differing work environments at operating reactors and at reactors with construction in progress. The technique developed in this paper relies on the Energy Economic Data Base (EEDB) for baseline estimates of the direct labor hours and/or labor costs required to perform specific tasks in a new construction environment. The labor productivity cost factors adjust for constraining conditions such 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. While the results do not portray all aspects of labor productivity, they encompass the major work place conditions generally discernible by the NRC analysts and assign values that appear to be reasonable within the context of industry experience.

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