A STRUCTURED APPROACH TO THE ASSESSMENT OF THE QUALITY CULTURE IN NUCLEAR INSTALLATIONS

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ABSTRACT

INSAG has emphasized that safety culture has two general components: the organizational framework and the attitude of the staff. To develop a structured approach to the assessment of safety culture, we propose that the highly formalized nature of Nuclear Power Plant organizations be exploited. The prime coordinating mechanism of NPP organizations is the standardization of work processes, where a *work process* is defined as a standardized sequence of tasks designed to achieve a specific goal (an example is the maintenance work process). The predictable nature of work processes is exploited by the *Work Process Analysis Model (WPAM)* to conduct a systematic analysis that identifies the desirable characteristics of work processes and develops performance measures for their strengths and weaknesses. These can provide a set of tangible characteristics of a good safety culture.

It is argued in this paper that the analysis of normal power production and investment protection and the analysis of safety cannot be separated when culture is investigated. The organizational dependencies are too strong for such a division. It is proposed that the plant should be viewed as an integrated sociotechnical system and that the broader concept of *quality culture* should replace the more limited one of safety culture.

1. Introduction

The International Nuclear Safety Advisory Group (INSAG) has defined the concept of safety culture as "that assembly of characteristics and attitudes in organizations and individuals which establishes that, as an overriding priority, nuclear plant safety issues receive the attention warranted by their significance" [INSAG, 1991]. They emphasize that "safety culture has two general components. The first is the necessary framework within an organization and is the responsibility of the management hierarchy. The second is the attitude of staff at all levels in responding to and benefiting from the framework." INSAG goes on to recognize that "such matters are generally intangible" and to state that "a principal requirement is the development of means to use the tangible manifestations to test what is underlying." This paper proposes a framework that contributes to the development of such tangible manifestations.

Nuclear power plant (NPP) safety can be addressed by the three familiar questions [Kaplan and Garrick, 1981], namely, "what can go wrong?", "what are the consequences?", and "how often does it occur?" It is now taken for granted that one knows both how each (hardware) system works and how it interacts with other systems. In assessing the NPP safety culture, however, two additional questions need to be addressed: "how does the NPP organization work?" and "how well does it work?" The former addresses the issue of organizational structure and the latter the issue of attitude and response. We begin by discussing the NPP organizational structure.

2. Work Processes

Two basic elements determine the structure of an organization: the division of labor and the coordination of effort [Galbraith, 1973]. The division of labor allows an overall task to be decomposed into subtasks that can be performed by highly specialized individuals (or groups). The coordination of effort integrates these subtasks into a single effort, so that the overall goal is achieved.

NPPs, like many other industrial facilities, exhibit in many respects the characteristics of what is known in organizational theory as a *machine bureaucracy*, namely, "highly specialized, routine operating tasks, very formalized procedures in the operating core, a proliferation of rules, regulations, and formalized communication throughout the organization, large-scale units at the operating level, reliance on the functional basis for grouping tasks, relatively centralized power for decision making, and an elaborate administrative structure with a sharp distinction between line and staff" [Mintzberg, 1979].

The prime coordinating mechanism of machine bureaucracies is the standardization of work processes, where a *work process* is defined as a standardized sequence of tasks designed within the operational environment of an organization to achieve a specific goal.

Figure 1 shows the flow diagram of the corrective maintenance work process. After a maintenance work request is issued, it is reviewed to determine its significance and the required *priority*. The request is reviewed by several individuals. Following these preliminary reviews, the work request is forwarded to the responsible department for *planning*. The main function of planning is to assemble a work package that addresses all issues related to the proper execution of the job. *Scheduling and coordination* of maintenance activities ensure that maintenance is accomplished in a timely manner. Concerns over the work are discussed during scheduled daily meetings. Once the work is scheduled, a field work package is assembled, which includes all the work permits, procedures, drawings, and instructions. The *execution* phase begins with the control room operators tagging out the necessary components and the technicians starting the field work. Depending on the situation, the work may be executed in the presence of health physics and/or quality control personnel. Upon competion of the job, the leadman describes the work in the work tracking form, which, in turn, is reviewed by the department supervisor, who forwards it to the work control center. The WCC supervisor reviews the work package and determines whether post-maintenance testing is required. After the tests, if any, are performed satisfactorily, the *return to normal line-up* takes place followed by *documentation*.

This very brief description (many of the actual details vary from plant to plant and have been omitted) of this work process helps to illustrate the highly standardized nature of the work processes in nuclear power plants. In addition to maintenace, there are work processes related to operations (plant start-up, power operations, shutdown, and system line-ups); engineering (technical and engineering support of plant activities); and, plant support (radiological controls, fire protection, et al). It is evident, then, that the work processes must play a prominent role in any investigation of, what INSAG has called, the structural characteristics of NPP organizations. However, this description must also include the organizational dimensions in order to be complete. These are discussed in the next section.

3. Organizational Dimensions

Jacobs and Haber [1994] propose five general categories of organizational dimensions (factors): ***administrative knowledge***, e.g. organizational knowledge, formalization; ***communications***, e.g., external, interdepartmental, and intradepartmental; ***decision making***, e.g., goal prioritization, organizational learning; ***human resource allocation***, e.g., performance evaluation, technical knowledge; and, ***culture***, e.g., ownership, safety culture.

As examples, we consider the definition of organizational learning: "the extent to which plant personnel and the organization use knowledge gained from past experiences to improve future performance." Goal prioritization is defined as "the extent to which plant personnel understand, accept and agree with the purpose and relevance of goals" [Jacobs and Haber, 1994].

Other groups of dimensions have also been proposed. Thus, Ostrom, Wilhelmsen, and Kaplan [1993] consider a set that includes safety awareness, teamwork, pride and commitment, and so

on. Montmayeul, Mosneron-Dupin, and Llory [1994] consider three groups of variables, i.e., those referring to the psycho-social climate (culture), "ambivalent" variables, and those that "do not appear in the appraisal of the psycho-social climate but which are referred to for the safety climate." An example of the latter is training. Clearly, these sets of dimensions overlap significantly.

The important point is that the work processes and the organizational dimensions provide the basis for answering the question "how does the organization work?" The search for "tangible evidence" of a good safety culture that INSAG seeks must be conducted in the context of these two defining elements of the NPP organizational structure. What we have not done yet is answer the question "how well does the organization work?' which, of course, is another way of referring to the question of tangible evidence. We investigate these issues in the next section.

4. The Work Process Analysis Model I (WPAM I)

The predictable nature of the WPs suggests that a systematic analysis can be conducted to identify the desirable design of a given process and to develop performance measures with respect to the strengths and weaknesses in the process. WPAM I [Davoudian, Wu, and Apostolakis, 1994] consists of a mostly qualitative analysis of a WP, including an assessment of the importance of the role of organizational dimensions in the overall quality and efficiency of that WP.

WPAM I utilizes a three-step procedure to investigate systematically the types of failures that may occur within a WP, the potential breaches of defenses, the organizational dimensions that may bring about these failures, and the relative importance of these dimensions. The three steps are: i. the performance of a task analysis of the WP; ii. the development of the organizational factors matrix; and iii. the determination of the relative importance of the dimensions for each task.

Task Analysis

The task analysis focuses on understanding the following three elements of the WP: the tasks, e.g., planning, that are involved; the actions in each task and their failure modes, e.g., identifying incorrect procedures during planning; and, the defenses or barriers relevant to each task, e.g., the various reviews.

The products of the task analysis are a flow diagram for the process, a cross-reference table, and a design/implementation checklist. The flow diagram shows the tasks involved (Fig. 1). The cross-reference table (Table 1) identifies the personnel, departments, and actions involved in each task. Finally, the checklist contains a series of questions aimed at comparing the design and implementation of tasks (Table 2).

Organizational Factors Matrix

This is the second step of WPAM I. Its purpose is to show the organizational factors that may impact on the safe performance of each rask. As expected, one organizational failure may cause several unsafe acts; for example, communication affects all tasks. This matrix helps in localizing the problem areas and to guide the direction of the analysis (for an applicaton to root-cause analysis, see Tuli, Wu, and Apostolakis, these proceedings).

Relative Importance of Organizational Factors

The organizational factors matrix tells us which dimensions may impact the various tasks of the WP, but it does not prioritize them. This can be achieved by employing the Analytic Hierarchy Process (AHP) which allows us to utilize expert judgment and prioritize. For example, Davoudian, Wu, and Apostolakis [1994a] give as an example the following ordering of the most important dimensions for the task "prioritization" of the maintenance WP: formalization, technical knowledge and time urgency, and interdepartmental communication.

5. A First Set of Tangible Manifestations of a Good Safety Culture

The process flow diagram, the cross-reference table, and the design/implementation checklist provide basic information about the operation of the organization, that is, how the organization is *supposed* to operate. In particular, the design/implementation checklist can provide some basic indicators regarding the quality and efficiency of task performance. For example, from the ergonomic point of view, the physical location of the work control center with respect to the control room may be of interest. Similarly, the number of items on the maintenance backlog is an indication of the quality of the plant safety culture.

While this analysis does give us an indication of the organizational structure at the plant, it does not tell us how well this structure is implemented. To check this we need to work more with the organizational dimensions, as explained in the next section.

6. How well does the Organization Function?

As stated earlier, the INSAG report identifies as the second (besides organizational structure) component of a safety culture the attitude of the staff at all levels. Pidgeon [1991] proposes "a working definition of culture as the collection of beliefs, norms, attitudes, roles, and practices shared within a given social grouping or population."

It is important to bear in mind that the actual beliefs, norms, and attitudes are not necessarily as prescribed in management directives and procedures. Montmayeul et al [1994] report the results of the analysis of data collected on full-scale simulators by Electricité de France (EDF). They

find that "the operations performed do not always correspond exactly to what is indicated in the instructions, not that deviations from them are necessarily errors." This confirms once again what has been known for a long time, namely, that an *informal structure*, in addition to the formal one, exists in organizations; their members constantly adapt to their environment and unofficial relationships may develop within a group.

It is evident that to answer the question "how well does the organization work" we need to employ the dimensions that have been mentioned in Section 3 and to devise scales that would allow us to "measure" these dimensions. These "constructed" scales are, in fact, utilized in one form or another by the cited references. Furthermore, methods need to be devised to capture the actual culture (the mix of formal and informal cultures). These include interviews and behavioral checklists. While there will be a great deal of subjectivity involved in these assessments, this is unavoidable.

Of particular interest are the Behaviorally Anchored Rating Scales (BARS; Jacobs and Haber, 1994). These scales provide examples of poor, average, and high behaviors for the assessed dimension and these are developed by expert groups that include plant people familiar with that dimension and with industry practices. Okrent et al [1993] have applied these scales to the dimension "deep technical knowledge."

Developing BARS for all the dimensions and the work processes at a plant is simply unrealistic. The prioritization of dimensions is discussed in the next section.

7. Prioritizing the Dimensions

Various schemes may be devised to limit the number of dimensions that need to be analyzed in detail. As stated in Section 4, one can use the AHP to prioritize the dimensions within a work process in a generic way, i.e., without specific reference to a particular maintenance act. The selection of the WPs that deserve this treatment will have to be based on the judgment of experts.

A more systematic way of prioritizing, but also more time consuming, is to utilize WPAM II [Davoudian et al, 1994b]. This part of WPAM provides the link between organizational factors and Probabilistic Safety Assessment (PSA) parameters. The quantitative impact of the dimensions of a WP on the core damage frequency could be used to identify the important dimensions. Unfortunately, the quantitative part of WPAM II is still in the development phase. Nevertheless, there are qualitative insights that WPAM II provides that may be immediately useful.

If a PSA for the plant is available, one can use WPAM II to identify the work processes that may have a significant impact on the major accident sequences. In particular, the model focuses on potential organizational dependencies of *dissimilar* events, such as human errors and Diesel engine performance (this is in contrast to the conventional common-cause failure analysis that

is concerned with nominally identical components only). These work processes, then, can be evaluated as before.

8. Safety or Quality Culture?

The concept of safety culture is very actively being investigated these days and rightly so given its tremendous significance to the operation of NPPs. It is timely to ask, however, whether this very focused approach to culture is, in fact, proper. The purpose of building NPPs is to produce power. Traditionally, the probabilistic analysis of reliable power operation (plant availability and so forth) and that of accidents have been separated by the large differences in the frequencies of the sequences that dominate the two regimes. Sequences leading to plant unavailability are much more frequent than sequences leading to core damage.

When the subject is culture, we must question the wisdom of separating safety culture from the culture that exists with respect to normal plant operation and power production. The dependencies between them are much stronger because they are due to common work processes and organizational factors. For example, the maintenance work process is as important to operations as it is to safety. Experience has also shown that protection of the investment and safety cannot be separated. For example, the investigation of the Davis Besse loss of main feedwater event [US Nuclear Regulatory Commission, 1985] has led the NRC investigators to state that "the shift supervisor appreciated the economic consequences of initiating make-up/high pressure injection (MU/HPI) cooling." In an integrated approach to culture, such priorities would have been analyzed under a number of organizational factors, such as goal prioritization, training, and technical knowledge.

It is evident, therefore, that it would be more appropriate to broaden the concept of safety culture and talk about the *quality culture* at a plant. This would allow us to investigate the NPP as an integrated system (*a sociotechnical system*), thus taking into account the full complexity and interdependencies of the plant organization.

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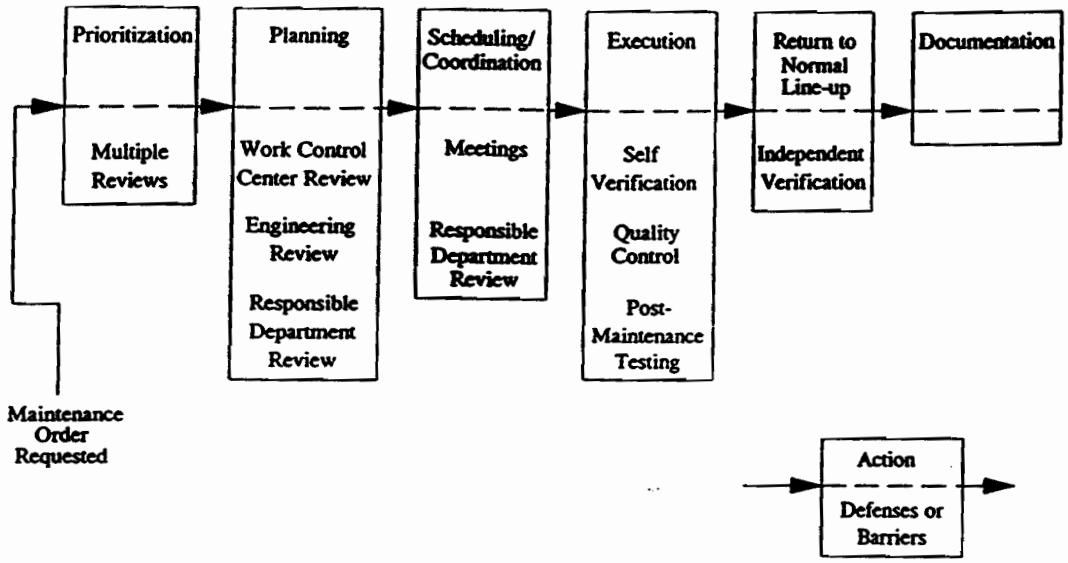

Figure 1 The flow diagram for the corrective maintenance work process.

Task	Action/Barriers	Department	Personnel
Prioritization	Prioritization Reviews	Work Control Center (WCC) WCC/Operations	WCC Supervisor Shift Supervisor
Planning	Planning WCC Review Engineering Reviews Responsible Dept. Review	Maintenance/I & C WCC Engineering Maintenance/I & C	Planner WCC Supervisor System Engineer Mech./Elec./I & C Engineer
Scheduling/Coordination	Scheduling/Coordination Meetings Responsible Dept. Review	Planning Dept. Various Depts. Various Depts. (Operations for system tagging)	Scheduler Variable (Operations for Work Authorization)
Execution	Execution Self Verification QC Post-Maintenance Testing	Maintenance/I & C Maintenance/I & C Quality Control/ Quality Assurance Maintenance/I & C/WCC	Mech./Elec./I & C Mech./Elec./I & C QC/QA Engineer Mech./Elec./I & C
Return to Normal Line-Up	Return to Normal Line-Up 2nd Verification	Operations Operations	Control Room Operator Control Room Operator
Documentation	Documentation	WCC (Nuclear Plant Reliability Data)	Clerk

Table 1 The cross-reference table for the corrective maintenance work process

DESIGN/IMPLEMENTATION CHECKLIST EXAMPLE

Design Checklist:

1. Is there a central organization (planning department and work control center) in charge of coordinating planned work?

2. What is the organizational relationship of the planning department and work control center to other departments in the working core; i.e., operations, maintenance, and instrumentation and control departments?

3. What are the barriers built into the system to correct errors made in the scheduling or coordination of maintenance work? And what are their functions?

4. What is the standard process for the scheduling and coordination of a maintenance work?

Implementation Checklist (Normative):

1. Where is the work control center located?

2. What is the information transfer mechanism used in the work tracking system?

Implementation Checklist (Behavioral):

1. How many items are on the maintenance backlog?

2. How many items on the maintenance backlog are of PRIORITY 1?

3. How many equipment deficiency tags are on the main control panels?

4. Does the plan-of-the-day schedule reflect the ongoing work?

5. Does scheduling reflect prioritization of work with respect to safety impact?

6. What is the management philosophy in scheduling; i.e., which type of work is usually assigned higher priority?

7. Does the shift superintendent need to review most of the work packages?

8. Are technicians often allowed to "negotiate" with the shift superintendent regarding assigned work?

9. Does the planning department communicate well with other departments?

10. Does the daily meeting on scheduling and coordination show conflicts among departments regarding scheduled work?

Table 2 A sample design/implementation checklist for scheduling and coordination of maintenance work.