

The Economic Organization of Nuclear
Plant Projects: Some Cross-National Comparisons
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THE ECONOMIC ORGANIZATION OF NUCLEAR POWER PLANT PROJECTS:
SOME CROSS-NATIONAL COMPARISONS

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ABSTRACT

This paper examines the relationship between the economic organization of the nuclear power industry and its performance in designing and building nuclear power plants. The institutional relationships that link French, West German and Japanese utilities with their nuclear plant suppliers are described and compared. The focus is on three interrelated aspects of these relationships: (1) the extent of utility involvement in the supply process; (2) the extent to which the various supply functions are "horizontally" integrated; and (3) the nature of the contracts linking the utilities and their suppliers. The transaction cost approach provides the framework for the analysis. The central idea underlying this approach is that important efficiency consequences flow from decisions concerning whether to organize transactions contractually between firms or administratively within them, and that for any given transaction an optimal governance structure exists which depends in a predictable way on certain attributes of the transaction.

There are substantial differences in nuclear power plant project organization among the three countries. The transaction cost approach cannot explain why these differences have arisen, since they are much less the outcome of the formal economic optimization process assumed in the theory than of state-specific factors, including industrial traditions, legal restrictions, political initiatives and administrative planning. Nevertheless, the approach provides qualitative insights into the economic implications of these differences. It also provides insights into why an organizational approach that is effective in one structural and/or national cultural context may be more or less effective in another.

I. INTRODUCTION

The purpose of this paper is to examine the relationship between the economic organization of the nuclear power industry and its economic performance in designing and building nuclear power plants. This study is part of a larger investigation of the causes of international variations in nuclear power industry performance. The present work is specifically concerned with the nature of the institutional relationships that link American, French, West German and Japanese utilities with their suppliers. The emphasis is on three aspects of these relationships: (1) the extent of utility involvement in the supply process; (2) the extent to which the various supply functions are horizontally integrated; and (3) the nature of the contracts linking the utilities and their suppliers. There are major differences between the four countries in each of these dimensions. The question is whether international variations in industry performance are related to these differences, and if so, to what degree.

Several recent organizational studies of nuclear industry performance have focused on problems of organization and management within firms (Borcherding et al, 1980; Osborn et al, 1983; Altman et al, 1984). Other studies have addressed the relationships between the aggregate structural features of the nuclear industry and its overall performance, with particular reference to the impact of utility and supply industry concentration on learning behaviour (Roberts and Burwell, 1981; Zimmerman, 1982; Lester and McCabe, 1986). The present work, by focusing on the economic relationships between the participants in individual projects, occupies an intermediate level of analysis. Our intent is not to challenge the significance of either

internal organization or aggregate industrial structure as determinants of performance. We conjecture, however, that the economic relationships between project participants - relationships that are shaped but not wholly determined by the basic structure of the industry - also matter to the outcome of the projects. Specifically, we expect that the characteristics of these interfirm links will constrain and otherwise channel managerial and organizational behaviour within firms in important ways. We further suggest that the outcome of individual projects is influenced not only by the total information available to the various participants in the project, but also by the way in which this information is distributed between them. These issues can be examined most effectively by taking the institutional relationships between project participants as the basic unit of analysis.

We use the transaction cost approach, pioneered primarily by Oliver Williamson, as the framework for our analysis.¹ The central idea underlying this approach is that important efficiency consequences flow from decisions regarding whether to organize transactions contractually between firms (i.e., using market mechanisms) or administratively within them (i.e., via vertical integration). The transaction cost argument holds that for any given transaction a governance structure (i.e., an organizational and/or contractual design) exists that will minimize the cost of carrying out the transaction, and that the governance structure which will achieve this economizing objective depends in a predictable way on certain attributes of the transaction.

¹The main elements of the transaction cost approach have been presented by Williamson in a series of books and articles over the last decade (1975, 1979, 1983, 1985).

In this paper we shall be concerned not with why particular governance structures have emerged in the different countries, but rather with the implications for economic performance of these differences. Our analysis thus differs from most previous empirical applications of transaction cost theory, which have sought to use the theory to explain why certain observed organizational configurations take the form they do. These explanations have generally been premised 'on the efficacy of competition to perform a sort between more and less efficient modes [of organization] and to shift resources in favor of the former' (Williamson, 1985, p.22). Whatever the merits of this assumption in general, its applicability to the case at hand is doubtful. Utilities, of course, are regulated monopolies, largely shielded from the forces of competition; moreover, in some countries antitrust regulations restrict the utilities' involvement in the manufacturing and construction of power plants.

The situation is further complicated by the special treatment that has usually been accorded to the nuclear power sector by national governments. In virtually every country where a major nuclear supply industry has emerged, the government - motivated variously by considerations of national security, economic strategy or public health and safety - played a key role in shaping the initial industrial structure, and in many cases has remained active in the nuclear sector. For this reason too, little stock can be placed in explanations for observed forms of organization that rely on assumptions of competitive decision-making.

Here, however, we are less interested in the origins than in the economic consequences of these organizational choices. In principle there is no reason why the same transaction cost arguments that are used to predict optimal

organizational form cannot also shed light on the extent to which actual arrangements depart from the optimum. We begin by summarizing the principal elements of the transaction cost theory, and then discuss some of the practical obstacles to its application in the present case.²

II. TRANSACTION COST THEORY

A firm wishing to obtain a particular good or service may decide either to produce it internally (i.e., by vertically integrating production) or alternatively to contract for its supply with a separate firm. If the latter approach is adopted, there is a range of contractual mechanisms to choose from which vary in the degree to which the parties establish specialized, durable institutions to administer the contractual relationship. Pure 'spot' market contracting, in which all obligations are fulfilled instantaneously, occupies one end of this spectrum. At the other extreme are highly complex contracts which bind the parties to a long-term relationship (i.e., bilateral governance).

Vertical integration (unified governance) and the various forms of external contracting differ in the incentives they provide to the participants in transactions and also in the ease with which the governance structures can be made to adapt to new conditions which may develop during the course of the

²The extensive literature on project management also makes frequent reference to alternative forms of organization. (See, for example, Mason and Gonzales (1978) on nuclear project organization, or Bennett (1985) on construction project management more generally.) In the main, though, contributions in this area tend either to be almost purely descriptive, in the sense that taxonomies of organizational forms are provided with little explanation as to why one particular structure should be chosen ahead of the others, or else the explanations that are offered tend to be too general and the organizational categories too broad to provide much insight into the consequences of the sort of organizational differences occurring within the nuclear power sector.

transaction. Adaptability is clearly important in circumstances in which change is likely, and hence in which adaptive, sequential decision making will probably be required. Adaptability is usually greatest under unified governance structures. Efficiency incentives, on the other hand, are highest for market transactions with fixed-price contracts (these are said to preserve 'high-powered' incentives) and lowest for unified governance structures where compensation is in the form of fixed salaries (i.e., 'low-powered' incentives). External contracting is not always guaranteed to preserve high-powered incentives, of course; cost-plus-fixed-fee contracts do not do so, for example.

The essence of the transaction cost approach is to associate a given transaction with a governance structure that will enable it to be completed most efficiently. An efficient result, in this scheme, is one that minimizes the sum of the ordinary production costs and the transaction costs. The transaction costs are the costs of establishing and administering the supply relationship; they are the costs of running the economic system and are the economic equivalent, to use Williamson's analogy (1985, p.18), of friction in physical systems. Both ex ante and ex post transaction costs must be considered. Ex ante costs are incurred when supply agreements are drafted and negotiated. Ex post costs include 'the setup and running costs of the governance structure to which monitoring is assigned and to which disputes are referred and settled; the maladaptation costs that are incurred for failure to restore positions on the shifting contract curve; the haggling costs that attend adjustments (or the lack thereof); and the bonding costs of effecting secure commitments.' (Williamson, 1985, p.388).

Which of the possible modes of governance - firms (vertical integration); markets (contracting); or some hybrid structure - is most appropriate in a particular situation depends on certain underlying properties of the transaction in question. Williamson identifies three key attributes: (1) the degree to which investments in durable, specialized assets are made in support of the transaction; (2) the frequency of recurrence of the transaction; and (3) the uncertainty associated with the transaction.

1. Asset Specificity:

A transaction-specific (or 'idiosyncratic') asset is one whose value would be significantly reduced in its next best alternative application. If substantial investments in specialized assets are required in order to consummate a transaction there will be a 'fundamental transformation' to a condition of bilateral monopoly between buyer and supplier once the latter is selected, even if there had been competitive bidding among several rival suppliers for the original contract. In turn, this sets the stage for the possibility that one or other of the parties will exercise its monopoly power opportunistically during the course of the transaction - that is, that it will attempt to exploit whatever opportunities may arise to shift the terms of trade in its favor. If there were no transaction-specific assets, either party, if faced with opportunistic behaviour by the other, could simply terminate the original transaction prematurely and go to the market to write a new contract without a loss of productive value. As the degree of asset specificity increases, however, the costs of premature termination also increase, and therefore so does the risk that one of the parties will try to 'hold up' the other. More safeguards against such behaviour must be built

into the contractual relationship so as to protect the supporting investment.

If the parties to the transaction were totally prescient, all possible outcomes could be predicted and planned for in advance; and by building the appropriate penalties and rewards into the contract, the incentives of the parties could then be fully aligned. However, one of the key behavioural assumptions underlying the transaction cost approach is that the parties to the transaction display 'bounded rationality' - that is, that there are limits on their ability to process information and solve problems. The other key assumption, that the parties may behave opportunistically, implies, inter alia, that full disclosure of information ex ante cannot be assumed. For both of these reasons, instead of attempts to plan for all possibilities ahead of time, the emphasis ex ante shifts to the creation of governance structures designed to instill confidence in each party that the integrity of the transaction will be preserved, even though the future (including the future behaviour of the other party) is uncertain. A central objective of such efforts is to establish acceptable mechanisms for settling disputes which may arise during contract execution. These governance structures become more elaborate and more costly to create and to sustain as the degree of asset specificity increases. Eventually, when transaction-specific investments exceed some threshold of importance, the option of vertical integration of the supply function may be preferred. There is a tradeoff here. On the one hand, the internalization of production eliminates (or at least reduces) the risks of opportunism and hence the need for costly protective safeguards. On the other hand, it may also entail the sacrifice of economies of scale; moreover, by sheltering production from the rigors of direct market competition, incentives to produce efficiently may be eroded. The scale economy penalty

declines as the degree of asset specificity increases. In the limit, as the human or physical assets supporting the transaction become totally specialized, no economies of scale could be realized by an external supplier that would not also be available to the vertically integrated firm. On the other hand, as organizations increase in size and scope bureaucratic inefficiencies (i.e., organizational diseconomies of scale) may arise.

Asset specificity can take several forms. Williamson (1985, p.55) lists site specificity (i.e., collocation of buyer and seller facilities to save transportation and/or storage costs); physical asset specificity (e.g., a highly specialized production plant); human asset specificity (occurring as a result, for example, of learning by doing); and dedicated assets ('general investments that would not take place but for the prospect of selling a significant amount of product to a particular customer' (Joskow, 1985, p.38)).

2. Frequency:

The relative attractiveness of alternative governance structures for a given transaction will be affected by the frequency with which the transaction is expected to recur. The more specialized the governance structure (i.e., the further removed it is from the limiting case of spot market contracting), the more expensive it will be to create and sustain. These costs will be less burdensome if the individual transactions are large and if they recur regularly. Also, for any form of interfirm contracting, the expectation of a high transaction frequency will strengthen reputational inhibitions on opportunistic behavior.

3. Uncertainty:

Governance structures vary in their ability to adapt to exogenous disturbances. As uncertainty increases, it becomes more and more difficult and costly to write contracts that anticipate and provide for the resolution of all possible problems that might arise during contract execution. Beyond a certain level of uncertainty, contracts will generally be 'incomplete', in that not all contingencies will be specified. If a condition of asset specificity also holds, there will consequently be an increased need for governance structures that will protect each party against the risks of opportunism and provide mechanisms for resolving disputes. A failure to establish such governance structures will result in 'costly haggling and maladaptiveness' (Williamson, 1985, p.79). However, costs will also be incurred in setting up and sustaining these structures.

A unified governance structure (i.e., vertical integration) is generally more flexible than when the response to external change must be negotiated between firms. In the case of vertical integration the interests of buyer and seller remain convergent under the new conditions, there is less need for performance monitoring, and there is no need to engage in costly renegotiation of interfirm agreements. Thus, given a condition of asset specificity, vertical integration tends to be favored over market contracting when uncertainty is large.

* * *

By matching the attributes and requirements of a given transaction with the particular capabilities of alternative governance structures, the transaction cost approach in principle enables the analyst to predict the form

of organization that would minimize the sum of the production and transaction costs. According to Williamson (1985, p.22), such predictions are facilitated by the fact that it is only the relative size of these costs under different governance structures and not their absolute magnitude that is important. In practice, however, aggregation of different types of costs may be necessary, and in such cases a purely comparative approach, in which measurement of absolute costs can be avoided, will not suffice. For example, the choice between vertical integration and market contracting may require a trade-off between the lower costs of administering the supply relationship in the former case and the latter's advantages with respect to the preservation of strong efficiency incentives and the realization of available economies of scale. Qualitative comparisons may indeed be possible within each cost category, but some sort of cost calculus will be needed to make an overall comparison unless it is clear that one type of cost dominates all others.³

Other methodological difficulties arise from the complexity of the case at hand. The supply of a nuclear power plant generally involves not one but many separate transactions. Thus, to the task of aggregating different cost categories for a single transaction is added the problem of further aggregating these costs over multiple transactions. The latter, moreover, will depend on the form of organization that binds these transactions

³We are aware of several other empirical studies which have adopted the transaction cost framework, including the papers by Eccles (1981), Monteverde and Teece (1982), Masten (1984), Joskow (1985) and Globerman and Schwindt (1986). As already noted, the approach taken in these studies is to compare observed organizational structures in a particular industry with the predictions of transaction cost theory. Either by appropriately limiting the scope of the theoretical application, or by stratifying the empirical data so as to control for variations in other cost categories, or simply by qualifying the conclusions, each one of these studies avoids the problem of combining transaction costs with the other components of overall supply costs.

together. In other words, both the organization of the individual transactions and the organization of the interfaces between them must be considered in a comprehensive efficiency analysis.

These difficulties are compounded when both organizations and outcomes are compared across national boundaries. As in all cross-national comparisons, attention must be paid to a great many variables - political, cultural, historical and economic - which cannot readily be controlled for and hence disregarded for the purposes of explaining differences. Even the development of a self-consistent measure of performance is problematical in this case. An obvious measure of economic performance is plant capital cost, but because of currency and interest rate fluctuations, differences in utility accounting practices, differences in relative factor costs, and commercial confidentiality, international capital cost comparisons are very difficult to make.⁴

For all of these reasons, we do not attempt here a formal four-country comparison of theoretical predictions with empirical cost estimates. We proceed instead in two stages. First we analyse nuclear projects in Japan, West Germany and France. The nuclear industries in these three countries are fairly homogeneous: the economic organization of nuclear projects does not vary widely within each country, and a single representative organizational structure can be specified in each case. But because of the difficulties posed by international comparisons, we use the transaction cost framework at this stage only to gain comparative insights into the role of 'frictions' in the economic relationships between the utilities and their suppliers in these

⁴Some of these difficulties have been discussed in detail in OECD (1983).

three countries.

In the second stage, we focus on the U.S. industry. This is easily the most heterogeneous of the four industries under consideration, and, although the internal organizational variations are smaller than those between the four nations, several distinct project structures can be identified. Because differences in the political, economic and cultural context of U.S. nuclear projects are smaller and more readily accounted for than those encountered in cross-national comparisons, and also because self-consistent economic comparisons of project outcomes are more straightforward, we attempt a more quantitative comparison of the predictions of the transaction cost theory with empirical observation at this stage. These results will be presented in a subsequent paper.

The remainder of this paper is organized as follows. In Section III we identify the main transactions in the nuclear power plant supply process and, considering each of them in turn, discuss the suitability of alternative governance structures. In Section IV we examine the performance implications of alternative organizational configurations for the project as a whole. In the second part of the paper, the project configurations observed in West Germany, France and Japan are described and compared using the transaction cost approach.

III. A TRANSACTIONAL ANALYSIS OF NUCLEAR POWER PLANT SUPPLY FUNCTIONS

Nuclear power plants are large, expensive and highly complex systems, and the commercial arrangements for their supply are correspondingly complex. The main 'line' functions include design and engineering, materials and equipment procurement, equipment manufacture, construction and commissioning. Key

project-wide technical/administrative functions include licensing, quality assurance and overall project management. Since the primary focus of this paper is on the economic relationships between utilities and their suppliers, we will investigate only those transactions in which the utilities are directly involved (i.e., first-tier supply relationships). Lower-tier contracting strategies are not considered, though their impact on overall efficiency may be substantial. In this section we focus on two important functional areas in which there are major cross-national organizational variations: design and engineering, and construction. The two are considered separately. The question of functional integration is addressed in the next section.

Design and engineering:

In the design and engineering process the general requirements and preferences of the plant owner are converted into progressively more detailed plans, culminating in engineering and architectural drawings, site layout plans, specifications for materials and construction procedures, design and manufacturing specifications for equipment and systems, and so on. The design and engineering of a nuclear power plant is a lengthy, complex task, which typically consumes thousands of man-years of effort and accounts for a significant fraction of the total plant cost. It is important to note, however, that the output of the design and engineering process is an intermediate product, and a comprehensive evaluation of the economic performance of plant designers must take into account not only the cost of generating the design but also the costs of building and operating the plant. Economizing on design and engineering inputs (mostly professional time) does

not necessarily lead to economies in construction and operation.

The option of using arms-length 'spot' market transactions to commission the design and engineering work can be quickly ruled out. The design process involves countless decisions which require trade-offs to be made among different objectives (e.g., cost minimization, reliability, ease of maintenance, operability, and ease of construction). It would be prohibitively costly and impractical for the owner to articulate all of its conceivable preferences and disinclinations in advance. Clearly, therefore, arrangements must be made for continuing consultations between the plant owner and designer as design proceeds.

The specificity of the assets which support the design and engineering process also suggests the need for a more durable, flexible contractual relationship. The specialized investments required here mainly take the form of human capital. (The physical capital investment requirements are fairly modest and not highly idiosyncratic.) Members of the design team will invest considerable effort in learning to work with and understand the expectations of the operator, and vice versa. This knowledge may be acquired over the course of several projects. Consequently, neither side will find it attractive to resolve difficulties that may arise during the design process through premature contract termination and rebidding, since for both parties significant transition costs would be incurred. A governance structure that provides a mechanism for 'working things out' ex post is therefore desirable. Thus, the basic organizational choice here is between, on the one hand, a form of external contracting in which the autonomy of the owner and the designer is preserved but a highly specialized, durable governance structure is created (as is the case when a utility hires an architect-engineer), and, on the other

hand, a unified governance structure, where the transaction is removed from the market completely and is organized within the utility (i.e., vertical integration).

Which of these two structures is preferable on efficiency grounds depends on a complex set of tradeoffs involving the economies of scale and scope associated with the design and engineering activity, the incentive attributes and bureaucratic distortions of the two governance structures, and the relative costs of adaptation to change in the two cases.

The economies of scale potentially available in design and engineering will depend in part on the degree to which nuclear plant designs have been standardized throughout the industry. If the utility industry is less concentrated than the supply industry, external contracting will be more advantageous from the standpoint of scale economies as standardization increases. Moreover, if the utility is expecting to make investments in new plants only occasionally (as is the case for all but the largest firms), the costs of maintaining a large internal design staff and the difficulty that such a staff would have in keeping abreast of new technological developments would both be substantial. In contrast, an independent designer serving several clients and retaining the option to diversify into other industrial sectors would be able to offer longer-term, steady employment to highly qualified specialists and to maintain a more stable workforce, with consequently fewer hiring and firing costs. The independent designer can also spread the costs of developing expensive computerized design techniques over a larger number of projects.

External contracting in principle also holds out the prospect of preserving the 'high-powered' incentives characteristic of market transactions

(although, as discussed below, in an uncertain environment this may not be possible). If design is carried out internally, the utility will almost certainly opt for a low-powered incentive scheme, involving salaried compensation for the design team. Under a bilateral governance structure in which high-powered incentives have been preserved, the propensity to innovate will tend to be stronger (although there may be a bias here in favor of labor-saving innovations in the design process itself unless the contract expressly provides for the design firm to appropriate some of the benefits of design improvements leading to reductions in construction and operating costs). An independent designer serving several utilities might also be more effective in embodying the lessons of operating experience in design improvements by virtue of its access to a larger base of operating information.

Against these advantages of external contracting must be set the likelihood of closer communication between the designers and the utility's operating department if the design function is vertically integrated. Furthermore, the vertically integrated organization will generally respond more efficiently to external disturbances or user-requested changes than would a bilateral governance structure in which high-powered incentives have been preserved: when a single firm spans both sides of the transaction, adaptations are possible by management fiat, without having to revise interfirm agreements, and hence without incurring the additional costs and risks that that entails. As uncertainty grows - the result, perhaps, of changing user requirements, or increased regulatory activity - vertical integration thus becomes relatively more attractive. Beyond a certain threshold of uncertainty, in fact, it may no longer be possible to preserve high-powered

incentives in the bilateral contracting mode. Independent design firms would be unwilling to bear the risks, and would only be willing to supply their services on a cost-plus-fee basis (i.e., a low-powered incentive scheme). This is, in fact, a common arrangement for the provision of engineering services. Scale economy considerations might still favor outside contracting (although increased uncertainty may inhibit standardization efforts as well). But above this threshold the bilateral governance mode can no longer claim the efficiency and innovation advantages associated with high-powered incentives. Moreover, compared with the design department of a utility, an independent design firm working under a cost-plus contract will be more inclined to behave opportunistically, for example by incurring extra costs (in response, say, to regulatory change) which can plausibly be charged to the utility. These tendencies will be strengthened if cost and decision auditing across firm boundaries is less effective than internal auditing. Williamson (1985, p.154) suggests that this is typically the case because of the stronger community of interests between the auditor and at least some members of the internal department being audited in preserving the overall integrity of the organization.

Thus far we have considered design and engineering as a monolithic activity. What if it were to be subdivided into discrete packages instead? The appropriate institutional comparison here is between a single independent design contractor and two or more design firms contracting separately with the utility for the design of different sections of the plant. Suppose, first, that high-powered incentives can be preserved in each contractual relationship. Suppose also that the same economies of scale can be realized in both cases. The differences, if any, will therefore be confined to

governance cost effects. In general these costs will increase as the design function is disaggregated. Even if the design and engineering subtasks were technologically independent, an increase in the number of separate bids to be solicited and evaluated and contracts to be negotiated, monitored and possibly revised in the event of change would lead to an increase in governance costs. In practice, however, it is more likely that the subtasks will be strongly interdependent - that is, design choices made in one part of the plant will typically have implications elsewhere. Thus, technological interfaces will have to be defined explicitly during the contract negotiation stage, and monitored thereafter. Moreover, adaptations to external change (e.g., regulatory change) may require simultaneous negotiations with the different design firms in order to redefine the technological interfaces. Consequently, governance costs are likely to increase rapidly as the design function is subdivided.

The initial assumption made in the comparison that high-powered incentives are preserved in each case may, however, create an unfair bias against the disaggregated design organization. This is because the threshold of uncertainty above which only cost-plus contracting is feasible is not necessarily located at the same level for the two cases. Thus, at a level of external uncertainty that exceeds this threshold for an integrated design contract (and that would therefore dictate a cost-plus contractual arrangement), it may still be possible to preserve high-powered incentives in some of the contractual relationships if the design task is disaggregated.

In summary, neither external contracting nor vertical integration can be said to offer unequivocal advantages in all circumstances for the organization of nuclear power plant design and engineering. The preferred structure

depends on the environment and on the industrial structure. The internal organization option gains relative to external contracting as exogenous uncertainty increases, as the frequency of ordering by individual utilities increases, and as the level of concentration in the utility industry increases. On the other hand, increases in the level of design standardization will favor external contracting because of improved economies of scale, provided that the utility industry is less concentrated than the supply industry. Dividing the design function among separate firms may result in sharp increases in transaction costs, especially in an uncertain environment.

Construction:

Construction of a nuclear power station begins with civil engineering work, which is followed by building erection, process system and equipment installation, and commissioning. During much of the construction period these tasks are carried out in parallel. Enormous volumes of material inputs and very large numbers of electrical, structural and mechanical components are required for these projects. During the peak of construction activity several thousand workers are typically present on site. Many different trade specialities are needed, and the work and scheduling of each type of craft labor must be carefully coordinated with the others. The stringent quality standards on nuclear construction demand that virtually every activity be meticulously documented. The projects require highly advanced construction techniques and management systems, and usually take from five to ten years to complete. Few other types of construction project are comparable in either scale or complexity.

Four possible organizational configurations are shown in Figure 1, arranged in order of increasing utility participation.⁵ In the first approach (A), the utility contracts with a general contractor for the construction of the entire plant. The general contractor may do all of the work with labor on its own payroll, or, more likely, subcontract some of it to specialty firms. In either case, the general contractor typically also acts as construction manager, with responsibility for materials procurement, hiring and supervising labor, scheduling tasks and deliveries, and ensuring that the project is proceeding within time and budgetary constraints.

In the second approach (B), the utility engages a construction management firm to act as its agent. The construction manager oversees all site activities. It draws up detailed installation schedules, establishes site construction procedures, hires and supervises construction and craft labor, and is responsible for the selection and coordination of specialty contractors, for materials procurement and for cost control. The contractors enter into contracts directly with the utility, however.

The third approach (C) is a variation of the second, in which the utility acts as its own construction manager. In the final alternative (D), the utility actually undertakes a substantial portion of the construction work with labor and supervisory staff on its own payroll, with help from specialty subcontractors as required.

⁵The nature of the lower tiers of the construction organization (i.e., the relationships between primary and secondary contractors and between the contractors and craft and unskilled labor) also have important efficiency implications. (For a valuable discussion of these issues, see Eccles (1981).) In keeping with the principal focus of this paper, however, our investigation of the vertical structure of construction organization will extend only to the first tier of supply relationship linking the utility to its primary contractors.

We defer consideration of Alternative B, since in none of the three countries considered here do the utilities employ agent-managers. (In the U.S., by contrast, agent-managers have been ubiquitous in power plant projects.) The remaining alternatives constitute a spectrum of levels of utility participation, with Alternative D itself being made up of a continuum of possibilities.

It is difficult to generalize about the transactional attributes of the many tasks involved in nuclear power plant construction. As with design and engineering, the physical assets required are fairly modest and, by and large, not highly idiosyncratic. There are, however, some important exceptions, such as specialized heavy lifting equipment, on-site prefabrication shops, and other temporary site construction facilities. Human asset specificity may be more important. Construction tradespeople must invest a substantial amount of time in learning site procedures (including quality assurance programs) and in learning to work with each other, as well as with design engineers, equipment and material suppliers, and the construction management organization. Human asset specificity is most pronounced for the construction management function; a change in the identity of the construction management organization during the course of the project would be particularly disruptive and costly.

Compared with mass production and process technologies, external uncertainties are typically greater for construction projects, and this is especially true for nuclear power plant construction, where the effects of changing regulatory requirements and public opposition often dominate the more conventional uncertainties concerning site conditions, labor availability, weather, and so on.

Each of the possible organizational configurations can claim a different set of advantages whose weighting depends on external conditions. Compared with Alternative C, Alternative A allows scarce administrative capacity within utility organizations to be conserved. The cost advantages of A in this regard will be greater to the degree that the general contractor can exploit administrative economies of scale that are unavailable to the utility. A further advantage of A is that construction management and at least some of the primary construction trades are vertically integrated. This reduces governance costs, both because the number of competitive bidding contests is reduced and because the costs of adaptation to change will generally be lower than if the adjustments have to be made across market interfaces.

On the other hand, Alternative C may provide the utility with cost and quality control advantages over A, especially if in case A the utility is obliged to engage the general contractor on a cost-plus basis. (The willingness of the general contractor to share the risks of construction will depend on its perception of the external uncertainties bearing on the project, together with its own competitive environment.) Even with risk-sharing, the general contractor will have substantially more complete knowledge of the project than the utility, and such information asymmetries may promote opportunistic behaviour. The risk of opportunism will be enhanced if there is a low probability of repeat business. Bad behaviour by the contractors will tend to be a lesser risk in the case of C, by virtue of the utility's more active participation, but may still be a factor where the contracts create imperfect incentives for cost and quality performance.

Compared with Alternative C, D offers the benefit of greater adaptability - a feature which gains in importance as external uncertainties mount - and a

lower risk of opportunism. The reassignment of labor to new tasks as the need arises may be easier to accomplish if the workers are on the utility payroll than if they are hired to perform specific tasks under specialty contracts, especially if the contract labor is unionized. But these advantages are achieved at the cost of lost scale economies (for all but the largest utilities) and the weakened performance incentives and bureaucratic inefficiencies that tend to be associated with the direct employment of special trades.

IV. HORIZONTAL INTEGRATION OF NUCLEAR POWER PLANT SUPPLY FUNCTIONS

Of the project functions (i.e., design and engineering, procurement, equipment manufacture, construction contracting, commissioning, licensing, quality assurance, project management) that are not performed internally by the utility, to what extent is it desirable to subdivide the work among independent contractors? At one end of the spectrum, all of the functions are incorporated within a single work package. (If, in addition, the utility's own involvement is small, the resulting arrangement constitutes a turnkey project.) At the other extreme, contracts for separate work packages are let directly between the utility and a large number of specialty contractors.⁶ The performance implications of this choice can again be examined using the transaction cost framework.

⁶In practice, of course, a particular utility's perceived options will generally only extend a short way along this spectrum; its choices at any particular time will be constrained by tradition, by the structural characteristics of the supply industry at that point, and by its internal manpower resources. Our purpose at this stage, however, is to explore the consequences of the full range of alternatives in a general way, without reference for the moment to the constraints imposed by particular circumstances.

In general, an increase in the number of independent work packages results in an increase in both ex ante and ex post transaction costs. As the number of work packages increases, so too does the number of bids to be solicited and evaluated. For each package, moreover, the scope of work must be specified in enough detail to permit the cost and schedule impacts of any change in scope to be determined. The complexity of this task increases with the number of discrete packages. Furthermore, because of the technical interdependencies between different plant systems and components, a change in work scope in one area is likely to affect several other work packages, necessitating a complex, coupled set of negotiations with separate suppliers in order to redefine contractual objectives and allocate incremental costs should changes actually occur.

We have already discussed the implications of disaggregating technically interdependent activities within functional areas. Similar arguments apply to the organization of the different functions. Engineering, equipment manufacture, procurement and construction overlap in time, and are linked at a vast number of technical interfaces. Some of the coordination problems have been summarized by Sailer et al (1980, p. 247):

The architect-engineer designs the power plant system by system. Those responsible for construction, on the other hand, build by area or elevation and by craft or trade. The architect-engineer designs from the roof down, calculating loads and then designing the foundations for these loads. Construction, however, works from the ground up. Interface problems that require careful definition and control of information exchange also exist among the engineering disciplines involved in the design phase. The systems produce the power, while the structures support the equipment within the systems. Since the structures must be constructed first they should theoretically also be designed first. However, because of the need for information on equipment location, loads, and load combinations, structures cannot be designed in detail until after the systems have been designed in detail. In this regard, it is often necessary to place certain equipment purchase orders very early in order to obtain the vendor drawings to be completed. In the case of feedwater heaters and large pumps, for instance,

the vendor drawings provide information about loadings on structural foundations, bolt spacing for embedments, pipe routings and connections, and electrical information.

Similarly (p. 260):

It is extremely important, for instance, that the construction method which is to be used be communicated to the design engineer. As an example, the major nuclear steam supply system vessels (such as the reactor vessel or steam generator) may be rigged by using a gantry type rig, a polar crane or a stiff leg derrick. Each of these will affect the structural design of the buildings involved in a different manner. In a similar fashion, design restrictions such as the designer's decision to limit the use of the turbine room crane until the turbine room floor is poured and cured (to ensure structural integrity) must be properly communicated to the construction engineer.

An important corollary of the transaction cost increases caused by lateral disaggregation is that proportionally more of these costs must be borne by the utility. In the limit of complete horizontal integration, the task of defining and coordinating the organizational and technical interfaces between supply functions is the exclusive responsibility of the turnkey supplier. As the number of suppliers separately contracting with the utility increases, however, more of the burden of ensuring efficient coordination shifts to the utility; more of the project information must flow through the utility, which typically also plays a greater role in project scheduling and cost control.

The problem of measuring the performance of individual firms is also compounded as lateral disaggregation increases, adding further to the transaction costs. The combination of technical complexity, system interdependence and multiple contractors means that in many cases it will prove difficult to hold a single supplier unambiguously responsible for poor performance. One inevitable result is to restrict the scope of warranty coverage; suppliers will be unwilling to guarantee the performance of their products if this is likely to be compromised by non-identifiable actions of

others. Beyond this, such measurement problems will tend to erode reputational constraints on opportunistic behaviour.

A further consequence of lateral disaggregation is to reduce incentives for certain kinds of innovations requiring coordinated action across functional interfaces. Consider, for example, modular construction techniques, whose potential for reducing construction lead-times is widely recognized, and which are increasingly in evidence (see, for example, Ikegame and Kanai, 1986). A program of modularization entails coordinated actions by designers, equipment manufacturers and constructors. One of its impacts is to shift work from the plant site to the shop floor. The benefits are thus not uniformly distributed, and adoption of modular construction techniques is less likely where separate firms undertake these various functions than if a single firm can capture all of the benefits.

Other factors favor a certain amount of lateral disaggregation, however. Restricting invitations to bid on nuclear projects to turnkey plant suppliers limits the effectiveness of competition as a factor in keeping costs down, since so few contractors are capable of bidding on a package of such breadth. Moreover, early in the life of the project the utility may be either unable or unwilling to define the work scope with enough precision and with sufficient guarantees of stability for the full-scope contractor to be prepared to offer a firm-price bid. In contrast, if a large number of work packages are employed, some can be deferred and hence defined in sufficient detail to elicit firm-price bids from prospective suppliers, thereby at least partially preserving high-powered incentives. Furthermore, by subdividing the work packages the utility has additional flexibility to specify the contracts in such a way as to maximize the number of suppliers capable of bidding on them.

By separating the packages according to the level of quality assurance that is required, for example, contractors that have chosen not to acquire nuclear certification will be able to bid on some parts of the project from which they might otherwise have been excluded (Theodore Barry and Associates, 1979). Finally, as the utility takes on more of the risk and responsibility for project coordination, it avoids having to pay the risk premium figured in the price quoted by a general contractor. These risk premiums are often inflated in the presence of information asymmetries. Thus, increased lateral disaggregation can provide a cost advantage as long as the utility has adequate internal coordination capabilities and does not have to sacrifice important scale economies.

Alternative Models of Project Organization:

We next introduce four alternative organizational models for nuclear power plant projects. The models, shown schematically in Figure 2, range from the highly integrated (Model I) to the highly disaggregated (Model IV). In Model I a single turnkey supplier is responsible for all of the main functions, including architect-engineering, equipment manufacture and construction. In Model II, each of these three functions is organized under separate direct contracts with the utility; engineering and construction services are each procured from a single contractor, but several separate contracts are signed with equipment and component manufacturers. Model III is more disaggregated, with either the engineering and the construction functions (it is not necessary at this stage to specify which) also subdivided among several separate contractors. Finally, in Model IV all three primary

functions are subdivided among multiple contractors.⁷

These four models span the actual range of organizational structures observed in the countries under consideration. As we shall see, the situation in West Germany, where a turnkey contractor supplies goods and services amounting to over 90% of the total cost of the plant, is most closely approximated by Model I. Japanese nuclear projects are also best described by Model I, although the Japanese turnkey contracts are less comprehensive than their German counterparts. In France, by contrast, the state utility, Electricité de France, deals directly with hundreds of contractors. (U.S. nuclear projects exhibit a range of intermediate organizational forms.) These various project structures are described in more detail in Section VI.

V. SUMMARY

The organizational choice problem for utilities embarking on nuclear power plant projects has three interrelated aspects: Which functions should be carried out internally and which should be performed by external contractors? To what extent should the work that is contracted out be subdivided into separate work packages? And what contractual terms should govern these external supply relationships?

⁷Note that these models are defined without specifying the primary contractors' subcontracting strategies. It should once again be stressed (see footnote 5) that these may have a major impact on overall project performance. However, the focus of the present inquiry is on the efficiency implications of the degree of disaggregation in utility-primary contractor relations, and our working assumption is that sub-tier performance efficiencies are invariant with respect to this factor.

The transaction cost approach provides insights into the economic consequences of these decisions. Because of the scale and complexity of nuclear projects, an essentially infinite number of possible organizational configurations can be imagined. In practice, however, the decisions taken by utilities on these matters are constrained by many factors, including corporate traditions, antitrust restrictions, available internal manpower resources, and the current organization of the supply sector (itself at least partly the result of earlier decisions of the same kind).

According to the transaction cost approach, the optimal organizational arrangement is that which minimizes the sum of the ordinary production costs and the costs of administering the supply process. Based on the preceding analysis, there appears to be no organizational form that can claim superiority under all circumstances. Rather, the relative attractiveness of alternative forms is determined by the interaction of the technical characteristics of nuclear power plant construction with the basic structural features of the nuclear power industry and certain key attributes of the external environment. How these factors combine to influence the choice of organization is summarized in the following paragraphs:

1. Vertical Structure

The internalization of design and/or construction tasks by utilities reduces the likelihood of costly incentive misalignments. It also facilitates vital communications between plant operators and design and/or construction engineers. And it results in an organizational structure that responds more flexibly to external changes. On the other hand, a vertically integrated governance structure may result in the weakening of high-powered efficiency incentives, and may also entail the sacrifice of available economies of scale.

The size of the latter penalty will depend on the relative concentration levels in the utility sector and on the supply side.

2. Supply-Side Structure:

A reduction in the number of separate contracts and independent project participants yields ex ante and ex post transaction cost savings overall, and reduces the administrative burden on the utility or its project manager. Functional integration may also encourage innovations involving more than one functional area which might otherwise be inhibited by the inability of separate suppliers to appropriate enough of the benefits. Also, a decline in the number of independent participants reduces performance measurement problems and hence strengthens reputational constraints on opportunistic behavior.

But as the contractual scope of supply is reduced, more firms will be capable of bidding on the work package, thereby increasing the effectiveness of market competition as a factor promoting good contractor performance. Also, by disaggregating the work packages and distributing the various bidding contests over time, the individual tasks can be specified with precision and the need for ex post revisions minimized; in this way high-powered incentives can be more readily maintained. Finally, increased lateral disaggregation reduces informational asymmetries between the utilities and their contractors; one consequence is to reduce the possibility of inflated risk premiums (a form of contractor opportunism).

3. External Environment:

Exogenous changes occurring during project implementation may either

increase or reduce ordinary production costs but invariably result in higher transaction costs. The transaction cost effect is a strong function of the number of independent participants in the project. Consequently, the more changeable the external environment the stronger the case for an integrated project structure.⁸ (This can occur through vertical integration by the utility or functional integration on the supply side, or through some combination of the two.)

4. The General Trading Context:

The ranking of alternative forms of organization frequently hinges on a trade-off between production and transaction cost economies. Transaction costs are at least partly determined by the prevailing commercial culture; the general level of tolerance for opportunistic behaviour, for example, varies between societies. Cultural differences may therefore strongly influence the desired form of organization.

VI. THE NUCLEAR POWER INDUSTRY IN WEST GERMANY, JAPAN AND FRANCE

We next describe the economic organization of nuclear power projects in West Germany, Japan and France, and then interpret these data using the transaction cost framework.⁹

⁸Note that uncertainty about the prospects for future projects leads to the opposite strategy - spreading the risk of investment in specialized productive capacity over as many independent firms as possible. Unfortunately, the two types of uncertainty may be coincident.

⁹The information presented in the following sections was obtained mostly during a series of interviews conducted by the authors in France and West Germany in early 1986 and in Japan in 1983, 1984, and 1987. The interviews took place with the understanding that specific remarks would neither be attributed to individuals nor to the organizations with which they were associated. A list of those organizations is provided in the Appendix.

The development of nuclear energy in these three countries has followed broadly similar paths. None of the three is well endowed with indigenous fossil fuel resources, and in each case vigorous efforts were made to expand the role of nuclear power following the world oil market disruptions of the early 1970s. Today, nuclear plants are making important contributions to all three countries' electricity supplies. Both the absolute size and fractional contribution of the nuclear industry are greatest in France, where 44 nuclear power reactors produced almost 65% of that nation's electricity in 1985. In Japan in the same year 32 power reactors provided 22% of the electricity, while in West Germany the corresponding figures were 16 reactors and 31%.

Power plants of the light water reactor (LWR) type are the mainstay of all three nations' nuclear programs. Though LWR technology was originally introduced into each country from the United States, self-sufficient, technologically advanced nuclear power plant supply industries have subsequently been developed in each case.

Yet there have also been notable differences between the three countries in the structure of both the electric power and nuclear power plant supply industries, as well as in the political and regulatory climate for nuclear energy development.

Electric power sector:

In France, 90% of the electricity is generated by the state-owned utility, Electricité de France (EdF). EdF is the sole owner of commercial

nuclear power plants, and has taken the lead in implementing a program of nuclear plant design standardization featuring pressurized water reactors (PWRs) going well beyond anything of the sort achieved elsewhere. Since the mid-1970s, EDF's practice has been to build long series ('tranches') of almost identical plants. The first of these tranches, launched in 1974, consists of eighteen 900 megawatt units. The design was closely modelled after a Westinghouse reactor system design of the period. A second tranche of ten 900 megawatt units, very similar in most respects to the first, was initiated in 1977. The third series consists of twenty 1300 megawatt reactors, the first of which was ordered in 1976. The most recent series, of 1450 megawatt units, was designed in its entirety in France (the first plant of this series is not expected to enter commercial operation until 1991). Most of the French reactors are sited in 4-unit clusters although more recently there has been a shift to 2-unit stations.

The electric power supply industry is much more fragmented in West Germany. There are approximately 1000 German public utilities, which together supply 84% of the nation's electricity. (Most of the remainder is generated by industrial power plants.) Of these, some 328 actually generate power, and the remainder are transmission and/or distribution entities. Eight of the largest generating companies form the membership of the Deutsche Verbundgesellschaft (DVG), a utility association that operates and controls access to the high voltage network.¹⁰ The combined service areas of the DVG members cover the entire Federal Republic. The DVG members account for 43% of electricity sold by German utilities, and they and their subsidiaries provide 60% of German

¹⁰There were originally nine members of the DVG; in 1985, however, two of the members, Nordwestdeutsche Kraftwerke (NWK) and Preussenelektra, merged.

electrical capacity.

Ownership of nuclear plants in Germany is typically shared. As Table 1 illustrates, six of the eight DVG utilities either own or share ownership of at least one operating unit. The largest of the utilities, Rheinisch - Westfälisches Elektrizitätswerk (RWE), is the principal shareholder in five nuclear projects. Most of the others are principals in two or three. In only one case is a non-DVG utility the leading shareholder in a plant.

The degree of concentration in the Japanese electric utility industry is intermediate between the French and German cases. Most of the electric power is supplied by nine privately owned, vertically integrated regional electric power companies. There are two other organizations with substantial amounts of generating capacity, the Electric Power Development Company and the Japan Atomic Power Company, both of which wholesale the power they generate to the nine regional utilities.¹¹

Eight of the nine regional electric power companies have at least one nuclear power plant in operation or under construction; however, the two largest firms, Tokyo Electric and Kansai Electric, with 10 BWRs and 9 PWRs in service respectively, together account for almost 70% of the total installed nuclear capacity, and provide technical leadership for the smaller,

¹¹The Electric Power Development Company (EPDC) owns and operates large-scale hydro and coal fired power stations and also operates transmission lines connecting the service areas of the nine regional utilities. It is jointly owned by the government (72%) and the nine regional utilities (28%). The Japan Atomic Power Company (JAPC), created in 1957 in order to facilitate the introduction of nuclear technology into Japan, owns and operates four nuclear power plants. Its main shareholders are the electric utilities (90%) and companies belonging to Japanese nuclear power industry consortia (8%). JAPC continues to serve as a pioneer of nuclear technology in the Japanese context. For example, its newest plant, Tsuruga 2, is the first Japanese plant to utilize a prestressed concrete containment vessel (PCCV).

less-experienced firms.¹²

Table 2 provides a summary of the role of nuclear power in each of the three countries.

Regulatory Structure and Political Environment:

The French nuclear program has been characterized by a strong and continuing political commitment to nuclear power development and a highly centralized institutional structure, consisting primarily of the Ministry of Industry, EdF, the governmental Commissariat de l'Energie Atomique (CEA) and the sole French vendor of PWR nuclear steam supply systems, Framatome. Decision-making on nuclear power questions has provided few opportunities for intervention by opponents of the nuclear program, who have, in any case, found less support for their views among the general electorate than in any other Western nation.

Nuclear power regulation in France is the responsibility of the Central Service for the Safety of Nuclear Installations, an administrative body which reports to the Minister of Industry. For the utility, the regulatory environment has generally been stable and predictable. Relations between the industry and the regulatory authorities are cordial and collegial, and safety issues are normally resolved with little public discussion. For the standardized part of the plant, a single licensing review is conducted for all of the units in the series. Where safety-related backfits have occurred, the actions have often been taken at the utility's initiative, rather than at the

¹²Partly to conserve limited technical resources, every Japanese utility except the Japan Atomic Power Company has adhered to the practice of only building either PWRs or Boiling Water Reactors (BWRs).

insistence of the regulatory authorities.

In Japan, as in France, the government has been a strong and effective supporter of nuclear power development. The Ministry of International Trade and Industry (MITI) has played a leading role in promoting a technically strong and financially healthy utility and nuclear supply industry. MITI is also the main licensing authority, and is responsible for administering the safety regulatory process.

The Japanese utilities perceive the regulatory organization not as an inherently adversarial body, but rather as one which shares their objective of efficient nuclear power generation. There is a high degree of informal communication between MITI officials and utility representatives. Drafts of all regulatory guidelines and standards are submitted by MITI for discussion to working groups which include representatives from the utilities and the manufacturers. In practice MITI will not implement new regulations if one group objects strongly. Informal discussions between MITI and utility officials also occur during the licensing process. Both utility and MITI representatives argue that this flexible approach to regulation is possible because of the good record of the utilities in the areas of quality assurance (QA) and advancement of safety. The utilities have actually taken the lead in addressing safety issues on many occasions, and often adhere to stricter levels of safety than is required in the regulations.

Negative public opinion towards nuclear power plants has frequently exacerbated siting problems in Japan, and in a number of cases has led to substantial delays in construction starts. The opportunities for public intervention rapidly decline after the siting stage, however, and public opposition has had little impact on the implementation of nuclear projects

once construction has begun.

In Germany, successive governments have also favored the development of nuclear power, but direct governmental intervention in support of the nuclear industry has been limited compared with France and Japan. Under the German federal structure, the states have responsibility for licensing and overseeing the safety of nuclear power plants. A unique feature of the German regulatory process is the reliance on independent regional expert groups, known as Technical Surveillance Associations (Technische Überwachungsvereine, or TÜVs) for the verification of manufacturing and construction quality. The safety regulations themselves are established at the Federal level, in a process which typically involves negotiations among representatives of the Federal and state governments and the nuclear industry. This process of establishing safety standards by consensus is officially sanctioned in Germany, as compared with the situation in Japan where a consensus is reached more informally. Safety standards are set by the Nuclear Safety Standards Commission (Kerntechnischer Ausschuss) which consists of representatives from five groups: the Federal and state regulatory authorities; owners and operators; manufacturers and constructors; independent experts (TÜVs); and other organizations with special technical knowledge. Since a 5/6 majority is required for the adoption of a new safety standard, the opposition of just one of the groups involved is sufficient to block its passage.

Before the introduction of the standardized Convoy design in the early 1980s, which greatly streamlined the regulatory process, as many as 22 licensing steps were required for individual projects. Under German law, plants must meet the state-of-the-art in technology at each licensing stage. Since the state-of-the-art was evolving rapidly in the late 1970s, plants that

were under construction at the time experienced many design changes.

Public opposition to nuclear power in Germany has been more vocal than in either France or Japan. In the late 1970s this opposition was reflected in numerous court challenges involving nuclear power plants under construction, some of which caused extensive delays. Most of the cases were finally settled in favor of the nuclear industry. Public opposition to nuclear power abated somewhat in the early 1980s, but differences between the major political parties on nuclear power policy have sharpened in recent years, and since the Chernobyl accident in March 1986 antinuclear activity has gained considerable momentum.

VII. NUCLEAR POWER PROJECT ORGANIZATION IN WEST GERMANY, JAPAN AND FRANCE

West Germany

Nuclear plants in Germany are supplied by Kraftwerk Union (KWU) on a turnkey basis. (KWU, a wholly-owned subsidiary of Siemens, will shortly be re-absorbed by the parent company.) At least 90% of the total value of the plant is included in the turnkey contract. The excluded fraction varies somewhat from plant to plant, but typically includes items such as administrative buildings, warehouses, water treatment systems, cooling towers and part of the civil works. KWU takes on overall responsibility for planning, design and construction of the plant. The level of involvement of the utility clients varies. Some utilities have traditionally taken a more active role in plant layout and design decisions. Since the introduction of the standardized Convoy design in the early 1980s, however, the scope for individual utility involvement in design decisions has diminished, although the utilities actively participated in the development of the Convoy design

itself.¹³

Other aspects of utility involvement include contracting for the equipment and services not covered by the turnkey contract, licensing, and monitoring the performance of KWU. In some cases this monitoring function is partly subcontracted out to engineering consultants. Responsibility for quality assurance and control is largely assigned to KWU, though the utilities generally send representatives to the manufacturing plants and to the site to monitor quality efforts.¹⁴ KWU is also obligated to provide all documentation and technical data required for the licensing process, and is indeed a co-holder of the plant license until the plant is turned over to the utility. The number of utility personnel with technical and management responsibilities during plant construction typically ranges from 20 to 50 - far less than the number assigned to projects by KWU. For most cases in which the plants are jointly owned, one utility is assigned full technical responsibility for the project.¹⁵

Under the turnkey contracting arrangement, a fixed price is specified, with escalation formulae indexed to input costs. (For the Convoy plants the

¹³The initiative for the Convoy concept came from KWU and the utilities, although the licensing authorities and the regional TÜVs were also closely involved in its implementation. The main goal of the Convoy program was to streamline the licensing process and to achieve design standardization among the group of plants that were about to be constructed.

¹⁴The regional TÜVs provide third-party quality assurance but the actual responsibility for QA rests with KWU. KWU also takes complete responsibility for monitoring the QA of its subcontractors.

¹⁵The two Philippsburg plants are an exception. These are jointly owned by Badenwerk and EVS. Each utility owns a half share in the units, and all technical work related to design and construction is done collaboratively.

price is also contingent on the number of Convoy units ordered.) KWU is responsible for meeting all relevant safety regulations and providing the state-of-the-art in safety technology as of a contractually specified date. To avoid ambiguity in this key area, the regulations in effect at the time, as well as agreed-on interpretations of them, are spelled out in the contract. The contract contains a complete description of the plant layout and the technical specifications of components. KWU is required to pay a percentage of the costs of design modifications and backfits occurring during construction, even if the changes are initiated by the regulatory authorities. The percentage is small, but is intended to deter the supplier from making unnecessarily expensive modifications. Joint meetings between the utility, the vendor, and the regulatory authorities to discuss the implications of regulatory changes also provide the utility with assurances that unnecessary expenditures are not occurring. The utility may on occasion take an active role in subcontractor selection decisions. If the utility insists on a more expensive subcontractor, it is generally required to pay any additional costs incurred.

The plant is handed over to the utility after successful completion of the trial operating period, which includes four weeks at 100% power. At this point, several operating guarantees go into effect, as well as guarantees that the plant was built according to agreed-on specifications and in compliance with relevant regulations. Under the early contracts, KWU typically provided guarantees of plant availability for the first two years of operation. If the average availability fell below a fixed level set in the contract (reportedly 75% in at least one case) during this period, the supplier was obliged to compensate the utility at a set rate if it could be shown that the losses were

not caused by poor operating practices. For the more recent projects the contracts have not included such guarantees, but general guarantees on materials and components for periods of up to several years remain.

KWU undertakes most of the design and engineering for the turnkey section of the plant itself, and even writes the technical specifications for those parts of the plant that are outside the turnkey scope and for which the utility contracts separately. Only a relatively small fraction of the systems and components are manufactured internally; the main items are the turbine generators, the core internals, the fuel assemblies, the fuel storage racks, the containment locks, and the control rods and drives. Of the rest, most of the electrical equipment and instrumentation and control systems are subcontracted to Siemens, the parent company of KWU, and the remainder is subcontracted out to independent equipment suppliers. KWU supervises construction, but labor contracting is left to the subcontractors. Procurement and cost control responsibilities are centralized at KWU headquarters.

Japan

Japanese electric utilities have also adopted a form of turnkey contracting for the supply of their nuclear power plants. The utility awards a major contract to one of the three Japanese plant vendors (Mitsubishi, for PWRs, and Toshiba or Hitachi, for BWRs) for the supply of 65-80% of the plant. Each vendor is associated with a large industrial consortium, other members of which also participate in the projects. Under the main plant contract, the contractor is responsible for architect-engineering, procurement,

construction, preoperational testing and overall project management.¹⁶ The contractor also manufactures some of the principal systems and components; many of the others are supplied by the other members, affiliates or associates of its consortium. Subcontracts for electrical and mechanical works and building erection are also typically awarded to members of the consortium. Thus, the leader of the Mitsubishi Atomic Power Group, Mitsubishi Heavy Industries, designs and manufactures the main components of the plant, including the nuclear steam supply system; Mitsubishi Electric Corp. designs and manufactures the instrumentation and control systems and the generator; and Mitsubishi Atomic Power Industries undertakes general design work for both the plant and the fuel. In addition, Mitsubishi Nuclear Fuel supplies the fuel, and Mitsubishi Metal Corporation manufactures cladding tubes for the fuel.

The utility awards a separate contract for the civil works. The civil contractors are the largest construction companies in Japan, including Kajima, Taisei, Shimizu Construction, Takenaka Komuten and Ohbayashi Gumi. Recently, in response to the economic problems facing the construction industry, the utilities have adopted the practice of awarding civil contracts to joint ventures of these companies. The scope of the civil contract extends only to the actual construction work. The design and engineering associated with civil works is incorporated within the main contract, though much of it is

¹⁶The Japanese plant manufacturers have only recently acquired a plant-wide architect-engineering capability. The first plants purchased by Japanese utilities were ordered from U.S. vendors. The units were supplied on a turnkey basis, with architect engineering services provided by U.S. firms. Although later units of the same design were built with progressively increasing participation by the Japanese plant suppliers, the first unit of each design vintage was built by an American vendor, again with the assistance of an American architect-engineering firm.

subcontracted to the civil contractor. The reluctance of the large Japanese construction companies to subcontract to Hitachi, Toshiba or Mitsubishi for the entire scope of the civil works is reportedly the main reason for the utilities' practice of contracting separately for civil construction.

The contracts awarded to the plant vendors are of the fixed price type, with escalators tied to price indices. The contractor carries much of the financial risk of delay or cost overruns, unless it can determine that changes in safety requirements are responsible. The cost of safety-related backfits is kept down by requiring the main contractor to pay a percentage (albeit small) of the resulting cost overruns. In the 1970's, when the problems experienced in operating plants led to design and material changes for plants under construction, the utilities paid for some of the cost overruns which were incurred in those cases where the main contractors could not have reasonably anticipated the problem. In general, the utility and its main contractor renegotiate their contract only a small number of times, and backfits are treated en bloc. Since backfitting during construction has decreased significantly in the 1980's, Japanese utilities anticipate that there may be no renegotiations necessary for the plants coming on line in the near future.

The prices quoted in the main contracts tend to be highly aggregated, and the utility does not receive detailed cost breakdowns. Although the utilities verify the technical qualifications of all the subcontractors used by the main contractor, they do not request any cost or bidding information. Contractual warranties are fairly standardized in Japan and are provided on materials, components and services for 2-5 years after plant turnover depending on the system. There is no guarantee of overall plant availability, but vendors

frequently stand behind their products and services beyond the warranty period.

Despite the fact that several plant and civil works contractors are active in the Japanese market, price competition does not appear to play a large role in the award of the major contracts, and bids are more accurately characterized as negotiated than competitive. Like most Japanese firms, the Japanese utilities attach a great deal of importance to the maintenance of stable, durable relationships with their suppliers, and tend to contract repeatedly with the same firm. This tendency is reinforced by the utilities' practice of only building either PWRs or BWRs. Indeed, the Mitsubishi group, as the only supplier for the PWR utilities, faces no competition, and there are also indications that the ordering patterns of the BWR utilities have been partly influenced by a perceived need to ensure adequate business for both BWR suppliers.

The supply relationship extends throughout the life of the plant. The plant vendor is typically also the primary maintenance contractor, and in some cases undertakes as much as 70% of the maintenance work, as well as any plant modifications.

Although the plant contractor's scope of supply is very broad, the client utility is actively involved in all phases of the project. One official at one of the larger utilities estimated that up to 200 utility engineering personnel are present on site during construction of a multiple unit station in a supervisory capacity, and a further 100 are involved in the project at the home office. The numbers are smaller for some of the smaller utilities, who tend to rely more heavily on the main contractor. The utilities are especially active with respect to quality assurance, reviewing design

documents and construction procedures and monitoring quality assurance activities at manufacturing facilities and on the construction sites. Utility personnel conduct their own inspections as well as witness inspections conducted by supplier quality assurance staff at pre-specified holding points in the construction schedule. The utility also has primary responsibility for licensing, although it relies heavily on the main contractor to provide the necessary documentation.

France

In France nuclear power plants are not supplied on a turnkey basis, and the utility, Electricité de France (EdF), is centrally involved in the supply process, acting as the architect-engineer, construction coordinator and overall project manager.¹⁷ Its two principal suppliers on each project are Framatome, for the NSSS, and Alsthom Atlantique, for the turbine-generator, both of whom also assume responsibility for installing, testing and commissioning their equipment under EdF supervision. Many other suppliers are also involved, either as direct contractors to EdF or as subcontractors to the two main suppliers. EdF enters into several hundred separate contracts for systems, equipment and components, and electrical, mechanical and civil works. The 15 largest contracts cover 70-75% of the total cost of the plant. In many cases more than one contract is placed with a single supplier. Most of the contracts (except, of course, those awarded to Framatome and Alsthom) are bid competitively; one EdF official estimated that competitively bid contracts

¹⁷EdF is precluded from being directly involved in manufacturing or construction by the law by which it was created in 1948. The intent of the restrictions was to avoid nationalization of the construction industry or the electrical equipment supply industry.

(including subcontracts) account for 50-60% of the total direct cost of each plant. All contracts are fixed price, with escalators indexed to input costs. Many contracts are awarded not for a single plant but for all of the plants in the standard series. The largest such contracts were placed in 1974 for the units of the first 900 megawatt series (the CP1 series); orders were placed with Framatome and Alsthom for twelve nuclear reactors and turbine generators, with options (subsequently exercised) to purchase four more of each. As with KWU in Germany, prices are quoted as a function of the number of units actually ordered.

EdF's Engineering and Construction Division (Direction de l'Equipement) is responsible for designing and building the plants. The Division consists of three central departments (administration, manufacturing and construction control, and design) and five regional departments. The design function is surprisingly decentralized. The central design department, SEPTEN, does the preliminary design work, performs plant-wide optimization studies, writes the general specifications for the plant series, and generally oversees the implementation of the standardization policy, but responsibility for detailed design and engineering rests with the five regional departments.

Each regional department is responsible for designing those parts of the plants to be built in its area that are site-specific, and also for designing an assigned section of the standardized portion of the plant. (The site-specific parts of the plant vary from about 7% of total cost for a river site to about 20% of total cost for a site with open cooling and unfavorable terrain). Detailed design and engineering of the NSSS and turbine generator systems are undertaken by Framatome and Alsthom respectively, but responsibility for technical coordination of the interfaces between these

systems and the rest of the plant rests with the EdF regional offices. Detailed design of the auxiliary systems and the balance of plant is undertaken by the regions themselves. The regional design assignments have varied from one series to the next, and not all of the regional departments have been involved in each series. The design process is coordinated by a committee consisting of the heads of each regional department, and design problems affecting more than one department are generally resolved at the regional level and not by headquarters.¹⁸

Each regional department is also responsible for preparing and negotiating the contracts for its assigned portion of the plant, and for monitoring supplier performance. Division headquarters also participates in the negotiation of the very large contracts, and provides centralized monitoring of contract price trends. EdF's cost monitoring efforts were recently extended to the subcontractors of its major contractors.

¹⁸ Prior to the rapid expansion of the nuclear program in the early 1970s, the power plant design process had been still more decentralized within EdF. Although the general size and technical specifications for fossil plants had been relatively uniform, each regional department had designed and built its own plants. Given the demands of the massive nuclear construction program and, especially, the expected benefits of standardization, such a decentralized approach to design and engineering was clearly no longer practical. On the other hand, complete centralization of the design function within SEPTEN was also not an attractive option. SEPTEN had previously been primarily a research and development organization. The practical architect-engineering experience was concentrated in the regional departments. Transferring the architect-engineering capability to SEPTEN would have been highly disruptive, and would have weakened the existing close links between the design and construction functions, since the latter would still be undertaken by the regional departments. Moreover, the design of the several standardized series overlapped in time, and the burdens on a central organization pursuing several major design projects in parallel would have been considerable. The organizational scheme that was chosen can be interpreted as a compromise between the benefits of standardization and centralization, on the one hand, and regionalization, on the other. An interesting question is whether this will remain the most attractive approach during a period when the design workload will be sharply reduced.

The five regional departments are responsible for supervising the construction of the plants built within their regions. There are typically 100 - 150 Engineering and Construction Division personnel on site for a 2-unit project, of which over half are engaged in contractor coordination and surveillance. Overall responsibility for quality rests with the utility, which prescribes quality assurance programs for its contractors, and conducts frequent quality audits both at manufacturing facilities and on site. The plant operations staff begins to assemble at the site several years before the plant is commissioned and participates in equipment testing and commissioning, but overall responsibility for the plant remains with the Engineering and Construction Division until the first connection to the grid is made. At that point, a complete transfer of responsibility to the Operations Division takes place.

VIII. Comparative Analysis of Project Organization

Table 3 summarizes the principal differences in the organization of nuclear power plant projects in the three countries. We next examine the economic implications of these differences using the transaction cost framework.

The German utilities externalize a high proportion of the supply tasks, most of which are incorporated within a single supply contract. Scale economy considerations favor external contracting, in view of the small size of most utilities' nuclear programs. Further, the integration of these functions within a single turnkey contract yields several benefits, including greater ease of coordination, fewer project coordination burdens on the utilities, and

fewer performance measurement problems.¹⁹ But these advantages must be weighed against the transaction cost penalties associated with the potential for opportunistic behaviour by KWU arising from its status as a powerful monopoly supplier.

The safeguards against these hazards have taken several forms. The risk sharing provisions of the turnkey contracts have been a major factor in building utility confidence in the integrity of the supply arrangements. Although KWU's contractually obligated share of the costs of unforeseen regulatory changes has apparently fallen over time, its continuing obligation to pay a percentage of all ex post modifications provides assurance that unnecessary changes are not being made.²⁰ This expedites agreement among the parties as to what should be done, and reduces the risk of costly construction delays caused by haggling over who should pay. A common practice is to lump the costs of modifications into large blocks and to conduct cost allocation negotiations between the utility and KWU at a later date.

The availability guarantees provided by KWU were reportedly an especially important factor in building utility confidence in the early years of the program. According to several utility spokesmen, the reason that the guarantees did not appear in later contracts was that they had outlived their usefulness; the operating performance of KWU plants was proven, and the

¹⁹ A KWU spokesman reported that there were over 60,000 design 'interfaces' requiring technical coordination in a PWR plant design. The nature of these designs is such that if design responsibilities were divided among two or more firms, many such interfaces would inevitably have to be negotiated across corporate boundaries, however the division was made.

²⁰ In the earliest contracts KWU reportedly agreed to pay 33% of the costs of unforeseen regulatory changes.

guarantees were no longer worth their cost to the utilities. The remaining guarantees for materials and components are only in effect for two years and at least one utility spokesman suggested that they do not pose much of a financial risk to KWU. On the other hand, KWU retains contractual responsibility for component and construction quality and for correcting any quality deficiencies detected during construction. Utility spokesmen stressed that these contractual responsibilities, combined with the third-party quality verification efforts of the TÜVs, provide important assurances of the quality of the completed plants.

Information asymmetries between the utility and KWU are reduced by the performance monitoring teams located at utility headquarters and on site, and also by what spokesmen for both KWU and the utilities described as close communications between the utility companies.²¹ To further reduce information asymmetries, utilities have often hired outside consultants to evaluate KWU cost estimates (especially for backfits). More generally, the relatively small scale of the German nuclear program, and the fairly closely knit character of relations between the principal participants in industry and government, have probably acted to reinforce the reputational constraints on opportunistic behaviour by KWU. One utility spokesman suggested that although increased competition would provide the most effective constraints on

²¹The Federal Interior Ministry at one stage considered introducing legislation requiring each utility to designate a coordinator of inter-utility information exchanges. This initiative was reportedly dropped when it became clear that extensive information sharing was already taking place informally. An important official forum for technical exchange is the Technische Vereinigung der Grosskraftwerksbetreiber (VGB) which was originally created to address operating problems with fossil-fueled plants but has more recently expanded its activities to deal with nuclear power plants.

opportunism, KWU's aspirations for further domestic and export orders and the reputational concerns of its parent, Siemens, had helped to prevent it from fully exploiting its monopoly position in the past. Finally, the Convoy program, though its primary stated purpose was to reduce regulatory uncertainties and promote economies of scale, can also be interpreted in transaction cost terms. The combination of regulatory stabilization and design standardization has reduced the need for costly ex post contractual renegotiations and hence has reduced the risk of ex post opportunism by KWU.

The scale economy and transaction cost arguments that shed light on the advantages of turnkey contracting in the German context also suggest why the scope of the turnkey contract is incomplete. Separate contracts are written for parts of the plant whose design is highly site-specific (e.g., cooling structures), or where the freedom to choose is valued by the utility but has little bearing on the design of the rest of the plant (e.g., administrative buildings and warehouses), or where the utility has long had special competence (e.g., civil works in the case of RWE).

Further, the turnkey contract scope varies depending on the technical and managerial resources of the client utilities, again as expected. RWE, the industry leader, has been at the forefront of efforts to dilute the market power of KWU. It has typically taken direct responsibility for a higher fraction of the total plant worth than the industry average, for example subcontracting directly with its civil engineering subsidiary for all of the civil works. During the late 1970s, moreover, it reportedly sought to move away from the turnkey approach towards a split package scheme, although interest in this initiative waned following the Three Mile Island accident, as the value of an integrated approach to plant design and engineering became

more evident. Nevertheless, RWE's reservations about the turnkey approach continue, and the utility has recently proposed a scheme under which KWU would retain plant-wide responsibility for design and licensing but the utility would be more actively involved in procurement and hence able to promote more competition among suppliers.²² Predictably, the smaller utilities, who are generally less able than RWE to do anything about these issues, have also tended to show less concern about them, and several officials from these companies were sceptical about the postulated economic benefits of a departure from the turnkey concept. Since RWE is clearly viewed as the industry leader, the other utilities are able to enjoy some of the benefits of RWE's more activist posture towards KWU without incurring the costs, and can therefore probably afford to take a somewhat more relaxed view of KWU's monopoly position.

As in Germany, the general pattern in the Japanese nuclear industry has been for the utilities to externalize most of the principal supply functions and for the latter to be largely incorporated within a single contract. Compared with their German counterparts, however, the Japanese utilities appear to take a significantly more active role in coordinating, supervising and monitoring their suppliers. The larger utilities are among the largest and most powerful industrial corporations in Japan, and, despite the great

²²RWE's preoccupation with the lack of competition in the supply industry is longstanding. In 1973, it contracted with Babcock-Brown Boveri Reaktorbau (BBR) in association with the Brown Boveri Company (BBC) for the turnkey supply of the Mühlheim Kärlich plant in an effort to reverse this. This plant has encountered a number of problems during construction, however, and is not regarded as an encouraging precedent. During the early 1970s other utilities explored the purchase of NSSS systems from U.S. vendors, but these discussions were discontinued when the costliness of the adjustments that would have to be made to comply with German regulatory specifications became evident.

size and strength of the nuclear supply consortia, appear to deal with them on technical matters on at least an equal footing.²³

In recent years the utilities have become increasingly concerned over the rising costs of nuclear power generation. The cost advantage relative to fossil power plants, once substantial, has now largely disappeared according to data recently released by the Ministry of International Trade and Industry. The utilities have begun to focus more strongly on cost reduction measures, and have let it be known that a 10% reduction in cost per unit of capacity will be required for the next round of plant bids. Among the utilities' other targets are the potential inefficiencies associated with the low level of competition in the supply industry. Several utilities reported plans to increase their influence over the subcontracting practices of their main contractors. Tokyo Electric's announcement, in 1981, of plans to study the feasibility of introducing KWU PWRs can similarly be interpreted as an attempt to increase pressure on the domestic suppliers. Interestingly, however, unlike the German utility RWE none of the Japanese utilities whom we interviewed expressed any interest in departing from the turnkey-style approach to contracting; indeed, all of them indicated a strong preference for this arrangement over any alternative.

Also, the efforts to increase supply-side competition have not been accompanied by a focus on measures to strengthen ex post contractual safeguards. In our interviews the utilities generally evinced little concern over the risks of incentive misalignment and supplier opportunism during

²³The utilities, led by Tokyo Electric and Kansai Electric, have, for example, played a key technical role in the development of the latest generation of LWR designs, the first for which the Japanese nuclear industry has had lead technical responsibility.

contract implementation. Utility spokesmen pointed out that their main contractors were well aware that the sustainability of the national policy consensus in favor of nuclear power depends strongly on the continuation of the nuclear cost advantage over fossil fuels, and that this should be a powerful motivation to keep costs down. But the utilities' stated confidence on this point must also be seen in the general context of a domestic commercial environment in which there are powerful institutional and cultural checks on opportunistic behaviour. Contractual relationships are typically stable and close. A high value is placed on continuity and the preservation of amicable relations, and the penalties associated with a loss of reputation are correspondingly high. Williamson (1985, p.123) cites Kitagawa, an expert on Japanese contract law, on this point:

Japanese businessmen place more emphasis on building up a personal relationship than on drafting a detailed contract; all decisions are made by the group rather than the individual; lawyers are usually not consulted during the negotiations. (Kitagawa, 1980, p.1-24).

Expressed in transaction cost terms, parties enter into commercial relationships with greater confidence in the integrity of the transactions, and less emphasis is placed on the negotiation of formal contractual safeguards against bad behaviour.

The French nuclear power plant supply process has been characterized by a higher rate of reactor ordering (until recently) and a higher level of standardization than in either Japan or West Germany. Large economies of scale, both static and dynamic, have been realized as a result. In West Germany, because of the fragmented structure of the utility industry and the relatively small scale of the nuclear sector, the price of standardization was the concentration of industrial power in the hands of a single integrated

supplier and the various transaction cost penalties that go along with such an arrangement. In France, by contrast, standardization has been possible without these transaction cost penalties. Because EdF is the sole owner of nuclear plants and because of the large scale of its nuclear program, it has been able to internalize the project management and architect-engineering functions, thereby economizing on transaction costs in these areas, without at the same time sacrificing any economies of scale.

In turn, standardization has helped to reduce other transaction costs. The placing of orders for entire plant series economizes on both the ex ante costs of negotiating contracts and the ex post costs of contractual governance structures. Also, the fact that very few changes in design and construction occur over the course of a series means that ex post contract renegotiations are in any case not common. Third, since engineering is largely completed before manufacturing and construction of all but the first member of a plant series has even begun, and since the likelihood of change during the series is low, fixed price contracting for construction work is expedited. And fourth, the high level of standardization allows meaningful measurement of contractor performance from one job to the next. EdF's contractors are in any case motivated to perform well because of the strong likelihood of repeat business.

EdF's practice of awarding a relatively large number of separate work packages has increased the ex ante contracting costs (e.g., more as well as more detailed specifications, more bids to evaluate, etc.). But it has also worked to EdF's advantage in that the precise specification of individual work packages has further facilitated fixed-price bidding. Moreover, this disaggregated approach to procurement has given EdF greater flexibility to achieve the optimal balance between the exploitation of competition, on the

one hand, and economies of scale, on the other. Thus, in areas such as NSSS and turbine generator supply, where static scale economies and learning effects were expected to be large, EdF has directed its procurements to a single supplier. Similarly, highly skilled craftsmen specializing in nuclear-grade work such as reactor equipment installation have typically been rotated from site to site. On the other hand, EdF has promoted inter-supplier competition in areas such as civil works where there is generally less potential for learning or static scale economies.

IX. CONCLUSIONS

The preceding comparisons have shown that there are substantial differences between West Germany, France and Japan in the level of utility involvement in nuclear power plant projects and in the degree of functional integration in the supply industry. The discussion has also shown how, as a result of these organizational differences, the relative contributions to overall economic performance of production scale economies, transaction cost economies and the efficiency gains of market competition have varied in the three countries.

The German utilities have been the least actively involved in design and construction, and the nuclear power plant supply process in Germany has most closely approached the single contractor, turnkey plant model. In Japan the scope of plant supply contracts has been almost as broad, but the utilities have played a more active role in project management and quality assurance, and also in design decisions. Electricité de France has acted as its own architect-engineer and project manager from the outset, and enters into many separate contracts for equipment and services, a large fraction of which are

bid competitively.

By contracting almost exclusively with KWU, and more recently by adopting the standard Convoy design, the German utilities have permitted whatever economies of scale were available in the relatively small domestic market to be exploited. The penalty associated with this strategy has been a general absence of supply-side competition and a user-supplier relationship in which the potential for supplier opportunism is considerable. Contractual incentives, design standardization and regulatory stabilization have helped to reduce the hazards of opportunism.

In Japan, the division of the nuclear plant market between three suppliers has meant that potentially available scale economies have not been exploited; and the offsetting benefits of market competition between suppliers have been reduced by the utilities' practice of only building either PWRs or BWRs. On the other hand, the risk of ex post opportunism by Japanese plant suppliers is lessened by a combination of contractual incentives, reduced information asymmetries (as a result of the bigger utility role) and cultural and institutional constraints on opportunistic behaviour.

In France, EdF has been able simultaneously to realize scale economies and exploit market forces through a combination of design standardization and work package disaggregation. The latter has led to increased contractor coordination costs, but the penalties here have been lessened by the stable environment in which the projects are conducted. Also, because of its size and status as the sole French utility, EdF has been able to economize on transaction costs by internalizing the project management and architect-engineering functions without at the same time sacrificing scale economies.

The transaction cost approach cannot explain why these international differences in project organization have arisen, since they are much less the outcome of the formal economic optimization process assumed in the theory than of state-specific combinations of industrial tradition, legal restrictions, political initiatives and administrative planning. Neither is the transaction cost framework sufficiently well developed to predict quantitatively how these differences will affect economic performance. Nevertheless, within each country the theory can provide useful qualitative insights into the likely economic outcome of proposed organizational changes or of changes in the external environment - for example, a shift away from the turnkey approach in Germany, or a decline in the reactor ordering rate in France. And it can also provide insights into why an organizational approach that is effective in one national industrial and cultural context might be more or less effective in another - for example, why a set of institutional arrangements that works well when there is a general expectation of frequent ordering, and when there are powerful cultural constraints on opportunistic behaviour, may be quite unsuited to circumstances in which ordering is infrequent and opportunism is more prevalent.

In addition to the organizational differences that we have observed, several similarities also deserve emphasis. First, in each country a matching of financial risk with technical control has been achieved, and the limits of contractor responsibility are generally well defined. Second, in no case has the project management function been delegated to an independent third party firm. Either the utility acts as its own project manager (France), or it delegates this responsibility to its prime contractor (Germany), or the utility and the prime contractors share the task (Japan). Third, in all three

countries the suppliers have maintained close links with the utilities after their plants have gone into operation. Finally, in most instances the expectation of both the utility and the supplier has been that the two will collaborate on future projects.

* * *

ACKNOWLEDGEMENT

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Table 1: German Nuclear Utilities^{1,2}

Utility	Nuclear units for which utility has lead technical responsibility		Nuclear units in which utility has over 10% ownership	
	In operation (MWe)	Under construction (MWe)	In operation (MWe)	Under construction (MWe)
RWE	4892 (4)	1223 (1)	4892 (4)	1223 (1)
Bayernwerk	2099 (2)	1285 (1)	4597 (4)	1285 (2)
NWK ³	1860 (2)	--	3891 (4)	--
Preussenelektra	1931 (2)	1307 (1)	3161 (3)	1307 (1)
Hamburgische - Elektrizitätswerke	2031 (2)	--	2661 (3)	1307 (1)
EVS	1394	--	2460 (3)	1239 (1)
Badenwerk	1066		2460 (3)	--
Neckarwerke ⁴	810 (1)	1239 (1)	1138 (2)	1239 (1)
VEW	--	1242 (1)	--	1242 (1)
Other ⁴	--	--	--	--
TOTAL	16,083 (16)	6,296 (5)		

¹Status as of January 1, 1985 (compiled from Elektrizitätswirtschaft, Vol. 5, 1985, p. 165)

²Figures in parentheses denote number of units.

³NWK merged with Preussenelektra in 1985.

⁴Non-DVG utilities.

Table 2: The Nuclear Power Industry in West Germany, France and Japan¹

	<u>West Germany</u>	<u>France</u>	<u>Japan</u>
Total electricity generation (Twh):			
• total including industry owned	408.6	328.8	648.6
• electric utilities	346.4	297.7	582.2
Percentage of electricity generated by nuclear power:			
• total including industry owned	30.8	64.8	20.7
• electric utilities	36.3	70.9	22.9 (22.4)
Total nuclear capacity in commercial operation (MWe)	16,084	37,800	20,561 (24,521)
Percentage of capacity supplied by nuclear power			
• total including industry owned	17.5	43.5	12.7 (16)
• electric utilities	20.5	n.a.	13.9
Total Number of nuclear reactors in commercial operation	16	44	28 (32)
Number of PWRs	9	38	13 (15)
Number of BWRs	7	--	14 (16)
Average number of nuclear units completed per year: 1/81 - 1/86	1.2	5.2	2.2
Projected nuclear share of generation in 1995	32.5	74.9	35.8

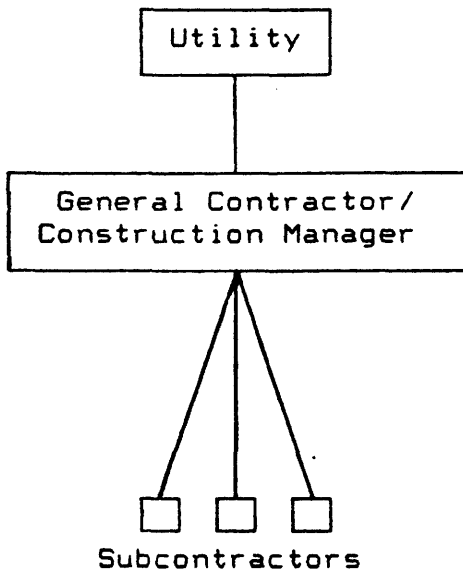
¹The data for West Germany and France are as of the end of 1985. Data for Japan are as of 3/31/85; data for the end of 1985 are given in parentheses when available.

Table 3: Nuclear Power Plant Project Functional Responsibilities

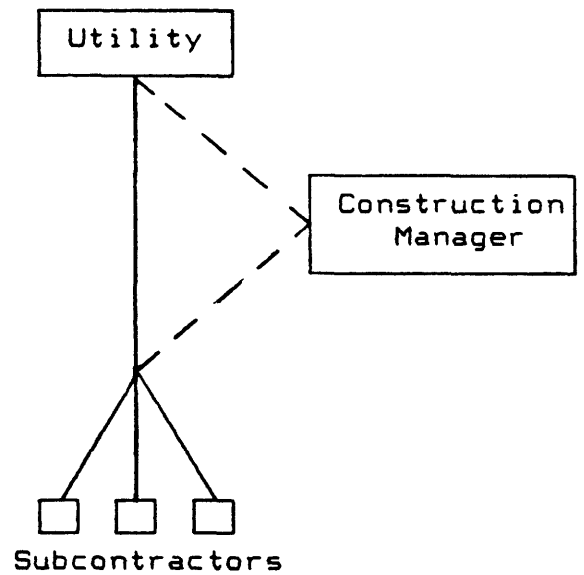
	West Germany	Japan	France
Turnkey	Yes	Yes	No
Design and engineering	Supplier	Supplier	Utility
Construction workforce	Supplier	Supplier	Supplier
Construction management	Supplier	Supplier/Utility	Utility
Project management	Supplier	Supplier/Utility	Utility
Licensing	Supplier/Utility	Utility	Utility
Quality assurance	Supplier	Utility/Supplier	Utility
Supply-side functional integration	High	High	Low

FIGURE 1

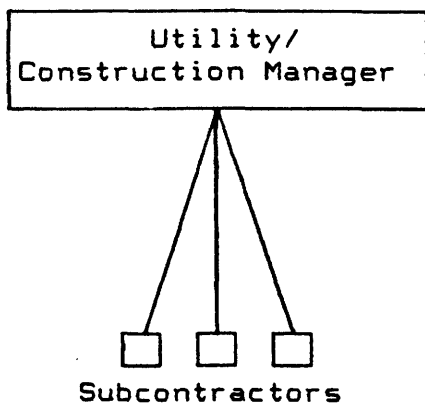
ORGANIZATIONAL STRUCTURES FOR POWER PLANT CONSTRUCTION



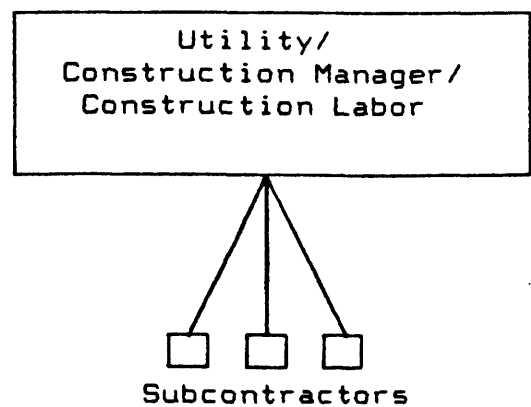
(A)



(B)



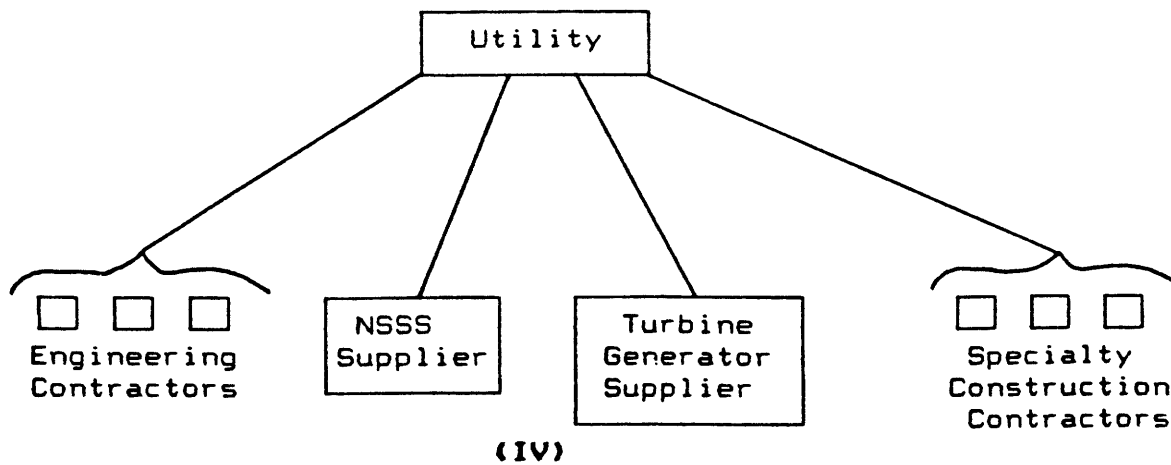
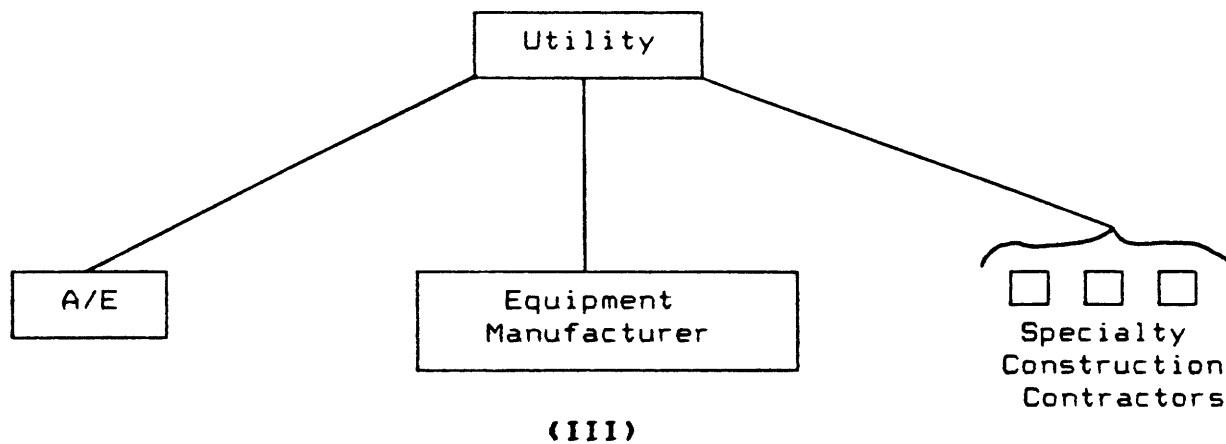
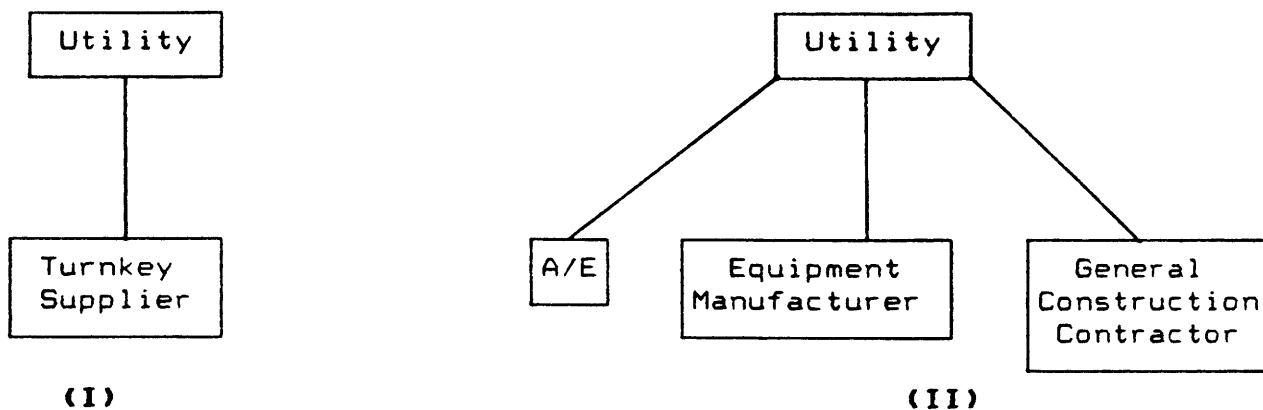
(C)



(D)

FIGURE 2

ALTERNATIVE NUCLEAR POWER PLANT PROJECT STRUCTURES



APPENDIX

Interviews with the representatives of the following organizations were conducted by the authors in West Germany during January 1986:

Federal Ministry of the Interior

Ministry of Trade and Commerce for North Rhine Westphalia

Gesellschaft für Reaktorsicherheit (GRS - Reactor Safety Company)

Kerntechnischer Ausschuss (KTA - Nuclear Safety Standards
Commission)

Technischer Überwachungsverein (TÜV) Rheinland (Technical
Surveillance Association for Rhineland)

Technische Vereinigung der Grosskraftwerksbetreiber (VGB -
Association of Large Power Producers)

Kraftwerk Union (KWU)

Badenwerk AG

Bayernwerk AG

Energieversorgung Schwaben AG (EVS)

Preussische Elektrizitäts AG (Preussenelektra)

Rheinisch-Westfälisches Elektrizitätswerk AG (RWE)

During April 1986, interviews in France were held with representatives from several divisions in Framatome, and with officials of the Direction de l'Equipement (Division of Engineering and Construction) of Electricité de France (meetings were held both at division headquarters in Paris and at SEPTEN in Lyon).

During 1983, 1984, and 1987 interviews were conducted with representatives of Tokyo Electric Power, Kansai Electric Power, Chubu Electric

Power, Shikoku Electric Power, Tohoku Electric Power, the Japan Atomic Power Company, the Electric Power Development Company, Mitsubishi Heavy Industries, Toshiba Corporation, Hitachi Ltd., Shimizu Construction Company, the Japan Atomic Industrial Forum, the Agency for Natural Resources and Energy of the Ministry of International Trade and Industry, the Science and Technology Agency, and the Japan Atomic Energy Commission.