NUCLEAR POWER OPERATIONS: A Cross-Cultural Perspective

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Being a nuclear operator is like having memorized a very long, difficult Goethe poem, but you never get the opportunity to recite it. At least you hope you don't.
A German Senior Control Operator

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INTRODUCTION

The work reported here is somewhat unusual for a comparative article in *Annual Review of Energy and the Environment*, because its focus is on operations rather than outputs, and it is cross-cultural and sociological rather than cross-national and aggregative. International comparisons of energy use or environmental quality, for example, tend to consist of formidable ensembles of charts, tables, and other numerical data, painstakingly collected, usually from secondary sources, and assembled to report trends and prognosticate future developments with the abstracted nation-state as the unit of analysis.

Cross-national is usually a term flexible enough to describe the analytic boundaries of a wide variety of comparative studies, but it suffers from uncertainty as to whether the context of interaction is culture or some other social variable (1). For our purposes, the term cross-cultural is more precise and more rigorous. Moreover, the nation is the context of our inquiry, not its object (2); the purpose of broadening the scope of the research was not to compare national performance, but to compare plants operating in the broadest possible range of social and cultural circumstances. By demonstrating the salience of social and cultural settings in the case of a very advanced and relatively homogeneous international technology, we point out the importance of including such variables as functional elements of operational analysis and technological assessment.

In the course of extending previous research on reliability in nuclear plant operations to a comparative cross-national study for the purpose of seeking the social origins of US operational and regulatory practice, we found cultural differences that were operationally and functionally significant (3). Moreover, other recent work at the operational level indicates that the importance of such cultural variances is often ignored, even in the process of developing new rules for plant operation and safety (4–7). There is a marked gap in the literature between studies that address nuclear power in normal operation at the general level (8–12, for example) and those that address specific incidents of notable failure in great detail. It is this gap that the present work, and this review, seek to bridge.

Comparative research emphasizing the importance of the cultural and social environment on industrial operation has historically been concerned more with the status and social development of the worker than with the operational safety, reliability, or performance of the plant. The literature on cross-national studies of more traditional industries has found national, regional, and even local culture to have a strong effect on worker performance and attitude (2, 13–18). Little of this work has been extended into the area of energy and the environment.

In recent years, a new body of literature concerning safety and reliability has emerged that addresses operations as an integrated sociotechnical system,
emphasizing the processes by which operators construct and maintain integrative, cognitive maps (19-25). But much of this work assumes that the social context in which these cognitive configurations are constructed is sufficiently described by specifying plant and technology as the primary task environment. If, on the other hand, cultural differences persist even in advanced, sophisticated technologies such as nuclear power plants, then studies of cognitive maps, and therefore of plant operational safety and regulatory procedures and regimes, should explicitly take cultural differences into account.

Our study was deliberately confined to large commercial pressurized-water reactors (PWRs) as deployed in the United States and Europe. The choice of similar plants controlled, as far as was practicable, the technically determined variance in equipment and operational practice. Limiting the inquiry to countries that are at similar stages of technical, social, and economic development further controlled the range of social variables. The result is an exploration of the potential for in-depth comparative socio-cultural analysis at the operational level, performed in the most demanding case of the simplest possible comparative environment.

We present here a summary of similarities and differences observed in reactor control rooms, in the context of a review of the literature that framed and shaped our inquiry. After a brief overview of the scope, background, and origins of our study, we set it into the context of cross-cultural research, with particular attention to the methodological strengths and shortcomings of working in depth with a small number of cases. Following a summary of our observations and a discussion of their relevance, we conclude that the cultural variations we observe are indeed functional adaptations to specific social and cultural environments.

Despite the preliminary and exploratory nature of our own work, we find that even in this relatively narrow range of technical and social circumstances there is a wide range of acceptable strategies for operating or regulating a plant or an industry, based on practical and pragmatic adaptations to national, and sometimes local culture, circumstance, and history. This emphasizes the importance of giving an expanded role to social and cultural work in future research on operational reliability and safety—not only for the nuclear power industry, but also for other industries whose potential hazards to human health and the natural environment require a high degree of operational vigilance and performance.

BACKGROUND

Origins of the Study

Our foray into cross-cultural research began as an outgrowth of an empirical study of organizations tasked with operating sophisticated and complex tech-
nical systems in such a way as to actively control the hazards to which workers or the public is exposed (26–28). Despite the concern over the consequences of failure in these critical organizations, we had no baseline from which to judge their ordinary performance. With few exceptions (29), remarkably little work has been done on the culture of advanced technical operations except in the wake of failure.

Since every form of complex industrial or technical operation has its own unique characteristics, the base study was comparative from the outset (28). Permission was eventually obtained to study en-route air traffic control, flight operations aboard US aircraft carriers, and utility grid management (27). Because each has been able to operate well and reliably while protecting workers and the public, we hoped to be able to shed some light on organizational strategies for actively minimizing risk even in inherently hazardous operations (30).

As an unexpected extension of our utility work, we were then further encouraged to study the performance of the utility’s nuclear power plants—primarily for the sake of broadening the base of our field work. Within this broader scope, the authors of this review performed many months of direct observations and interviews over two years “in the field”—in this case the control room of a large commercial PWR.

Nuclear power operations turned out to be surprisingly different in several functionally important dimensions (31, 32). Because of the general social and historical circumstances surrounding nuclear power, operations come under unique industrial and regulatory scrutiny. In reaction to public concerns, the US Nuclear Regulatory Commission (NRC) maintains a pervasive, critical, and often adversarial presence at the plant (33–35). Of late, this has been supplemented by a variety of other institutional reviews of plant performance, some sponsored by the industry itself and others required by the NRC. Many operations managers expressed to us in interviews a concern that the attention to compliance or getting a “high grade” was seriously affecting operator behavior. Yet, little is known of the degree to which efforts to limit dramatic single-instance accidents help or interfere with day-to-day operations (7, 36, 37).

It is clear that regulation and scrutiny are affecting operator behavior. But which behavior and with what consequences? It was nearly impossible to say. The plant has almost totally internalized those modes of behavior directed towards regulatory compliance, to the point where they overlap and integrate with functionally derived ones (32). Moreover, because NRC penalties are strict, and sometimes severe, avoiding them has become functional regardless of whether the plant operators themselves think that plant safety is involved. But once in place, routines are almost never altered without some serious external reason. The nature and scale of the potential risk—social and regula-
tory as well as technical—are such that the organization is unlikely to experiment to see whether an established pattern of behavior is or is not functionally important (31). The costs of error are simply far too high (32, 38).

Seeking to distinguish functional behavior from superficial reaction to the stress of the social and regulatory environment, we decided to do a comparative study with another plant—preferably one that was technically similar but located in a very different political and regulatory setting. Through a series of fortuitous circumstances, we were able to identify and gain access to a plant of nearly identical design in Germany. But it was more difficult than we had thought to separate the variance. Although it is known that national styles of regulation vary (39–41), and that national cultures matter even in the case of nuclear power (42, 43), we found many more similarities and differences in operation and regulation that seemed to be tied to national and local variations in culture than we had expected. Accordingly, to plants of similar design in France, Switzerland, Sweden, and, eventually, a second plant in the United States.

The US Context

If there is any one single point upon which all of the parties to the ongoing nuclear power debate agree, it is the importance of ensuring safe and reliable operation (10–12, 44). Efforts to further this goal fall into three sets of requirements: first, that as much protection as possible be engineered into the technical systems (45, 46); second, that regulation be comprehensive, pervasive, omnipresent, and detailed (11, 32, 33, 35, 42, 47); third, that operations be configured to minimize the potential for human error (25, 48–52). The resulting regulation of plant operations is unprecedented (53, 54), to the extent that there is some concern that regulatory behavior has played a major role in driving up operating costs both directly (55) and by the constraints imposed upon operational discretion (11, 56).

Prior to the accident at Unit 2 of the Three-Mile Island nuclear plant (TMI-2) in March of 1979, studies of nuclear plant safety were focused largely on technical aspects—primarily the design, construction, and reliability of the equipment (57, 58). Sophisticated engineering techniques such as probabilistic risk assessment (46, 59), developed specifically to address matters of plant safety, tended to regard the human operators as little more than possible initiators of failure sequences (60–62). In the wake of TMI-2, many of those involved with quantitative risk assessment began to question whether the human dimension of safety analysis had been adequately taken into account (22, 23, 50, 63). Increasing attention was given to the possibility that human error was at least partially due to systems that taxed or exceeded the capabilities of human operators (25).

In the United States, the Institute of Nuclear Power Operations (INPO) was
created by industry specifically to improve plant operations and go beyond formal standards for safety. One of its first accomplishments was to increase general awareness that plant operations was an important technical discipline; that a plant had to be operated was something of an afterthought not only to the vendors, but also to the design- and engineering-oriented people at the NRC, and even the utilities themselves (64). INPO was largely responsible for giving operators and their supervisors proper recognition for their positive contributions to plant safety and reliability (64). Over time, human factors research on nuclear power became something of a discipline (65). But much of this was highly reductionist research on individual or small-group psychology or on the man-machine interface.

The circumstances leading to the severe accident at Chernobyl brought to the fore a second recognition about plant operations—that operators are not isolated human beings performing differentiated and individuated actions in response to technical and instrumental demands. Whereas it could be argued that TMI-2 was a case in which human operators could do little but try to contain the damage once the sequence of events was initiated (19, 62, 66), the operators at Chernobyl deliberately took the reactor into an operational configuration known to be dangerous (10, 67–70). This gave a further impetus to the program for folding “human reliability analysis” into quantitative risk analysis methods, albeit with somewhat mixed and controversial results (19, 22, 23, 50, 60).

The most recent development in human factors analysis has been the recognition that the operation of nuclear plants and many other complex, potentially hazardous technologies is a craft performed by a highly trained and coordinated team of operators (5, 7, 25). Of particular interest in this growing literature are those studies that take the social-organizational context as a primary determinant of the human dynamics of operation (20, 26, 38, 61, 66, 71–74). This work underlaid and framed our research.

A Cautionary Note on Safety

The plants we studied were all highly regarded in the industry, were “available” to generate electricity a high percentage of the time and, in the case of the US plants, had high ratings from the NRC. Some of our observations almost certainly bear on maintaining reliability, particularly under recent social and institutional pressures for change. But a certain amount of caution must be exercised before concluding that our results bear directly on safety. Maintaining reliability and efficiency is not always congruent with ensuring safety and may sometimes work against it (37, 75).

Moreover, since our study involved only a few visits of limited duration, we have very few observations of plant operations during the infrequent periods of relatively high stress. In the absence of any serious longitudinal
diachronic research (an absence that also characterizes such recent efforts as visits by US plant operators to eastern Europe or the worldwide circulation of INPO and NRC teams), it is perhaps dangerously unsound to generalize about the overall quality of organizational performance, particularly under stress (15, 76).

CROSS-CULTURAL RESEARCH

Studying Culture

"Culture" has become somewhat of a cliché in comparative studies of technology, a portmanteau for those aspects of behavior that are not readily quantifiable or explainable in terms of technical rationality. Taken as an implicit feature of social life, "culture" describes roles and interactions that derive from deeply held norms and values in the sociological tradition, or from beliefs and attitudes in the psychological one (77, p. 50ff.). But culture is not a well-defined concept even in the social sciences (78, 79). There are several disciplinary schools, each with its own terminology, and at least two major approaches—culture as structure and culture as product—that cut across disciplinary lines (77).

The growing interest in cultural studies of social agency over the past decade has tended to focus on culture as an explicit social construct or product, to be studied in terms of external manifestations (80, 81). The "social movement" school, to which most of the existing cross-national and comparative studies of nuclear energy belong, falls into this category (82–86), as do most prior comparative studies of nuclear regulation (34, 35, 40, 42). What we learn from the above studies, however, is more about the interaction between national and nuclear cultures than about plant operations (87).

In contrast, this review focuses on the physical operation of the plants. We take culture to be neither a holistic narrative or philosophical text, nor a formal construct or property subject to quantifiable analysis as it is in studies of "organizational" culture (72, 88), nor even a means or mechanism for capturing a wide variety of performative variables as it is in most studies of "safety culture" (51, 52, 89, 90). Rather, it is a heuristic device for exploring and describing historically and socially determined behavior (91). To study culture in this light is to search for the often masked constitutive rules of collective behavior, to tease out the underlying framework that shapes the way in which internal as well as external social relations and social interactions of organizations are constructed (92, 93).

Until recently, very little work had been done on the effects of culture on the normal operation of complex, modern technologies. Its causal role had been raised primarily in the context of technical disasters. Accidents such as
those at Bhopal (94), Chernobyl (69), and Tenerife (95) were attributed at least in part to some degree of incompatibility between the social and cultural predispositions of the operators and the "demands" of the plants they operated. Even so, the question remained as to whether incompatibilities between complex equipment and its human operators were primarily socio-cultural or were variants on other common themes: embedded human error (21); human incapacity to deal with complexity (24, 49); or "normal" accidents that resulted from the nature of the interaction (62, 66).

Our comparative study of the operation of nuclear plants therefore mirrors in the context of the operation of advanced technologies a wider debate over the utility of cultural studies in the social sciences. The central question is easier to express than to explore: Are there behavioral effects of the general social and cultural environment that are central and functional to operational safety and reliability in addition to those that are merely descriptive and epiphenomenal? Our answer is an emphatic "Yes!" Furthermore, it is not always possible to separate the deeply consequential aspects from the apparently superficial ones.

Convergence and Contingency

In contrast to historical assumptions of the dominance of culture and history in shaping industrial organization, the 1960s saw the emergence of arguments for convergence in industrial organization that were based upon universal properties and the abstracted role of bureaucracies. The assumption was that there was a single universal or optimal pattern of structure or organization to fit every setting (96). Most widely known is the institutionalist school (97), which argued that there is only a limited range of variance for organizing an industry based on a given technology; the more complex and sophisticated the technology, the narrower the range. The dynamic pattern of industry, workplace, and social and political accommodation will eventually converge for workers in all societies (98).²

Convergence theory has been criticized on the grounds of overgenerality, ideological and normative bias, technical determinism, and weaknesses in methodology and approach (98). Meaningful empirical tests are hard to come by because they require expensive, lengthy, in-depth comparative longitudinal studies, which are rare in organizational sociology (101). Although there is some supporting evidence (102), most of the empirical studies were directed

²Similar in prediction, if not in structure, were two other schools that have proved less robust. The social-psychological variant made a similar argument by treating the workplace as a tool for personal and social education to create a universal "industrial man" (99). The "evolutionary" hypothesis (100) made similar claims from a more societal perspective, in which convergent evolution was shaped through effects on social structures.
towards manufacturing or other mundane industries. Over time, even the strongest supporters of the school began to minimize the technological imperatives implicit in early theorizing (102a).

A more sophisticated argument that technical organization would free itself from cultural influences arose from contingency theory, which postulates that organizations adapt to context and environment in response to immediate demands or needs. The central hypothesis is that as technologies grow more demanding, contingencies of scale, technical development, and so on impose a common logic of work that becomes a functional imperative (103); over time, these override original differences in culture, background, and general social milieu (104). What remained open was the question of the key variable. Some have made strong arguments that size or environment (context) matters most (103, 105, 105a). Others insist that technology or industry is primary in determining work behavior and structure (17, 106).

The most crucial case for the culture-free hypothesis among industrialized countries is that of Japan, whose “unique” culture has been invoked by many to explain its comparative success. Earlier studies supported the view that worker culture did matter more than for European countries (107, 108). More recent sectorally focused work concludes that even in the Japanese case, convergence has been stronger than popularists would have us believe, and that technology rather than size determines both the structure and the social integration of the firm (109, 110).

Contingency and Culture

We first broadened our study to other countries on the premise that the study of similar plants in different national contexts could be used to evaluate preliminary conclusions drawn solely from US data. But as the study progressed, it became clear that the differences we observed arose more from variations in culture than from those in formal structures—an observation that was reinforced by noting the degree of variation even between two quite similar nuclear plants operated by different utilities in two different regions of the United States.

There is a body of literature that argues that the culture-free thesis is of limited importance. Although much of the research has concentrated on worker attitudes more than performance, some of the observations of intensive cross-country studies are nevertheless salient. For example, researchers have found culture to be responsible for functionally significant differences between similar plants in Great Britain and Germany, (103), and between similar plants in those countries and France (16, 111). An intensive comparative study of France and Germany showed that variances between operators and maintainers of highly automated production technologies were determined almost entirely by differences in national culture rather than work or job status (112).
This work is very much in accord with the general objections first raised by Crozier (113) and later by others (93, 112, 114) to the cultural homogeneity of contingency theory. For example, French operators are more likely to see themselves as located at the base of the class structure in opposition to management than are their German counterparts, while German workers place greater emphasis on workplace hierarchy and formal organization. Social factors such as these strongly affect performative structure and operational design.

Hofstede found significant cultural differences in a 40-country survey of subsidiaries of a single multinational corporation, despite great similarities in formal structure, task environment, and “company” culture (13, 14). Lammers & Hickson (15) have mapped Hofstede’s categories of “hierarchical power distance” and “rule orientation” into a matrix of four cultural archetypes: “Latin” countries, which include France as well as Latin American and most of non-German-speaking Europe, were high on both indices; “Germanic” countries (which included Israel as well as Austria, Germany, and Switzerland), in which up-through-the-ranks crafts had considerable authority, were high on rule orientation but low on power distance; Scandinavian and British countries (i.e. Great Britain and her former colonies), which tended to be low on both scales; and Japan and some other Asian countries, which tended to be high on power distance and low on rule orientation.

These findings regarding the first three archetypes correlate with our own observations, and represent direct cultural influence on organizational structure and operational function. The findings on the fourth category correlate well with reports of similar research done on nuclear plant operation in Japan (M Crocker, private communication).

Large PWRs as a Problem Frame

The few extant comparably culture-oriented cross-national studies of nuclear plant management or regulation are based largely on surveys and static interviews, and tend to address error avoidance or overall approach rather than operational performance (42, 43; JS Carroll, private communication). One of the few studies similar in approach to ours was done 20 years ago on operators at 37 thermal power plants in eight countries, ranging from the most developed (United States, Canada, Japan) to the upper tier of the developing (India, Pakistan, Malaysia) (17). Although the objective was to analyze the prospect for technology transfer, the findings are worth noting for their force. After surveying plants that varied widely in social milieu and technical characteristics (centralization of controls at a single panel then being a relatively new development), the study concluded that organization, job structure, and job culture were determined solely by technological factors, independent of national, cultural, or racial differences (17, pp. 26–32).

The embedded hypothesis is that technology forces a convergence in organ-
izational design, operation, and management over time, regardless of culture (98, 102), and across a wide range of societies (104, 115). In its strongest form, this hypothesis suggests that the internationalization of advanced technologies creates a transnational community of engineers, consultants, etc, whose common approach gives function precedence over culture unless there are vast differences in educational or developmental levels. Large PWRs will therefore have similar design, similar modes of operation, similar components, and so on whether the plant is built in the United States, France, or Japan (6). With few exceptions (3, 4, 6), most studies of nuclear power operations adopt this culture-free hypothesis as a frame, assuming that the functional details of operation of plants of similar design (e.g. large PWRs) will vary little from reactor to reactor, from one part of the United States to another, or even from one country to another. Much of the recent research on the social or human factors dimensions of nuclear operations continues to make similar assumptions (25, 49, 51).

Our primary hypothesis is that the unique historical, social, and cultural environment of each plant does have functional operational consequences. The null hypothesis is that any functionally important differences between plants correlate only with variances in formal structure and design (2, p. 79). Since a great deal of what we saw operators do is held in common from plant to plant with many of the variances explained by details of structure and design, the null hypothesis has considerable predictive power. But it is incomplete in three ways. The first objection is empirical. We have observed significant variations in operations among the several plants that correlate best with differences in social setting and socio-cultural environment, in some cases without any discernible difference in technical or structural characteristics.

A second objection raised by Nicolet (6) is methodological. Studying only individual plants and their organizational environments neglects the possibility that observed convergences are not the result of contingencies at all, but are deliberately designed in by a process of cross-national socialization in which designers self-consciously apply the same shared principles and philosophies (103), thereby suppressing visible expressions of culture.

The third objection is epistemological. For most organizational studies, "cultural" variables are studied by comparative analysis of readily observable formalities of social and organizational structures (104, 110, 116, 117). But this can be a self-defeating strategy for comparing high-technology organizations (105a). Relating organizational structure only to the generalized contextual variables of contingency theory biases the outcome (16, 111), since such variables as size and technical sophistication are by definition universal and relatively invariant across societies or cultures (15, 105a).

Similar objections have been raised by Fujita et al (4), who pointed out that "objective" international surveys used to study plant performance do not work
well in Japan, where workers tend to answer what they think they ought to be saying and tend to present themselves and their companies in the most positive manner possible. Moreover, the notion of technical convergence was directly attacked:

Because nuclear power plant control rooms and systems are very similar in Japan and the United States, [it may appear that] performance criteria should also be similar. The problem associated with this assumption is that truly objective criteria exist for only a small number of performance factors … These criteria are not necessarily meaningful for use in understanding routine performance (e.g. under normal operating conditions). As a consequence, subjective performance criteria need to be introduced. It is easy to imagine that these criteria involve cultural factors. In fact, findings … have shown that social factors play a role in control room operations (4, p. 193).

As Nicolet (6) has put it: “Every high-tech system or network, once conceived by this meta-culture, will have to function in the context in which it exists. If this environment is very different from the one that gave it birth, the cultural gaps to be overcome could be considerable.”

Nowak (118) has pointed out that the more complex the objects of study, the more independent the antecedents of observed behavior, and the more diversified the societies under study, the more difficult to verify comparative work. The assumption of a considerable degree of cross-national similarity is therefore almost a prerequisite for performing methodologically sound research on cross-cultural differences (119). The PWRs we studied are very similar both in size and in technical detail, narrowing the possible range of influence of either technology or size on structure. And the countries we studied are all “North Atlantic” countries at very similar stages of social and technical development. If the null hypothesis holds, there should be no significant differences in structure, management, or operation among the several plants. If there are, culture matters.

RESEARCH DESIGN

Prior to our initial PWR work, we spent several weeks at a fossil-fuel power plant to become familiar with steam plant operations and train ourselves as observers in such a setting. This was important in order to understand the main characteristics of the technical equipment and processes, as well as to become sensitive to the interactions among plant personnel, which are often brief, quiet, and involve jargon and abbreviations, and can therefore be almost impenetrable even to a technically knowledgeable outsider (120). Having been properly socialized, we spent many weeks over the course of more than a year at first training and then doing research at the US nuclear plant before visiting one
nuclear power plant each in Germany, France, Switzerland, and Sweden. Every reactor we observed was of the pressurized-water type (PWR), constructed during the 1970s to produce between 900 and 1300 megawatts (electric).

Every plant we visited had a performance and safety record that was at or near the top of the industry in its country. This was significant for our research in two ways. As stated above, our interest in nuclear power plants emerged in the context of studying how some organizations manage to satisfy performance and safety demands very effectively—in other words, how they succeed in committing fewer errors than one might expect given the nature of their tasks and constraints. Insights related to this question can be obtained from plants with excellent records. Such plants also tended to be willing to grant access to researchers and to have personnel willing to communicate openly with us. The study of “bad” plants as a research control was not an available option.

We interviewed plant staff from different departments, including engineering, maintenance, and management as well operations. Their levels of seniority and responsibility ranged from assistant maintenance personnel and auxiliary operators in their training phase to plant managers. Our particular focus, however, was on physical operation, and the majority of our conversations were with personnel on duty in the control room, i.e. control operators, senior control operators, and shift supervisors. These individuals typically had 10 or more years of operating experience. Due to time constraints, we were able to gather the most representative samples of interviewees at the US plant.

Methodology

Our method of observation, socialization, semi-structured interviews, and elaborated discourse is a blend of the in-depth case study method in the Verstehen tradition (121) and “thick description” (122), which uses ethnographic and interpretive methods (78, 123, 124) to study culture as a frame that establishes mental attitudes and frameworks for action, both in operation and in management of the plants. Although more common in anthropology than in organizational sociology (116), this method has a growing currency in organizational studies (92, 125). It is particularly useful for our purposes in providing a more detailed and naturalistic account of work practices than do cultural survey instruments or other more formal studies of organizational rules, division of labor, and so on (123).

Our most important observations involved rather subtle aspects of individuals’ perceptions of the plant, its operation, and their specific jobs. Such phenomena would be difficult, if not impossible, to fit into a rigid format of data representation without trivializing them. In order to allow for the greatest possible depth of responses, it was necessary to grant interviewees flexibility
in their expression. We were also interested in dynamics such as interpersonal conflicts or authority relationships that differ from the formal organizational structure, which subjects might be reluctant or unable to describe in the context of formal questioning.

Such research must be performed in the field; secondary research, formal surveys, or examination of the typical paper trail laid down by nuclear power plants can only augment and not substitute for direct observation and interactive, semi-structured interviewing at the work site. Accordingly, we proceeded to arrange for site visits and control room access in plants in as many countries as we could reasonably afford to visit.

With ample resources and adequate time, it might have been possible to construct more extensive, rigorous, and formal intercountry comparisons. Given our limitations, we partook of the small-N comparative method as defined by Lijphart (126). Beginning our research with a deep understanding of one plant, and then expanding to a few other cases, allowed at least some basis for generation and testing of hypotheses (127). Our selection of cases allowed us to control the comparison by matching as many variables as possible, using selection to substitute for more formal statistical or experimental controls (127, 128).

Interviews were also used to develop additional hypotheses and lines of inquiry. Subjects often introduced new issues during the course of our conversations that we had not or could not have anticipated. Using the approach of "grounded theory" (129), we did not commence our field research with completely preformed hypotheses. The inductive methodology of grounded theory allowed us to develop a more general theoretical account of our observations while simultaneously grounding it in empirical observations or data (130), and to produce theoretical accounts understandable to those we interviewed (131).

The combination of approaches fostered comparative cultural discourse by providing us with a means for developing in the field a description of those system variables that could not have been identified prior to the field work (92). When studying organizations that manage complex technological systems, it is difficult to know at the outset which observations are relevant; rather, "the system trains the researcher" (28). Our field research thus consisted of touring the plant with personnel, observing and speaking with operators in the control room, observing regular staff meetings, conducting scheduled interviews with individuals in their offices, and having unscheduled, casual conversations on convenient occasions as they presented themselves, e.g. at lunch or in the hallway. In addition, we spent considerable time mastering details of technology, construction, and practice. Our goal was to blend in well enough so that our presence (or absence) would not seriously distort the normal flow of work and conversation.
OBSERVATIONS

In addition to many similarities in plant operation, we observed many differences. Some were substantive variations in context, procedure, and regulation; many of these were readily identified by our interviewees as functionally significant distinctions. Many more were small or subtle: Seemingly insignificant when taken individually, they produce unique and characteristic impressions of the culture of each plant when considered as an ensemble.

Similarities

One obvious similarity among the plants we studied was in the division of work according to formal knowledge requirements: In all of the plants, tasks such as operations, maintenance, nuclear physics, instrumentation and controls, and engineering were separately organized and administered. Another noticeable similarity was in the substantive training of operators, which in each case involved an apprenticeship period during which they toured the turbine building and containment and performed hands-on tasks in the plant as “auxiliary operators” before learning to operate from the control room. We focus here on less obvious similarities that we believe to be representative of the cognitive processes that shape plant operation (132).

Safety Culture

The first of these lies in what is often termed “safety culture” (52, 89, 133–135). When we asked the question, “What do you think is most important for the successful and safe operation of your plant?,” we received essentially the same answer from operators and managers in every country. Aside from the obvious necessity of certain knowledge and skills, what is most important is an atmosphere of openness and responsibility, one in which all individuals regardless of rank feel responsible for every detail of plant operation they can observe, and in which they feel free to point out their observations without fear of adverse consequences to themselves (27).

The unwritten social rules of the plant must allow an individual to discover and draw attention to an error or problem without being blamed for it, and must guarantee that any individual’s concerns are taken seriously and will be responded to. They must also allow an individual to err on the side of safety, i.e. to alert managers to a potential problem or hazard, often delaying other work processes and thus costing the plant money, without penalty or ridicule if there turns out to be no problem after all.

At every plant we were also able to identify an attitude of relentless striving for perfection. This does not imply a belief that perfection in a real power plant is actually achievable, but rather the sense that “good enough” never is. This manifested itself specifically as an awareness that even when the plant is running well, one ought not to become complacent. Thus, we saw operators...
during “quiet times” busy sharpening their analysis, evaluating historical data, and discussing hypothetical scenarios. Managers, too, seemed relentlessly driven by the question, “What could we do better?”

Such continuous striving for perfection, coupled with an atmosphere of honesty and responsibility, represented “safety culture” to almost every one of our interviewees in all five countries. These characteristic attitudes agree well with the definition of safety culture proposed by the International Nuclear Safety Analysis Group (INSAG), which emphasizes attitudinal factors such as “a general habit of thinking in terms of safety, implying a systematic attitude of double-checking, a refusal to content oneself with given results, a permanent concern for perfection, and an effort of personal responsibility and group self-discipline in safety matters” (51, 134). They are also in accord with our earlier work on high-reliability organizations (26, 28, 31, 136).

PROFESSIONALIZATION  The second deep similarity concerns the diversity of organizational subcultures within a plant and an industry. Of the many we observed, we focused specifically on the interaction of “operator” and “engineering” subcultures, labels that mark noticeable differences in cognitive representation and problem-solving styles. Those who partake most strongly of the “engineering” subculture [which tends to coincide better with the professional definition of engineers in the United States than it does with that in European countries (16)] generally hold a view of the plant that can be characterized as abstract, analytical, deterministic, and static. Event and sequence characterization tends to be “linear”—formalized and sequential. In contrast, “operators” generally share a physical, holistic, empirical, and dynamic view (5). Their cognitive map tends to be “nonlinear”—less formal, more integrated, and less subject to sequential dissociation (19).

Our archetypal “engineer” conceptualizes the plant in abstract and formal representation, as a chart where symbols represent idealized components. The plant is understood as the sum of its individual components, connected by specific and discrete linkages; its behavior is predictable according to formal rules governing the behavior of each component (i.e. if all the rules and boundary conditions were known, the state of the physical system at any future time could be predicted unambiguously). The parameters describing components and their interactions are thought of as essentially time-invariant, and invariant with respect to events or conditions not explicitly linked to these parameters (137).

Our archetypal “operator,” on the other hand, thinks of plant components in terms of their physical appearance, sound, feeling, and actual location in the plant (23, 138). Even components that look identical in drawings are recognized for their “personalities” (e.g. a sticky valve). The plant is concep-
tualized as an organism whose components are linked performatively rather than formally. These linkages, and accordingly the behavior of the entire organism, will deviate subtly from the predictions based on idealized components. Therefore, a plant can only be thoroughly understood through empirical observation and operating practice. Interaction with the plant always occurs on a real-time basis, with a continually changing reference frame for interpreting data.

These seeming stereotypes could always be clearly identified—even by the interviewees themselves. In addition to the cognitive differences, there are also external behavioral identifiers such as socialization style, clothing, and sense of humor, which, after some correction for national culture, clearly distinguish operators from engineers. Although both subcultures were represented at every plant, the dividing line between them fell in different places with respect to departmental boundaries or social class; for example, the archetypal “engineers” in Switzerland are those who graduated from a specific university.

Tension between the two subcultures was often expressed in statements such as, “They just don’t understand.” Struggles between the groups for authority or status, within the plant or within the industry, were frequently described. A common area of conflict, for example, was the extent to which engineers have access to and discretion within the control room.

It is remarkable that despite a general awareness of these tensions, both ways of thinking were recognized as having their own legitimacy at every plant; each manager asserted in his own way that both are necessary for successful plant operation. During unusual occurrences that begged immediate explanation, or in situations when consequential decisions needed to be made (e.g. whether to shut down a unit in order to perform repairs or to continue operating), we observed decision-makers drawing on the interpretations of both operators and engineers as having equal status but different perspective without subordinating one to the other.

This remarkable emphasis on system integration at nuclear plants has been noted elsewhere (31). Interdepartmental problem-solving discussions were routine at all plants. They typically involved what amounted to a negotiation as to which representation was more applicable or useful in a given situation. This remarkable ability to maintain what we have termed “representational ambiguity” provided a form of redundancy, offering some insurance against shared misconceptions about the plant (e.g. misjudging the significance of an instrument reading). Cultural diversity and representational ambiguity within the plant therefore appear to be functional adaptations to successful operation; as such, they constitute a remarkable example of organizational convergence in structure and function, with culture entering only in the details of interpretation and implementation.
AUTOMATION

Full automation of the controls was uniformly rejected by almost every operator we spoke to as unworkable, unachievable, and dangerous. All were in accord with the analytical observation that by taking away the easy part of an operator's task, automation can make the difficult parts more difficult (139, 140). Faced with a similar threat, commercial airline pilots were able to argue convincingly that the "glass cockpit" would eventually fill the air with pilots who did not know how to fly the aircraft by hand or anticipate by instinct the onset of trouble (141–143). The problems to be faced as nuclear plants move toward greater automation appear to be very similar (7), but plant operators lack the status and public visibility to mount a similar challenge.

Plant operation has traditionally been a form of integrated parallel processing (5, 7, 20, 65, 138, 144). Operators integrate the disparate elements of the board conceptually, scanning instruments in known patterns and monitoring for pattern as well as individual discrepancies; when an alarm goes off, or there is some other indication of a discrepancy, they scan rapidly across their varied instruments, seeking known correlations that will help diagnose the severity and cause of the event. There is uniform concern that automation will undermine this ability, reducing the ability of the operators to respond quickly in complex situations.

"Clumsy automation" is also a real concern. At times of crisis, automation could actually increase workload; operators may be unable to get to a critical display in time to keep pace with events (138). Individual consoles improve data access, but deintegrate the team, posing challenges to the way in which crews coordinate their activities. Because all controls and displays in a traditional control room have fixed, known locations, operators are able to maintain a situational awareness of each others' actions and make inferences about their intentions by observing their location and movement at the control panels. The use of CRT (cathode ray tube) displays and diagnostic aids such as expert systems linearizes and divides the process, organizing both data and presentations hierarchically and categorically according to engineering principles (7). Computer-based control rooms may make individual actions less apparent to fellow crew members, or may result in fixation on the computer's diagnostic to the detriment of independent thinking (7, 140).

Differences

The most directly functional cultural differences—in control automation, human factors, and regulation—arise when the operators have to be treated as independent human beings rather than intelligent servo-mechanisms.

THE MAJOR DIFFERENCE: REGULATION

The differing character of nuclear regulation among various countries is widely recognized (33, 34, 39, 40, 42, 43, 145). The US style is command-and-control based on strict regulation and
compliance. This is in accord with previous observations that US regulatory practice tends to follow the structure of US political organization (43), which emphasizes separation in the interest of objectivity and distrusts too much cooperation as fomenting collusion (33, 42). NRC inspectors, for example, are explicitly forbidden to fraternize with plant staff. This differs from the state-centered and often corporatist approach more generally used in Europe, in which utilities and regulators are taken to be coparticipants in the process of social development (34, 39(101,912),(995,998)).

The US approach is highly legalistic, emphasizing increasingly detailed prescriptive regulation. Successful operation is largely defined in terms of step-by-step compliance with highly formalized rules and procedures (33, 40). Tasks in the plant are often conceptualized in terms of these procedures and referred to by the procedure number in the manual. Deviating from approved procedures would generally constitute an NRC violation, even if no harm was done (47). If a departure from the operating manual does turn out to be necessary, the burden of proof rests on the operator to show that the existing procedures were inappropriate. Modifying procedures and receiving NRC approval tend to be involved processes. In the words of one US shift supervisor: "We have a manual specifying procedures for changing procedures."

The regulatory presence in the United States has been criticized as overly formalized (35), intrusive (33), adversarial (11), acrimonious (34), and even inconsistent and irrational (34, 35, 56). Two NRC inspectors are permanently on-site at every plant. This omnipresence is reflected in the relative prominence of the NRC in the minds of those working at US plants, where the awareness of potential regulatory violations and monetary fines surrounds every operating decision (35).

European regulatory agencies are as concerned with providing support to an industry as with controlling it (34, 39, 40, 43). Inspection and review are carried out largely through reporting requirements and intermittent visits. The goal-based European approach might be characterized as: "We will not look over your shoulder to verify constant compliance; but if you break the rules and break the plant, you’re in big trouble." These differences in regulatory philosophy can be seen as stemming in part from the specific histories of the nuclear regulatory agencies, but they also reflect more general national cultural differences that can be observed in other areas of society (39, 42, 43).

Though rules exist and fines are sometimes imposed for violations, the focus is more on ultimate impact than on operational details. The cooperative approach is mirrored in the operational style at the plant. For example, a German shift supervisor emphasized that he considered the most important part of his

3Although the difference in technology precludes our trying to make a direct comparison, the Canadian approach seems very similar to the European. See, for example, (42).
operating manual to be the first page, which listed five basic goals to be kept in mind at any time—especially during an emergency. These were as general as "keep the core covered with water." Although there are many more specific written procedures, they are understood more as guidelines: means to an end rather than ends in themselves. Several operators and managers argued that one needs to focus on the plant, not the procedure. Another shift supervisor commented that a person who cannot perform a job without detailed procedures will find a way to commit errors even with them.

Regulatory requirements are interpreted with varying degrees of flexibility. For example, in one European plant we observed the operators and the plant manager calmly discussing the problem of controlling effluent water so as to maintain an externally measured temperature within legal limits. In their consideration of the trade-off between plant efficiency and regulatory compliance, it was apparent that a violation of the temperature limit by a fraction of a degree was expected to be judged by regulators in proportion to its relatively minor implications for health and safety; the plant was not expected to be cited according to the letter of the law if its operating practice remained true to the spirit of the law. Such tolerance by the NRC would not be expected in the United States; indeed, the conversation in this example would be unthinkable in a US control room.

The social and historical development of US practice might well be compared with that of Germany, where the regulatory style was least adversarial and least legalistic of the countries we observed. The Technische Überwachungs-Vereine (TÜV) have existed in the various Länder since the second half of the 19th century as self-administrative organizations (Selbstverwaltungsorganisationen) of industries to control boiler hazards, intended to support rather than constrain. Indeed, unlike in the United States, where nuclear regulation falls exclusively under federal law, much of the regulatory responsibility in Germany still rests at the level of the Länder, both through the TÜVs and the Länder governments granting licenses. All actors including the government agreed in the early 1960s on the priority that the development of the German nuclear industry not be hampered by premature definitions of rules, guidelines, and regulations (146, p. 192). Federal guidelines for safety evaluations were deliberately called into being as suggestions (Merkposten), not requirements, because it was anticipated that "bureaucrats would tend to demand the answering of all points on the checklists without weighing their meaning and relevance." While federal safety guidelines are binding in Germany today, there remains a shared understanding that the specificity and rigidity of regulations should be in proportion to their relative importance.

It has been generally agreed in Germany since the beginning of the nuclear industry that regulation should be sensitive to culture. German government and nuclear industry alike shared the desire to avoid simply importing existing
safety regulations from the leading nuclear countries (specifically the United States). Among the arguments were that US regulations were developed in the military, "where one often saw things differently than would be appropriate and necessary for the peaceful utilization of nuclear energy in Germany," and because "differences in the geography of reactor sites and in political aspects would require a different evaluation of safety issues" (146, 147, as cited in).

Other countries we studied lay between the United States and Germany in their approach. In Sweden, for example, updates sent to the plant by Westinghouse after TMI-2 were edited and adopted according to Swedish preferences. In France, workers were prepared to be insulted when they thought we were regulators on an unannounced visit. In Switzerland we were allowed an escorted visit into containment without the extensive training and screening required in the United States.

The disparity of regulatory styles also reflects differences in worker culture corresponding to the professionalization of technical workers in the national culture in general. In Germany and Switzerland, trained craftsmen have long enjoyed the status of Meister, which is recognized and respected throughout society (18). Generally speaking, the professional competence of a Meister is accepted to the point where he carries legal responsibility for the work done under his direction, and would likely consider it an affront to be told how to do his job by an outsider to his specific profession. Even without such status, workers in France expect to be given a great deal of latitude in interpreting even formal rules (16, 113).

Many Europeans live in the same town and work for the same company for most of their lives. The tongue-in-cheek answer to the question of what happens when an individual moves to work at another plant is often, "It never happens." In Sweden, mobility is so low that individual plants are granted considerable discretion in the training and licensing of personnel (including operators). The emergence of close-knit local and professional communities makes long-term experience an important factor when responsibility is given to an individual. This becomes particularly apparent when the same contractors are hired year after year during refueling outages. In the United States, where status and job mobility tend to be high, processes and practices to ensure the competence of a given individual are more formalized.

Ethnic and cultural homogeneity also seems to contribute to the confidence of some Europeans in their coworkers. This was particularly apparent in Switzerland, where an operations manager emphasized that all of his men were Swiss. This was such a priority that despite the lack of experienced steam-turbine operators in Switzerland (where non-nuclear electricity generation is

4The pronoun reflects the reality of gender distribution.
almost exclusively hydropower), no foreign operators were hired. Swiss turbine designers were retrained.

Along with the greater personal familiarity, there tends to be more work specialization in Europe and an emphasis on having experts at every job. In Sweden, for example, the reactor operator and the turbine operator have separate licenses. In Germany and Switzerland, they have equivalent licenses but rarely trade positions. The US style emphasizes rotating operators among various control positions in the interest of improved general understanding, coordination, and teamwork, though necessarily at the expense of familiarity with a particular job.

This combination of cultural, historical, and political factors strongly affects the degree to which primary trust is allocated between operators and procedures in each instance, complementing and in some case reinforcing historical differences in regulatory philosophy and approach.

MODERATE DIFFERENCES: COMPUTERIZATION Displays and operating consoles differed considerably. The Westinghouse panels at the US plants with their characteristic large handles and dials are highly differentiated in visual and tactile presentation, whereas the Siemens panels used by the Germans and Swiss show ranks of nearly identical push-button switches and miniaturized 90° dials. French and Swedish designs are intermediate cases. These differences were reflected in the integration of computers and CRT displays into the control rooms. At one of the US plants, a few recently added CRTs seemed convenient for the display of time-series data to facilitate analysis, and at the other, the operating manual had been completely computerized, but in neither case were the CRTs a tool that operators would choose to rely upon in an acute emergency situation. German operators, whose CRTs were integrated quite seamlessly into their consoles, appeared to trust their computers more readily, expressing no discomfort with the notion that in an emergency the computer will make sure that the display “will show me the most important data.” In contrast, US operators expressed concern that the computer program might err in choosing what is truly important. But whether the implicit dominant model of task performance is as heroic individual “pilot” or member of a coordinated and integrated team, all operators agreed that the computer must be a used as a tool, not an authority.

Human factors aspects of the introduction of computers were more problematic, particularly as they affected the character of the shift away from dials and strip charts to computerized CRT displays. In a conversation with a Swedish shift supervisor about the dissonance between the very traditional dial-gauge-handle-annunciator Westinghouse-type control panel and the advanced CRT displays, he pointed out that none of the operators was wearing a digital watch. Plant status, he said, is something you read analogically; with
experience, you learn where all the needles should be. If one deviates, you notice that something is wrong even before you figure out which one it is. Even an array of computer screens can only hold so much integrated analogic information. Digital display of information is useful only for minor things; when something major happens, the numbers tend to scroll off the screen before you can assimilate them.

There was no universal attitude towards acceptance of more integration through increasingly capable computers. Further relinquishing manual control would be a matter for negotiation in Germany; it could most easily be imposed by management without consultation in France. In Sweden, operators absolutely insist on participating as a team in every element of design and installation, as they did when their panel was upgraded with visual displays. In the United States, acceptance at a given plant was clearly conditional on the presence of computer-savvy operators who could credibly advise the others that the system had been thoroughly wrung out and adapted to their needs.

That care must be given to the group dynamics when designing computer-based control rooms is increasingly apparent. There are manifest differences between those who design in the abstract seeking immunity from operator error and the operators, who rely on practice and real-time knowledge (5). Moreover, because the dynamics of the control room differ from country to country (and possibly from plant to plant), the design must take cultural differences into account. The role of operator cognition and cognitive maps has been drawing increasing attention in recent years, both in general studies of safety (21-24, 61, 148) and in the industry itself (7, 19, 50, 65). But cognitive maps involve social as well as technical variables; it is in this specific context that gaining further understanding of the role of national, regional, and local cultures is of greatest importance (4, 5).

TÉLÉPILOTAGE  An interesting example of what is simultaneously a similarity in operator attitudes and a difference due to the plant’s contextual environment is automated control of power by the dispatcher. Remote control of power output is commonly used at conventional (fossil-fuel) steam plants in the United States to match system load, but not at nuclear plants. Both US plants we visited initially had remote power-control hardware installed, but never used it. The technical argument given was to avoid materials fatigue due to repeated thermal expansion and contraction, especially in the pressure vessel. Operators also expressed a general feeling of discomfort with the notion of someone else exercising even partial remote control of a plant for which they continue to carry full responsibility. Aside from raising actual concerns about safety, the issue touched upon a sensitivity regarding the boundaries of the operators’ domain of authority, and regarding the possibility of being held accountable for problems due to influences beyond their control.
In France, where nuclear plants supply three-quarters of electrical energy, it is impossible to operate them all exclusively as baseload plants. Here the operators have accepted télépilotage as a fact of life. Their sense of "defending their turf" only became apparent in their very strong emphasis on the limits of the remote control—namely, that power could only be changed within a window of 60 megawatts, and be ramped at a maximal rate of 11 megawatts per minute. This response to télépilotage seemed to conform with a general sense of succumbing to the powers of a large, distant bureaucracy—a sentiment characteristic of French worker culture in general (16, 112–114).

Remote control of their plant was unthinkable to the Swiss, even if were demonstrably economic. Again, this attitude resonates with the national culture, which in this case places an especially high value on independence and self-determination. The German operators, sharing the sentiments of the Swiss but under considerable administrative pressure to accept remote control of their plant, won the battle through tactical negotiation: They insisted, on the grounds of safety, that power could be ramped remotely at a rate of only two megawatts per minute, whereas they could safely ramp from the control room at a much higher rate. As expected, the frustrated dispatchers, requiring a faster response, grudgingly relinquis hed control to the operators.

LESSER DIFFERENCES The differences outlined so far can be traced readily to the national regulatory and cultural environments combined with contingent responses to identifiable external pressures. We also observed numerous smaller variations whose individual origins are less obvious and that therefore may appear to be purely random or merely epiphenomenal: The Swedish control room was decorated with a landscape punctuated with amusing trolls; German shift supervisors had an expensive Blaupunkt radio installed in the middle of a console that separated the two supervisory chairs; in unionized France and Sweden there are free coffee machines—and the French discarded the machine coffee with disdain, salvaging only the cup to offer a visitor some of their own home brew.

Other small differences often occur simultaneously with similarities on another level of the same context, leaving the researcher only to conclude: "It is the same, but different!" But similarities can also have subtle cultural adaptations that improve functionality at a given plant. The crucial question will be which is which. For now, we note only that the individuals involved often take such details very seriously.

The most obvious variations were in control room size and décor, ranging from very capacious to very tight, and from clinical pale green paint to wooden panel frames, with in some cases plants, or even a colorful mural. In several cases, lighting retrofits had been installed for optimal brightness and reduced...
glare, though the individual solutions varied. Some were imposed, some self-designed; operator opinions seemed to covary.

Control rooms are governed by different sets of rules for conduct and space allocation. For example, US operators bring their lunch to their consoles; French operators smoke and drink coffee but never eat in the control room; Swiss operators do neither on the grounds that fumes from smoke or coffee oxidize the switches. Some German operators wear uniforms; at one US plant, all personnel wear clothing color-coded to their job, at the other, operators emphatically oppose the idea of any dress code; some French operators flaunt the lack of a code. Several oddities stand out: Swedish operators have a small back lounge with a table and television; US operators are explicitly forbidden to wear hats in the control room; the French plant has a real kitchen. Though the arrangements may seem odd, each had been specifically thought about and negotiated.

An important aspect of control room space allocation is the definition of areas accessible only to operators. This issue becomes especially pressing during refueling “outages,” when the control room is abuzz with engineers performing analyses and maintenance personnel receiving work orders and “clearances” from operators to work on specific components. The hierarchical dynamics of this situation appeared to be invariant with respect to national culture: The slumped body posture of a maintenance person waiting for a clearance, or an operator’s silent shrug to comment on an engineer studying the control panels, are universal expressions. All operators preferred to keep the transactions as far away from their consoles as possible, but the mechanisms for demarcating space and administering work orders and clearances varied.

In one US plant, all transactions were conducted inside the control room, with a carpet denoting areas off-limits to non-operators; in the other, the exclusion areas were “understood” and not marked, and transactions took place in an outside vestibule. The Germans had installed a bank teller window between the control room and a hallway, leaving the operators with a noticeable sense of authority over their capacious control room. French operators’ only recourse against visitors pouring into the control room was to raise their voices, but the bulk of the paperwork was exchanged in a separate office down the hall. In Sweden, visitors were confined to a back gallery; work orders were passed in and out through rotating carriers set into walls or windows.

Similar variances in such maintenance-related details as different routines and procedures for the placement of clearance tags on important components in the plant to ascertain that they are off-line are too varied and detailed to report here (M Bourrier, private communication). Many are clearly related to mutual trust and confidence; others may also intersect with larger issues such as regulatory compliance and approach; still others may be purely a matter of intraplant cultural symbolism.

Some operators, having seen other control room designs, offered their hu-
morous, caricaturized impressions of how their colleagues across the Atlantic interact with their instruments. Though most expressed a strong preference for their own panels, they also stated that this was not due to any intrinsic superiority of design, but rather a matter of familiarity. In fact, operators universally agreed that their mental image while reading data and manipulating controls is of the actual physical plant. The panels are representations whose meaning is integrated through experience and training, and are quite meaningless by themselves. For example, the Swiss adaptation of the Siemens panels involved reversing the white and green lights indicating the “on” and “off” position of every push-button switch. In marked contrast to the efforts of and approach of some human factors consultants seeking to devise and implement a single, uniform standard, operators argued that it did not matter that much what the design was once they had become accustomed to it—but that change in a familiar design was far more problematic.

Another seemingly small example of cultural differences is the suggestion box. These are widely used in Japanese plants, rarely in US plants. In Sweden, prizes were given for the best suggestions. At the German plant, employees cannot be rewarded for improvements or suggestions. And the idea of a suggestion box seemed totally foreign at the French plant, where the relationship between workers and supervisors is more distant and formal.

One final difference of questionable significance is in the handling of the issue of drugs and alcohol. In 1989, the NRC initiated a “Fitness for Duty” program which requires, in addition to mandatory educational seminars and employee rehabilitation opportunities, random breath and urine tests for all individuals with unescorted plant access (including researchers) (149). These procedures can present a significant logistic challenge, unexpectedly delaying on the order of one percent of plant employees for up to an hour on any given day. In the US context, resistance proved futile, and even union opposition was overcome by the combination of regulatory, political, and public pressure. Europeans place more emphasis on reporting and counseling by cohorts than on rigid formalisms and external policing. Their reactions to the US approach ranged from polite skepticism to sheer incredulity.

Levels of Culture: Levels of Analysis

We have sketched here a number of differences that are driven more or less directly by the plants’ cultural environments. It is not always clear, however, that it is in fact the national culture that provides the correct frame of reference. In some instances differences appear to be driven by regional or even local culture. A briefer visit to a second US plant showed interplant variations of detail that might be attributed to corporate or plant management style, to the composition of personnel (civilian vs navy-trained operators), to different practices between NRC regions, or simply to regional or local cultures. A
survey of results of fitness-for-duty (drug) testing in all five NRC regions, for example, showed significant plant-to-plant variation that correlated with the local population density and crime rate (149).

The smallest unit within which cultural character can be defined is the shift, each of which consists of about a dozen operators. Every shift we observed, at every plant, had its own "personality," which was clearly discernible to us, not least in terms of the warmth of reception we were given as visiting researchers. Where shifts are kept together in the work schedule, their "personalities" are explicitly recognized, and may even be taken into account when certain operations are scheduled. These micro-variations emphasize how many levels of culture must be taken into account when analyzing the operation of a given nuclear plant, beyond satisfying the universal requirements of the technology. We have tried to make some plausible hypotheses about connections with "national" cultural and character, but only more extensive comparative work can supply enough data to allow a rigorous separation and analysis.

SUMMARY

To rephrase the original question of this research: Given the high degree of similarity and convergence among the plants, are the cultural differences we observe indications of significant functional adaptations to cultural circumstances? The answer is that some are, some are not, and some that have no perceptible functionality may be indicators of less visible but nonetheless functional cultural adaptations.

Some apparently superficial variances represent meaningful adaptive differentiation. Turbine buildings, for example, varied widely. The German building with its gleaming stainless steel flange and pipe shrouds looked like a set for a futuristic movie. The Swiss apologized for a patch of mismatched paint on a spotless floor in a very industrial building. The French turbine building reminded us forcefully of fossil fueled plants. In Sweden and Switzerland, and most strongly in France, there was a strong contrast between the nuclear culture of the reactor building and the industrial culture of the turbines; in Germany and the United States very little.

These point to substantive differences in the "feel" of the plant, an impression gained through socialization and full familiarization in the field that is not easily quantifiable or describable by any single observation. US plants convey the impression of a somewhat temperamental machine that must be directly operated to perform reliably; the submarine analogy has been pointed out by others, especially Europeans. In contrast, "spaceship" is a better analogy not only for the physical appearance of the German plant but for the attitude of the operators and their approach to the controls. In France, the impression was of a somewhat specialized piece of sophisticated industrial machinery,
different more in detail than in kind from other complex and potentially hazardous types of equipment. Sweden was something like the United States, but treated the plant as industrial technology—more like France than the United States, with a particular technocratic twist ("advanced technology is what we do"). Switzerland was more like Germany, with an industrial veneer.

These somewhat inadequate overall summaries of attitude and approach were played out in many aspects throughout the plant, from operator attitudes and relationships with management to details of how one learns the pattern of signals at the controls or how to diagnose problems. In Germany, as has been reported for Japan, the major concern is that operators trust the plant so much that an alarm sends them to diagnosing the alarm circuits rather than the plant. In France, it is that operators may treat the plant too casually, with familiarity breeding perhaps a little contempt for the consequences of error. In the United States, it is that the operators may try to "pilot" by hand when they should be seeking more professional advice.

CONCLUSION

Our research compared plants that were very similar in age, size, type, design, and construction. Moreover, each was regarded as an excellent performer and a "good example" within its own national setting. From the observed variances, we conclude that technology per se is not wholly determining: Within a broad band of acceptable practice, neither technical detail nor plant size carries with it an unequivocal culture-free tendency toward a single strategy or approach. Many researchers have already begun to criticize the historical tendency toward overly general and abstract approaches to human performance, automation, and other aspects of operations. Our observation of many clearly functional cultural variations suggests another, cross-cultural dimension to those critiques.

We cannot argue that the particular strategies and adaptations we observed at any specific plant were optimal for that plant, or that they would be less successful in different social and cultural settings. But specific operational strategies often appeared to be functionally adaptive within the given cultural milieu; moreover, the unique general style of operation we identified for each example seemed to harmonize well with its socio-cultural environment. Each of the varied styles and approaches to regulation also seemed reasonably adapted to national or regional culture. If these variations prove to be functional adaptations to socio-cultural requirements, attempts at regulatory integration or standardization must also show a great deal more sensitivity to context and situation.

The differences we observed in regulatory presence and style have been noted before (33–35, 40, 42). European nuclear regulation tends to be less
prescriptive, and far more supportive and cooperative, than the adversarial US style. However, most of these surveys are overviews of comparative national styles based on summary reviews of national policies. What that is new might be learned from an intercomparison at the operational level?

From our preliminary investigations, we suggest that as with other aspects of plant operations, operators and managers of "good" plants are able to adapt to a wide range of regulatory approaches and styles within the boundaries of their own safety culture—provided that the regulatory presence does not go against deeply ingrained social and cultural standards and norms. Regulators almost always insist that their actions are meant to encourage or nourish the safety culture, but many of the operators we interviewed pointed out that awkward or clumsy regulation can also interfere with the safety culture.

Many interviewees expressed to us directly and emphatically on cultural (not technical) grounds their view that the style in which they understood plants in other countries to operate would be dissonant and stressful for them. We agree. The omnipresence and insistence on strict rule compliance that characterizes US regulation, for example, would be as disruptive at German plants as the loose and indicative German style would be in the present US operating environment, where strict proceduralization is seen at least partially as a necessary defensive strategy in a highly litigious environment.

Our results indicate that there is a broad band of acceptable strategies for operating a plant and for regulating an industry. But the question remains: Are there regulatory regimes and approaches that lie outside the bounds of tolerance within which an organizational "culture of safety" can be nurtured and sustained? That would certainly appear to have been the case in the former Soviet Union, where evidence suggests that the regulatory presence was neither supportive nor restrictive. On the other hand, our work also suggests caution before attempting to blindly transfer US or any other regulatory approaches developed in a radically different technical and cultural context.

Over the years, several authors have suggested that US regulation has evolved to the point where it may actually interfere with plant operations and the development of the pride and confidence that underlie the emergence of a safety culture (33–35, 42). Our findings support these arguments from a new perspective, that of the plant operators, who expressed concerns that the growing tendency to include regulatory compliance as a major factor in operational decisions may at times interfere with taking decisive actions on the basis of technical and other immediate operational evidence (3, 7, 36, 37). Given our limited sample, and the absence of poorly performing plants from our data set, these findings cannot be taken as conclusive. But the range of variation we found even between the two US plants does suggest the need for further social and organizational studies at the operational level to determine how, or whether, the US style could be better adapted.
Our results are neither definitive nor prescriptive. But they do raise a flag of caution. Socially and culturally insensitive changes in procedures and practices intended to "improve" plant performance might also lead to increased stress or interfere with strategically successful adaptations, with unexpected and potentially adverse results. To tinker with staff and departmental organization, assignments of responsibility, delegation of authority, operator discretion, or even control-room design and integration without understanding the role of culture is to perform a real-time experiment with possibly irreversible consequences. In particular, attempts to evaluate a plant in one country by the operating or regulatory standards of another seem to us to be at best imperfectly informed and at worst potentially harmful. It would be far better to first acquire a better understanding of which method or approach would be best adapted to a given plant, a given situation, and a given social and cultural environment.

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