Safety Culture in the Nuclear Power Industry: Attributes for Regulatory Assessment

by

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ABSTRACT

Safety culture refers to the attitudes, behaviors, and conditions that affect safety performance and often arises in discussions following incidents at nuclear power plants. As it involves both operational and management issues, safety culture is a sensitive topic for regulators whose role is to ensure compliance with safety requirements and not to intervene in management decisions. This report provides an overview of proposed safety culture attributes and worldwide approaches to safety culture assessment and identifies those attributes that should be of high priority to a regulator deciding to assess safety culture.

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Acronyms

ACRS	Advisory Committee on Reactor Safeguards
AECB	Atomic Energy Control Board
ASCOT	Assessment of Safety Culture in Organizations Team Guidelines
BARS	behavioral anchored rating scales
CAMM	Canadian Adaptive Machine Model
CNSC	Canadian Nuclear Safety Commission
CRDM	control rod drive mechanism
FENOC	First Energy Nuclear Operating Company
IAEA	International Atomic Energy Agency
INPO	Institute of Nuclear Power Operations
INSAG	International Nuclear Safety Advisory Group
LOCA	loss of coolant accident
NEA	Nuclear Energy Agency
NEI	Nuclear Energy Institute
NRC	United States Nuclear Regulatory Commission
NRR	Office of Nuclear Reactor Regulation
OECD	Organization for Economic Cooperation and Development
RES	Office of Nuclear Regulatory Research
SCWE	safety conscious work environment
SKi	Swedish Nuclear Power Inspectorate
SRM	Staff Requirements Memorandum
STUK	Finnish Radiation and Nuclear Safety Authority

1. Introduction

Safety culture often arises in discussions following incidents at nuclear power plants. Although no single definition of safety culture is universally accepted, it commonly refers to the attitudes, behaviors, and conditions that affect safety performance. It is well known that human factors play a large role in safe plant operation, but safety culture still poses a challenge for regulatory bodies. The role of regulators is to oversee licensee operations to ensure that licensees comply with safety requirements and not to intervene in management decisions until a serious incident has occurred or is imminent. The licensees retain full responsibility for safe operation of their plants. Safety culture is a sensitive issue for the regulator because it is cross-cutting, involving both operational and management issues. If regulators were to be more proactive toward safety culture, as some critics suggest they should be, regulators would have to focus on those attributes of safety culture that are performance-based in order to avoid undue interference in licensee management.

The objective of this project is to provide an overview of proposed safety culture attributes and worldwide approaches to safety culture assessment and to identify those attributes that should be of high priority to a regulator if it chooses to proactively assess safety culture.

2. Historical perspectives on 'safety culture'

The United States Nuclear Regulatory Commission (NRC) began to formally address the human factors of safe plant operation after the Three Mile Island accident in 1979. In its post-accident investigation report, the NRC concluded that a large contributor to nuclear accidents had previously been overlooked. "The one theme that runs through the conclusions we have reached is that the principal deficiencies in commercial reactor safety today are not hardware problems, they are management problems [1]." The report also acknowledged that the NRC had virtually ignored areas such as operator training, human factors engineering, and technical qualifications in overseeing its licensees.

To remedy this lack of oversight, the NRC first established the Human Factors Program to minimize human errors in plant designs, procedures, operations, and maintenance. The objective of the program was to review human factors programs of the licensees applying for construction permits, operating licenses, standard design certification, combined licenses, and license amendments. Later, the NRC established the Division of Human Factors Safety in the Office of Nuclear Reactor Regulation (NRR) and the Human Factors Branch within the Division of Risk Analysis in the Office of Nuclear Regulatory Research (RES). These offices became responsible for addressing human factors issues in operator licensing, procedures, human-system interface, training, staffing, and management. Several NUREG documents were subsequently issued to provide human factors-related guidance based on the NRC's findings [2, 3].

The term "safety culture" was not introduced until after the Chernobyl accident in 1986. The ensuing investigation concluded that management attitude was a significant contributor to the chain of events leading to the accident [4]. The International Nuclear Safety Advisory Group (INSAG), an advisory group to the Director General of the International Atomic Energy Agency (IAEA), stated in its post-accident report [5] that, "The vital conclusion drawn is the importance of placing complete authority and responsibility for the safety of the plant on a senior member of the operational staff of the plant. Formal procedures, properly reviewed and approved, must be supplemented by the creation and maintenance of a 'nuclear safety culture.'"

INSAG-3 [6] named safety culture among the fundamental management principles along with the responsibilities of the operating organization and the provision of regulatory control and verification of safety-related activities. "The phrase 'safety culture' refers to a very general matter, the personal dedication and accountability of all individuals engaged in any activity which has a bearing on the safety of nuclear power plants."

A formal definition, however, was not developed until INSAG-4 [7]:

> Safety culture is 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.

This particular definition was deliberately constructed, the report stated, "to emphasize that Safety Culture is attitudinal as well as structural, relates both to organizations and individuals, and concerns the requirement to match all safety issues with appropriate perceptions and action." It also theorizes that a successful safety culture requires both commitment and competence at all levels of the organization to ensure that "all duties important to safety are carried out correctly, with alertness, due thought and full knowledge, sound judgment, and a proper sense of accountability." INSAG-4 concedes that "such matters are generally intangible," but argues that tangible manifestations still result and may be used to assess the underlying cause. INSAG begins with this assumption that the intangible attributes lead naturally to tangible characteristics of a strong safety culture without offering evidence. The body of the report expands on the practical value of the concept and then enumerates 143 questions to be used for evaluating the effectiveness of safety culture in a particular case.

Also omitted from the report is any specific direction on how to use these questions to judge whether a particular safety culture is acceptable. The IAEA's succeeding publication, titled "ASCOT Guidelines (Assessment of Safety Culture in Organizations Team Guidelines)" [8], suffered the same exclusion. The ASCOT guidelines were written to serve as a test of a particular safety culture against the principles put forth in INSAG-4. The guidelines offer an expanded version of the questions listed in the appendix of INSAG-4 and key indicators that are intended to illustrate what is considered a sound safety culture. The assessment guidelines assert that in order to accurately assess a safety culture, all organizations that influence it must be considered, namely the regulator and utility headquarters in addition to the plant itself. The guidelines do not offer any instruction on how to draw a conclusion from the answers to the questions, but simply advise that the review team's report should "highlight any areas in which safety culture could be strengthened" and "...avoid any suggestions of grading, rating, or comparison..." One critic points out that a facility with a poor safety culture might be left with an overwhelming list of corrective actions and no guidance on how to proceed [9].

Several years later, the Nuclear Energy Agency (NEA), an agency of the Organization for Economic Cooperation and Development (OECD), published a pair of policy papers [10, 11] which suggested that a nuclear plant's regulatory body may be best suited to guide a plant with safety performance problems toward a healthier safety culture. The first of the two papers, "The Role of the Nuclear Regulator in Promoting and Evaluating Safety Culture," outlined the dual role of the regulatory body as both the model of a strong safety culture and the evaluator of the culture of its licensees through performance- or process-based inspections. The following report explored different regulatory response strategies for addressing a nuclear power plant with safety-performance problems that could indicate a declining safety culture.

The IAEA did not disengage itself from the topic of safety culture in the following years. In 1999, it issued INSAG-13 [12], "...to build upon the ideas outlined in 75-INSAG-4 and to develop a set of universal features for an effective safety management system in order to develop a common understanding," and INSAG-12 to revise the first safety culture report, INSAG-3.

Although INSAG introduced and defined the term 'safety culture' for the nuclear industry, it did not offer an explanation of why it chose those particular words. Schein [13] formally defines culture as "a pattern of basic assumptions—invented, discovered or developed by a given group as it learns to cope with its problem of external adaptation (how to survive) and internal integration (how to stay together)—which have evolved over time and are handed down from one generation to the next." His simplified version is "the way we do things around here." Schein contends that culture dictates what we pay attention to, what things mean, and what actions to take when. A culture is not simply an inherent quality of a group, however; it is something learned from a long history of shared experiences.

Schein models culture in three levels: artifacts and behavior, espoused values, and basic assumptions. Artifacts and behaviors are the most observable aspects of a culture; they include everything that can be seen, heard, or felt. Performance indicators would be found among artifacts and behaviors. This level does not, however, offer any explanation of why things appear the way they do. Espoused values are those values that people say they support. There can be inconsistencies between artifacts and espoused values. Basic assumptions are more difficult to ascertain. These assumptions are fundamental beliefs, engrained in the subconscious of a cultural group, which reflect, in the case of an organization, its history, the values, beliefs, and assumptions of the founders, and the key leaders who have made it successful [14]. Schein reflects on the leader's role, "...one could argue that the only thing of real importance that leaders do is to create and manage culture..."

Bridges [15] is wary of borrowing the term 'culture' from anthropologists and using it in the context of an organization. He warns not to assume that a so-called organizational culture even exists, much less can be reasonably defined and then altered.
Collins [16], on the other hand, argues that the term itself is not the problem, but how it is defined. He proposes that safety culture is what influences organizational culture and human performance and that leadership expectations and behaviors are responsible for influencing safety culture. He redefines safety culture to be a leadership attitude that ensures a hazardous technology is managed ethically to ensure that individuals and the environment are not harmed.

Using *safety* to modify *culture* implies that safety culture is a subset of a greater plant culture. Apostolakis and Wu [17] question this partition. "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."

3. Attributes of safety culture

Once the importance of safety culture had been realized, attention within the research community turned to studying the building blocks, or attributes, of safety culture in an effort to learn how safety culture affected human performance.

3.1 Previous studies on safety culture attributes

Varying terminology causes some confusion on the subject. Researchers, industry, and regulators use the terms attributes, principles, characteristics, symptoms, and factors when describing the various aspects of safety culture. Each has a slightly different connotation, and the lists of these elements are compiled to serve different purposes. Despite these differences, the literature on this topic can be generally grouped into two categories: the causes/contributors, which are usually described as factors or attributes, and the effects of safety culture, which are usually listed as characteristics or symptoms.

3.1.1 Organizational factors that affect safety performance

In 1991, Haber et al. [18] sought statistically valid relationships between organizational factors and safety performance using an organizational processes approach. The approach consisted of three parts: describe the human organization of a nuclear power plant, identify the organizational and management functions and process related to safety performance, and develop methods for measuring organizational and management factors. Through studies at one fossil power plant and one nuclear power plant, five organizational factors affecting safety performance were identified: communication, organizational culture; decisionmaking; standardization of work processes; and management attention, involvement, and oversight.

Jacobs et al. [19] developed a similar categorical list in 1993: culture, administrative knowledge, communications, decisionmaking, and human resource allocation. Jacobs, however, expounded on this list and created twenty organizational factors that fell into those five categories. The latter list was included in a joint paper by Jacobs and Haber that was published the following year [20]:

Centralization
Coordination of work
External communication
Formalization
Goal setting/Prioritization
Interdepartmental communication
Intradepartmental communication
Organizational culture
Organizational knowledge
Organizational learning
Ownership
Performance evaluation
Performance quality
Personnel selection
Problem identification
Resource Allocation
Roles and responsibilities
Safety culture
Time urgency
Training

Weil and Apostolakis [21] attempted to identify the most important organizational factors from Jacobs and Haber's list of twenty by doing root-cause analyses on a number of real incidents to understand how an organization works and what can go wrong. Their objective was to reduce the list to a more manageable size by eliminating those factors that do not greatly impact performance, in order to increase the efficiency of the incident investigation methodology. They were able to condense Jacobs and Haber's list of organizational factors to the list of six identified in Table 1.

Table 1. Important organizational factors specified by Weil and Apostolakis [18].

Organizational factors	Definition
Communication	Refers to the exchange of information, both formal and informal
Formalization	Refers to the extent to which there are well-identified rules, procedures and/or standardized methods for routine activities and unusual occurrences
Goal prioritization	Refers to the extent to which plant personnel acknowledge and follow the stated goals of the organization and the appropriateness of those goals
Problem identification	Refers to the extent to which plant personnel use their knowledge to identify potential problems
Roles and responsibilities	Refers to the degree to which work activities are clearly defined and the degree to which plant personnel carry out those work activities
Technical knowledge	Refers to the depth and breadth of requisite understanding that plant personnel have regarding plant design and systems, and the phenomena and events that bear on the safe and reliable operation of the plant

Weil and Apostolakis used a work process approach to reduce the list to these six factors. They narrowed their list by identifying which work tasks each factor influenced and how frequently their influence resulted in errors. Safety culture, organizational culture, and organizational learning were removed from the list because they were too general, not because they were not seen as important factors influencing performance. Weil and Apostolakis did not see a need to distinguish between external, interdepartmental, and intradepartmental communications. Resource allocation and time urgency were eliminated from the list because they were seen to be dictated largely by goal prioritization. Technical knowledge was seen to encompass training. Lastly, ownership was lumped together with problem identification. Although a sense of ownership may improve problem identification, it is not mandatory and may be out of the control of plant management.

Donald and Canter performed a study to examine organizational factors relating to safety in the chemical industry [22]. They developed a list of factors from relevant literature and expert judgment and then tested those proposed attributes empirically using an employee survey. The survey examined three facets of safety attitude: people, attitude behavior, and activity. The facets were then divided into elements, and the results of the survey were used to measure worker attitudes toward safety and their perception of other people's attitudes. These attitudes showed "a clear and strong relationship" with self-reported accident rates.

Regulators have also identified organizational factors that influence safety performance. In a state-of-the-art report in 1999 [23], the NEA held a Workshop on Organizational Factors Identification and Assessment and invited 28 participants from member countries and Russia who represented utilities, regulatory bodies, and the academic community. From the operating experience gained from a number of significant operating events world-wide, the members of the Workshop agreed on twelve organizational factors that contribute to plant safety performance: external influences; goals and strategies; management functions and overview; resource allocation; human resource management; training; coordination of work; organizational knowledge; proceduralization; organizational culture; organizational learning; and communication. Most of these are incorporated into Jacobs and Haber's more extensive list.

3.1.2 Symptoms of declining safety performance and safety culture

Another approach to analyzing safety culture is to identify symptoms, or characteristics, of strong or weak safety culture/performance. Rather than pinpointing the root cause of an incident, the purpose of identifying safety culture symptoms is to recognize declining safety performance before a significant accident occurs. These lists usually do not attempt to be exhaustive but simply offer suggestions and give readers a better idea of what the concept of 'safety culture' entails.

One of the most recent attempts by IAEA to list characteristics of safety culture was in a report published in 2002 [14]. Their report approached safety culture with Schein's three level model of culture. Most characteristics are classified as artifacts, which are the easiest to identify but the most difficult to interpret. Examples of characteristics at the artifacts level are quality of documentation and procedures, absence of safety versus production conflict, and sufficient and competent staff. Less abundant are those characteristics that fall under the espoused values category and the basic assumptions category. Characteristics at these levels include a 'safety can always be improved' mentality and view of mistakes as learning opportunities.

A slightly earlier report empirically examined some proposed safety culture attributes at the British Sellafield nuclear reprocessing plant [24]. These safety culture attributes were developed from a short list of characteristics of plants with good safety records: high level of communication; good organizational learning; strong focus on safety; strong commitment to safety by senior management; democratic, cooperative, humanistic management leadership style; more and better quality training; clean, comfortable working conditions; high job satisfaction; and workforce retention is related to working safely. The list of attributes developed from these common characteristics [Appendix] is primarily attributes of worker safety attitudes (satisfaction with, perception of, and confidence in safety-related issues). These proposed attributes were tested with an evaluation process involving both focus groups and an employee questionnaire. Compared to the self-reported rate of accidents which caused at least three days of missed work, a very high statistical correlation was found with 15 of the 19 factors.

Industry itself has also tried to describe the essential attributes of a healthy nuclear safety culture. One of the most recent efforts is the Institute of Nuclear Power Operations' (INPO) "Principles for a Strong Nuclear Safety Culture" [25] in which it lists eight principles, which, it says, if embraced, will influence values, assumptions, experiences, behaviors, beliefs, and norms. Some of these principles appear on other lists of characteristics, such as 'Trust permeates the organization' and 'Decision-making reflects safety first.' One principle that is unique to INPO's list is 'Nuclear is recognized as different,' which it expands into several more familiar characteristics such as 'activities are governed by high-quality processes and procedures' and 'equipment is meticulously maintained well within design requirements.' Other industry efforts to characterize safety culture were made by the Utility Service Alliance [26] and the Nuclear Energy Institute (NEI) [27].

3.2 Fundamental safety culture attributes

Despite the differences in terminology and approach, many of the attributes listed are fundamentally the same. The goal here was to isolate a limited number of frequently agreed upon safety culture attributes that constitute the basis of safety culture. The isolated attributes were management commitment to safety, learning culture, roles and responsibilities, problem identification, technical knowledge, and communication. Of these attributes, problem identification and learning culture may provide performance based indicators for regulatory monitoring.

3.2.1 Selection of attributes

Many safety culture attributes, described as organizational factors or characteristics of safety culture, are listed by researchers, utilities, and regulators in their discussions of safety culture. Sometimes they are essentially describing the same attribute, just with different wording; in many cases they are just very closely related. The attributes were reduced to a list of the most important based on the frequency with which they were cited and their effect on other aspects of safety.

The process to determine the most frequently cited attributes consisted of three steps. Eleven lists of possible safety culture attributes were selected. The attributes used included those discussed earlier as well as several presented at the Advisory Committee on Reactor Safeguards (ACRS) Safety Culture Workshop [28-30]. All attributes were listed together to look for exact matches. Organizational management and self-assessment were two that appeared frequently at this stage. The matching requirements were then loosened to include attributes, which, subjectively, described the same thing. An example of this reduction were the two separately listed attributes 'risk insights in decision making' and 'appreciation of risks'. In a different situation, if a single list cited two attributes which were seemingly the same and subsequently combined, the attribute was tallied as being listed once by that author. The final step was the removal of any attribute cited only once. The more frequently cited attributes are listed in Table 2.

Table 2. More frequently cited safety culture attributes.

ATTRIBUTES	Jacobs and Haber	IAEA	NEA	Lee	INPO	NEI (Dugger)	Murley	Whitcomb	Utility Service Alliance	Donald and Canter	INSAG 15	TOTAL
Roles/responsibilities/accountabilities	X	X	X		X		X	X	X	X		8
High priority to safety	X	X	X	X			X		X		X	7
Openness and communications	X	X	X	X		X		X			X	7
Organizational learning	X	X	X	X	X				X		X	7
Top management commitment to safety		X		X	X		X			X	X	6
Initial and continuing training	X		X	X			X			X		5
Employees have a questioning attitude		X		X	X						X	4
Recognizing employee's efforts		X		X		X				X		4
Appreciation of risks					X		X			X	X	4
Self-assessment	X	X				X	X					4
Technical competence	X	X						X	X			4
Compliance w/regs and procedures		X				X			X			3
Finding problems and fixing them	X					X			X			3
Organizational knowledge	X	X	X									3
Proceduralization	X	X	X									3
Proper resource allocation	X	X	X									3
Working conditions (pressure/workload/stress)		X		X						X		3
Management leadership/oversight								X	X			2
Organization culture	X		X									2
Exchanges of info with other plants							X		X			2
Relationship between managers and employees		X			X							2
Relationship with regulators		X					X					2
Role of managers		X	X									2
Time focus	X	X										2

The most frequently cited attributes are very similar to those proposed by Weil and Apostolakis [21] in their list of organizational factors reduced by empirical evidence. Table 3 presents the two lists side-by-side. The first notable difference between the lists is 'organizational learning'. The discussion of the construction of the earlier list acknowledges that "…organizational learning may be [one of] the most important factors influencing performance," but it was excluded because it was viewed to be "too far-reaching to provide the plant much benefit when cited in an investigation." Organizational learning is changed to learning culture and given a very narrow meaning in order to improve its usefulness if identified as a plant weakness. The final list also adopts problem identification from the earlier list and defines it as a combination of 'employees have a questioning attitude' and 'finding problems and fixing them.' 'Goal prioritization' on the first list is closely related to 'management commitment to safety' on the second list. If safety is a top priority of the management team, then it will be committed to safety; therefore, these two attributes were combined in the final list. Technical knowledge appears on both lists but is more widely defined on the second to include training. A final observation is the absence of formalization on the second list. Proceduralization, closely related to formalization, was not among the most frequently cited attributes; this may indicate that proceduralization is dependant on other attributes, such as commitment to safety and communication, rather than a direct contributor to safety culture.

Table 3. Comparison of reduced organizational factors and important safety culture attributes

Reduced organizational factors	Important safety culture attributes
Communication	Communication
Formalization	Learning Culture
Goal Prioritization	Management Commitment to Safety
Problem Identification	Problem Identification
Roles and Responsibilities	Roles and Responsibilities
Technical Knowledge	Technical Knowledge

The next step in reducing all proposed attributes to a list of just the most important ones was to examine the dependence of one attribute on another and the contribution of one attribute to another. This enabled something resembling an attribute hierarchy to be developed [Figure 1]. 'Management commitment to safety' is placed alone, directly under safety culture. A strong safety culture cannot exist without it, even if all other attributes are present. This commitment to safety is the basis of the next five attributes: technical knowledge, roles and responsibilities, communication, learning culture, and problem identification. These five are not independent of each other, however. The arrows in Figure 1 can loosely be interpreted as "...is a good indicator of..." For example, "*Problem identification* is a good indicator of *technical knowledge*."

The bulleted lists associated with each of the six attributes are a collection of all of the characteristics previously cited that could be associated with the general attribute; almost all of the characteristics can be categorized. These associated characteristics cannot necessarily be interpreted as the definition of the attribute.

The attributes are classified into two groups (see the dashed line in Figure 1). One group of attributes, composed of management commitment to safety, technical knowledge, and roles and responsibilities, is solely of licensees' responsibility. The other group, problem identification and learning culture, is more performance-based and would be of interest to a proactive regulator. Schein's artifacts and behaviors would most likely be indicators of attributes in this second group. Communication falls on both sides of the line. While regulators are not concerned with the exchange of information within a plant, communication between the plant and the regulator is a candidate for a performance-based indicator.

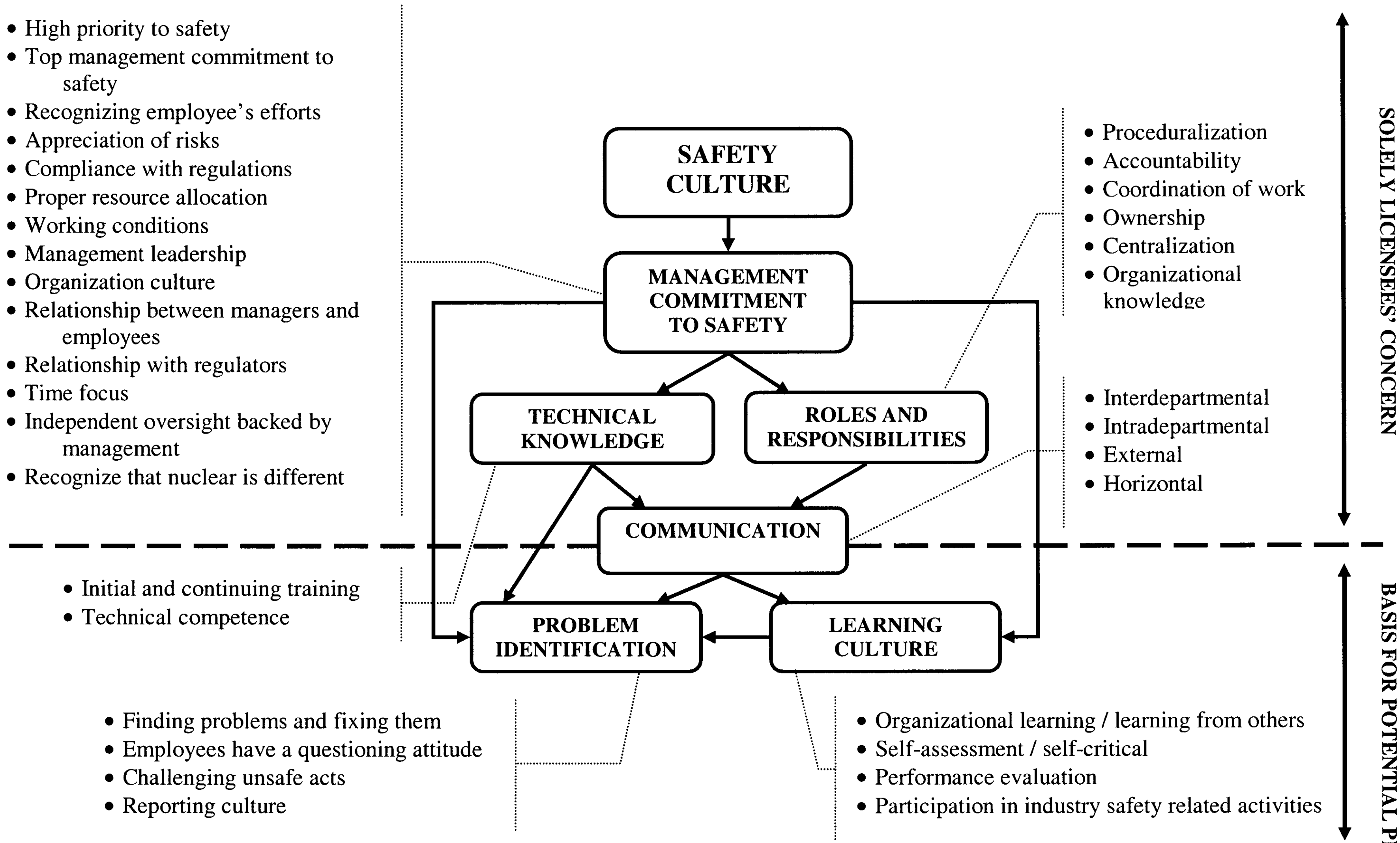

Figure 1. Relationship of safety culture attributes

3.2.2 Definitions of attributes

Management commitment to safety. If all levels of management are truly committed to safety, all other safety culture attributes should come naturally. A commitment to safety means that safety is a top priority and there is no conflict between safety and production. After all, a safely operating plant will be more likely to continue operating long-term. No safety risks should be taken to keep the facility running. A committed management will have a conservative approach to reactor safety. Nuclear power is recognized as being different than other conventional energy sources, and the associated risks are taken into account in decisionmaking. This management will also be committed to allocating the resources needed to ensure safety, whether this is money, time, personnel, or their own attention. The effect of this management commitment will be timely maintenance and response to reported problems. A commitment to safety will also be evident in a plant's compliance with regulations and procedures.

Communication. Communication is an exchange of information on many levels. Communication begins with individuals and teams working effectively together and then extends to teams working within a department. The relationship between managers and employees is also dependent on communication to develop mutual respect and trust, especially in a hierarchical organization. Employees must have a means to voice their concerns. A variety of channel options are available for management to communicate with the employees as well. Openness and access are key elements of communication among the plants and between the plants and the regulator.

Learning culture. Learning culture simply means a desire to improve and a willingness to learn from others. In a learning culture, every problem or mistake is an opportunity to learn. A plant with a learning culture is proactive; it will seek out experience from other plants and take heed of problems others have encountered first. Total safety is difficult to achieve, and a plant with a learning culture could be successful in its quest for improved safety performance. Change is encouraged, and challenging how things are done is a way of life. Similarly, there is no fatalistic assumption that things are how they are and should be left alone.

Problem identification. Problem identification has two different parts. First, there is the ability of workers to use their knowledge to identify potential problems in the plant. These problems may be in hardware or work processes or in the organization of the plant itself. The purpose of self-assessments is to identify areas that can be improved. Problem identification simply means finding the problems wherever they are. This aspect of problem identification is a skill; the second part is an attitude. Employees must want to find these problems and be willing to report them and raise their concerns. An environment which encourages a questioning attitude is sometimes called a safety conscious work environment (SCWE). A corollary of SCWE is a blame-free work environment in the whistleblower is not punished and the worker who made the mistake is not unfairly blamed. The focus is on identifying and correcting the mistake.

Roles and responsibilities. 'Roles' refers to how clearly work activities are defined and to what degree personnel carry out those work activities. Responsibility is then divided among those roles. If done properly, there should not be any confusion. Accountability is also part of roles and responsibilities. Accountability means that people are evaluated on their performance and there will be consequences for good and bad results both for individuals and the organization.

Technical knowledge. Technical knowledge is the foundation of competent personnel. Safety risk increases if workers do not have the skill set for the tasks they are expected to perform on a daily basis and in emergency situations. Technical knowledge is an ongoing process. Employees need a solid background in the fundamentals of their jobs, training on the specific duties of their job just before taking over those responsibilities, and supplemental training as a refresher and as new experience is gained in the field.

3.3 Important attributes in operational experience

Recent operational experiences have emphasized the importance of these six safety culture attributes. Several of these incidents occurred in US plants. The freshest memory is the late discovery of the degradation of the reactor pressure vessel head (RPV) in the Davis-Besse nuclear plant. The conclusion of the NRC's Incident Investigation Team was that Davis-Besse had failed to adequately review, assess, and follow up on relevant operating experience [31]. Engineers and regulators alike were aware of the potential problem-- reactor vessel corrosion due to boric acid was also seen in 1987 at Turkey Point Unit 4. However, a learning culture did not exist at Davis-Besse, and future inspections failed to detect the progressing degradation. Only when a separate problem, circumferential cracking of control rod drive mechanism (CRDM) nozzles, was detected at Oconee were other plants with high susceptibility asked to shut down for more in-depth inspections. FENOC requested that Davis-Besse be allowed to delay the shut down until its next scheduled outage in March 2002.

Other plants are also receiving unwanted attention from the public because of safety culture related problems. At Indian Point 2, communication problems and inadequate procedures were cited as contributing factors to the manual reactor trip following steam generator tube failure. The investigation into a boron dilution event at the same plant found a skipped step in procedure and a lack of clarity in the leader in the evolution [32]. In addition to these problems, four of seven operating crews failed the requalification operational exam. Millstone also had to address safety culture problems when all three of their plants were shut down for an extended period in 1996. Among the root causes identified were a loss of trust in plant leadership and a lack of understanding of safety culture [33]. Wolf Creek found a weakness in its problem identification ability following an analysis of a drain-down event. Among the contributing management and organizational factors were heavy dependence on the control room to identify problems and poor mental models of systems and valves. Problem identification and corrective action were also cited during an incident in 1996 [34].

Plants outside the U.S. have also cited safety culture attributes as contributors to significant operating events. Germany's Philippsburg 2 was shut down by regulators after discovering the cover-up of emergency borated water management issues. First, operators failed to identify a problem with a valve and, then, that oversight was dismissed as a "human factor incident" and went unreported to regulators [35]. Plant management's first response to irregularities in borated water shortly after restart was to ignore them. Regulators also challenged the management's commitment to safety at Brunsbuettel when indicators of an auxiliary coolant pipe rupture were allegedly deliberately overlooked until the next scheduled outage.

The Canadian Nuclear Safety Commission and Canada's nuclear industry have also been accused of lacking a learning culture for inadequately addressing the potential for a loss-of-coolant accident (LOCA) from stress corrosion cracking. It was assumed that a LOCA would not occur because a leak would be seen before a break. A second failure occurred just three months later [36].

Japan has also found unhealthy safety cultures in some of its plants. Among the problems was a systematic cover-up in inspection reports of 13 reactors; one employee said this had been the practice since the late 1980s. Lack of technical knowledge contributed to the root cause of the Tokaimura accident in which poorly trained employees in improper attire using an illegal process added seven times too much uranium to a purification tank containing nitric acid, starting the nuclear chain reaction. Poor communication made the situation worse. Local authorities were not notified immediately and then were slow to issue the evacuation order. The Science and Technology Agency also received part of the blame because the facility did not have any official procedures for handling a criticality accident (Tokaimura is a fuel processing plant, not a power plant) [37].

4. Assessment of safety culture

Once the importance of safety culture is recognized and its essential attributes are identified, the next step in improvement is to assess the current strength of a particular safety culture. The discussion about safety culture assessment centers around two questions: 'How can an assessment be done fairly and correctly?' and 'Who should be responsible for conducting these assessments?' Industry and regulatory bodies worldwide have taken steps toward assessing various aspects of safety culture.

4.1 Industry initiatives

In the wake of the March 2002 Davis-Besse incident, the safety culture assessment method of the plant's utility, First Energy Nuclear Operating Company (FENOC) [38], is probably under the most scrutiny. FENOC began its own evaluation of the safety culture of the plant several months after the incident. In August 2002, FENOC conducted an Employee Safety Conscious Work Environment Survey. Shortly after that, an independent review of Davis-Besse safety culture was conducted and determined the root cause of the RPV head degradation to be a less-than-adequate nuclear safety focus among plant management.

In response, FENOC developed a safety culture model adapted from that of the IAEA [14]. The model breaks safety culture into three areas of focus: individual commitment, plant management commitment, and policy- or corporate-level commitment. The individual commitment includes qualities such as drive for excellence, rigorous work control, and nuclear professionalism as well as two attributes frequently cited by other organizations, a questioning attitude and open communications. Commitment at the plant management level also includes attributes that appeared near the top of the frequently cited table: a commitment to safety, ownership and accountability, and a commitment to continuous improvement. The policy or corporate level commitments appear to be less attitudinal and more action-oriented.

FENOC also developed a method to assess the strength of its organization in each commitment area by identifying attributes related to each category associated with it. The attributes usually could be evaluated quantitatively and a color coded rating would be assigned. For example, Program and Process Error Rate was identified as an attribute related to a questioning attitude (within the individuals' commitment area), and the attribute was given a rating based on how many program and process errors occurred per 10,000 hours worked. Other examples of attributes related to a questioning attitude were management observations and field observations of individuals' willingness to raise problems encountered in the field and the quality of pre-job briefs.

Based on the results of this assessment and other independent recommendations, FENOC took many actions to improve safety culture. Among the initiatives at the policy- or corporate-level was a strengthened Employees Concerns Program, the establishment of a Safety Conscious Work Environment Policy, and the creation of an Executive Vice President – Engineering position. At the policy making level, a new, proven Senior

Management Team was appointed, and managers established an Engineering Assessment Board and revised competencies in the appraisal process to include nuclear professionalism and nuclear safety consciousness. Many of the improvements at the individual level concerned training and re-qualifications and improved communication methods. All of these actions were part of the Management and Human Performance Excellence Plan, one of seven elements in FENOC's Return to Service Plan to get Davis-Besse "back, better, and beyond."

The Utility Service Alliance, keeping in line with its strategic objective to improve station operational safety and effectiveness, also developed an assessment method to uncover any of the same weaknesses/symptoms that existed at Davis-Besse at its seven member power stations [22]. The Utility Service Alliance devised its assessment strategy using guidance from many sources. Among other INPO recommendations, the Utility Service Alliance utilized Principles for Effective Operational Decision-making, Warning Flags from Recent Extended Shutdowns, Safety Focus During Changing Times, and Principles for Effective Self-assessments and Corrective Action Programs. USA also reviewed insight gained from Davis-Besse 0350 Panel public meetings and Davis-Besse root cause evaluations. The Alliance also borrowed a credible survey from the NEI [41] which posed twenty-one questions in four areas: safety conscious work environment, employee concerns program, management conduct and performance, and corrective action process.

The assessment method developed by the Utility Service Alliance involves a list of interview questions and a scoring matrix. One of the attributes being assessed might be "Conditions that potentially challenge safe, reliable operation are recognized and promptly reported for resolution." Behaviors associated with this attribute are a) ensuring personnel are knowledgeable and understand safety expectations, including design and licensing bases, b) ensuring personnel are aware of proper equipment or system operation and trends, and c) ensuring personnel maintain a questioning attitude. A question in the interview question bank will specifically pertain to one of these behaviors such as "Does the station have trending program to assist in the identification of repetitive equipment issues?" Based on the answer to the question, the associated behavior is then scored according to the following criteria: (1) needs much improvement, (2) needs some improvement, (3) competent, (4) strength, or (5) exceptional. Separate lists of questions are developed for different divisions within the plant (senior/middle management, engineering, operations, etc.), and the scores are posted for employee review. Average scores below three indicate warning flags.

As of June 2003, the Utility Service Alliance was able to demonstrate some success with its new assessment method through Site Assessment Reports that had been developed for five of their member plants. Strengths and areas in need of improvement had been identified in each plant. Though all of the five averaged an approximately 'competent' score, encouragingly, the Utility Service Alliance method was able to discern levels of safety culture at the plants by comparing quantities of warning flags.
INPO states that safety culture is fundamental to its mission, but its own approach to assessing safety culture is not as developed or prescriptive as that of the Utility Service

Alliance. Though not necessarily by that name, INPO says, "safety focus," "deep respect for the core," and "reactivity management" are its motivation for focusing on functional issues like operations, maintenance, and engineering. INPO defines safety culture as "that set of attributes that results in nuclear safety being the overriding priority at the station."

The philosophy behind INPO's approach to assessing nuclear safety is that if a safety culture is unhealthy, it will show up in symptoms. Some of the symptoms INPO uses were frequently cited by others such as how comfortable the plant staff is in raising problems and how risk is measured and managed. Other symptoms may be detectable in plant records, such as whether safety systems are unavailable longer than need be and whether modifications that are installed adequately consider the margin-to-safety. These and other symptoms will be identified by a team of professionals with broad experience.

Following the Davis-Besse incident, INPO wrote its own significant operating event report and developed several recommendations both for the plants and itself [40]. To the plants it recommended (1) that all members of the management team participate in a case study discussion, (2) that each plant perform a self-assessment of safety culture, and (3) that the plants identify and document long term unexplained conditions. INPO also learned that it needs to better recognize and more openly address safety focus and improve its ability to uncover the organizational factors that detract from a strong safety culture. It is currently in the process of developing a safety culture task force which will incorporate industry and international input.

4.2 International regulatory bodies

One of the first regulatory bodies to formally acknowledge the importance of safety culture in its regulation was the Finnish Radiation and Nuclear Safety Authority (STUK). Finnish experts also participated in drafting INSAG-4, in which the now generally accepted definition of safety culture was first proposed. Safety culture was included in Finnish regulation in 1991 as Section 4 of the "General Regulations for the Safety of Nuclear Power Plants." According to the legislation, STUK is responsible for setting safety requirements and verifying compliance of the four Finnish reactors. For this end, STUK has developed a set of safety guides known as the YVL-guides. The guides give instructions and recommendations on all areas of nuclear power plant operation, including general safety principles, personnel qualification and training, utilization of operational experience, and inspections and safety assessments.

Shortly after the legislation was enacted, STUK prepared Safety Evaluation Memoranda for each of its power plants in which many of the important safety culture attributes were addressed, including the following:

- Past management decisions where it had been necessary to make a choice between shutting down a plant for safety concerns or continuing operations and taking action later.
- Resources invested in maintaining a high level of safety.

- Co-operation and information exchange between organizational units.
- Methods for maintaining and upgrading plant personnel's professional skills and knowledge.
- Openness in uncovering and solving problems.

STUK also included an evaluation of safety culture strength as part of renewing the operating licenses of the plants in 1998. The evaluation was based on self assessments as well as STUK's own observations of safety culture attributes. Other initiatives for the regulator to interact with the plants on safety culture issues are periodic "Safety Management" inspections, quality assurance audits, and root cause analyses. Licensee senior plant managers also meet annually with STUK to discuss their findings related to safety culture. In 1999, STUK established the "Human and Organizational Factors" unit within the Department of Nuclear Reactor Regulation to further safety culture oversight [24].

Canada has also decided to actively review licensees' safety cultures. The Atomic Energy Control Board (AECB), which existed until 1999 when the Nuclear Safety and Control Act created the Canadian Nuclear Safety Commission (CNSC), decided that the newly realized importance of safety culture justified a proactive approach and sought to develop a systematic, objective process for assessing the licensees' organization and management. AECB's philosophy was that if the organization and management foundation of a plant was flawed, then potentially serious problems existed in the entire defense-in-depth system.

The ultimate goal was to develop a method to assess licensees' organization and management systems and processes as a standard component of AECB's formal regulatory process. Several prerequisites for the method were specified, notably that assessments use objective measures yet be both quantitative and qualitative to fairly obtain an accurate understanding of the situation at the plant. Another early concern was that the method must focus clearly on safety requirements and not dictate a particular management philosophy. The factors the method would assess were also pre-determined using Jacobs and Haber's organizational factors. The model used to develop the assessment method, termed the Canadian Adaptive Machine Model (CAMM), was a version of the NRC's NOMAC, modified to accommodate the Canadian nuclear environment

AECB incorporated several previously validated evaluation tools into its method. In addition to documentation review, surveys, and walk-throughs, the method developers designed a structured review protocol and built a database of relevant questions to assess pre-identified issues. The method developed would also utilize behavioral checklists and behavioral anchored rating scales (BARS) that would allow behavioral examples to be incorporated with general performance dimensions.

About nine facilities had been evaluated by the new CNSC as of 2003. Evaluations are labor intensive and require 4-6 inspectors to spend 10-14 days onsite. The licensee in the field trial reportedly agreed that the process was systematic and resulted in legitimate data and an accurate assessment. Other licensees since have expressed some concern about the regulator's intrusiveness.

Though safety culture is not explicitly part of CNSC's considerations for license renewal, the commission is given the burden of confirming that the applicant "makes adequate provision for the protection of the environment, the health and safety of persons and the maintenance of national security." To fulfill this mission, the license renewal decision uses compliance verification activities, safety performance indicators, and review of safety significant events. Though traditionally a non-prescriptive regulatory body, CNSC is moving towards more explicit requirements in order to be more predictable and understandable to industry and the public [24].

The Swedish Nuclear Power Inspectorate (SKi) also takes a non-prescriptive approach to nuclear safety regulation. Under the Act on Nuclear Activities, the licensees have the full and undivided responsibility to take all measures necessary to achieve safety. The role of the SKi is to provide clear definitions of requirements and to supervise compliance with those requirements largely by focusing on organizational processes and activities. The associated regulatory strategy gives equal weight to technical and organizational factors that influence nuclear safety.

An updated set of general safety regulations was issued in 1998 along with general recommendations on their application. In general, the provisions extended and reinforced many of the earlier requirements, particularly those related to human factors and organizational issues. Though the regulations do not make specific safety culture requirements, there is a focus on the quality of key processes for safety such as ensuring satisfactory working conditions, ensuring the maintenance of a competent and adequate staff, conducting safety reviews, and ensuring a systematic analysis of incidents.

The approach for assessing aspects of management functions and oversight was developed in the SKi Inspection Guidebook-Maintenance in 1994. The method identifies five resource functions (people, tools, materials, information, and coordination) essential to effective maintenance programs. It also emphasizes that a program must be viewed as a system of interrelated elements and activities and goals must be evaluated within each element. A list of general questions is offered to assist the inspector in his evaluation. This guidebook is also available to the utilities to use in self-assessments.

SKi conducted an intensive inspection at one site following the identification of several indicators of deficiencies in safety management. Using a mixed team of inspectors with backgrounds in plant operation and experts on man-technology-organization interaction, the inspection also looked into organization and safety culture, self-assessment, management of human factors, and management training. Feedback of their findings was given to the managers in meetings on site. The effort was found to be very useful and SKi decided to continue the in-depth inspections at one site per year even without indicators of declining safety performance [24].

The U.S. NRC currently does not regulate safety culture. It has, however, taken actions to provide some guidance to its licensees on safety culture and the development of a SCWE. In its Policy Statement on the Conduct of Nuclear Power Plant Operations in January 1989 [41], the Commission includes a sentence reminiscent of the Occupational Safety and Hazard Act, "Management has the duty and obligation to foster the development of a "safety culture" at each facility and to provide a professional working environment, in the control room and throughout the facility, that assures safe operations." In May 1996 the Commission defined a SCWE, in its Policy Statement on the Freedom of Employees in the Nuclear Industry to Raise Safety Concerns without Fear of Retaliation [42], as a work environment in which "employees feel free to raise safety concerns, both to their management and to the NRC, without fear of retaliation."

The Commission does, however, attempt to assess safety culture and SCWE through indirect means. In a Staff Requirements Memorandum (SRM) in 1998 in response to SECY-98-059 [43], it approved the staff practice of inferring licensee management performance from routine inspections and event follow-ups, but also eliminated resources allotted for developing a systematic method for determining management performance. Similar to INPO's philosophy, the premise of the NRC reactor oversight process is that a poor safety culture will be evident during baseline inspections. Aspects of safety culture, such as problem identification are investigated during these inspections. Later that year, the Commission also approved the assessment of licensee SCWE on an individual basis but encouraged licensees to use third parties evaluations.

When significant issues are identified, supplemental inspections are also warranted. One focus of these inspections is licensees' dedication to identifying and correcting the root cause of performance deficiencies. Plants in an extended shutdown may also be subject to further inspections focusing on cross-cutting issues that contributed to the plant's shutdown.

This is where NRC draws the line. On March 26, 2003, the Commission issued an SRM [44] disapproving a recommendation in SECY-02-0166 for rulemaking with regard to SCWE. In place of regulation, it requested that a guideline of "best practices" to encourage a SCWE be developed in consultation with stakeholders. It also directed that efforts by foreign regulators to develop objective measures that serve as indicators of possible problems with safety culture as well as efforts to regulate safety culture be monitored. The NRC has not developed any performance indicators or other inspection tools of its own that are used routinely during inspections.

4.3 Obstacles to safety culture assessment

Safety culture assessment is a complex matter for both the utilities and the regulators. Much of the hesitancy of the NRC and other regulatory bodies is not due to a lack of recognition of its important role in the safe operation of a nuclear power plant but the obstacles and consequences involved. One fundamental question is 'Who should be performing safety culture assessments?' The mission of the NRC is to protect the public health and safety and the environment from the effects of radiation from nuclear reactors, materials, and waste facilities. However, the plants maintain full responsibility for safe operation. These roles cause some confusion as to who is responsible for assessing safety culture. Assessment and inspections by the regulator are very closely linked to regulations and requirements. Industry argues that safety culture regulations would mean interference in management and points out that if the licensees are to be ultimately responsible, they must have some say in the way safety is ensured.

A second argument against safety culture regulation is that safety culture initiatives are most effective when generated by the utility itself. A study on human factors in the United Kingdom found that the "most impressive achievements appear in companies where the pressure for safety has been generated within the organization, apparently independent of external standards." Assessment and regulation of safety culture by the regulator may discourage licensees from self-assessment and seeking continuous improvement in safety standards.

Regardless of who is doing the assessment, the greatest obstacle is figuring out how to assess safety culture correctly and fairly. A common complaint about how aspects of safety culture are currently inspected today is that the methods are not objective. Different inspectors acting in accordance with some current methods can come to different conclusions about the state of a particular safety culture. If this is so, plants cannot be expected to act on the feedback they receive, and prospective regulation could not be enforced. Data collection via surveys is also subjective as is its interpretation. Some argue that objective methods to assess safety culture are not possible because safety culture itself is a matter of attitudes.

If objective methods to assess the important safety culture attributes were found, the debate over their usefulness would still continue. While indicators would allow a detection of safety performance trends, they could only be an indirect measurement of safety culture. The consequences of using the indicators would also be an issue. If managers know what is being measured, they will undoubtedly focus their attention on improving their performance on those indicators. For example, if the indicator is the ratio of number of maintenance problems identified by the plant compared to the number identified by inspectors, the number of maintenance problems reported (big or small) is likely to increase. Managers want the plant to have successful ratios, so they encourage maintenance workers to include trivial findings in their reports. A large gain in the ratio may not necessarily correspond to great improvements in safety culture. This leads to another question—once an indicator is used to measure safety culture, will the assessment be valid if it is used again? Many questions stand in the way of a successful assessment of a plant's important safety culture attributes.

5. Conclusion

Safety culture is not a new topic of discussion in the nuclear power industry; it dates back to the TMI accident in 1979. Twenty-five years later it is more important than ever. Despite technological advancements, accidents and close misses still occur in nuclear plants. One recent reminder of the importance of safety culture was the 2002 Davis-Besse pressure vessel head degradation.

Although safety culture definitions vary, there is some consensus as to its fundamental attributes. Some approach the subject by examining organizational factors that cause changes in safety performance and some look at characteristics of plants with good records of safe operation. Six attributes (and variations thereof) are frequently cited: management commitment to safety, technical knowledge, roles and responsibilities, communication, problem identification, and learning culture. This consensus suggests that these attributes should be considered by those devising strategies to enhance safety culture. However, not all of these attributes would be appropriate for assessment by regulators.

Successful safety culture assessment must overcome many obstacles. Utilities and regulators alike are struggling to create objective methods to measure something that by its very nature is subjective. Many regulatory bodies to-date have chosen not to directly inspect or regulate the safety culture of their licensees. If in light of the operating experience, a regulator chooses to become more proactive in licensee safety culture, the first step will be to devise performance-based indicators able to warn of declining safety performance. Problem identification and learning culture would be good places to begin.

Appendix: Safety culture attributes from previous studies

Author	Proposed safety culture characteristics/symptoms and organizational factors affecting safety performance
Jacobs and Haber	Problem identification Organizational learning Performance evaluation Goal prioritization Resource allocation Time urgency Personnel selection Technical knowledge Training Organizational knowledge External communication Interdepartmental communication Intradepartmental communication Ownership Roles and responsibilities Coordination of work Organizational culture Safety culture Centralization Formalization
Nuclear Energy Agency	External influences Organizational learning Goals and strategies Resource allocation Training Organizational knowledge Human resources management Communication Coordination of work Management functions and overview Proceduralization Organizational culture
Weil and Apostolakis	Communication Formalization Goal prioritization Problem identification Roles and responsibilities Technical knowledge

Lee	High level of communication Good organizational learning Strong focus on safety Strong senior management commitment to safety Democratic, cooperative, humanistic management leadership style More and better quality training Clean, comfortable working conditions High job satisfaction Workforce retention is related to working safely
International Atomic Energy Agency	Employees have a questioning attitude Handling of conflict Involvement of all employees Organizational learning Self-assessment Measurement of safety performance View of mistakes Safety can always be improved Top management commitment to safety Absence of safety versus production conflict Man, technology, and organization knowledge Proper resource allocation Compliance with regulations and procedures Strategic business importance of safety High priority to safety Sufficient and competent staff Good working conditions (time pressure/ workload/stress) Quality of documentation and procedures Systematic approach to safety Motivation and job satisfaction Good housekeeping Awareness of work process Visible leadership Collaboration and teamwork Relationship to regulators and other external groups Relationship between managers and employees Openness and communications Clear roles, responsibilities, and accountabilities View of safety Role of managers Proactive and long term perspective Time focus Management of change

Institute of Nuclear Power Operations	Nuclear safety is everyone's responsibility Leaders demonstrate commitment to safety Trust permeates the organization Decision-making reflects safety first Nuclear is recognized as different A "what" if approach is cultivated Organizational learning is embraced Nuclear safety undergoes constant examination
Nuclear Energy Institute (Dugger)	Operate the plant safely Maintaining equipment in top working order Finding problems and fixing them Recognizing employee's efforts Being self-critical Communicating effectively Fostering professionalism
Donald and Canter	Management commitment Safety training Open communications Environmental control and management Stable workforce Positive safety promotion policy Importance of safety training Effects of workplace Status of safety committee Status of safety officer Effect of safe conduct on promotion Level of risk at the workplace Management attitudes towards safety Effect of safe conduct on social status
Murley (Safety Consultant)	Organizational commitment to the priority of safety matters Clear lines of responsibility within the regulatory body Program of initial and continuing training to maintain regulatory staff competence Personal commitment to safety from every staff member Clear guidance for conducting safety inspections and reviews Clear regulatory acceptance criteria Commitment to regulatory intervention that is proportionate to the safety implications Use of risk insights in decision making Effective plan management Effective work planning and programs Self-assessment and quality assurance audits Clear accountability and responsibility for fixing problems Management cooperation with regulator Timely response to regulatory commitments Participation or exchanges of info with other plants Participation in industry activities with current performance

Whitcomb (Attorney at Law)	Management leadership Personnel integrity Technical competence Personal reliability Two-way communications
Utility Service Alliance (O'Connor)	Safety over production Management oversight Rigor staff capability Problems identified and reported Independent oversight backed by management Learning from others Regulatory compliance Maintain or improve safety margins Safety is a clearly recognized value Accountability for safety is clear Safety is integrated into all activities Safety leadership process exists Safety culture is learning-driven Not complacent Non-isolationism No arrogance Intrusiveness
INSAG 15 (as adopted by NRC)	Commitment Use of procedures Conservative decision Making Reporting Culture Challenging unsafe acts Learning organization Communications Clear priorities Organization

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