Human Factors Engineering in Manual Ultrasonic Testing

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Abstract. The Electric Power Research Institute (EPRI) is working with human factors engineering subject matter experts (SME), nuclear power plant (NPP) industry leaders, and regulatory bodies on a human factors research study focused on manual ultrasonic testing (UT) for non-destructive evaluation (NDE). Last year, EPRI reviewed the existing research literature and plant operating experiences. EPRI staff and human factors SME were also privileged to visit two U.S. power plants during Fall 2016 outages in order to observe a variety of manual UT activities first hand. In addition, the human factors SME visited laboratory facilities, and spoke with ultrasonic SME, at the EPRI NDE facility in Charlotte, NC. Human factor SME attended the annual EPRI NDE Technology Week and the ASME Code Week to further build their appreciation for other related research, practice, and regulatory activities. Based on this background work, the following initial observations were made: (1) incidences of reported human errors during NDE leading to reportable consequences is statistically low, (2) industry efforts to date to ensure safety have been diverse and extensive, (3) there is a desire to maintain, and where possible identify improvements for NDE performance in terms of safety, effectiveness, efficiency and job satisfaction, and (4) the need for formal attention to human factors engineering has been recognized. The next step is to continue working with NPP industry leaders and regulatory bodies on a focused task analysis to ensure the range of manual UT tasks are captured, and they can be prioritized based on necessity. The paper will provide an update of EPRI's ongoing human factors research activities.

1. Background and Motivation

Nondestructive evaluation (NDE) in the nuclear power industry represents one of the most extreme and taxing work roles and work environments for skilled personnel. Examiners perform their jobs under conditions of physical and psychological stress from a variety of sources, including heat, radiation exposure, time pressure, noise and the possibility of a catastrophic radioactive leak if they fail in their task. These variables induce substantial sensory, physical and cognitive load on examiners. The previously proposed Modular Reliability Model, as shown in Figure 1, defines four primary influencing factors of NDE reliability [1]:

1. Application Parameters
2. Intrinsic Capability
3. Human Factors
4. Organizational Context

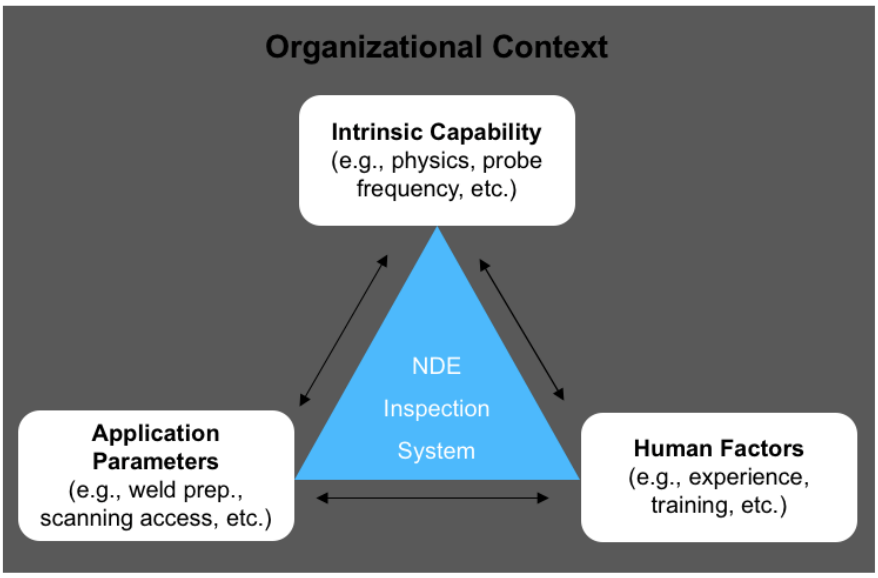

Fig. 1. Modular Reliability Model as Developed by [1].

Of the four primary influencing factors, as described by the Modular Reliability Model, human factors and organizational context have received the least amount of research attention in NDE. EPRI is currently exploring new opportunities for NDE reliability in these two areas through the discipline of human factors engineering.

The discipline of human factors engineering considers the people/workers, tasks, equipment and the environment to look for opportunities to improve human and system performance and to reduce error. Major considerations within the discipline of human factors engineering include:

- The end user, operator, examiner:
  - Physical characteristics such as ergonomics
  - Psychological factors such as decision making

- Scenarios and tasks:
  - What is the person trying to accomplish?
  - What training and procedures are available?

- Equipment and tools:
  - Human-system interface
  - Tool design

- Environment of use:
  - Physical environment
  - Management and organizational factors
  - Regulatory Considerations.

Human factors in NDE, specifically for ultrasonic testing (UT), have been studied by a variety of organizations and industry leaders. However, the scope of such studies have been limited and lacks a significant amount of quantitative evidence.

Dozens of performance shaping factors (PSFs) can be postulated to influence NDE reliability in the field. Many of these, while of theoretical interest, are not actionable when an examiner

is conducting NDE within a nuclear power plant. For example, it is well known that individuals have different cognitive styles that could be reasonably expected to impact their performance. Therefore, describing this variability is an important part of the theoretical literature on human factors in NDE.

On the other hand, controlling or changing cognitive styles across all examiners is an impossible undertaking. Researchers and practitioners simply cannot eliminate human variability, which means it will continue to exert a non-zero impact on NDE reliability in the field. In other words, as desirable as it might be to control a specific examiner's stress response, distractions, decision-making skills and other personal factors, there is inherent variability in human cognition and behaviour, which will decrease NDE reliability across all examiners. In applied research, the problem to be addressed is how to increase NDE reliability through best-possible performance of individuals, to the greatest extent within the stressful environment of a nuclear facility, while acknowledging that human variability exists. Therefore, human factors research must characterize the most critical, actionable factors that influence examiner performance in a field NDE environment.

The following presentation first focused on a review of existing research summarizing the available evidence on NDE reliability and describes the two major NDE environments (laboratory vs. field). The laboratory environment is considered as of as a comfortable classroom environment for learning or testing purposes. A review of operating experiences and observations of field NDE were conducted. Finally, the current research efforts by EPRI, which is a task analysis for NDE examiners, will be briefly described. Furthermore, the Nuclear Regulatory Commission (NRC) is conducting a similar research study. EPRI and NRC are working together and coordinating human factors research efforts on these project through a Memorandum of Understanding.

2. Research Focus

2.1 Literature and Operational Experience Review

This literature review focuses specifically on the use of manual UT NDE in the nuclear industry. Manual UT can be conventional (single beam angle) or phased array (multiple beam angles that form an image). Encoded or automated ultrasonic methods, which record data, are not primarily evaluated in this study.

In the behavioral sciences, including the field of psychology (human factors is a sub-discipline of psychology and engineering), peer-reviewed journal publications are considered the most intellectually rigorous, along with multiple, quantitative empirical studies of independent variables of interest. The body of literature reviewed consisted of theoretical articles, experimental studies, and survey designs. From the literature review it was found that the human factors research pertaining to nuclear industry ultrasonics is relatively small, qualitative, and lacked a significant amount of independent empirical validation of causal factors for NDE reliability. It was also noted during the literature review that NDE examiner experiences or perceptions are rarely considered or measured.

In addition to research literature, a review of nuclear power plant operating experiences was conducted. EPRI experts provided and discussed operating experiences of over a dozen real events that occurred in the past ten years [2]. Given the extremely low quantity of NDE failures occurring in the past decade, these data suggest an exceptionally low error rate given

the frequency of occurrence of examinations. Of course, it is critical to note that the NDE failure rate is unknown: the industry cannot identify 100% of flaws that have been missed in the field; only some percentage of missed flaws have been discovered. Thus, a negligible NDE error rate implies there is virtually no way to increase an already extremely low metric, like the rate of airline crashes in aviation. Nonetheless, human factors work in aviation has focused on improving training of pilots, standardization of procedures and documentation and equipment usability and standardization, all areas of potential future research in NDE.

2.2 Nuclear Power Plant Field Observations

Two nuclear power plants in the Eastern United States were visited by human factors experts to observe NDE first-hand. The purpose of the visit was to listen to present-day examiners and others describe challenges and opportunities to continue to ensure low NDE error rates across the industry. Furthermore, the field observations allowed the creation and refinement of a set of common work artifacts associated with human factors: personas and scenarios. These artifacts are used to describe and better understand the individuals and environments involved in a complex system. An example of a persona developed for an NDE examiner is presented in Section 2.4.

2.3 Laboratory versus Field Differences

There are clearly major differences between laboratory and field environments as summarized in Table 1. The area of training may be particularly fruitful for decreasing the gap between the relative calm and quiet of the laboratory and the myriad disruptions and challenges posed by the typical nuclear plant environment. While a testing environment is not intended to be and will never be a replication of the field experience, it's useful to understand these discrepancies for potential opportunities.

Table 1. Performance Shaping Factors for Laboratory and Field Environments

Factor	Laboratory	Field
Fine Motor	- optimal weld positioning for manipulation	- weld may be awkward position (may be need to hold tools simultaneously)
Gross Motor & Anthropometric	- comfortable position	- can be awkward position or different position for every weld inspected - may be physically impossible for some examiners to access component and must rely on colleagues - quiet classroom environment
Perceptual	- excellent lighting - directed attention (single focus) - quiet classroom environment - optimal temperature - high alertness due to new environment and/or performance anxiety	- lighting may not be optimal - may be distracted by sounds/sights/etc. - may be noisy factory environment - may be hot/cold - variable daily alertness/fatigue
Cognitive	- many faults presented for testing purposes - stress as must pass exam needed to get or keep job	- faults less prevalence (search fatigue) - stress as vigilance required when fewer faults are present (low signal-to-noise ratio) - heavy memory load - impact of what has happened the hours/days/weeks/years before - multiple distractions
Social	- able to communicate/collaborate with peers & trainer during training - work alone during examination	- working with colleagues - reputation is on the line, "don't want to be that guy"

2.4 NDE Examiner Personas

Personas, or narrative descriptions of critical individuals in a complex system, are used to communicate important human characteristics that may impact the system. In the case of NDE, examiners are typically divided into three subgroups based on their level of certification. The two field observations informed personas for NDE examiners, which includes details about the individual, his job and the challenges facing him (note that most examiners are men so the personas reflect this fact).

Personas were developed as composites of information gleaned from the research, refined with additional details from the field observations. They will serve as generalizations of the individuals and environments encountered and support future research efforts that target individual performance of NDE examiners. An example of a UT level III examiner is given in Figure 2.

Sam

Sam has worked in the nuclear power industry for over 20 years. He has been Level III certified for 15 of those years. He is proud that his job helps to ensure the integrity and reliability of nuclear power plants. He knows that examiners like him are what protect the public and ensure the safety of the entire industry. As a mentor, Sam wants to pass along his knowledge to those newer to the field.

"*Our vigilance has paid off in identifying potential problems before they caused a failure."*

About the Job

- Usually works 40 hours a week, with longer hours during outages

Spends about a third of his time

- In the field
- In the office
- Providing training and mentoring

About the Challenges

The aging of the units requires even greater attention to increased chances for failures.

Requirements for documentation have increased, and he worries this takes time away from doing the job.

As he has gotten older, physical demands at work are more taxing, so he appreciates leaving most of this to younger examiners.

His military and industry background have given him rich experience in the field, and he wonders if he will be able to convey this to newcomers.

Fig. 2. Level III Examiner Persona

2.5 Task Analysis

In addition to ensuring we represent the NDE examiner, EPRI is conducting a high-level task analysis to identify and prioritize the actions and processes required for an NDE examiner to complete their job.

The purpose of the task analysis is to ensure critical tasks receive the attention they deserve in:

1. Training
2. Procedures
3. Equipment design
4. And other human factors considerations.

EPRI is currently conducting one-on-one phone interviews with current-day practicing examiners representing diverse nuclear power utilities and vendors. The industry has been terrific in their response! Recurring themes in examiner responses will be identified in a formal content analysis and prioritized accordingly in upcoming research. For example, one question (of 14 total) asked during the interview and sample examiner responses are provided below in Table 2:

Table 2. NDE Examiner Responses to an Open-Ended Interview Question

Question	UT Examiner Responses
What aspects of training could be improved and how?	"… look at more flawed samples. More training equals a better examiner." "Training needs to be on good mockups, situations you run into in the field,…" "… the part I like to stress is scenario training for new examiners." "… just scanning samples is very valuable."

As shown in Table 2, examiners are requesting accessibility to practice samples for manual ultrasonic scanning. Based on just this one question, we can propose a potential aid for NDE examiners: an UT simulator may be a missing link. EPRI's Virtual NDE v1.0 product is an example of the industry making strides toward addressing this issue already [3].

Currently, "The Virtual NDE v1.0 is windows-based software that allows users to simulate conditions and functions of manual ultrasonic inspections for training, practice and testing prior to conducting work in the field" [3]. There are numerous benefits to this technology and EPRI is expanding the Virtual VNDE's capabilities to further meet the demands of current-day NDE examiners.

3. Conclusions

Before embarking on any new research, EPRI has been respectful of existing resources. In general, the nuclear-specific NDE research literature is relatively qualitative and lacks independent empirical validation of causal factors for NDE reliability. To supplement the research literature, EPRI experts provided operating experience of over a dozen real events that have occurred in the past ten years. Incidences of reported human errors during NDE leading to reportable consequences is statistically low but still important to study. To further supplement EPRI's understanding of what is already working well and what if anything should be improved, two nuclear power plants were visited during recent outages by human factors and EPRI specialists to observe manual UT first-hand. At these sites, there were opportunities to watch and listen to present-day examiners and others describe challenges and opportunities to continue to ensure a low error rate across the industry. EPRI has found it notable that actual first-hand examiner experiences or perceptions have been rarely considered or measured. To remedy this, EPRI has developed representative personas, scenarios, and is working on a task analysis for NDE UT examiners as a foundation to help guide research activities. Hearing from current-day examiners, in their own words, is of the utmost importance. EPRI is currently working on research projects to help meet the requests of NDE examiners. For example, an ultrasonic simulator will provide accessibility to a practically endless supply of samples.

References

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