IAEA Nuclear Energy Series

No. NG-T-2.7

Managing Human Performance to Improve Nuclear Facility Operation

IAEA
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MANAGING HUMAN PERFORMANCE TO IMPROVE NUCLEAR FACILITY OPERATION

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The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world".

IAEA NUCLEAR ENERGY SERIES No. NG-T-2.7

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INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2013

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1400 Vienna, Austria
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tel.: +43 1 2600 22417
email: sales.publications@iaea.org
http://www.iaea.org/books

Printed by the IAEA in Austria
December 2013
STI/PUB/1623

IAEA Library Cataloguing in Publication Data

Managing human performance to improve nuclear facility operation. — Vienna : International Atomic Energy Agency, 2013.
p. ; 29 cm. — (IAEA nuclear energy series, ISSN 1995–7807 ; no. NG-T-2.7)
STI/PUB/1623
ISBN 978–92–0–144610–7
Includes bibliographical references.

1. Nuclear facilities — Management. 2. Nuclear facilities — Employees. 3. Nuclear power plants — Employees — Training of — Evaluation. I. International Atomic Energy Agency. II. Series.

IAEAL 13–00867

FOREWORD

One of the IAEA's statutory objectives is to "seek to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world." One way this objective is achieved is through the publication of a range of technical series. Two of these are the IAEA Nuclear Energy Series and the IAEA Safety Standards Series.

According to Article III.A.6 of the IAEA Statute, the safety standards establish "standards of safety for protection of health and minimization of danger to life and property". The safety standards include the Safety Fundamentals, Safety Requirements and Safety Guides. These standards are written primarily in a regulatory style, and are binding on the IAEA for its own programmes. The principal users are the regulatory bodies in Member States and other national authorities.

The IAEA Nuclear Energy Series comprises reports designed to encourage and assist R&D on, and application of, nuclear energy for peaceful uses. This includes practical examples to be used by owners and operators of utilities in Member States, implementing organizations, academia, and government officials, among others. This information is presented in guides, reports on technology status and advances, and best practices for peaceful uses of nuclear energy based on inputs from international experts. The IAEA Nuclear Energy Series complements the IAEA Safety Standards Series.

IAEA Nuclear Energy Series No. NG-G-2.1, Managing Human Resources in the Field of Nuclear Energy, was published in 2009. In that publication, four interrelated objectives of the management of human resources were identified and discussed: ensuring that nuclear industry personnel have the necessary competence for their jobs; effectively organizing work activities; anticipating human resource needs; and monitoring and continually improving performance.

This publication addresses the fourth objective and, in particular, summarizes good practices in the area of managing human performance. It describes how human performance can be managed within an overall performance improvement model.

The need for IAEA involvement in this area and to address key issues highlighted in IAEA Nuclear Energy Series No. NG-G-2.1 were reinforced during the meetings of the Technical Working Group on Managing Human Resources in the Field of Nuclear Energy (TWG-MHR) in 2008 and 2010.

The importance of human performance in the safe operation of any nuclear facility is no longer in doubt. The contribution of human performance to the occurrence of significant events and, consequently, to overall performance in the nuclear field has been well documented. Monitoring and continually improving human performance has now become one of the key challenges in the management of human resources for nuclear facilities.

To facilitate meeting the challenge of improving human performance, a model of performance improvement is presented that provides a framework which can be used to improve individual, process and organizational performance. It is generally postulated that without human performance improvement, a safe working environment is impossible to maintain. While there are many different perspectives from which safety issues might be addressed, there are several factors significant for human performance improvement that are consistent, useful and necessary to understand.

This publication is not intended as an all encompassing guide to managing human performance, but, rather, provides a summary of concepts and good practices for organizations to consider in their design of various programmes and in the performance of activities. In addition, tools that are helpful for managing human performance are discussed, and references for more detailed information on these concepts and tools are provided.

Appreciation is expressed to the Member States for their valuable contributions and to all of the participants listed at the end of this publication. The IAEA is particularly grateful to S. Haber (United States of America) and A. Kazennov (Russian Federation) for their assistance in preparing this publication. The IAEA officer responsible for this publication was B. Molloy of the Division of Nuclear Power.

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

This publication is prepared in support of IAEA Nuclear Energy Series No. NG-G-2.1, Managing Human Resources in the Field of Nuclear Energy [1]. The guidance provided in that publication comprehensively addresses four aspects of managing human resources in the nuclear field:

(1) Ensuring that individuals have the competencies needed to perform their assigned tasks;
(2) Organizing work effectively;
(3) Anticipating human resource needs;
(4) Monitoring and continually improving performance.

This publication addresses the last aspect — monitoring and continually improving performance — with an emphasis on the role of human performance in managing human resources for sustaining and improving the performance at the nuclear facility.

The emphasis on human performance is based upon its contribution to the occurrence of significant events and, consequently, to the overall performance of the nuclear industry. Figure 1 depicts, for example, that at nuclear power plants, 80% of significant events can be attributed to human error, while only 20% of significant events can be accounted for by equipment failure [1, 2].

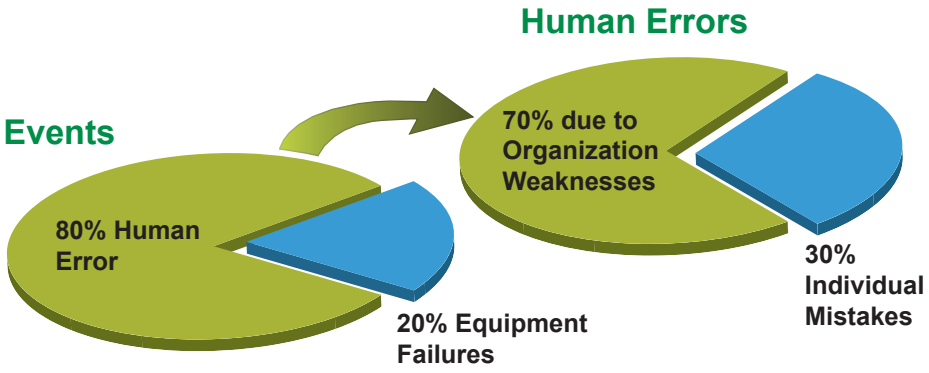

FIG. 1. Contribution of human error to the occurrence of events (courtesy of the USDOE).

The historical belief has been that human error is an individual-focused phenomenon or motivational issue, promoting the idea that failures are introduced into the system only at the lowest level. However, it has recently been identified that weaknesses in organizational processes and cultural values have contributed significantly more to the occurrence of nuclear facility events than have individual mistakes [3]. As shown in Fig. 1, 70% of human errors (or 56% of all events) at nuclear plants were found to be the result of organizational, rather than individual, weakness [2]. While these organizational deficiencies are often hidden in management processes, values or organizational structure, they can create workplace conditions that lead to a human error or degradation in the integrity of defences, such as quality of procedures or reliability of systems.

In order to fully understand how human performance can be managed to facilitate performance improvement, three levels of performance need to be considered: organizational, process and job levels. Table 1 describes the elements of these levels [1, 4].

Event-free performance in the nuclear industry requires this integrated view of human performance that includes the overall strategy and structure of the organization in order to accomplish work, the alignment of organizational processes and values in achieving facility operational and safety goals, and the behaviour of individuals performing their jobs [5]. This publication focuses on the job and process levels and acknowledges the interrelationship of all levels when appropriate. More detailed discussion of the organizational and cultural level can be found in Refs [6–11].

TABLE 1. LEVELS OF PERFORMANCE IMPROVEMENT

Level	Goals	Key performance tools	Principal management level
Organizational level	Organization goals	Strategies, design/structure, allocation of resources	Executives/senior managers
Process level	Process goals	Process improvement and effective teamwork	Middle level managers
Job level	Job goals	Job design, coaching, performance management and training	First-line supervisors and workers

It is intended that the information in this publication be used proactively by line managers responsible for human performance at any nuclear facility to proactively manage and improve human performance and only secondarily as a reactive means of implementing change once an event has occurred. The guidance presented in the following pages provides managers with proven and demonstrated strategies for behavioural change that will reduce the likelihood of human error and thus improve overall performance. This publication is not intended to be a comprehensive treatment of the subject, but, rather, provides managers with an overview of the concepts and some practical ideas and tools for effectively implementing those concepts. As appropriate, references are provided to other publications which further outline and specify the concepts and tools discussed.

Multiple publications, in particular from the IAEA, the Institute of Nuclear Power Operations (INPO), the International Society for Performance Improvement (ISPI), the United States Department of Energy (USDOE) and the World Association of Nuclear Operators (WANO), address the improvement of human performance. Much has been written about the management and improvement of human performance in the nuclear, aviation and health-care industries. This publication summarizes many good practices, presents the material in a framework that supports IAEA Nuclear Energy Series No. NG-G-2.1 [1] and consolidates the most important points regarding the improvement of human performance from the references that have been identified. While many of the good practices that are presented have been successfully implemented at nuclear facilities primarily located in the developed world, the publication is prepared in a way that will allow managers from all types of nuclear facility, in all States, to obtain a comprehensive understanding of human performance and to consider how to implement necessary improvements for their own facilities in their own culture.

1.2. PURPOSE

The purpose of this publication is to provide support to managers of nuclear facilities in their management of human resources to sustain and to improve nuclear facility performance. This publication describes a human performance improvement (HPI) model that provides a framework which line managers can use to improve job, process and organizational performance. A systematic process is outlined that begins with the identification of the desired results and follows through to the evaluation of performance results compared to the originally stated goals and expectations. This publication is intended to provide a summary of HPI principles and to discuss good practices in the use of HPI tools.

1.3. SCOPE

This publication provides managers of a nuclear facility with several critical tools for achieving excellence in human performance within an overall performance improvement model. An introduction to human performance provides a clear definition for the reader to proceed through the publication. A model of HPI is presented as a working tool for managers to use. The role of leaders and leadership in implementing performance improvement is discussed, as is the importance of the work environment, organizational processes and culture to defining, shaping and improving performance.

The steps of the performance improvement model are discussed in detail. The relationship of human performance and the HPI framework to the model are discussed, and tools for each component of the HPI framework

are presented. Appropriate references that provide additional details on these tools, techniques and behaviours are included for the reader with interest in accessing additional information on these topics.

The emphasis of application for this publication is on the job and process levels of performance and the role of individuals and leaders in improving that performance. Performance improvement directly related to organizational behaviours and values is detailed in Refs [6–11] and discussed here only as appropriate.

This publication is applicable to nuclear facilities, including nuclear power plants and nuclear fuel cycle and waste management facilities. This publication is applicable to the entire life cycle of nuclear facilities, including siting, designing, constructing, commissioning, operating, modernizing and decommissioning. Approaches, good practices and recommendations provided in this publication apply to both established nuclear programmes and States that are considering the introduction of nuclear programmes.

1.4. USERS

It is anticipated that the main users of this publication will be managers of nuclear facilities and managers of the entire nuclear programmes responsible for ensuring that the performance of personnel meets the high standards required by the nuclear industry.

Additionally, this publication will be useful for regulatory staff, human performance and training specialists, and for those individuals who are involved in establishing or maintaining integrated management systems for their facilities.

2. INTRODUCTION TO HUMAN PERFORMANCE

To achieve event-free performance, a nuclear facility should have an integrated view of HPI that considers the organizational, process and job levels. The idea of creating a programme just for HPI is not a recommended strategy. Rather, all the basic principles and tools for excellence in human performance should be effectively integrated into all ongoing processes and programmes at a facility to ensure the desired results. The overall strategy and structure of the nuclear facility should be designed with the alignment of its processes and values for achieving the identified and communicated operational and safety goals. This also supports individuals using the behaviours expected by the organization in doing their jobs to achieve the desired performance. This publication focuses on the job and process levels and acknowledges the interrelationship of all levels when appropriate. More detailed discussion of the organizational and cultural level can be found in Refs [6–11].

The value of understanding and managing human performance for improved nuclear facility performance is best understood through a practical example. The impact of any individual's job performance can be considered in thinking about the relevance and importance of human performance for the facility's operation. A common function across the nuclear facilities being considered in this publication is the role of maintenance. The role of maintenance errors among the principal causes of several major accidents across different industries is discussed in Ref. [12].

2.1. DEFINITION OF HUMAN PERFORMANCE

Human performance comprises many variables that influence the observable behaviours that are used to accomplish specific task objectives, or what we know as results. In practical terms, the maintenance technician performs some task, for example tightening a valve. The success of the task performance is based on the behaviours the technician uses to accomplish the valve tightening and the support of the organization. Good results (a tightened valve) can sometimes be achieved with questionable behaviour — that is, behaviour that does not meet the organization's values or standards (e.g. not following procedures). Conversely, bad results (a leaking valve) can result even though the technician exhibited all the right behaviours — that is, following and meeting the organization's expectations [13]. As long as the valve is tightened and not leaking, why is it important to concern ourselves with the way in which the task objective was accomplished? While poor human performance does not

in every instance lead to undesirable outcomes, over time poor human performance is more likely to lead to other undesirable outcomes, for example to a compromised organizational culture (once this kind of culture 'solidifies', it is very difficult to change; but this kind of culture, in turn, may cause wrong behaviours). Over the long term, the expected benefits of excellent human performance include [1]:

(a) Reduction in the number and consequences of significant events;
(b) Increased involvement by employees in the organization to achieve its goals;
(c) Improvement of core and supporting processes in the organization;
(d) Attention to issues at a lower level before they become significant issues;
(e) Improvement in quality and safety;
(f) Reduction in total operating costs;
(g) Increased trust of stakeholders in the organization.

2.1.1. Behaviour

Behaviour is what people do and say, and it is a means to an end — the results. It is observable and measurable. The maintenance technician can be observed tightening the valve. When individuals exhibit behaviour that does not meet the organization's expectations and standards, it can be because of a deficiency in skills, use of rules or lack of knowledge. It can also be the exact action called for in the procedure, yet the procedure was flawed (lacked quality). Error modes that are the prevalent ways people err for the particular performance mode are discussed in Ref. [2]. The prevalent error mode for skill based performance is **inattention**. Skill based errors are primarily execution errors, involving action slips and lapses in attention or concentration. The prevalent error mode for rule based behaviour is **misinterpretation**. The prevalent error mode for knowledge based behaviour is an **inaccurate mental model** of the system, process or facility status. More detail on knowledge, skill and rule based behaviours and the variables that impact these types of behaviour can be found in Ref. [2].

What some may identify as wrong behaviour may also occur because it is acceptable within the culture to disregard some written actions because results are the focus of the organization more so than behaviours. Behaviours are also sometimes a result of:

(a) Negative attitudes or lack of motivation (e.g. individuals not caring about their job performance);
(b) A work environment unsupportive of good performance (e.g. the appropriate tools and equipment are not available for the workers to perform their job correctly);
(c) Personal influences on the worker (e.g. state of mental or physical health);
(d) An unnecessary burden of excessive administrative duties.

An understanding of these different variables which influence behaviours is important in determining which type of tool would be most effective in managing human performance. Understanding the cause of the behaviour (e.g. why procedures were not used), and what influences it, is vital in designing improvement efforts to anticipate, prevent, catch or recover from the behaviours. Behaviours that do not meet expectations and standards are also known as human errors, and they can lead to undesirable results (events).

2.1.2. Results

Results are the outcomes of behaviour, for example a tightened valve or a leaking valve. They can obviously be good or bad, but in either case they represent the processes and efforts that went into performing a task. In the nuclear industry, outcomes related to safety, reliability and production are critical. Results that have an unintended negative consequence or a potential negative consequence are referred to as events. Event-free performance is desired. When considering the contribution of human performance to these types of occurrence, event-free performance can best be achieved by reducing human error and by improving the barriers to events to protect the facility from errors that might still occur.

2.1.3. Influences on human performance

With regards to human performance, consideration has to be given to the different influences that can impact the desired results at each level of performance. These include:

(a) **Job or individual level**: The influences at this level are focused on the performance of individuals or groups of individuals performing job tasks. Employees in any position in the organization or a group of employees working together towards a common goal (e.g. the mechanical maintenance technician or a maintenance team) are considered. The individual performance of leaders and managers is also considered as an important influence at this performance level. Performance improvement tools at this level tend to focus on improving individual or team performance on a task or set of tasks and on minimizing surrounding conditions that can lead to increased human error rates.

(b) **Process level**: This influence on performance focuses on the manner in which tasks are accomplished within the organization — the process by which work is done. Processes may include core processes (e.g. operation and maintenance), management processes (e.g. assessment and improvement of performance of work) and support processes (e.g. training). Performance at all organizational levels can influence, and be influenced by, the processes in the organization.

(c) **Organizational level**: This influence on performance deals with the overall organizational strategy, design and structure, and manner in which resources are allocated throughout the organization. It is visible in the shared values and performance expectations that are seen in the organization (e.g. the expectation to follow procedures while performing work). Communication and organizational culture are central elements of the influence of the organizational level on performance. Individuals across the organization can influence, and will be influenced by, organizational elements. As previously mentioned, 70% of human errors (or 56% of all events) at nuclear plants were found to be the result of organizational and process weaknesses, not individual behaviour.

To achieve excellence and consistency in human performance, there must be a work environment in which the appropriate processes (e.g. performance management or training) are in place to encourage and to reinforce the desired behaviours that will in turn lead to the desired results. For those appropriate processes to be effective, the values and performance expectations identified and communicated at the organizational level must be supportive of those processes. The individual behaviours and processes in place will be only as good as the organizational structure that supports them. It is possible for events to occur even with individuals who are capable of performing work and the appropriate processes in place. Events may occur because the processes and correct individual behaviours are not appropriately valued within the organization (e.g. the culture of the organization does not support the right behaviours). For example, appropriate individual behaviours (e.g. following procedures) must occur in conjunction with appropriate processes (e.g. good maintenance processes) and organizational values (e.g. clear expectations to use and to follow procedures). The alignment of these three components in the right environment will go a long way to fostering excellent human performance.

2.2. HUMAN PERFORMANCE IMPROVEMENT

Performance improvement is the systematic process of determining desired performance, continually monitoring performance, discovering and analysing performance gaps, designing and developing effective interventions, implementing these interventions, and continually evaluating the results of improvement interventions within performance monitoring to assure that the improvement process takes place [1]. The focus of this publication is on managing and improving human performance, which is one aspect of overall performance improvement goals. The goal of excellence in human performance is to attain event-free performance at the nuclear facility. By proactively managing human performance and strengthening the defences of the facility, the performance of individuals, processes and the organization will be optimized, errors will be minimized and events will be eliminated.

The underlying principles that form the basis for excellence in human performance were first clearly identified by INPO in Excellence in Human Performance [13] and later elaborated on in the INPO Human Performance

Reference Manual [5] and the USDOE Human Performance Improvement Handbook [2]. These underlying principles, when considered together, can be viewed as the foundation for the HPI model and include (see Ref. [2]):

People are fallible and even the best make mistakes.

People will make errors and no amount of coaching, training or punishment can totally eliminate human error [2, 5]. James Reason, in Human Error [14], writes:

> "It is crucial that personnel and particularly their managers become more aware of the human potential for errors, the task, workplace, and organizational factors that shape their likelihood and their consequences. Understanding how and why unsafe acts occur is an essential first step in effective error prevention."

Systemic errors can be removed through the use of specific tools such as self-checking. Random errors can be reduced but never eliminated. In the earlier example of tightening a valve, there is always a possibility that people will make a mistake in performing this activity. The question becomes why the mistake is made and trying to take all possible precautions to prevent its occurrence. When a mistake is made, having more than one barrier in place to prevent failure (e.g. procedures, peer checking and labelling) will minimize the consequence of that mistake. There is always some likelihood of a human error. Therefore, it is vital to create an organizational infrastructure that supports facility programmes and processes to identify and to protect from human error before that error leads to a more significant event.

Error-likely situations are predictable, manageable and preventable.

Despite the fact that human errors are inevitable, there are things that can be done to predict, manage and ultimately prevent systemic errors and most random errors from occurring [15]. Recognizing error traps and proactively communicating these to others help to manage situations and to minimize the occurrence of error. By changing the work situation to prevent, remove or lower the presence of conditions that bring about error, task and individual factors in the work environment can be managed to minimize the chance for error [2, 5].

In the example, when the worker is sent out to tighten a valve, it may be in close proximity to another similar valve that could be inadvertently tightened instead of the correct valve. It is important to recognize this as an error-likely situation and to take steps such as colour coding, clear labelling, caution flags within procedures and conducting pre-job briefings to prevent that mistake from occurring.

Individual behaviour is influenced by organizational processes and values.

The processes and values of an organization are developed and fostered to direct the behaviour of the individuals in the organization towards meeting the organization's goals. The ways in which work is divided up into different jobs and then coordinated to produce results provide the best picture of the organization. Management is there to direct the worker's behaviours towards producing the desired results. Work is accomplished not only through the management of individual based human performance but also within the context of organizational processes, culture and management systems. It is these factors that contribute to most of the causes of human performance problems and result in facility events [2, 4, 5].

In the example, suppose that two workers are sent together to work on the valve. It is important that these workers feel comfortable and work at a facility that supports their questioning the actions of each other if they have reason to believe a mistake may have been, or may about to be, made. Facilities that actively support such a questioning attitude are more likely to have fewer mistakes made than those in which a questioning attitude is not as valued by the organization.

People achieve high levels of performance based largely on the encouragement and reinforcement received from leaders, peers and subordinates.

All behaviour, whether good or bad, is reinforced in some manner either by immediate consequences or by experiences from the past. Behaviour is reinforced, or challenged, by the consequences that an individual

experiences when the behaviour occurs. The level of safety, reliability and production of a facility are directly dependent upon the behaviour of the individuals who work there. Understanding what happens to an individual when they exhibit certain behaviours is important for improving human performance. Positive and immediate reinforcement for expected behaviours is ideal [2, 5].

In the example, when tightening a valve, a worker may notice that a label is missing or that the procedure is not clearly written. If that worker were to bring such a situation to the attention of management, what would be management's response? Is that worker praised for making a 'good catch' or is that worker treated as someone who delays work by asking too many questions? Employees who work in an organization that positively reinforces workers making a 'good catch' will be more likely to bring problems to the attention of management in the future and to reduce the likelihood of events.

Events may be avoided by an understanding of the reasons why mistakes occur and the application of the lessons learned from past events.

Improvement in human performance has historically resulted from corrective actions that are derived from an analysis of facility events and problem reports. Corrective actions are generally a reactive method of learning which occurs after the fact, but they are still important for continual improvement. A combination of proactive and reactive learning is needed where the anticipation of how an event or error can be prevented is a more cost effective means of continual performance improvement [2, 5].

How often do we hear of facilities where repeat errors are made, sometimes even on the same system or piece of equipment? In the valve example, are prior experiences from tightening that specific valve or tightening other similar valves within the facility, or even from other facilities, shared with workers so they can learn from it? Do pre-job briefings incorporate this information? Are those involved in planning the work made aware of this information? In organizations where such learning is actively applied and incorporated into the ongoing work management system, error rates are lowered, rework is reduced and events are minimized.

2.2.1. Role of the individual in human performance improvement

The collective behaviours of individuals across all areas and levels at a facility determine the overall performance outcome achieved. The work conducted by individuals is the product of mental processes influenced by diverse factors related to the work environment and the demands of the task as well as the capabilities of each individual. In high performing facilities, individuals at all levels take responsibility for their behaviours and are committed to improving themselves as well as the task and work environment. Individuals in high performing facilities generally exhibit the following behaviours [13]:

(a) Communicate to create shared understanding;
(b) Anticipate error-likely situations;
(c) Confirm the integrity of defences;
(d) Improve personal capabilities;
(e) Use and follow procedures and other work documents as intended;
(f) Report deficiencies in processes, documents or at the workplace;
(g) Demonstrate uneasiness and wariness (expecting success while anticipating failure) towards activities that can affect equipment performance or personnel safety;
(h) Do not proceed in the face of uncertainty;
(i) Use non-technical, mental skills (error prevention tools) to anticipate, prevent and recover from error;
(j) Exhibit intolerance for error-likely situations and organizational weakness.

In discussing the role of individuals in HPI, consideration must be given to the role of leadership. Leaders are individuals within the organization who exert specific influence on the performance of other individuals within the organization. Leading is a set of behaviours practised continuously to direct and to focus individual effort towards accomplishing the organization's goals. The 'leader' is any individual who influences the actions of others or organizational processes. Effective leaders understand the variables that influence both individual and organizational performance. It is important to align organizational processes and values. Leaders integrate

appropriate positive reinforcements into the work environment to encourage the desired behaviours and results. In general, leaders in high performing facilities exhibit the following behaviours [13]:

(a) Facilitate open communication;
(b) Promote teamwork to eliminate error-likely situations and strengthen defences;
(c) Search for and eliminate organizational weaknesses that create conditions for errors;
(d) Reinforce desired work behaviours;
(e) Value the prevention of errors;
(f) Serve as a role model for the right behaviours, where managers and supervisors routinely communicate and reinforce desired behaviours through observation, coaching, counselling and performance feedback.

Examples of these behaviours are discussed in Section 4 as part of the HPI framework.

2.2.2. Role of processes in human performance improvement

All of the processes that are in place within an organization have a strong influence on an individual's ability to perform the job effectively and, therefore, to achieve successful outcomes. Processes standardize the work that is conducted in an organization by providing:

— Structure to the manner in which work is conducted through the formalized procedures and job practices in place;
— Structure to the knowledge of the workforce through training and qualifications;
— Structure to the way in which decisions are made, problems are identified, work is coordinated and corrective actions are implemented.

By ensuring effective processes are in place, the following can be accomplished [1, 16]:

(a) Processes are implemented as designed and are assessed to verify that appropriate barriers exist and will minimize the likelihood of errors occurring. Key processes include work planning and scheduling, clearance tagging, plant modification and work control, as well as the use of operating experience.
(b) Procedures are developed, verified, validated, available for use and user friendly.
(c) Procedures are periodically reviewed and corrected when deficiencies are detected.
(d) Training, both initial and continuing, ensures that a competent and qualified workforce is available, with the desired technical knowledge and skills, work practices and human performance fundamentals. In addition, appropriately qualified individuals are selected for the performance of work activities.
(e) An effective corrective action programme is in place which incorporates root cause analyses as appropriate.
(f) Work preparation and execution activities use pre-job briefings commensurate with the risk and complexity of the tasks. First-line managers facilitate the identification and avoidance of situations that can result in events. Key elements of work preparation include identification of critical steps, potential human errors and effects on the plant, contingency plans and operating experience. Any changes to planned work activities are critically reviewed to ensure that the likelihood of errors and potential facility consequences are minimized.

2.2.3. Role of the organization in human performance improvement

The goals, policies and priorities of an organization directly influence individuals' behaviours by generating a pattern of shared understandings, processes and values. Managers are responsible and accountable for organizational support of worker performance on the job. However, all individuals within an organization should take it upon themselves to improve organizational processes and to promote values of excellence. The organizational elements important for successful performance include [13, 16]:

(a) Fostering a culture that values the prevention of events. Senior managers establish expectations for excellence in human performance and safety culture. Both strategic and business planning provides goals, objectives, resources and metrics to fulfil these expectations.

(b) Strengthening the integrity of barriers to prevent or to mitigate the consequences of error.
(c) Precluding the development of situations in which errors are more likely to occur.
(d) Creating a learning environment that encourages continual improvement.
(e) Ensuring effective communication mechanisms are in place to promote timely and accurate dissemination of information throughout the organization. Communication of information that can affect human or equipment performance is highly valued.
(f) Designing an organizational structure that ensures appropriate responsibilities and authorities in the organization.
(g) Establishing healthy relationships across the organization based on trust, respect and fairness and that are supported by motivating reward and accountability practices. Rewards and discipline are linked to specific behaviours.
(h) Establishing and maintaining an organizational intolerance for process, document and workplace deficiencies.

Examples of organizational characteristics that will facilitate excellent human performance are discussed in Section 4 as part of the HPI framework. Specific examples and more details on the role of the organization in HPI are available in Refs [6–11, 17–19].

3. PERFORMANCE IMPROVEMENT MODEL

In order to be successful in achieving excellence in human performance, the context of overall performance improvement for the facility should be clearly identified, communicated and understood by all levels of the organization. Performance improvement can be understood as a systematic process which, if successful, will result in [1]:

(a) Reduction in both the frequency and consequences of events;
(b) Increased involvement by individuals in helping the organization to achieve its goals;
(c) Improvement of core and supporting processes in the organization;
(d) Attention to issues at a lower level before they become significant issues;
(e) Improvement in quality and safety;
(f) Reduction in total operating costs;
(g) Increased trust by stakeholders of the organization.

Figure 2 depicts a simplified modification of a performance improvement model, originally developed by INPO [20], that identifies the significant steps of the systematic process by which to achieve success in performance improvement [1]. Many of the organizational processes described are discussed in more detail in Refs [6–11].

3.1. IDENTIFY DESIRED PERFORMANCE

Expectations and standards for excellence in performance should be clearly identified, communicated and understood throughout the facility. Expectations should be established for strategic and business plans which define goals, objectives, resources, performance measurements and oversight. They should be established for products and services, safety, reliability of processes and human performance. Expectations can be established using benchmarking activities, industry standards and organizational learning from relevant events.

Organizational infrastructure should be provided to facilitate meeting the identified expectations. A clear understanding of the consequences of failing to meet these expectations should be communicated to, and understood by, all levels of the organization.

In the valve example discussed earlier, the desired performance is the individual appropriately tightening the correct valve using all the job tools that are available and required for the task (e.g. pre-job briefing and procedures). Undesirable performance would be the individual performing this same task in a manner that differs from this

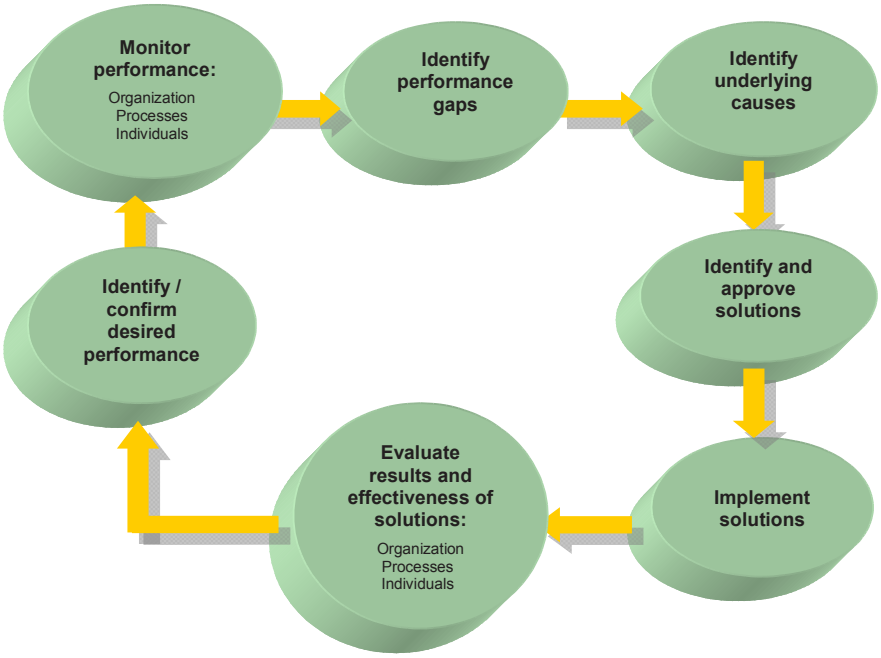

FIG. 2. Example of a performance improvement model.

expectation in any way, even if the right outcome is achieved. So, if the individual appropriately tightened the correct valve but did not use procedures in performing the task, it would be considered an undesirable performance even though the correct outcome was achieved. As important, the desired performance would also include the individual using appropriate error reduction tools, maintaining a questioning attitude and calling attention to any problems encountered with the activity before proceeding.

3.2. MONITOR PERFORMANCE

Performance monitoring activities involve the observation and measurement of actual performance in the organization and the desired performance identified in the first element of the model. The monitoring should take into consideration each of the three levels of human performance previously discussed: organization, process and individual. Performance monitoring is somewhat unique because it contains both proactive and reactive elements.

The proactive aspect of performance monitoring involves identifying precursor level problems for resolution before they become larger organizational issues. Included are such activities as self-assessments, use of low level performance indicators to identify declining performance or behaviours, benchmarking, and routine trending and performance assessment [20–23].

In the valve tightening example, monitoring error rates with similar valve work, tracking issues that were identified and documented, performing management observation and coaching, or benchmarking similar activities at a facility known to be high performing would demonstrate proactive performance monitoring. Ensuring that this information is appropriately communicated to the individuals who will perform the work will increase the likelihood that the desired performance outcome will be achieved.

The reactive aspect of performance monitoring involves activities such as event investigation, problem identification and reporting, corrective action effectiveness reviews, and management review of, and response to, top level facility performance indicators, such as those depicting significant events and significant human performance errors [17, 20].

In the valve tightening example, the organization might perform a retrospective analysis of all valve tightening activities that have occurred over some specified period of time in an attempt to identify situations that were more likely to lead to human performance errors.

Various elements and activities that collectively support excellence in performance monitoring include the use of [17, 18, 20, 22]:

(a) Self-assessment;
(b) Establishment and monitoring of performance indicators;
(c) Tracking and trending performance;
(d) Benchmarking activities;
(e) Facility and industry operating experience;
(f) Independent oversight;
(g) Field observations and coaching;
(h) Problem reporting;
(i) Effectiveness reviews of improvement efforts;
(j) Event investigation.

Additional details for the effective implementation of these elements and activities can be found in Refs [20, 24]. Effective performance monitoring involves the use of multiple monitoring approaches. Defence-in-depth and the likelihood of identifying performance shortfalls are strengthened when several different sources of inputs and methods are used. Reference [7] indicates that an integrated approach should be used to provide a comprehensive framework for the arrangements and processes necessary to address all the goals of nuclear facilities. The publication also indicates that the practices and results achieved by nuclear industry organizations, the organizational culture and the management processes are strongly interrelated. The facility's policies and procedures should describe an integrated approach in which its employees and equipment carry out the processes that achieve its mission [1].

3.3. IDENTIFY PERFORMANCE GAPS

Performance gaps result from the comparison of the identified desired performance to the actual performance that has occurred. For this process to be most meaningful and useful, performance should be measured or described in measurable terms. In the case of tightening a valve, a performance gap could be the lack of use of procedures or leaving the valve in an incorrect position (e.g. valve was tightened but not sufficiently).

Measures for quantity or productivity and safety performance are often the initial point of description for the present level of performance in the organization. However, measures for quality, costs and time are also helpful in describing performance in measurable terms. Performance gaps can range from major facility performance weaknesses to minor adverse behaviour trends. The level of activity needed to complete analysis and corrective action identification and planning can also vary widely. Additionally, because some performance gaps are more important than others, there is a need to prioritize which issues to address first and to select solutions that integrate well with the overall level of facility performance and the management business planning focus areas [7, 20].

3.4. IDENTIFY UNDERLYING CAUSES OF GAPS

3.4.1. Methods to identify causes

Once performance gaps have been identified, various tools such as root or apparent cause analysis, job and task analysis, common cause analysis, event investigations, human performance error investigations and process analysis are used to identify the underlying causes of the gaps. Table 2 presents an overview of some of the tools and their uses that are employed to identify the underlying causes of performance gaps. The level of performance improvement they can be used for is also identified. Additional information and details related to all of these tools can be found in the references identified in the table. It should be noted that regardless of which tool is used, the competence of the individuals involved in causal analyses must be ensured through appropriate training and qualification on the methodology to be implemented.

TABLE 2. EXAMPLES OF TOOLS USED TO IDENTIFY UNDERLYING CAUSES OF PERFORMANCE GAPS

Reference	Tool	Use	Level of performance
[2, 17, 20, 25]	Root cause analysis	Significant programmatic issues	Organizational Process
[20]	Extent of condition and extent of cause	Other possibilities of root and apparent causes	Organizational Process Individual
[2, 20]	Common cause analysis	Similar occurrences and common elements	Organizational Process Individual
[2, 20]	Apparent cause analysis	Lower level gaps and adverse trends	Process Individual
[17, 20, 22]	Problem identification and corrective actions	Lower level issues to correct deficient condition	Process Individual
[20]	HPI investigations	Significant programmatic issues to lower level issues	Organizational Process Individual

In general, root cause analyses are performed for significant problems as defined by the facility. Root cause analyses would typically be performed for the events reported to a regulatory body, for example: significant programmatic issues; repetitive failures of components; and important events, such as the loss of a safety significant system. Root cause and selected apparent cause analyses identify organizational contributors to events. These can include failed barriers, such as the non-use or misuse of previous industry or internal operating experience, flawed decision making, deficient processes or procedures, and cultural concerns [17, 20].

Extent of condition and extent of cause can be either appropriately evaluated in root cause analyses and in apparent cause analyses for repetitive issues important to safety and reliability or examined independently. These analyses help to identify areas where the same condition or cause could exist and help to focus the organization on which areas require further review [20]. In the valve example, if there were multiple valves of the same type that were being maintained, extent of condition would require that all of the same valves be evaluated for the deficiency being corrected.

Common cause analyses are performed for a series of similar occurrences to better understand the common elements that need to be addressed or the underlying issues that may not have been identified when the occurrences were examined in isolation. Such analyses thus proactively seek to prevent future events by implementing more comprehensive corrective and preventive actions [2, 20].

Apparent cause analyses identify corrective actions intended to minimize the likelihood of a consequential or unplanned recurrence of an identified deficient condition. Apparent cause analyses are often used to gain a better understanding of what happened or to determine the causes of lower level performance gaps or adverse trends so that action can be taken to avoid a more serious event [2, 20].

Lower significance issues are typically assigned an immediate cause or causes based on the facts known at the time of problem identification. Corrective action for those issues focuses on correcting the deficient condition and may or may not correct the cause or causes. Trending and performance assessment are relied on to determine whether an adverse trend exists or emerges that needs more rigorous analysis and corrective action [17, 20].

HPI investigations focus on improving human and organizational performance and can be added to any of the reviews above. Recognizing the higher value of organizational contributions to human performance, it is very important to focus beyond the individual when conducting an investigation. Understanding the cause or causes is vital to designing improvement efforts to anticipate, prevent, catch or recover from the wrong behaviours.

HPI investigations help in identification of error inducing situations, designing improvement to catch errors before they cause an event and identifying organizational weaknesses.

The risk or seriousness of the issue to safe and reliable facility operation drives the scope and depth of any type of causal analysis. This 'graded approach' helps tailor the resource expenditure to the seriousness of the problem. Effective issue prioritization and management reviews are also used to focus the organization and ensure that [7, 17, 20]:

(a) The problem statement is correct so that the right issues are being addressed;
(b) The required cross-disciplinary coordination and support are applied;
(c) An integrated approach to performance improvement is followed, such that highest value improvements for the facility are fully supported.

3.4.2. Types of cause

The types of cause that will be identified from any of the methods described above can be categorized into equipment, process (e.g. configuration management), work environment, human performance (individual and process levels) and cultural (organizational level). For example, when the valve was tightened without the use of a procedure, the cause could have been due to the correct procedure not being available, or that the work was performed in an environment not conducive to procedural use, or that the culture of the organization does not encourage the use of procedures. Whatever the cause, it must always be considered, eliminated or remedied with application to all levels of performance. As described in Section 4, HPI will only be effective if the solutions implemented are within the overall objectives and goals of the organization.

Causes identified as human performance will require behavioural solutions to produce the desired results. The principles of excellence in human performance identified in Section 2.2 should be the bases for effective behavioural change. The human performance tools described in Section 4 can be implemented to resolve human performance causes of identified performance gaps.

3.5. IDENTIFY, SELECT AND APPROVE SOLUTIONS

Solutions to close the performance gaps based upon the causes specified are identified and corrective and preventive actions are selected commensurate with the risk or importance of the gap. Corrective actions specified from causal analyses should meet the following criteria [20]:

(a) They are focused on fixing the identified gap.
(b) They are directly linked to the identified causes or contributors of the gap.
(c) They are assigned to individuals for responsibility so that accountability for the actions is clear.
(d) They are within the control of the responsible individuals or their organizations.
(e) They are specific, measurable, agreed to by stakeholders, realistic and timely.
(f) They are compatible with the organizational culture and within the existing staff knowledge and skill base.
(g) They are assigned due dates consistent with the risk or importance of the situation or condition being addressed.
(h) They incorporate appropriate industry and internal operating experience.

It is important to remember that most events have multiple causes that combine synergistically to produce the event. If none of the causes are addressed, the original problem may not be fixed and may recur in the future. Gaps and gap contributors selected for correction are those of highest priority and importance from the standpoint of preventing recurrence and reducing the facility's susceptibility to future events. Each contributory cause not addressed, as well as the basis for taking no action, should be documented in the corrective action system.

It is important that backlogs of corrective actions and open, unresolved problems are kept low enough so that managers are not prevented from responding to other issues of safety significance in a timely manner. At the same time, managers should maintain awareness of lower priority issues in the backlog through periodic reviews and assessments.

Focused management reviews of proposed corrective actions promote alignment and understanding of the following [20]:

(a) The statement of the gap to be closed;
(b) The standards and expectations regarding how the causal analyses are conducted;
(c) The link between the specified causes and the specified corrective actions;
(d) The degree to which major improvement actions align with business goals and objectives;
(e) The actions to prevent recurrence of significant problems and selected other important corrective actions.

These reviews may be conducted by a management team (usually composed of line managers and often a senior manager), a special review board (such as a corrective action review board), or individual managers, depending on the significance of the issue. It is valuable to include specialists or managers from the training and human performance areas in these reviews. Typically, problem statements and identified causes and contributors for significant problems and corrective actions are reviewed to prevent recurrence of such problems. Such reviews promote the following [14]:

(a) Ensuring consistency in the quality and approach used for the problem analysis and identification;
(b) Thorough challenging of the analysis and intended corrective actions;
(c) Management acceptance of the analysis, results and planned corrective actions, especially those that require cross-functional support promoting line manager ownership of the quality of the outcome.

3.6. IMPLEMENT SOLUTIONS

The goal of implementing solutions is to carry out the actions developed in response to identified gaps in order to improve performance. The implementation of solutions begins after the identified performance gap has been analysed, the solutions chosen, the tasks prioritized with due dates assigned and management approval of all actions. It entails the detailed assignment, scheduling, implementation, management involvement, oversight and reinforcement of the improvement actions. These activities, if not done correctly, can undermine the effectiveness of the entire improvement effort [20].

Line managers own and drive implementation to achieve success in performance improvement, using various supporting processes and tools to assist in the effort. Senior managers reinforce and reward high quality, well implemented corrective actions that improve performance.

Some elements or considerations relevant to successful solution implementation are:

(a) **Task assignment**: Who will perform the job and do they have the requisite skills, knowledge, attitudes and authority to see it through to completion?
(b) **Resource management**: Are the appropriate resources in place to ensure the solution can be implemented?
(c) **Action tracking**: Does the organization have the ability to follow up assigned actions and ensure completion within the outlined schedule, for example using specialized software tools?
(d) **Management involvement, oversight and reinforcement**: Is management appropriately aware of the solution so they can be involved in implementation and can oversee, as well as reinforce, the solution once implemented?
(e) **Organizational accountability**: This exists when all members of the organization act, both individually and collectively, to promote the timely accomplishment of the organization's mission.

3.7. EVALUATE THE RESULTS

Success in implementation of solutions is evident when the identified performance gaps are closed. The thoroughness with which the actions are implemented helps to determine the effectiveness of performance improvement efforts. Accountability occurs when the results are evaluated to ensure the effectiveness of the corrective actions. Effectiveness reviews should be conducted to check whether, and to what extent, there is

improvement and assess the quality of the actions. Poor quality corrective actions can undermine the facility's performance improvement efforts and be a barrier for implementing and adhering to the facility's policies, potentially leading to recurrence of the original problem.

The performance improvement process is not complete until the results are evaluated against the originally identified desired performance. Expectations and standards may be modified and additional gaps identified. Through the combination of management monitoring and reinforcement and independent verification of the results, continual improvement will allow the facility to become a learning organization with an effective performance improvement process.

4. HUMAN PERFORMANCE IMPROVEMENT FRAMEWORK

The framework for HPI is dependent upon the alignment of the levels of the individual, the processes and the organization. During each step of the performance improvement model described in Section 3, all of these factors must be considered. Behaviours and characteristics for each of these levels that will promote the desired results have been presented in Section 2.2. Further details and attributes of these behaviours and characteristics are presented in Refs [13, 16]. Individuals at all levels of the organization must take responsibility for their own behaviour. Leaders who want to promote excellence in human performance need to model the right behaviours. Certain key processes should be in place for individuals to be able to perform their jobs effectively, and certain organizational characteristics must be present to foster the value of accountability in achieving excellent human performance.

4.1. HUMAN PERFORMANCE TOOLS

The strategic approach to improving human performance is really defined by two elements [2, 5, 16]:

(1) Anticipating, preventing, catching and recovering from errors on the job;
(2) Identifying and eliminating organizational weaknesses, which induce and set individuals up for failure, by establishing and managing error defences.

Human performance tools will assist personnel to perform their work, minimizing the possibility of error. The basic purpose of these tools is to help the individual maintain control over the work situation. Individuals at all levels of the organization should use these tools. A brief overview of these tools is provided below. More details on human performance tools can be found in Refs [1, 2, 5, 16, 18, 19, 24, 26–30]. In implementing the use of human performance tools, it is important to consider whether the tools need to be adapted to the national culture of the organization. The concept of the intent of the tool must remain, but it may be necessary to modify the tool to be more meaningful to the user.

4.1.1. Error prevention

Below is a brief overview of some of the tools available for error prevention. These tools can help to reduce the frequency of errors. Details about these tools can be found in Refs [1, 2, 5, 16, 18].

A set of human performance tools has been identified in Refs [5, 24] that focus on anticipating, preventing and catching **active** errors before they become events. These tools are categorized into fundamental tools which should be used all the time and include:

— Situational awareness;
— Task preview;
— Job-site review;
— Questioning attitude;

— Self-checking (also known as STAR: stop, think, act, review), stop when unsure;
— Procedure use and adherence;
— Effective communication;
— Three-way communication;
— Phonetic alphabet.

Other helpful human performance tools have been developed by individual organizations, based upon these concepts. Cultural issues must be considered in the decision on which tools should be used and the most effective ways to implement them.

Conditional human performance tools are used depending on the work situation and can include:

— Pre-job briefing;
— Verification practices, including concurrent verification, independent verification and peer checking;
— Flagging;
— Keeping track in procedures step-by-step (place keeping);
— Shift turnover;
— Post-job review.

4.1.2. Eliminating organizational weaknesses

Organizational weaknesses can be undetected deficiencies in processes (e.g. in quality management or configuration management), values or equipment that will create workplace conditions that will induce error (known as error precursors), or will degrade the integrity of the organization's defences.

Managing defences is fundamental to protecting against events. Properly applied, these can reduce the likelihood of event occurrences and their consequences. These defences can be described by four categories:

(1) **Administrative controls** are programmes and processes that provide for a consistent defence. The quality of procedures, the problem identification and resolution process, and the use of operating experience are good examples.
(2) **Engineering controls** include designs, modifications and interlocks.
(3) **Management and oversight controls** include, for example, supervisors at the workplace coaching and correcting, managers reinforcing expectations and independent inspectors providing oversight.
(4) **Cultural controls** are the acceptable workplace practices and what managers measure, monitor and control — indicating what is considered (by management) to be important.

Other human performance tools that support identifying and preventing **hidden organizational weaknesses** include:

— Management systems self-assessment;
— Training, qualification and authorization (licensing) of personnel;
— Benchmarking;
— Post-job critique;
— Trending;
— Surveys and questionnaires;
— Observations;
— Event and HPI investigations;
— Self-identification (reporting errors and near misses);
— Operating experience feedback;
— Management of change;
— Independent oversight;
— Work product inspection and acceptance.

More details on the organizational weaknesses and how to mitigate them can be found in Refs [1, 7–11, 18]. In addition, Ref. [24] includes information on the use of these tools.

4.2. ORGANIZATIONAL CULTURE

The discussion of an HPI framework is incomplete without the acknowledgement of the importance of organizational culture and its influence on human performance. Detailed discussions of organizational and safety culture are presented in Refs [6, 7, 21, 31, 32]. Relevant to this publication is the role that certain behaviours have in shaping the culture of the facility.

Several different principles, elements and characteristics of organizational and safety culture have been identified [6, 7, 31, 33, 34]. Consistent across these different frameworks are the behaviours that are necessary to achieve the desired results [35]. Some of these behaviours include:

(a) **Attention to safety** refers to the characteristics of the work environment, such as norms, rules and common understandings, that influence personnel's perceptions of the importance that the organization places on safety. It includes the degree to which a critical, questioning attitude exists that is directed towards organizational improvement.
(b) **Communication** refers to the exchange of information, both formally and informally, primarily between different departments or units. It includes both top down (management to staff) and bottom up (staff to management) communication networks.
(c) **Coordination of work** refers to the planning, integration and implementation of work activities of individuals and groups.
(d) **Decision making** refers to the extent to which decisions and authority is localized in one area or among certain people or groups.
(e) **Formalization** refers to the extent to which there are well identified rules, procedures and standardized methods for routine activities as well as unusual occurrences.
(f) **Goal setting and prioritization** refer to the extent to which facility personnel understand, accept and agree with the purpose and relevance of goals.
(g) **Organizational learning** refers to the degree to which individual personnel, and the organization as a whole, use knowledge gained from past experiences to improve future performance.
(h) **Performance management** refers to the degree to which facility personnel are provided with fair assessments of their work related behaviours. It includes regular feedback, with an emphasis on improvement of future performance.
(i) **Performance quality** refers to the degree to which facility personnel take personal responsibility for their actions and the consequences of the actions. It also includes commitment to, and pride in, the organization.
(j) **Personnel selection** refers to the degree to which facility personnel are identified with the requisite knowledge, experience, skills, abilities and attitudes to perform a given job.
(k) **Problem identification and resolution** refer to the extent to which the organization encourages facility personnel to draw upon knowledge, experience and current information to identify and to resolve problems.
(l) **Resource allocation** refers to the manner in which the facility distributes its resources including personnel, equipment, time and budget.
(m) **Roles and responsibilities** refer to the degree to which facility personnel's job positions and departmental work activities are clearly defined and carried out.
(n) **Training** refers to the degree to which personnel are provided with the knowledge and skills required to perform tasks safely and effectively, and desired attitudes are reinforced.

The role of the individual, the processes and the organization in achieving excellence in human performance is discussed in Section 2.2. In each case, the behaviours must be implemented, consistent with the organization's goals and objectives. The role of the organization's culture is instrumental in achieving alignment within the facility and in promoting the desired behaviours for overall performance improvement.

4.3. CONSIDERATIONS IN MANAGING HUMAN PERFORMANCE IMPROVEMENT

The management of human performance at nuclear facilities is best accomplished through the integration of HPI principles and tools into an existing management system and into all relevant programmes. The idea that HPI should be a separate initiative or programme is contrary to the very foundation of the concept. For those nuclear facilities that have not yet fully integrated the principles and tools of HPI into their organization, the following considerations are presented for effective implementation. For those nuclear facilities that have integrated HPI into their management system and programmes, the following considerations might be helpful for the continued improvement of human performance. The considerations are not all inclusive but represent some of the key areas for successful HPI.

4.3.1. Self-assessment for managing human performance improvement

A periodic self-assessment of the management processes that are established within the nuclear facility's management system should be conducted. In particular, there should be an evaluation of the use of principles and practices for improving individual, process and organizational performance, with an emphasis on the HPI tools that are being employed. Some particular questions to ask may include:

(a) Which performance improvement model is being used to ensure a systemic approach at the nuclear facility? Does it contain components similar to those identified in Fig. 2?
(b) Which HPI tools are already being used at the nuclear facility?
(c) Which tools still need to be incorporated into the integrated management system, overall performance improvement process and work practices?
(d) Are there procedures for the appropriate use of HPI tools and techniques?
(e) Which job aids are there for workers to use to reinforce the principles of HPI, for example a handbook containing all of the HPI tools discussed in Section 4.1 or laminated cards containing the tools to be used?
(f) Do the facility's procedures incorporate the use of human performance tools appropriately?
(g) What type of training is provided on HPI principles and tools?
(h) How have the instructors been trained on HPI principles and tools to provide training?

4.3.2. Corrective actions to manage human performance improvement

From the results of the self-assessment activities, the nuclear facility should be able to determine whether HPI principles and tools are being used appropriately throughout the facility. Some corrective actions to consider in enhancing the integration of HPI into the management system include:

(a) Senior managers of the nuclear facility must be involved and supportive of the integration of HPI into the overall management system. Managers should not only comply with the requirements established for the management system but should understand why development of the organization cannot be sustainable without effective HPI. Resources should be made available to conduct periodic self-assessments, provide necessary training and implement the necessary corrective actions. For those nuclear facilities that are just starting to introduce HPI principles and tools, a management steering committee that meets regularly might be useful in ensuring that all efforts are being supported.
(b) Problem identification and resolution is a key element of HPI. While many nuclear facilities have problem reporting systems, low level problem identification is essential in addressing potentially hidden problems before they result in an event. Managers of the nuclear facility need to encourage the identification of all types of problem, but additional emphasis should be placed on reporting lower level issues. Managers also need to ensure timely responses to reported issues so that employees are motivated to continue to identify problems.

(c) Many of the HPI principles and tools rely on an open and trusting working environment. Problems in the implementation of the principles and tools may be due to issues in the culture of the organization. An independent review of the nuclear facility safety culture, using a standardized framework with performance objectives and criteria (e.g. IAEA safety culture attributes [7]) should be helpful in identifying if and where such problems exist.

(d) The use of human performance principles and tools will only be effective with an engaged and involved organization. Efforts to use the most effective means of communication in working with the tools and involving those who will be required to use them, at all phases of their integration into the organization's processes, are key to their success. All levels of the organization need to understand and to support the value of human performance for the facility's performance improvement.

(e) To ensure high quality and consistency in the implementation and integration of HPI principles and tools into the nuclear facility's management system, training in these principles and tools may be necessary. Some actions to consider include:
  (i) Conducting an initial generic training session for all stakeholders involved in the implementation of HPI principles and tools;
  (ii) A more systematic approach for the detailed training for HPI implementation, including needs analysis and integration into existing training programmes;
  (iii) Periodic evaluation of the effectiveness of the training regarding the use of HPI principles and tools in the everyday work of the facility.

(f) The nuclear facility should have access to mechanisms to maintain awareness of lessons learned in the area of HPI (e.g. use of operating experience databases, attendance at industry meetings and conferences, and support and assistance of external organizations).

(g) The use of many contractors is a fairly common occurrence at most nuclear facilities (e.g. in construction, commissioning, modernization, refurbishment, outages, specialist maintenance and decommissioning). In implementing HPI principles and tools, contractors must be included and contractor managers should be held accountable for the application of the same high standards for their employees as the nuclear facility will apply for theirs. The nuclear facility managers should consider their role in encouraging the same open and candid discussion about identifying problems with contractors as they would with their own personnel.

Other specific corrective actions may result from the self-assessment activities. These might include the integration of HPI principles and tools in specific functional areas, for example work management (including planning and coordination) and engineering, all with the similar purpose to reduce the occurrence of errors and improve overall nuclear facility performance.

4.4. CONSIDERATIONS FOR NEWLY ESTABLISHED NUCLEAR FACILITIES

A nuclear programme is a major undertaking, requiring careful planning, preparation and investment in time and human resources. The decision by a State to embark on a nuclear programme should be based upon a commitment to use nuclear power for peaceful purposes, in a safe and secure manner. This commitment requires the establishment of a sustainable national infrastructure that provides governmental, legal, regulatory, managerial, technological, human and industrial support for the nuclear programme throughout its life cycle. The demonstration of knowledgeable compliance with international legal instruments, internationally accepted nuclear safety standards, security guidelines and safeguards requirements is essential in establishing a responsible nuclear power programme.

The development and implementation of an appropriate infrastructure to support the successful introduction of nuclear power and its safe, secure, peaceful and efficient application is an issue of central concern, especially for States that are considering and planning their first nuclear facility (such as a nuclear power plant). Decision makers, advisers and senior managers in governmental organizations, utilities, academic and training institutions, industrial organizations and regulatory bodies in those States embarking on nuclear programmes should ensure that the required national infrastructure is available. Reference [36] provides a framework of milestones and issues to be considered in the development of a national nuclear infrastructure. One of the issues to be considered is management. In the scope of this publication, managerial responsibilities for ensuring that personnel at

their facilities will perform to the high standards of performance required in the nuclear industry are of special consideration.

The roles and responsibilities of managers in HPI will change over time as the process of assessing and implementing a national nuclear programme progresses. The management of a nuclear programme is a demanding undertaking. Organization, processes, jobs and the people themselves will change as the nuclear programme progresses from pre-project activities through project decision making, design, manufacturing, construction and commissioning to operation (and further to decommissioning). It is a common, but incorrect, belief that the need for monitoring and continually improving performance is only required at the operational phase of a nuclear facility. The appropriate human performance management — as described in Ref. [1] and in this publication — should be established from the very beginning of a nuclear programme for two main reasons. First, the adequate management of such a safety related and resource intensive programme as a nuclear programme is simply impossible without adequate human performance. Second, management's initial approach to human performance, including organizational management, will have a significant influence on the establishment of the organizational culture of the facility. Once established, it is often very difficult to change the culture.

5. SUMMARY

Nuclear facilities depend on human performance, and excellence in human performance is essential to avoid incidents involving significant adverse consequences. While in the past, great emphasis was placed on designing system hardware and software to intercept and to mitigate events that could cause adverse consequences, dealing with the design of the human component has proven to be even more complicated. Examination of various safety related incidents makes it clear, however, that human performance plays a dominant role and must be addressed. It is generally postulated that without continuous efforts on HPI, safe performance of nuclear facilities would be unsustainable.

The goal of excellence in human performance is to attain event-free performance at the nuclear facility. By proactively managing human performance and strengthening the defences of the facility, the performance of individuals, processes and the organization will be optimized, errors will be minimized and events will be eliminated. Human errors are of various origins and typically result from issues in the organization, processes and programmes that contribute to unsafe acts which produce system failures. Analysis of events in the nuclear industry has found that a significant portion of them can be caused by both individual actions and by organizational weakness. To achieve event-free performance, a nuclear facility should have an integrated view of HPI that considers the organizational, process and job levels. While many different perspectives exist from which safety issues might be addressed, there are several factors significant for HPI that are consistent and useful to understand.

This publication has described how human performance can be improved, either reactively after an event, or preferably proactively before a problem arises, within the context of a general performance improvement model. It requires a systematic process of determining desired performance, continually monitoring performance, discovering and analysing performance gaps, designing and developing effective interventions, implementing these interventions, and continually evaluating the results of improvement interventions through performance monitoring for assuring that the improvement process takes place.

In describing the approach, the roles of the individual, the processes and the organization have been addressed. HPI tools which can be used for identifying, preventing and catching human errors and eliminating organizational weaknesses have been discussed. The implications for improving human performance at nuclear facilities are significant for overall improved facility safety, production, reliability and performance.

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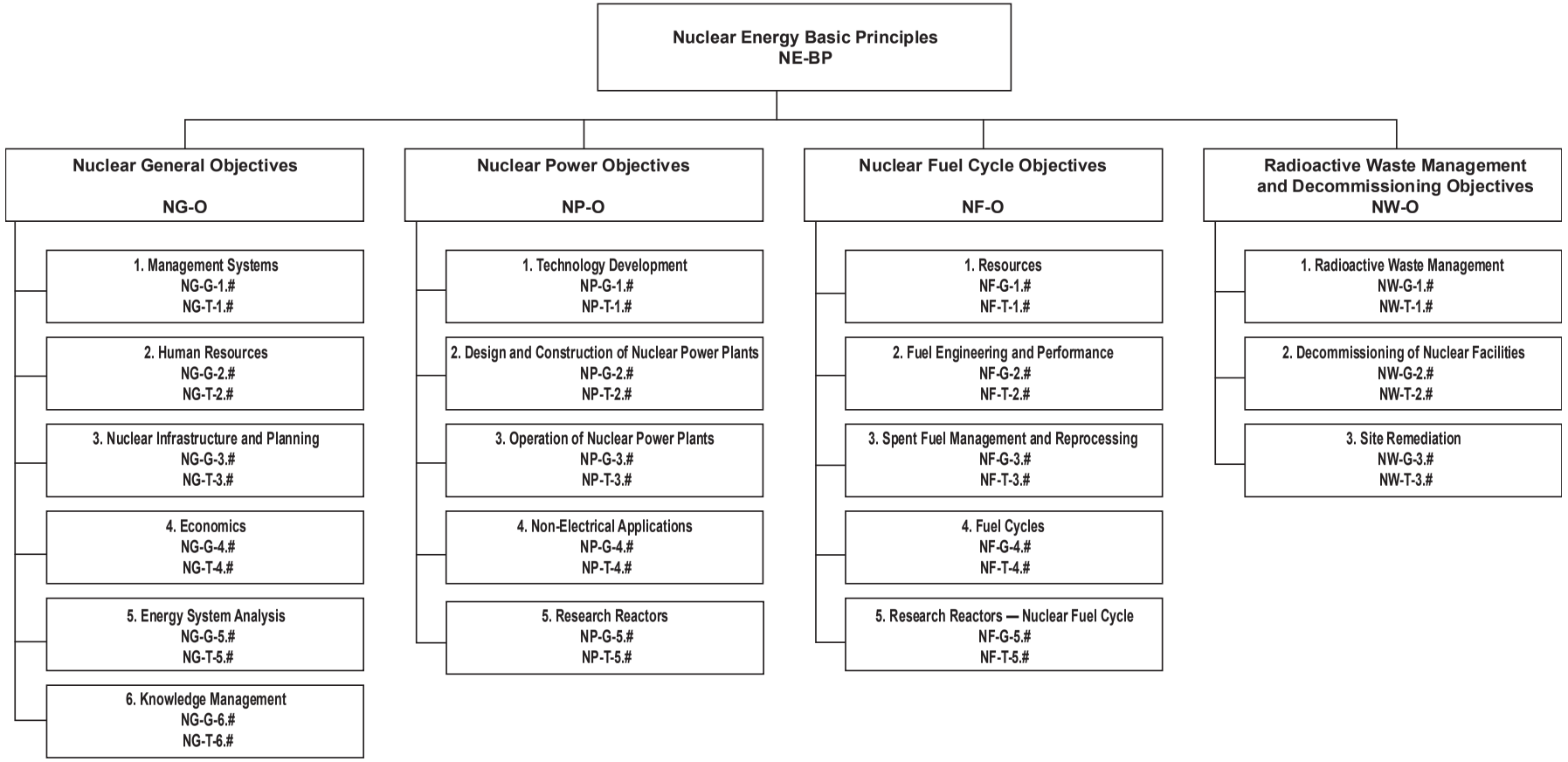

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ISSN 1995–7807