Management Process and Human reliability Analysis of In-service Inspection for the Mechanical Components in PWRs

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Abstract. Based on the management strategy of in-service inspection, emphatically analysing the human reliability of in-service inspection persons, aimed at improving the management system and raising the management level for in-service inspection for the Mechanical components in PWRs.

1. Introduction
The in-service inspection (ISI) activities are one of the most important steps in the whole refueling outage. Not only can it eliminate the potential safety risks in the running process, but also it helps promote the operation capacity in the next fuel cycle. The ISI activities on the nuclear island equipment are generally used to observe the defect change from the manufacture and installation, and find the new defects newly generated during the operating period. It will lay a foundation for the safe operation of nuclear power stations.

All kinds of equipment and pipes are widely distributed in the industrial factory buildings. The equipment is very complex and the pipeline networks are various, which may bring influences on the ISI activities. Therefore, many facts will influence the safety and quality of the ISI activities in the practical work, such as the continuous working, the cross working and the physical and emotional states of the ISI persons.

This paper emphatically analysed the main safety risks during the ISI activities based on the current ISI strategy and the actual implementation process. Aimed at the potential human errors, the human reliability analysis were given, which can be used for developing the safety of the ISI activities.

2. Management Strategy of ISI Activities
According to the RSE-M rules, non-destructive testing (NDT) is required for nuclear power equipment to ensure the safe operation. In the RSE-M rules, the inspection objects, the scope of examination and the technical points of NDT methods are specified in detail [1], which makes it easier to carry out the ISI activities in the nuclear power station. However, the implementation of the ISI activities is a systematic process, which involved in many departments and high risks. Therefore it is necessary to execute the technological process of NDT strictly, and abide by the plant safety and quality related regulations.

The main management processes can be grouped into three stages: the preparatory stage, the implementation stage and the summary stage.

2.1. Management Requirement in the Preparatory Stage

2.1.1. ISI Program. An implementation plan must be draw up several months before the refueling outage to ensure that the in-service activities are carried out smoothly and successfully. The plant ISI
programs include several procedure files, such as the pre-service inspection program, units plan program of ISI, the non-rules ISI general program, the ten-year plan and the annual plan for every refueling outage.

2.1.2. Personnel

(1) Inspection personnel

The implementation company needs to provide adequate and qualified NDT inspection personnel to meet the requirements of ISI projects [1]. The inspection personnel must go through the training and hold the NDT certification in accordance with nuclear safety regulations. The NDT certification must be within its validity [3].

(2) Quality Control (QC) personnel

In order to guarantee the work quality, the implementation company and the plant owner should assign one QC personnel respectively. As the independent personnel, QC personnel must supervise and examine the NDT implementation process, the in-service inspection quality and the schedule control. Normally, QC personnel should have rich work experience and achieve corresponding QC authorization.

2.1.3. Inspection techniques

(1) NDT methods

NDT methods shall comply with the relative criteria and safety technical norms, and meet the requirement of ISI activities. The commonly used methods include UT/TM, RT, PT, VT/ITV/CCTV, ET, MT and LT, etc. The selected methods in the pre-service inspection might not be exactly the same as that used during the in-service stage, but try to use the same method.

With the development of science and technology, the used inspection methods, techniques and the equipment may have many variations. However, it has to be proven that the new inspection system has the same or higher detectability than the previous one.

(2) Proficiency Testing

The proficiency testing of NDT methods used in ISI activities are carried out based on the relative national nuclear safety regulations. The proficiency tastings are divided into five categories, such as the special proficiency, comprehensive proficiency, the normal proficiency, specialists judging and non-proficiency.

2.1.4. Instrument and equipment

Inspection equipment includes the used NDT equipment and tools.

1) The quality, measuring range, and accuracy of the equipment used in ISI activities should conform to relevant regulations.

2) All the used instrument and equipment should be demarcated to ensure they are in the validity period of verification.

3) As to the demarcated component, they should conform to the same standard. If no applicable standard applies to them, the demarcated component should use the excess material with the same material and heat treatment state as the inspection object, or other materials with the similar material and heat treatment state.

4) All the used instrument and equipment should remain in safe states.

5) According to the ownership of the instrument and equipment, each owner should show the prescribed keeping requirement and establish relevant management system which aims at the keeping environment and maintenance measures during the keeping process.

2.1.5. Block

The calibration block used in ISI activities should conform to relevant regulations. The standard block and reference block should remain in safe states.

2.1.6. Working document

Working documents of ISI activities in the nuclear island include quality assurance program, ISI plan of nuclear island, inspection procedure, proficiency testing file, testing procedure, quality plan and other working documents [2].
2.2. Management Requirement in the Implementation Stage

2.2.1. General principle. The integrated planning of the refueling outage influences the arrangement of ISI activities. The whole ISI activities, including the first examination, the re-examination and the interpretation of examination results, must be finished before refuelling begins. The specific inspection items must be finished in the specific time interval. All the ISI activities should comply with the general principle above.

Planning Principle between different items. Some work item may have interaction effect with another. For these work items, the headquarters of the refuelling outage has responsible for their organization, coordination and implementation, to avoid affecting the examination time, precondition and the collective dose.

2.2.2. Working precondition. Working precondition must be checked before each ISI activity in nuclear island. Generally, many conditions would influence the work progress and quality, including the equipment state, boundary, ambient dose, working tools and cross-operation. Work leader and QC personnel cooperatively checked the above conditions. No inspection was performed until all conditions can satisfy the requirements of inspection procedure.

2.2.3. Maintenance activities. Some work items are carried out with relative maintenance activities. The NDT activities may be arranged before, during and after the maintenance activity. These ISI activities were planned, organized and coordinated by the headquarters of the refuelling outage.

2.2.4. Implementation process. The main implementation process included the pre-job meeting, checking working condition, verifying inspection equipment, NDT implementing, interpretation of NDT results, writing the examining result report, reviewing quality plan and closing working-ticket [2]. Process control of ISI implementation process included the supervision of NDT implementation and the reasonable control of QC personnel.

2.3. Management requirement in the summary stage

After finishing the inspection activities, it is necessary to summarize the management process and experience feedback, including the abnormal events, human errors and good practice. It is benefit for improving the quality of the future refueling outages.

3. Human Reliability Analysis of ISI Activities

ISI activities are comprehensive system which includes man, machine and environment. There are a series of uncertain factors in implementation process. There are usually three kinds of reasons for accidents, including human factors, machine factors and working environment. Among these reasons, human factors are the most important. Researches on the types, the reasons of human errors and pertinence measure, will help to improve the safety management level of ISI in domestic plants. It is one of the most important topics of industrial non-destructive testing that arouses people's considerable attention.

3.1. Definition of Human Reliability Analysis

Human reliability analysis is used to study how to analyse, predict, decrease and prevent human errors. These subjects are on the base of behavioural science, cognitive science, information processing, system analysis and probability and statistics, focusing on the analysis and evaluation of human behaviour [4]. By the definition, human reliability analysis of ISI activities could be used as a tool to plan, improve and prefect ISI items, and finally reduces the rate of human errors to the minimum value of evaluation system.

In the working system of ISI activities, many factors could be the potential reasons, including the high-risk ray source, the complex working conditions, the complex management process and the strict quality control regulations. In practice, the basic way to analyse the reliability of operators is theories analysis in some universal analysis methods, for example the bound method and fault tree analysis.
method [5]. By studying the case and issuing questionnaire, human reliability database and analysis system would be built, which is helpful for human reliability analysis.

3.2. Characteristics of Human Errors

Many human errors come from ISI activities. The most common examples are as follows: expiration of qualification authorization, working without proper labour protection appliance and area radiation monitors, violating craft card to control technological time, the lack of oversight when borrowing and returning the ray source. There are common features of the above-described behaviours that clear requirements and proper understanding for the proper behaviour exit, but correct actions and proper behaviours are not performed. The accurate definition of human error is that a task or an operation is not properly finished within stipulated time, leading to the decrease and degeneration of working system or at least influencing the system function [4]. Human error has become one of the leading factors in the failure of complicated systems. And the technique of human error analysis lacks consistency and is difficult to use.

Such studies on the features of human errors have important implications for improving the reliability of working system and ensuring the safety of ISI activities. According to theoretical research, the main features of human errors include repeatability, potentiality and irreversibility, the inherent changeability, reparability and that every person has ability to learn [4]. As for ISI activities during refueling outages, the reason for human errors are various, including the physical condition, the mental condition, the equipment state, environment and supervisory system, etc. In general, the main features of ISI activities during refueling outages are as follows.

(1) Human error can never be entirely eliminated

Many human errors happen because human ability (physical condition, mental state and skill level) would not always match the function ability and operability of equipment and working environment. When the inspection equipment and working condition is certain, one person can’t keep a rather high level of work. In other words, the total elimination of human errors will never be impossible. At the same time, it is possible to reduce human errors by developing working skills, investigating personnel's working status and remanding the dangers in work.

(2) Versatility and transmissibility of human error

The basic procedure of ISI activities involves the preparation of working document, the verification of preconditions, the pre-work meeting, the implementation process, the summarization of after-work meeting, and the preparation of the result reports and so on. Every activity is not independent with each other. They are in direct line of succession and linking with each other. A certain procedure may influence another procedure or many other procedures, and finally lead to an accident. Therefore, every link of ISI activities procedure should be taken into account to avoid human errors. And timely corrective action should be taken to deal with errors that occurred.

(3) Reparability of human error

Learning ability is a source of human wisdom. By studying and practicing, ISI activities operators can not only learn NDT skills and safety management rule regulations, but also train the ability to discover and correct specific errors. Human errors are unavoidable. However, if operators can timely find the mistakes and make satisfactory feedback, human errors can be effectively reduced and eliminated. As a result, the working procedure returns to the normal state. For example, ISI personnel may don’t properly wear radiation monitoring instrument before implementation. Another situation is that the welding seam of testing objects may be wrong. In above two situations, if we can timely find out and correct the error, no serious consequences will happen.

3.3. Primary Factors of Impacting Human Reliability

Human reliability is the result of the interaction of personnel internal states and external factors. It is not only influenced by physical state, psychological state and skill levels, but also restricted by the social environment, working environment and safety management rule regulations.

(1) Physical and psychological state impacting human reliability

Reliability is one of the most important natural properties of human. Unusable states such as disease and mood swings can easily cause wrong judgments and error behaviour, leading to
unexpected accident. Even if operators have a good state, it is impossible to completely avoid human errors. Insensitive and experientialism is always the source of human errors. Especially for ISI operators, once human errors occur, it may lead to serious consequences. Therefore, ISI operators should have good health, psychological state and prefect experience feedback before starting.

(2) Working stress impacting human reliability
Research has shown that moderate working stress can help you concentrate, increase productivity and reduce errors. However, an inordinate or little stress would have a negative impact on human behaviours. Operators may be too nervous or relaxed. During refueling outages, there are three major types of ISI operators’ working stress: short work period, high demand for work quality and personnel continuous operation.

(3) Skill levels impacting human reliability
Non-destructive testing skill is the foundation of ISI activities implementation. Skill levels would determine the quality of finished work. A measure of non-destructive testing skills include NDT qualification certificate, nuclear safety radiation protection training, the basic safety training and authorization and working experience of non-destructive testing items. Lower skill level manifest as lack of professional skill, poor work style and irresponsibility. All of these performances are the reasons of human errors. There are two ways to increase the reliability of RT operators: continuously learning non-destructive testing technique and emphasizing on the accumulation of experience.

(4) Environments (social environment and working environment) impacting human reliability
For ISI operators, two main types of environment refer to social environment and working environment. Environment could influence the psychological status, mental state and physical condition of operators, thus affecting the work quality and efficiency. Social environment factors include family’s harmoniousness, family life stress and personal development. Working environment factors include the height, temperature, humidity, dose level and noise of workshops. Every factor could more or less influence ISI operators’ mental and physical states. From the point of building company culture, to improve the working environment and increase the standard of welfare would also contribute to increasing human reliability.

4. Conclusions
According to the feedbacks of ISI experience in domestic plants, the current strategy has high reliability. However, it is worth discussing whether the period–oriented management strategy of the refueling outages is the optimal choice. Because the period oriented strategy brings high pressure to the ISI operators and sets a high demand for their reliability. The reliability analysis of ISI operators through the human reliability theories would not only contribute to decreasing the human errors from the source, but also help to develop the ISI management strategy in plants.

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