ORGANIZATIONAL FACTORS IN PRA: TWISTING KNOBS AND BEYOND

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Abstract

Organizational problems have long been viewed within portions of the probabilistic risk assessment (PRA) community as important and perhaps even dominant contributors to nuclear power plant risk. This view has been reinforced by recent operational experience, most notably the Fukushima Dai-ichi reactor accidents. Attempts to explicitly incorporate organizational factors in a PRA context have a similarly long history. Nevertheless, it appears that there remains a lack of consensus regarding the extent that such factors are already implicitly treated in PRA models, which PRA model elements need to be adjusted and to what extent, and what new PRA model elements are needed (e.g., to treat dependencies introduced by organizational structures, processes, and behaviors). This paper provides a perspective on these matters that is informed by operational experience and recent organizational research, as well as ongoing PRA-oriented development efforts documented in the literature. The paper does not suggest a “correct” approach to the treatment of organizational factors, but seeks to provide some considerations intended to help ongoing and future research efforts.

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Organizational problems have long been viewed within portions of the probabilistic risk assessment (PRA) community as important and perhaps even dominant contributors to nuclear power plant risk. This view has been reinforced by recent operational experience, most notably the Fukushima Dai-ichi reactor accidents. Attempts to explicitly incorporate organizational factors in a PRA context have a similarly long history. Nevertheless, it appears that there remains a lack of consensus regarding the extent that such factors are already implicitly treated in PRA models, which PRA model elements need to be adjusted and to what extent, and what new PRA model elements are needed (e.g., to treat dependencies introduced by organizational structures, processes, and behaviors). This paper provides a perspective on these matters that is informed by operational experience and recent organizational research, as well as ongoing PRA-oriented development efforts documented in the literature. The paper does not suggest a "correct" approach to the treatment of organizational factors, but seeks to provide some considerations intended to help ongoing and future research efforts.

I. BACKGROUND AND PURPOSE

As discussed in SECY-18-0060 (Ref. 1), the U.S. Nuclear Regulatory Commission (NRC) staff are proposing to develop processes and tools to expand their systematic use of qualitative and quantitative risk and safety insights as part of their efforts to transform the agency's regulatory framework, culture, and infrastructure. In support of this initiative, it is desirable that available probabilistic risk assessment (PRA) tools capture and appropriately characterize all sources of risk important to regulatory decision making. Current technology (i.e., methods, models, tools, and data) for nuclear power plant (NPP) PRA enables treatment of many sources observed in operational incidents and accidents. However, there are a number of gaps that appear to be potentially important contributors to "completeness uncertainty" and, depending on the needs of the decision problem at hand, require separate consideration in the agency's risk-informed decision making (Refs. 2 and 3). The treatment of organizational factors is one such gap.

"Organizational factors"[a] have long been recognized as an important influence on safety. Such factors played a significant role in the Three Mile Island, Chernobyl, and Fukushima Dai-ichi reactor accidents, and in other major incidents (e.g., the 2002 Davis-Besse reactor pressure vessel head corrosion incident). Recently, it has been argued that organizational factors can be a noteworthy source of dependency in multi-unit accidents (Ref. 4). It is also important to recognize that organizational factors have also had an observable, positive effect on safety, e.g., as evidenced by pro-active design and operational improvements leading to improved plant responses to actual incidents (Refs. 5, 6, and 7).

The incorporation of organizational factors into PRA has long been one of the recognized grand challenges to PRA. The basic challenges include:

- Problem definition: What is the analysis scope? Which organizations should be addressed? What are the "factors" to be considered?
- Modeling: How do organizational behaviors, which might be well-adapted to some situations but not others, link with the specific basic events in a

[a] There is no universally accepted definition of this term. Our perspective is provided in Section III.

PRA model? Should the model address individuals as well as groups and, if so, how?

- Quantification: What data are available and how should they be used? What other evidence should be obtained, how should this be done, and how should it be used?
- Use: How should decision makers interpret and use findings regarding the importance of different factors?

Addressing these challenges introduces other challenges, including the integration of technical disciplines (e.g., PRA-oriented systems engineering and organizational psychology), often with differing points of view regarding problem framing and appropriate methods of solution. NPP-PRA oriented research and development (R&D) efforts started in the mid-1980s (e.g., Refs. 8-10) and continue to this day (e.g., Ref. 11).

We, the authors of this paper, have not been directly involved in these R&D efforts. However, we have combined expertise in organizational science, PRA methods and model development, and operational experience data collection and analysis. The purpose of this paper is to provide some perspectives that might be useful to current R&D efforts. Some of these perspectives are well-known but bear repeating. We further expect that this paper will inform future NRC decisions regarding the potential for and performance of future NRC R&D activities.

II. PRA MODELS AND DEPENDENCIES

In principle, "organizational factors," such as those discussed in Section III, can affect the likelihoods of the myriads of basic events in a PRA model, and even the likelihoods of basic events considered but screened out of the PRA model.[b] Also, in principle, organizational factors can affect the coupling between basic events. For scenarios involving dissimilar basic events, this could introduce dependencies not included in typical PRA models. The treatment of dependencies is, of course, a critical element of PRA.

Moving beyond principle, we make a number of observations regarding human reliability analysis (HRA), hardware reliability analysis, and the overall PRA model structure.

II.A. Human Reliability Analysis

HRA methods can treat organizational factors in both the qualitative and quantitative analysis stages. For each human failure event (HFE) in the PRA model, the qualitative analysis identifies the specific performance shaping factors (PSFs)/performance influencing factors (PIFs) that can be adjusted due to organizational influences, and the rationale (e.g., underlying mechanisms) for adjustments. The quantitative analysis determines the degree of the PSF/PIF adjustments to the base human error probability (HEP).

Qualitative analysis is a critical but sometimes underemphasized element of HRA. Current HRA guidance for performing qualitative analysis provides limited instruction on treating factors discussed in Section III, but is not entirely silent. For example, some related contextual factors such as staffing resources and administrative controls and biases are included in current qualitative analysis guidance (Ref. 12).

The explicit treatment of cognitive mechanisms involved in crew decision making, a central element of some advanced dynamic PRA methods (notably ADS/IDAC Ref. 13) and the IDHEAS methodology (Ref. 14), provides a path to incorporate some potentially important organizational factors. For example, an emergency response organizational structure that involves external decision makers during severe accident management can be incorporated by appropriate definition of the "crew." The specific treatment of external decision makers is, of course, a modeling challenge.

Similarly, HRA methods that address the time required to perform actions (including the time required to make associated decisions) can address organizational factors (e.g., decision making) affecting a crew's ability and willingness to take actions without external input.[c]

HFEs involving the failure of physical tasks (e.g., ex-control room actions during event response; pre-

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[b] Note that the influences are not necessarily unidirectional. For example, an organization that emphasizes the importance of pre-emptive maintenance could be expected to experience fewer failures than one that prefers waiting until problems arise. However, the former approach could also lead to increased maintenance-related unavailabilities (perhaps during an outage) and even to increased likelihoods of system mis-alignments following maintenance. These trade-offs are well-recognized and are amenable to analysis using current PRA technology; the point is that the net effect of an organizational approach is not always obvious.

[c] As with the pre-emptive maintenance example mentioned earlier, the effect of crew independence and initiative can be complex. A crew not required or willing to wait for outside input could be more timely and agile in decision making, but could also miss the benefit of differing perspectives and expertise.

event maintenance errors) lend themselves to task-oriented modeling approaches. Such approaches, including simulation-oriented modeling (e.g., Refs. 15-17) and network modeling (e.g., Ref. 18), in addition to well-known logic-oriented approaches (e.g., Ref. 19), provide a natural framework for treating a number of organizational influences on task performance (e.g., staffing decisions that affect the resources available to perform a task).

Some PSFs addressed by common HRA methods, e.g., the quality of procedures and training, can be affected by economically-oriented organizational factors (e.g., goal prioritization, external influences). It is important to recognize that the PSFs should be analyzed in the context of the specific HFEs modeled (e.g., the quality of procedures relevant to the HFE), and that there can be significant time lags between changes in the organizational factors and their impact on the PSF, e.g., as discussed in Ref. 20).

The treatment of dependencies between HFEs remains a challenge for HRA. The widely-used THERP approach to quantify the effects of dependencies, which considers whether actions are performed by the same staff and/or if they are close in time, can account for some organizational factors (e.g., through decisions regarding staffing and scheduling) but appears to lack a strong empirical basis for quantification. It is important to recognize that some organizational dependencies (e.g., multi-unit dependencies between HFEs at different units due to common procedures) are appropriately treated through a conditional independence modeling approach, and need no additional special treatment.

II.B. Hardware Reliability Analysis

Some organizational factors are implicitly included in plant-specific estimates for PRA parameters modeling hardware failures (including common cause failure (CCF) model parameters). Of course, the rarity of actual failure events for NPP SSCs leads to significant uncertainties in the parameter estimates, and inhibit statistically-oriented attribution of estimate variations to potentially important influencing factors, including organizational factors.

To provide a rough indication of the potential impact of organizational factors on component failure probabilities, Table I provides estimates for two typical PRA parameters for a small sample of plants reporting disparate quantities of operational data (as determined from a review of proprietary Institute for Nuclear Power Operations – INPO – data). The variations in failure probability estimates can be due to a number of causes, e.g., different manufacturers, design, construction, environment, training, and/or maintenance practices, some of which might not be considered in organizational factor analyses that focus on the licensee's organization. It should also be recognized that voluntary industry reporting guidelines allow for licensee discretion in the degree and extent of reporting for many nuclear systems. Naturally, variations in licensee reporting can also lead to variations in failure probability estimates.

The estimates in Table I come from two plants (designated "Low") that have provided less data than two other plants (designated "High"). The two parameters, the failure probability for motor-operated valves (MOVs) and for standby turbine-driven pumps (TDP-SBY) were selected as being representative of parameters for which there are varying amounts of data. The estimates were developed using the standard Bayesian methods described in Ref. 21.[d]

It can be seen that the range of mean values across the four plants is roughly a factor of 7 for MOVs and 20 for TDP-SBY. Since, as discussed above, parameter estimate variability can be due to a number of causes, these values might indicate a rough bound for the potential impact of organizational factors on the selected parameters. Of course, strong conclusions cannot be drawn from such a limited exploration. Furthermore, we observe that the prior distributions often used in practical Bayesian analyses (e.g., non-informative or hierarchical) are not plant-specific. It is possible that organizational factors could have a larger impact on failure probabilities than would be shown by such analyses.

Table I shows that SSC failure data that are plentiful at an industry level can be sparse at a plant level. Data are particularly sparse for CCFs. Consequently, even plant-specific PRAs tend to use generic estimates. Given the general importance of CCFs, this provides a further illustration of the limitations of NPP-based statistical approaches for assessing the effect of organizational influences on PRA results and insights.

Generic reliability handbooks from other industries (e.g., Refs. 22 and 23) can also provide information regarding the relative impact of various influencing factors, and such information has been used to suggest potential degrees of variability in CCF model parameters (Ref. 24). Of course, the estimated influences are drawn from the experiences across different industries and their direct applicability to NPPs is uncertain. It should also be noted that the

[d] The industry average estimates are from: https://nrcoe.inl.gov/resultsdb_preview/publicdocs/AvgPerf/ComponentUR2015.pdf

TABLE I. Ranges of Failure Probabilities for Sample Basic Events

SSC/ failure mode	Source	Failures	Demands	Failure Probability		
				5%	Mean	95%
Motor-Operated Valve/ Fail to open or close	**Industry**	**554**	**725,900**	**2.1E-04**	**8.3E-04**	**1.8E-03**
	Plant 1 – Low	0	7,044	6.8E-05	2.7E-04	5.9E-04
	Plant 2 – Low	1	11,639	8.3E-05	2.6E-04	5.1E-04
	Plant 3 – High	14	3,844	1.4E-03	2.3E-03	3.4E-03
	Plant 4 - High	18	7,702	1.2E-03	1.9E-03	2.6E-03
Standby Turbine-Driven Pump/ Fail to start	**Industry**	**144**	**26,582**	**5.3E-04**	**5.9E-03**	**1.6E-02**
	Plant 1 – Low	0	1,413	6.3E-05	8.0E-04	2.3E-03
	Plant 2 – Low	0	551	1.4E-04	1.7E-03	4.7E-03
	Plant 3 – High	8	244	1.0E-02	2.0E-02	3.3E-02
	Plant 4 - High	9	359	9.5E-03	1.8E-02	2.8E-02

magnitude of influences are small with respect to typical PRA parameter uncertainties. This degree of variation, although potentially important from a power production standpoint, might not be significant in comparison with the uncertainties in typical PRA parameter estimates.

Mechanistic models for basic events (exemplified but not limited to "physics of failure" and "reliability physics" models) provide another approach to address the impact of organizational factors (e.g., through linkages between inspection and maintenance practices and their effect on failures due to the modeled mechanisms). Aside from the usual cautions of addressing uncertainties in the structure and input parameters of mechanistic models, particular care is required regarding completeness uncertainties as such models, by their nature, focus on specific failure scenarios and not on others.[e]

II.C. PRA Model Structure

Ultimately, the summary results of current NPP PRAs come largely from the contributions of a relatively small subset of the enormous number of possible cut sets. Each of these contributing cut sets typically involves multiple failures (including the initiating event).[f]

As compared with nominal conditions, negative organizational factor influences can increase risk estimates and change risk profiles through: a) increasing the likelihood of a very important basic event, b) increasing the likelihood of multiple basic events in multiple contributing cut sets, or c) introducing a new, important failure mechanism/scenario (e.g., for a dependency within or across cut sets) not included in the PRA model (including scenarios considered but screened). Regarding the last, new failure scenarios would still need to have the physical, functional impacts (e.g.,

[e] For example, in one multi-unit event identified by Ref. 25, operators tripped one unit when communications were lost with a diver who was in the common circulating water pump house, inspecting condenser piping for the sister unit (which was shut down and defueled). Of course, a mechanistic model for reactor trips would need to address the wide variety of potential causes of a reactor trip. Note also that this event, in which a positive safety culture led to a plant transient, provides a further illustration of the potential for complex impacts of organizational factors.

[f] Some PRA models can include single element cut sets (e.g., reactor pressure vessel rupture), but these can be viewed as modeling approximations for situations where further analysis is judged to be unnecessary. Should further analysis be required, we expect that chains of sub-events leading to that "single element" can be identified. Note that in some PRA models, chains of sub-events are implicit in some of the model's basic events. (For example, a basic event representing fire-induced damage to a component includes sub-events involving fire initiation and the failure of suppression before damage.)

loss of decay heat removal) already modeled by the PRA.

Positive organizational influences can reduce risk estimates through: a) reducing the likelihood of basic events with large importance measures, b) reducing the likelihoods of multiple basic events in multiple contributing cut sets, or c) the "practical elimination" of modeled mechanisms. Note that in absolute terms, the inertial effect of the multiple contributing cut sets tends to resist downward movement; reducing the effect of a single dominant basic event or cut set by a given factor will have less impact than increasing the effect by the same factor.

The treatment of basic events has been discussed in Sections II.A and II.B. Regarding mechanisms, we expect that a PRA-oriented review of past NPP accidents and incidents would be useful in identifying mechanisms, both positive and negative, that can/should be considered in an organizational factors analysis. As an example, the following section discusses an empirical review of multi-unit dependencies introduced by organizational factors.

II.D. Licensee Event Reports (LERs) with Organizational Dependencies

In a study of operational experience related to multi-unit dependencies, Ref. 25 evaluated LERs that were submitted to the NRC from 2000 through 2011.[g] Organizational dependencies were the most common source of dependence, and accounted for 41% of the 391 multi-unit LERs analyzed (4% of all LERs). Table II shows examples of these events and their mapping to the six factors identified by Ref. 26. As indicated in the table notes, classification of the reported failures based solely on text provided in the LERs can be difficult.

III. ORGANIZATIONAL FACTORS

III.A. What Do We Mean by Organizational Factors?

Organizational factors encompass the organizational structures, processes, and behaviors

Table II. Examples of Multi-Unit Dependencies Arising from Organizational Factors

LER Number	Excerpt from LER Text	Categorization
3872001001	"The cause of the SLCS design deficiency was a lack of coordination between the ATWS analysis and the SLCS design evaluation."	Communication
4542001001	"A formal engineering calc process was not utilized due to a lack of clear management expectations and detailed guidance to recognize when a formal calc is required."	Formalization
4562010007	"The cause of this event was the failure to consider bounding conditions when calculating the temperature limit to prevent flashing in the RH system."	Problem Identification/Technical Knowledge[a]
3612010006	"The apparent cause of these events is related to human performance deficiencies including inadequate pre-job brief, inadequate self-checking, and inadequate procedure usage and adherence."	Roles and Responsibilities[b]
2692002001	"The apparent cause was a fundamental lack of appreciation for the potential impact of PZR insulation deficiencies."	Technical Knowledge

[a]This could be either Problem Identification or Technical Knowledge, depending on the understanding staff had of the system. As Ref. 26 notes, Problem Identification "refers to the extent plant personnel use their knowledge." If the staff understood that the bounding conditions may need to be evaluated, but did not use that knowledge, this could be categorized as Problem Identification. If, however, they did not understand that bounding conditions, this event would be categorized as Technical Knowledge.

[b]Although the Ref. 26 model removed culture as a factor (see Section III below), events such as this may illustrate that in some instances, an overarching theme may be more appropriate than these more specific factors.

[g] LERs are submitted to the NRC after plant abnormalities in accordance with guidelines prescribed in 10 CFR 50.73. These LERs, which include latent conditions as well as actual event occurrences, discuss the apparent root causes of the events and actions that will be taken by the licensee.

that influence the actions of individuals at work. In particular, we are interested in those organizational factors that are predictive of plant safety performance, such that they may increase or decrease the likelihood of an accident or the severity of the consequences of an accident. One goal of incorporating organizational factors into PRA would be to provide an assessment of the risk impact of changes in organizations.

Various reports on the Fukushima Dai-ichi accident indicate multiple organizational contributors to the event that share much in common with other major disasters. Ref. 27 notes the following as particular organizational factors that played a role in the accident:

- Inadequate knowledge and training related to severe accidents (training failure);
- A lack of regulatory independence and the existence of a complex ‘chain of command’ (failure to deal with organizational interdependencies);
- A lack of cross-functional discussions (communication failure);
- A belief that a severe accident and loss of defense in depth was unlikely;
- Underestimation of tsunami height (design or other technological failure);
- A failure to consider the need to strengthen safety measures (decision making failure).

Many models tend to assume that organizational conditions are known in advance and termed “organizational failures.” However, latent conditions often seem innocuous and go unrecognized until after an incident occurs. The incident changes the perception of risk associated with the condition. This is also referred to as *outcome knowledge bias* in psychology, where knowing how an event turns out biases one’s judgment about the actions of those involved. Often, latent organizational conditions exist for a well-meaning purpose, such as to gain efficiencies in production, overcome other weaknesses (e.g., workarounds or use of tribal knowledge due to inadequate procedures), or due to competing safety priorities (e.g., industrial or radiological safety). These conditions reflect how the organization has adapted over time to balance safety and production—the lack of a prior incident is justification to continue on the charted course under the assumption that it is safe enough. Examples of latent conditions that could contribute to future incidents include:

- Visual inspections not performed due to ALARA.
- Equipment not readily accessible in emergency situations due to industrial safety concerns, foreign material exclusion programs, or seismic considerations.
- Lack of resources invested in engineering training program contributes to inadequate understanding of interconnectedness of systems during testing.
- Maintenance backlogs reduce priority of preventive maintenance program, increasing probability that a component will fail due to undetected fatigue, wear, etc.

III.B. Organizational Factors Identified as Important to Safety

There are many approaches to modeling organizational factors and associated lists of factors at various degrees of abstraction (Ref. 28). Past examples include Refs. 26, 29, and 30 (see Table III). In some

TABLE III: Organizational Factors from Ref. 30

<table>
<tr><td colspan="2">CULTURE
• Organizational culture
• Ownership
• Safety culture
• Time urgency</td></tr>
<tr><td>COMMUNICATIONS
• External
• Interdepartmental
• Intradepartmental</td><td>ADMINISTRATIVE KNOWLEDGE
• Coordination of work
• Formalization
• Organizational knowledge
• Roles/responsibilities</td></tr>
<tr><td>DECISIONMAKING
• Centralization
• Goal setting
• Organizational learning
• Problem identification
• Resource allocation</td><td>HUMAN RESOURCE ADMINISTRATION
• Performance evaluation
• Personnel selection
• Technical knowledge
• Training</td></tr>
</table>

cases (e.g., Ref. 26), the lists are trimmed for pragmatic reasons; discounted factors are not necessarily unimportant but are not addressed to enable project completion. Current researchers, of course, have created frameworks to provide theoretical underpinnings (Ref. 10). We observe that: a) there is, as yet, no consensus list of factors to be considered in a PRA, and b) although a consensus list can help with communication, data translation, and R&D collaboration, it is not necessarily a critical goal at this stage. Indeed, in areas of great uncertainty, it can be better to explicitly recognize the variance in views and the resulting potential variations in impact on PRA results and insights.

III.C. Organizational Factors and Safety Culture

The last two decades of organizational factors research in the nuclear industry seems to have coalesced around the concept of safety culture. Whereas safety culture was often included as an organizational factor in earlier work, it has become much more common to see other organizational factors subsumed under the construct of safety culture. In fact, it can be argued that the term “nuclear safety culture” has evolved into an omnibus concept encompassing all organizational factors to varying extents.

The transition from discussion of management and organizational factors to safety culture can be seen in the NRC’s journey of incorporating safety culture into policies and oversight processes. The NRC’s safety culture common language document (Ref. 31), which was developed in an effort to harmonize differences in terms that different groups have used to describe a healthy nuclear safety culture, lists ten traits of a safety culture[h]:

- Leadership
- Safety Values and Actions
- Problem Identification and Resolution
- Personal Accountability
- Work Processes
- Continuous Learning
- Environment for Raising Concerns
- Effective Safety Communication
- Respectful Work Environment
- Questioning Attitude
- Decisionmaking

Note the many overlaps among the NRC’s safety culture traits and past taxonomies of organizational factors (e.g., Communication, Decisionmaking, Problem Identification, Leadership, Work Process, Learning). Each of the ten safety culture traits are further divided into sub-categories, which are reflected in the NRC’s Reactor Oversight Process as cross-cutting aspects. Cross-cutting aspects capture the important characteristics of safety culture which are observable to the NRC staff during inspections and assessments of licensee performance. NRC inspectors assign a cross-cutting aspect to an inspection finding if the aspect is either a primary cause or significant contributing cause of the performance deficiency cited in the finding.

Recent efforts have been underway with international groups such as the World Association of Nuclear Operators and the International Atomic Energy Agency (IAEA) to incorporate the safety culture traits endorsed by the U.S. nuclear industry into a common language for the international nuclear community. Although more consensus-based than theoretically based, the promulgation of this safety culture common language might provide a consistent framework for describing organizational factors in the future. Use of a consistent framework in PRA and HRA applications, operational data collection systems, and causal analysis methodologies, would potentially facilitate data translation across these different applications.

III.D. Organizational Typologies

Westrum (Refs. 33 and 34) identified three types of organizational cultures based on how they deal with safety-related information: pathological, bureaucratic, and generative. Pathological cultures are characterized as shirking responsibility for safety, punishing failure, and discouraging new ideas, whereas Generative cultures are characterized as actively seeking information, sharing responsibility, and welcoming new ideas. Westrum’s typology of organizational cultures is similar to work by Fleming, sponsored by the UK Health and Safety Executive (HSE), to develop a safety culture maturity model for the oil and gas industry. Fleming’s (Ref. 35) safety culture maturity model consists of five levels: emerging, managing, involving, cooperating, and continually improving. Each level includes descriptions of how an organization approaches safety at the different levels

[h] Nine of the safety culture traits are the same as those listed in the NRC’s Safety Culture Policy Statement (Ref. 32), with the addition of Decisionmaking as a trait of particular importance in nuclear power plant operations, beyond its implicit representation in other traits, e.g., Leadership Safety Values and Actions.

to facilitate identifying what type of safety culture an organization currently has and identifying actions to help an organization "mature" to higher levels in the typology. More recent work by Hudson (Ref. 36) notes the expansion of Westrum's model into the HSE Culture Ladder with five levels of maturity: pathological, reactive, calculative, proactive, and generative. Fleming notes that the safety culture maturity model assumes that safety performance improves with increasing levels of maturity. However, this assumption is not directly supported by empirical research, but rather by case studies comparing features of high and low accident organizations. Psychological research in other domains, such as personality assessment, also calls into question the validity of discrete typologies. Decades of research suggest that people's personalities are best understood as profiles of high to low values on several dimensions rather than discrete types, e.g., Big Five personality dimensions vs. Myers-Briggs Type Indicator (Ref. 37). If organizational culture is a reflection of the "personality" of the organization, then discrete typologies may also prove to be an oversimplification of the construct. Just as with other studies of organizational factors and safety culture, maturity models suffer from a lack of theoretical grounding and establishment of causal relationships (Ref. 38).

III.E. Challenges to Incorporating Organizational Research into PRA

A common problem with translating organizational research into data usable for PRA is the differences in levels of analysis. Past organizational studies often correlate various organizational factors to organizational safety performance, whereas PRAs focus on basic events involving performance at a more detailed level. Karsh et al. write, "The gap within human factors and ergonomics generally is not lack of awareness of context or levels, but the absence of specific, tested, causal mechanisms between or among levels" (Ref. 39).

Challenges also exist in terms of determining how organizational factors are measured, in some cases who does the measuring, and then how those measurements are translated into the PRA.

Organizational scientists might have confidence in the assertion that organizational factors influence safety performance based on both empirical research and case studies of past accidents (c.f., Ref. 40), but data demonstrating the causal mechanisms linking organizational factors to human error or equipment failure rates are lacking.

From the IAEA report on Integrated Approach to Safety, "Human and organizational factors are often considered as discrete variables in that they are commonly viewed as separate and identifiable issues in the cause of an event. Examples include lack of training, incorrect procedures, poor decision making and ineffective communication. While these factors may very well play a separate and significant role in an operational failure, it is often a combination of several human, organizational and technological factors that leads to events and accidents" (Ref. 27).

As indicated earlier in this paper, we recognize that considerable efforts are being made within the PRA community to address the preceding concerns. From an organizational science point of view, there is a need to determine the extent to which these efforts meet the needs for:

- A consistent, theoretically-based taxonomy for organizational factors.
- The treatment of dependence between and overlaps among organizational factors, particularly with regard to taxonomies of organizational culture.
- The identification of clear, causal relationships between specific organizational factors and performance need to be developed.
- Means to translate current organizational research into meaningful inputs into PRA or HRA due to differing levels of analysis.
- Means to account for the combined effects of organizational factors, recognizing that individual factors in isolation may have a low effect, but combinations might have a non-linear effect.
- Means to determine when factors are an indicator of decreased risk (credit) versus increased risk, let alone means to assess quantitative risk impacts.

IV. CONCLUDING REMARKS

"Organizational factors" have long been recognized as an important influence on safety. Such factors have played a significant role in major incidents and accidents in both nuclear and non-nuclear industries. Understanding the impacts of organizational factors on risk and how to incorporate them into PRA has long been one of PRA's grand challenges.

HRA methods can be used to treat organizational factors in both the qualitative and quantitative analysis stages, and there have been several HRA development efforts to incorporate organizational factors. Further, some organizational factors are implicitly included in plant-specific estimates for PRA parameters modeling hardware failures. However, the rarity of actual failure events leads to significant uncertainties in the parameter estimates, and inhibit statistically-oriented attribution of estimate variations to important influencing factors.

Over the last two decades, organizational factors research in the nuclear industry seems to have coalesced around the concept of safety culture and the development of safety culture common language. The promulgation of this common language might provide a consistent framework for describing organizational factors in the future. Use of a consistent framework in PRA and HRA applications, operational data collection systems, and causal analysis methodologies, would potentially facilitate data translation across these different applications. However, given the large uncertainties inherent in the topic, it might also be useful to pursue a variety of frameworks and analytical approaches. For all approaches, a fundamental challenge is the identification, collection, analysis, and use of data that will further the incorporation of organizational factors into PRA.

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