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Regulatory Oversight of Nuclear Safety Culture and the Validation Study on the Oversight Model Components

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Objective: This paper introduces the regulatory oversight approaches and issues to consider in the course of safety culture oversight model development in the nuclear field. Common understanding on regulatory oversight and present practices of international communities are briefly reviewed. The nuclear safety culture oversight model of Korea is explained focusing on the development of safety culture definition and components, and their basic meanings. Oversight components are identified to represent the multiple human and organizational elements which can affect and reinforce elements of defense in depth system for nuclear safety. Result of validation study on safety culture components is briefly introduced too. Finally, the results of the application of the model are presented to show its effectiveness and feasibility.

Background: The oversight of nuclear licensee's safety culture has been an important regulatory issue in the international community of nuclear safety regulation. Concurrent with the significant events that started to occur in the early 2000s and that had implications about safety culture of the operating organizations, it has been natural for regulators to pay attention to appropriate methods and even philosophy for intervening the licensee's safety culture. Although safety culture has been emphasized for last 30 years as a prerequisite to ensure high level of nuclear safety, it has not been of regulatory scope and has a unique dilemma between external oversight and the voluntary nature of culture. Safety culture oversight is a new regulatory challenge that needs to be approached taking into consideration of the uncontrollable aspects of cultural changes and the impacts on licensee's safety culture. Although researchers and industrial practitioners still struggle with measuring, evaluating, managing and changing safety culture, it was recognized that efforts to observe and influence licensees' safety culture should not be delayed.

Method: Safety culture components which regulatory oversight will have to focus on are developed by benchmarking the concept of physical barriers and introducing the defense in depth philosophy into organizational system. Therefore, this paper begins with review of international regulatory oversight approaches and issues associated with the regulatory oversight of safety culture, followed by the development of oversight model. The validity of the model was verified by statistical analysis with the survey result obtained from survey administration to NPP employees in Korea. The developed safety culture oversight model and components were used in the "safety culture inspection" activities of the Korean regulatory body.

Results: The developed safety culture model was confirmed to be valid in terms of content, construct and criterion validity. And the actual applicability in the nuclear operating organization was verified after series of pilot "safety culture inspection" activities.

Conclusion: The application of the nuclear safety culture oversight model to operating organization of NPPs showed promising results for regulatory tools required for the organizations to improve their safety culture.

Application: The developed oversight model and components might be used in the inspection activities and regulatory oversight of NPP operating organization's safety culture.

Keywords: Safety culture, Safety culture components, Regulatory oversight, Validation study, Defense in depth

1. Introduction

Nuclear safety culture can be an overall representation on how much the operating organization of a nuclear power plant (NPP) combines nuclear safety with the organization's business goal, and operates the NPP for the combined goal with safety prioritized. The reason why the importance of nuclear safety culture has been continuously emphasized and studies on it have been carried out amid criticism or doubt on practical use in relation with conceptual obscurity is that safety culture is associated with the basic concept to ensure safety. Like an assertion of professor Reason (1998), "Because of their diversity and redundancy, the elements of a multilayered defensive system will be widely distributed throughout the organization. As such, they are only collectively vulnerable to something that is equally widespread. The most likely candidate is safety culture". Also the IAEA's publication, INSAG-10 (1996), specifies the prerequisite to defense in depth is safety culture, and demands caution to the organization and people that can affect all levels of defense in depth. Moreover, as insights from experiences are gained and trials and errors are accumulated from the attempts of safety culture at the initial stages, obscurity and doubt of utility are being overcome, while they are applied to actual organizations beyond research level.

This paper introduces the regulatory oversight of NPP operating organization's safety culture recently attempted in the nuclear field. Since safety culture was introduced in explaining the fundamental cause of the Chernobyl accident, the researches and application to actual worksite of safety culture have been carried out, focusing on how an operating organization can diagnose, evaluate and change safety culture. As the concepts to make safety culture feasible, the components, three-level model and development stage of safety culture have been developed, and safety culture has been dealt with as an organizational culture itself. In addition, comprehensive approach to promoting safety culture for an operating organization has been conducted with the proper considerations of them.

Various factors should be taken into account when conducting external oversight of safety culture besides the difficulties that an organization face when it deals with its own safety culture, namely the regulatory body's oversight of operating organization's safety culture: how a regulatory body having limited information should observe and evaluate some aspect of safety culture, how such a body should collect and analyze asymmetrical data, and how it should verify and utilize the reliability of analysis results. Especially, organizational culture's change direction can be revealed differently from its intention in some cases. An effort to change autonomously can produce an adverse effect by external intervention, and even worse case is that responsibility for safety can be diluted by such an external intervention. Therefore basic components should be selected in consideration of comprehensive effects of safety culture on organization, a method and means to handle invisible areas of culture need to be developed, and methodology that can present balance between external oversight and organization's internal voluntary efforts should be devised. Through all these, additional dispute on whether regulatory oversight activity can contribute to the retention and enhancement of safety can be resolved.

This paper examines international trends in regulatory oversight of safety culture, safety culture model from the regulatory oversight aspect, issues related with regulatory oversight, and validation and the application of the model.

2. Regulatory Oversight Approaches and Issues of Nuclear Safety Culture

2.1 Concept of safety culture oversight developed in nuclear field

It is clear that the IAEA (International Atomic Energy Agency) has made huge efforts to introduce, develop and provide safety culture concept in the nuclear industry, and the means for adoption and application of safety culture evaluation and improvement. However, the evaluation methodology suggested by IAEA has not been actively utilized by nuclear licensees or regulatory bodies seem to have several reasons: First, the qualitative, internal and comprehensive concept of safety culture is difficult to quantify, objectify and analyze in many aspects. Second, methodology that can objectively measure and evaluate safety culture level has not been properly established. Third, verification on correlation between safety culture and NPP's actual safety is difficult. That is, recognition on the role of safety culture as a medium for safety improvement, and utilization motive seem to be insufficient.

In the 2000s, various incidents occurred in key nuclear operating organizations including Japan JCO's criticality accident, Japan TEPCO's inspection report falsification event, the US Davis-Besse reactor vessel head degradation event and Germany Philippsburg NPP INES 2 event related to boron concentration test, which became an opportunity to make people realize the importance of safety culture. However, they did not become main concern on the part of IAEA. Nonetheless, they became a chance to start discussions on safety culture from the regulatory body perspective, centered on OECD/NEA [Working Group on Human & Organizational Factors (WGHOF) is installed and WGHOF leads information exchange among regulators on human and organizational factors in terms of NPP's safety]. WGHOF showed interested in the regulatory approaches on licensee's safety management in 2006, and issued a report of "State of Art Report on Safety Management" (CSNI/R(2006)1) through a relevant conference. In the report, WGHOF took notice of close correlation between safety management and safety culture, and recommended which regulatory approach on safety culture should be taken, unlike safety management. WGIP (Working Group on Inspection Practice) of NEA, together with WGHOF, surveyed how the member countries carried out inspection on safety culture, and pointed out there was a need to more systematically approach the inspection method of safety culture. Based on this, OECD/NEA activated discussions on regulatory oversight, as OECD/NEA co-hosted the "Maintaining Oversight of Licensee Safety Culture - Methods & Approaches" workshop in 2007 with IAEA. In 2011, the follow up conference was held. OECD/ NEA discussed by focusing on the method to reinvigorate safety culture efforts that nuclear licensees miss from the regulatory body's perspective, rather than safety culture from the nuclear licensee's perspective. OECD/NEA has made efforts to converge international consensus on regulatory oversight of safety culture since 2007.

As discussions on safety culture have been newly activated due to Fukushima Nuclear Power Plant accident in 2011, IAEA commenced a safety culture program and published a technical document on regulatory oversight of safety culture, (IAEA-TECDOC-1707, Regulatory Oversight of Safety Culture in Nuclear Installations, March 2013). In this way, the two international bodies attempt new approaches on safety culture. OECD/NEA is focused on regulatory oversight on nuclear licensee's safety culture, and the safety culture of regulatory bodies affecting the licensee's safety culture, while IAEA comprehensively develops work targeting systemic approach by linking the interactions of nuclear licensees, regulatory bodies and even overall society with safety culture.

The regulatory oversight on licensee's safety culture is a field currently underway, rather than the field armed with established concept and methodology. There are some cases in which positions can be slightly different according to different systems and regulatory practices by each country from the nuclear safety regulation aspect. There are also some cases in which the verified methodology cannot be combined from the existing regulatory system. As such, the progress speed of regulatory oversight shows differences according to each country's situation. However, requirements on safety culture that each member country should apply from the IAEA's safety standard system is expected to be published soon (IAEA plans to publish Safety Standards Series, GSR Part 2, "Leadership and Management for Safety"). Therefore it can be said regulatory oversight of safety culture have a direction. All the more, the regulatory experiences on safety culture oversight are continuously accumulated. Norway already

started regulation on safety culture in 2002 in the offshore platform area, and published revised regulatory requirements and policy in 2011. The implications of Norway's introduction of regulations have affected field practices through regulatory activities, and have become a key motive power for change (Of course, there are some scholars with critical view on the Norway's introduction of safety culture regulations. In "Why regulators should stay away from safety culture and stick to rules instead", Grote and Weichbrodt (2013) pointed out that specific type of intervention of regulations cannot draw proper cultural factors in a situation that different types of regulatory systems, risks and management methods exist in a mixed way. However, in retrospect of authors' insertion, Fleming and Scott, it can be viewed as presenting what a regulatory body should do for safety culture).

The issue of regulatory oversight of safety culture is to decide at policy level which is more effective between leaving in the autonomous area and designating it as one of the oversight subjects of regulators. Many conflicting discussions and evidences exist so far, and also many discussions on what to focus have been conducted. The commonly accepted matters in relation with regulatory oversight in the nuclear field are as follows.

2.2 Common understanding on regulatory oversight of safety culture

The purpose of regulatory oversight of safety culture is to consider potential vulnerabilities within licensee's nuclear facilities that may cause decline of performance, and make the licensee be equipped with cultural characteristics at organization level to take actions and manage the vulnerabilities gravely. Nuclear licensee can prevent such future potential performance decline by internalizing and sharing a preventive standpoint, and can take actions to improve overall safety within the organization by finding various improvements. Regulatory oversight of safety culture plays a role in complementing regulation-observance based regulatory activities through proactive management activities. The regulation-observance based regulation targets the surface level of culture, focused on ensuring status of current state of safety criteria, and does not aim to affect the surface level. Meanwhile, regulatory oversight of safety culture aims to play a role in presenting a direction to be equipped with culture for an organization to proactively manage safety culture.

Here, a question of "What is the regulatory oversight?" is encountered. It is different from the regulation-observance type concept checking the status and forcing safety criteria. To shape good safety culture, the role and responsibility of NPP operators should be put in priority. The regulatory oversight of safety culture is not intervening in and forcing NPP operators' safety culture activities, but aiming at independently monitoring operators' safety culture activities, presenting regulatory body's expectations and encouraging them. In other words, regulatory oversight is not the narrow sense of concept having the limited meaning of setting up a certain limitations to the activities of people and companies, or controlling to go beyond the limitations, but is based on an oversight concept having an encouragement by monitoring individual's or organization's activities not to go wrong, and to order or implicit punishment, if necessary. The oversight of safety culture should be carried out by nuclear licensees themselves, and the regulatory oversight concept is to independently carry out oversight by regulatory body level to check such an oversight.

Actually, matters that should be carefully discussed about safety culture regulatory oversight are presented commonly: First, regulatory oversight needs to be handled in a separate manner from compliance based command and control in terms of safety culture's conceptual character. This is derived from the fact that observation of visible phenomena and review of records are difficult to identify cultural sources that other organizations have. Like the assertion of E. Schein that a goal to observe and change an organization's culture alone can affect the organization's goal, the command and control approach cannot be effective, since what have been identified as current organization's cultural characteristics with just evaluation, measurement or review for regulatory oversight become those of the past. Therefore intervention in the direction of organizational change, rather than the command and control of an organization at a specific point in time is required, and a separate method is needed to do so.

Second, communication between a nuclear licensee and regulatory body is essential to acquire accurate understanding of safety

culture. Communication starts from building the common language and system that can mutually perceive and develop the importance of safety culture from the safety aspect. Intervention from the regulatory aspect can be effectively delivered and implemented through communication, once the common understanding of to which direction an organization should be changed is premised. Communication enables open discussion including respect for each one's role by nuclear licensee and regulatory body, and helps to find a method to continuously draw safety-related improvements.

Third, because change of safety culture is an activity requiring long period of time, a device for a licensee to have continuous interest and motive is needed. In many cases, the term of management at NPP is generally shorter than the period cultural change requires. For this reason, a suitable regulatory method should be devised for organization members' continuous involvement and participation.

Fourth, intervention that can affect licensee's behaviors in a direction to reduce the licensee's responsibility on safety must be avoided. Safety culture approach should affect in a direction that an organization should enhance responsibility on safety, and should not be regarded as intervention in everything of the licensee organization. For continuous improvement of safety to be organization's practice, the organization should achieve it on its own, and be careful about a reversal phenomenon making the perception of safety improvement is not the organization's role, because of the existence of a regulatory body demanding improvement.

It is necessary to have a method and system to actually implement regulatory oversight in consideration of all those. The methodologies that have been adopted or utilized for regulatory oversight of safety culture so far are as follows.

2.3 Regulatory oversight approach in nuclear field

Although consensus on basics of regulatory oversight of safety culture has not been formed, a methodology suitable for each country's situation and reality is developed and utilized in the methodology and institutionalization process that actually implements the method. Therefore there are differences among countries in followings: relevant requirements, guidance, inspection method, corrective action according to inspection result, inspector's training on regulatory oversight, method to ensure consistency and objectivity of regulatory oversight and disclosure of oversight results (Choi et al., 2015). One common thing, however, is that regulatory oversight starts from nuclear licensee's approach to safety management system. IAEA's publication, INSAG-13 (1999), presented that a nuclear licensee should be equipped with a system beyond the ensuring of regulation-observance based safety through discussions on the licensee's safety management system. IAEA insisted that a regulatory body (within a licensee's organization) should effectively activate operating organization's safety management system by assuring critical self-evaluation and corrective activities are operated as a role of the regulatory body on nuclear licensee's safety management system. IAEA emphasized that such a role of the regulatory body should avoid behaving in a direction to reduce licensee's responsibility on safety. IAEA presented an approach to safety management system, mentioning, "A regulatory body monitors operating organization's performance, and should take an action, if the safety management system is ineffective, or organization's safety performance declines". Based on all these, IAEA (2006) demands to consolidate safety culture through the safety management system, as it provides the safety management system requirements as one of the safety criteria. The base of safety culture regulatory oversight through such a safety management system is recognized as a minimum regulatory action that needs to be taken in priority.

Furthermore, how to check when a regulatory body needs to take an action can be classified into three approaches: The first approach is monitoring onsite vulnerabilities. This is an approach analyzing the causes of safety culture, identify vulnerabilities from the safety culture aspect, and demanding the correction of safety management system or safety culture itself in relation with NPP's performance decline or work imperfections. The U.S. can be a typical country adopting such an approach. NRC (Nuclear Regulatory Commission), the U.S. nuclear regulatory authority operates ROP (Reactor Oversight Process) as a regulatory oversight

system of nuclear power plants. The NRC evaluates safety importance on onsite problems through ROP, and monitors safety culture factors as a common issue. Based on such monitoring results, differential regulatory actions are taken, if serious level of safety culture decline occurs.

The second approach is review on normative evaluation. This is standardizing the normative evaluation method on safety culture, and presenting it to a nuclear licensee. When the licensee conducts its own evaluation of safety culture, and submits the evaluation results to a regulatory body, the regulatory body reviews the propriety of evaluation and suitability of the corrective action plan. The Oversight Method for Nuclear Licensees' Safety Culture planned by Canada can be a representative approach. In Korea, a nuclear licensee evaluate each NPP's safety culture in every ten years, and a regulatory body review them, and checks matters to improve for safety according to the RSR (Period Safety Review) system.

The third approach is a method using safety culture indicators. This is an approach setting up indicators assuming the characteristics of safety culture is revealed, observing and evaluating them, scoring them, and carrying out safety culture inspection, if indicator values drop. Germany's KOMFORT (Catalogue for recording organizational and human factors during on-site inspections) and KOTKA (Tool to collect and analyze inspection findings) once used by Finland can be representative oversight methods according to inspection tables. Such safety culture indicators do not represent total safety culture, but function as a proxy. Therefore there should not be misunderstanding that they indicate safety culture level.

3. Nuclear Safety Culture Oversight Model

The regulatory body's role on nuclear safety culture, international development aspect of regulatory activities, major concepts and methodologies have been examined so far. Based on such a background, efforts for regulatory oversight of safety culture for NPP operators have been made in Korea, since the Fukushima Nuclear Power Plant accident. To this end, this paper looks into how regulatory oversight model was built first, and introduces the validation of validity and pilot application results of the model in the following chapter.

3.1 Safety culture definition and components

As described above, the regulatory oversight of safety culture is an activity to independently monitor NPP operator's safety culture activities, present regulatory body's expectations and encourage to achieve them. Regulatory oversight starts from presenting regulatory body's expectations on safety culture. Forming common understanding among regulators, NPP operators and stakeholders on safety culture aimed at from regulatory oversight is essential, and there is a need to start from the definition of safety culture. Safety culture is defined as the behavioral patterns, core values and basic beliefs of organization members on the importance of nuclear power in the regulatory oversight model. The meaning that such a definition has as follows: First, the definition of safety culture mainly used by IAEA and many international regulatory bodies uses such expressions as safety comes first (IAEA) and safety is emphasized in priority (NRC). Therefore, safety culture is defined concerning good safety culture. This paper regards safety culture is located in some part of the repeating line of safety culture expressed as good safety culture (positive, healthy, or robust) and bad safety culture (weak, poor or deteriorated), and takes a mode to define safety culture as a value-neutral expression, "sharing of safety's importance". By doing so, the foundation to discuss the change of safety culture encouraging good safety culture elements and improving vulnerable safety culture causes is provided.

Second, this paper constructs the definition of safety culture with behavioral patterns, core values and basic beliefs so that the key components of artefacts, espoused values and basic assumptions presented by three levels organizational culture model of Schein (2010) are included. Such a construct is associated with "behavioral norms: the way we do things around here", "values: what is important" and "beliefs: how things work" presented by Reason (1997).

Third, IAEA's publication, INSAG-4 (1991), emphasized the linkage of safety culture with an organization and individuals, and Reason (1997, 2008) awakens the importance of improving not only individuals' errors, but vulnerabilities at organizational level. Schein (2010) stressed leader's role in the creation and change of organizational culture. Therefore both individuals and organization are handled in safety culture, and management, managers, leaders and employees are defined to be included in the organization members.

Fourth, organizational culture is defined as basic assumptions' pattern that an organization acquires and shares to solve external adaptation and internal integration according to Schein (2010). Therefore organization's safety culture is shared among organization members, and has a possibility to be fortified, weaken or change through the sharing process. In the regulatory oversight of safety culture, responsibility of individual competencies and the responsibility of understanding and sharing of organizational management and safety culture are encompassed by emphasizing the characteristics shared by organization members. Such a point of view has a meaning of adopting a dynamic concept undergoing cultural formation process in which individual behaviors are evaluated, accepted or rejected by interactions among individuals from the concept concentrating on individuals in terms of the source of problems.

Fifth, a behavioral pattern means visible symbols, rituals and activity types revealed in the process and result of all activities (decision making, work, conversation) conducted for organization members to achieve organization goal. A core value means the value acknowledged as the most important thing by the member's adopting or supporting of the principles, rules and policies in and outside of an organization. A basic belief means basic thinking and belief unconsciously accepted by organization members naturally.

From such conceptual definition of safety culture, the safety culture components for operational materialization should be set up. NPP operators develop and adopt components suitable for their own NPP, and use them for safety culture enhancement, while the components presented by a regulatory body have materialized the espoused values related with safety culture utilized for regulatory body's oversight. The components drawn from NPP operator's own definition may not be consistent with those of regulatory body. An NPP operator needs to cope with such a thing in terms of the part that a regulatory body does not intervene, and even the inefficient part, although the regulatory body does not intervene by more concretely setting up the components by the NPP operator rather than the regulatory body. Table 1 [(See the research project report (Choi et al., 2015)] of KINS safety culture regulatory oversight basis building and system development for the comparative analysis results of literatures associating the concrete meaning of each item, and expressing behavior criteria or decline trends of safety culture) shows the components presented by the regulatory oversight model and expectation level of each component. The components consist of the following: First, the components include safety culture management system, safety leadership and change management in reflection of the details of IAEA GSR Part 2. Second, they include problem identification and solution, diagnosis and improvement intensively managed by the US NRC. Third, they include the working environment that is emphasized by NRC from the 1980s, and that regards safety highly in relation with J. Reason's reporting culture placing itself as the core factor of safety culture in the aviation area. Fourth, the components encompass decision making, work practices and work management presented by IAEA, the US NRC, DOE and INPO (Institute of Power Operations) in regards with human performance directly related with onsite NPP safety. Fifth, the components contain the reflection of operation experiences from the reactive perspective, and diagnosis and improvement items from the proactive perspective as the elements to improve continuous safety. Sixth, Korea's human error report can be activated by including just culture that becomes the basis of reporting culture. Seventh, organizational competence items are included to improve the performance evaluation focused on economic efficiency, which was a cause of Kori Unit 1 Station Black Out (SBO) Concealment Event, and to induce safety-focused evaluation, promotion and reward.

Table 1. Nuclear Safety culture oversight model and components

Safety culture components	
Area	Expectation
Human Performance Management (HP)	Decision Making (DM): Individuals use decision making-practices that design, work (operation, test, maintenance and changes), and actions taken to abnormal events are judged, assessed, and accomplished in a conservative manner.
	Work Management (WM): The organization implements a systematic process of planning, review, coordination and execution associated with work important to safety. Individuals communicate and coordinate their activities within and across organizational boundaries.
	Work Practice (WP): The organization builds environment for procedure adherence, and strives to reduce human errors using appropriate program/techniques, to accomplish work important to safety completely.
	Resource Management (RM): The organization ensures that personnel, document, equipment, working environment, and other resources are available and adequate to support the work important to safety.
Management for Improvement (MI)	Operating Experience Feedback (OEF): The organization systematically and effectively collects, evaluates, implements, and shares relevant internal and external operating experience in a timely manner.
	Problem Identification and Resolution (PIR): The organization implements a corrective action program to identify potential safety issues, to evaluate their safety significance systematically, and to ensure that corrective actions are taken in a timely manner.
	Diagnosis and Improvement (DI): The organization implements a review mechanism to do in-depth analysis of safety-significant events in the aggregate to identify programmatic and common cause issues of program, system, and practices. The organization ensures that resolutions address common causes and their causal factors in advance.
Safety Conscious Working Environment (SCWE)	Employee Protection (EP): The organization implements a policy that supports individuals' rights and responsibilities to raise safety concerns, and internal regulation and supervision not to give disadvantages to people who raise safety concerns. Managers consider the potential chilling effects of personnel actions.
	Information Sharing (IS): The organization builds working environment in which workers communicate safety information actively, and safety concerns or issues are raised freely. The organization manages alternative path for raising safety concerns that is independent of line management influence.
	Just Culture (JC): The organization implements a policy that evaluation and decision of disciplinary action for workers involved in accident, incident, or error in the workplace are made based on fairness principle
Leadership and Organizational Control (LOC)	Leadership for Safety (LS): Top management ensures that personnel, equipment, and other resources are available and appropriate to support all activities of individuals in the organization to ensure nuclear safety as overriding priority. Leaders demonstrate a commitment to safety in their decisions and behaviors
	Organizational Competency (OC): The organization implements learning, personal management, and performance evaluation systems which value nuclear safety competency of the organization and safety performance of NPP. Incentives, sanctions, and rewards correspond to safety competency of individuals. Individuals have clear role and responsibility.
	Change Management (CM): The organization implements systematic process for environmental, organizational, institutional, procedural changes that could affect safety so that changes to be classified and managed according to their safety significance.
Safety Culture Management System (SCMS)	Management System: The organization establishes and implements a management system to promote a safety culture which corresponds to global safety standard. The management system includes definition, model, and implementation framework for continuous improvement of safety culture.
	Implementation Organization: The organization cultivates safety culture experts. The organization shall have a team with exclusive charge on the implementation of safety culture management system.
	Implementation Framework: The organization establishes an implementation framework including regular assessments of safety culture using state-of-the-art methods, monitoring to detect early signs of decline in safety culture and analysis of trends, causal factors analysis to identify potential safety culture problems within major issues, and corrective actions with effectiveness evaluation of cultural change.

3.2 Safety culture oversight framework

As stated above, regulatory oversight of safety culture can be constructed with three approaches, and Figure 1 shows the schematization by combining the defense in depth of NPP system. The stability of an NPP can be explained with a concept of defense in depth. Through defense in depth consisting of multiple physical barriers and multi-level defense strategies, the equipment failures or human errors occurring at nuclear facilities are complemented. Physical barriers or safety facilities can be the barriers from a sort of hardware aspect, and operations, a maintenance program and procedures can be the barriers from the software aspect. These barriers must meet the requirements of laws and regulations and technical level in terms of performance or operational competency under the regulatory system. Among the barriers, independence should be ensured, and the basic principle of defense in depth that the next barrier complements, if one barrier fails, is not observed. The root-cause approach, which is a safety culture improvement approach by root-cause analysis of vulnerabilities as shown in Figure 1, expresses identifying the correlation between the causes revealed in or inherent to various barriers and parts of safety culture, and taking an action of the parts to improve at safety culture level. The symptom-approach expresses activities to improve the core of safety culture through starting point of a normative model for safety culture. This includes drawing the measureable indicators in the facility, operation and organization areas, and evaluation and inspection through them.

This paper took a method setting up four organizational barriers ensuring the human organizational soundness of NPP operating organizations and each barrier's core activities as components by combining the concept of defense in depth, the foundation of ensuring NPP safety.

The basic concept of organizational barrier is as follows: From the human performance improvement aspect in which decision making on work is conducted by coming close to NPP system the most, and work is carried out, human performance management was set up as the first barrier. For second barrier, experience feedback and management of improvement were set up as an effort required for improvement. Systems, procedures and actual activities for finding various errors existing in a system as many as

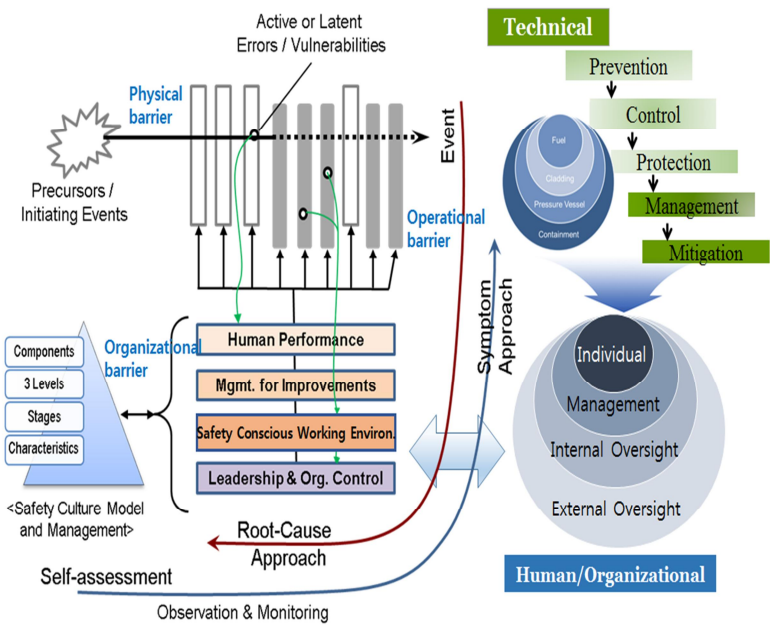

Figure 1. Concept and approach for safety culture oversight model development

possible and taking actions belong here. If system vulnerabilities that may induce human errors are filtered, human performance can be improved. The third barrier is safety conscious working environment required for experience sharing and operation improvement to be effectively implemented. Policies and systems need to be established, various reporting paths where secrets are guaranteed should exist, and just culture needs to be established to build atmosphere in which safety information is freely raised, shared and solved. For the fourth barrier, leadership for safety, organizational competency and change management to be backed up at organization level are required. Lastly, continuous safety culture enhancement through a safety culture management system including the model, organization and implementation system to manage organization's safety culture is needed.

4. Validation and Application of Regulatory Oversight Model

The research on validation of safety culture model in the nuclear field carried out in the U.S. in 2010 was the first one (Stephanie Morrow and Valerie Barnes, 2012, "Independent evaluation of INPO's nuclear safety culture survey and construct validation study", US NRC). KINS carried out the benchmarking of domestic and international research results, acquisition of safety culture quantitative data and statistical analysis and actual application to Korean NPP operating organizations for validation of a safety culture oversight model developed for regulatory oversight of Korean NPPs' operating organizations. This paper presents by summarizing each method and result. As for the validation scope, this paper deals with content, construct and criteria validities, which are the validity measure of research in the social science field. 13 items in the four areas associated with safety culture components except for safety culture management system area out of 16 components of the safety culture oversight model.

Concerning content validity, it indicates representation level of major characteristics of the content to be measured, and experts' subjective knowledge becomes judgment criterion. This paper comparatively analyzed the safety culture components used by key literatures, overseas nuclear regulatory bodies and international organizations associated with nuclear safety culture, reflected Korean experts' reviews, and revised and complemented the details of each component.

Construct validity indicates the corresponding level of the content to measure to theoretical construct or a hypothesis on the subjects. Construct validity is proved through validation of component structure such as convergent and discriminant validities and individual component's reliability. To this end, quantitative data on the current picture of safety culture of Korea Hydro & Nuclear Power (KHNP) workers, the application subjects of safety culture oversight model are required. To acquire quantitative data of safety culture, face to face interviews of Korean NPP workers were used. This paper referred to the methodology of IAEA (2002) and US NRC (Inspection Procedure 95003-02) to enhance the accuracy of questionnaire responses, easiness of validation and reliability of questions in the development of questions and planning and implementation process of the questionnaire survey. The questionnaire was revised through one pilot survey. The 7-point Likert scale response results acquired from 1,170 workers in 12 nuclear power plants in Korea in regards with 59 questions were used for construct validity validation. All the 13 components' Cronbach's coefficient alpha values were higher than 0.8, and showed high internal consistency, and therefore sufficient reliability was shown as individual components. The alpha value of the total safety culture items (mean of 59 questions in total) was 0.987, and was higher than those in the researches in the U.S. and IAEA model. Figure 2 shows correlation structure using dendrogram based on Pearson correlation coefficient between component pairs to analyze convergent and discriminant validities. Although distance between the components is not far concerning 13 components, it was confirmed that the distance between the components in the same area was close, and the distance between the components in different fields was relatively far. Criterion-related validity is a concept judging whether the content to measure is consistent with the subject's performance characteristics. This can be validated by analyzing the correlation between the safety culture data used in the construct validity above and the NPP safety performance data.

As for NPP safety performance data, this paper analyzed Pearson correlation coefficient between safety culture components and safety performance using 16 available data from the regulatory inspection, NPP accident occurrence, NPP operation performance

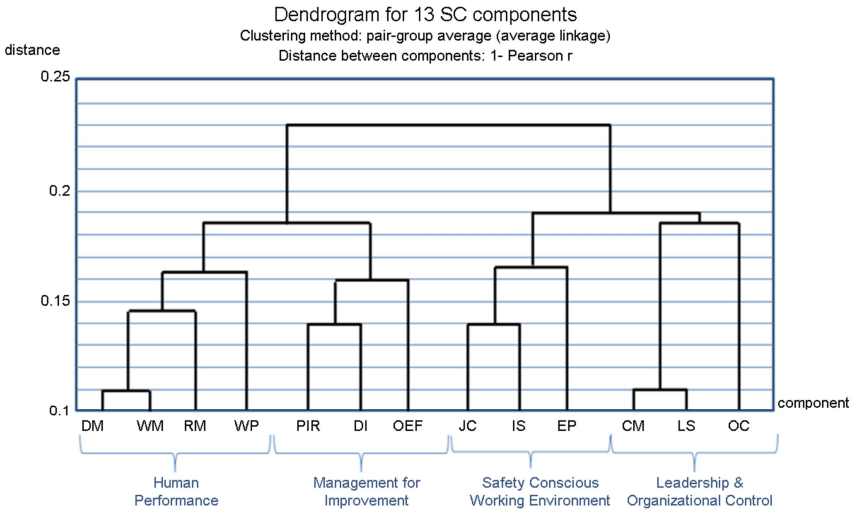

Figure 2. Distance between SC components

and KINS safety performance indicators. As a result, findings of regulatory inspection (for the recent three years) and non-operation rate of reactors showed a strong negative correlation with safety culture components. Also, the number of reactor scram (overhaul) due to human errors, the number of grade 1 and higher accidents of INES scale, unplanned reactor suspension and radiation dose in NPPs showed relatively high negative correlations.

The validation above evaluated the validity of the safety culture oversight model from the broadness of content, reliability of individual components, structured model and correlation with safety performance aspects. This paper confirmed onsite suitability in the safety culture inspection on organizations targeted for regulatory oversight. Safety culture inspection on KHNP was carried out four times during the overhaul period and six times during the operation by onsite visit to NPPs for two to three days from 2013 to 2015. KINS inspectors carried out inspections of KHNP head office in 2014 and 2015, respectively, for three to four days. As for inspection details, inspection items according to international model practices are developed for each safety culture component, and analyzed improvement points found in the inspection process. Inspection was conducted by checking base for behaviors like perception that the workers have on the safety culture components, and system and procedure, and also behavioral results. Perception was identified through in depth interview of the workers, focus group interview and questionnaire, and the document review and interview of the management. As a result, two to six recommendations are derived for each NPP. In the 2015 inspection, whether the recommendations derived in the 2014 inspection were properly implemented was inspected. Because safety culture is not improved nor changed effectively in a short term, this paper ascertained that safety culture needs to be implemented for a long-term plan. And the effectiveness of the change and internalization should be checked periodically.

5. Conclusion

Domestically and internationally successful results were hardly acquired in the past, since nuclear safety culture was handled with a normative and managerial perspective. To bring safety culture within the scope of the regulatory oversight, a methodology to concentrate on and check the area associated with safety performance, and to draw improvements was demanded other than past conventional approach. This paper examined key issues by starting from fundamental concept of safety culture regulatory oversight, described the development of a regulatory oversight model suitable for Korean situation with the considerations of overseas regulatory experiences, and presented an effort and the results acquired by applying the model. Statistical validation of

the developed model was conducted, and several improvement areas in Korean NPP's safety culture were successfully identified through the application of the model. From this, the regulatory oversight model was ascertained to be properly structured and proved useful to identify vulnerabilities in an organization's safety culture. The regulatory oversight model for safety culture was from the concept of defense in depth in the normal state of an NPP. Future research areas would be what safety culture characteristics an organization need to have in order to recover a defense in depth function, when a nuclear power plant is in an abnormal, unexpected or accident state. In such a situation, how to patternize organization's characteristics revealed by NPP organizations, and what to be managed as core components can be different from the organizational characteristics in the normal state. Dynamics among organization members in each situation, namely conflicts and change of power structure is the field to be established in order to properly cope with an accident. Further research on this field is expected.

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