A STUDY ON AN ASSESSMENT METHOD FOR IMPROVING TECHNICAL SPECIFICATIONS USING SYSTEM DYNAMICS

KYUNG MIN KANG and MOOSUNG JAE*
Department of Nuclear Engineering, Hanyang University
17 Haengdang-Dong, Sungdong-Gu, Seoul, 133-791, Korea
*To whom correspondence should be addressed. jae@hanyang.ac.kr

Limiting conditions for operations (LCOs) are evaluated dynamically using the tool of system dynamics. The LCOs define the allowed outage times (AOTs) and the actions to be taken if the repair cannot be completed within the AOT. Syste-m dynamics has been developed to analyze the dynamic reliability of a complicated system. System dynamics using Vensim software have been applied to LCOs assessment for an example system, the auxiliary feed water system of a reference nuclear power plant. Analysis results of both full power operation and shutdown operation have been compared for a measure of core damage frequency. The framework developed in this study has been shown to be very flexible in that it can be applied to assess LCOs quantitatively under any operational context of the TS in FSAR.

KEYWORDS : limiting conditions for operations, system dynamics, probabilistic risk assessment, technical specifications

1. INTRODUCTION

The Technical Specifications (TSs) of a nuclear power plant define the limits and conditions that ensure that plant operation is consistent with the analyses and evaluation in the plant safety analysis. The TS typically includes the following major sections: safety limits, LCOs including AOTs and required actions, surveillance requirements (SRs), design features, and administrative controls [1]. However, the TS have been defined based largely on engineering judgments and a deterministic analysis. Under the discipline of the probabilistic safety assessment (PSA), a considerable number of studies have been carried out to improve the TS by quantitative analyses. Some PSAs and plant operations have thus far revealed that the TS are too conservative for effective operations as a whole. This study carries out modeling for the changes of the LCOs using the current PSA methods and system dynamics.

This study develops a new framework for LCO influence assessment. The framework is required to evaluate LCOs qualitatively as well as quantitatively, and might contribute to improving the TS eventually [2]. The LCO assessment requires a treatment of time variables. The AOTs specifies the time interval in which components can be down in order to restore operations. If a component is not repaired within the AOT period, the plant must be taken to shutdown.

Many ongoing efforts have been made to analyze the dynamic reliability of Nuclear Power Plant (NPP) systems. However, these efforts have failed to include the experts needed to consider the balance between the resources to be invested and the quality to be achieved by applying the proposed dynamic analysis. Since the nature of reliability of a NPP is extremely complicated, taking the dynamic features into account in the reliability analysis appears to be a formidable task. However, the system dynamics for the application of the time variables focuses on pattern behaviors, which are time dependent. It is therefore useful to analyze the AOT and to develop a time dependent framework for a quantitative assessment of the LCOs.

This study has assessed an LCO risk quantitatively for the standard operational modes. First, we applied a dynamic methodology using system dynamics to quantify the risk and to simulate the dynamic assessment for 130 procedures, and to obtain the results on dynamic risk associated with LCOs. This study should contribute to enhancing reactor safety and gaining economical benefits.

2. LCO AND OPERATIONAL MODES

2.1 Limiting Conditions for Operations (LCO)

Operational strategies based on a defense-in-depth philosophy are very important as a fundamental principle for nuclear power plant safety. These strategies are required bases for both reactor design and reactor operations. The operation strategies, which are considered the core of reactor operation, are included in the Technical Specifications. The framework has a concept where multiple levels of protection are carried out by a number of types of actions to secure safe operation. The allowed operation area to conservatively maintain reactor operation is defined as the LCO.

The LCO is the lowest acting level or the lowest functional capability for the plant's safety operation system. If an LCO is not met, the licensee of the plant should provide notice to the regulatory body after applying the required action. Thus, the LCO is the lowest level that provides a safe boundary of operation and the tool by which faults of the reactor systems are first detected. Therefore, reactor safety is guaranteed when the LCO is well observed and plant safety remains constant. If reactor operations do not observe the LCO, the reactor should not be allowed to enter a dangerous state through automatic reactor shutdown by limiting the safety system settings and safety conditions. In the meantime, the safety limits are represented by important process variables. These limits are necessary to protect the integrity of the physical barrier to block radioactivity release.

The LCO assessment requires a treatment of time variables because the AOTs specify the time interval in which the components can be down in order to restore operations. If a component is not repaired within the AOT, the plant must be taken to shutdown. The nature of dynamic reliability is very complicated, and as such taking the dynamic features into account in the reliability analysis is extremely difficult.

2.2 Operational Modes

An operational mode denotes the status of the plant's operation. The operational mode corresponds to any one inclusive combination of core reactivity condition, power level, average reactor coolant temperature, and reactor coolant pressure; it is thus a factor representing reactor status. The mode is classified according to the reactor status ranging from shutdown operation to full power operation [2].

The standard operational modes for the reference plant (CANDU) have three factors for classifying plant status: 'core reactivity condition', 'power level', and 'average reactor coolant temperature'. The operational modes in general have five categories: power operation, low power standby, hot shutdown, cold shutdown, and guaranteed shutdown. The technical background and base for setting the standard operational modes for CANDU are described as follows [3-5].

Operational mode 1 denotes the state to produce the electric power associated with a nuclear power plant's practical goal. With its core reactivity condition, when a plant is at a critical point, it continually obtains the energy produced by fission processing in its core. Operational mode 2 is a low power standby operation, a lesser power level of 2 % that operates high pressure and high temperature. If a plant violates the LCO that must be observed in mode 1, operational mode 2 must finally be taken to enter the safety region for plant protection. After shutdown, decay heat generated in modes 3, 4, and 5 and reserved heat in the core must be removed to ensure the safety of the reactor operation. Because decay heat generation in modes 3, 4, and 5 is smaller than that in modes 1 and 2 shutdown is permitted to enable the partial flow path of the heat removal system. And operational mode 4 has a temperature below the average reactor coolant temperature of 100˚C as a cold shutdown state. The plant assumes reactor shutdown status in case it is below a reactivity condition of (0.99). Also, after the reactor shutdown and reactor cooling, the plant maintains mode 4 until plant protection action is taken. In the same manner, operational mode 5 can maintain a continuously sub-critical state without an alternative plan, as the plant is completely shutdown. After the plant is assured to be correctly entering guaranteed shutdown, it carries out preventive maintenance for reactor recovery. The guaranteed shutdown mode is one of the major characteristics of the CANDU reactors [6-9].

3. MODELING METHODS

3.1 A Modeling Tool of System Dynamics

It is known that the LCOs are generally based on engineering judgments and deterministic analysis. This section introduces illustrations to explain how to utilize system dynamics for analyzing LCOs with time dependent modeling. The characteristics of system dynamics can be described as follows. A system approach is very useful to conceptualize a comprehensive understanding and explanation of human interactions and complicated phenomena. First, the system dynamics approach methodologically includes a dynamic behavior approach that ensures a causal relationship for structuring the elementary feedback loops. Second, the system dynamics approach is useful for analyzing the phenomena of a complex system as well as the behavior of structure values with respect to time [10].

System dynamics does not end with the design of diagram models. It is a method to give a comprehensive analysis that verifies changes in the variables of the structure with graphical and quantitative output as a progressive and useful analysis tool. This study uses a simulation language called VENSIM (Ventana Simulation Environment) to solve homogeneous differential equations. The purpose of this study is to develop a system dynamics model for evaluating a new framework developed for LCO influence assessment. Development of a system dynamics model and its application should contribute to enhancing nuclear system safety. There are two approaches to develop the system dynamics model: an engineering approach using tools such as ergonomics and Probability Safety Assessment (PSA) and a socio-psychology approach. Both have contributed to finding the new assessment framework for LCO influence and to presenting guidelines to maintain operational safety in nuclear power plants. To date, these approaches have restrictions to assume that the relationship among factors is independent. They therefore do not model the interactions among the factors or relevant variables. To overcome these limitations, a system dynamics model, which allows feedback and cause-effect relationships among factors for quantifying the LCO influence assessment framework, has been developed and applied. By applying this model to assess the LCOs, insights to improve plant safety as well as the optimal values of the LCOs are obtained.

3.2 Basic Concepts of LCO Operation and Shutdown Risk

When a safety system enters an LCO upon occurrence of component failures, TS allows one of two alternatives. First, the plant enters full power operation and repairs the failed component within a defined AOT. Second, the plant enters shutdown mode to complete the repair within the shutdown status. We refer to these options as the basic operational alternative, and we also consider the risk associated with these alternatives. The risks associated with repairing the equipment during full power operation are denoted by the LCO operating risk; the risk associated with shutting the plant down is defined as the LCO shutdown risk.

If a component of the safety system is not available, while in full power operation, repairs should be completed to maintain plant safety within a defined AOT in the TS. Therefore, when a component goes down, there is generally a risk increase due to loss of the component function. The AOT specifies the periods in which the component can be down, while operation restorations occur. If a component is not repaired within the AOT, the plant must take action to shutdown. These action requirements are primarily directed towards minimizing risk during power operation, with the expectation that shutting down the plant is relatively safer. This is not necessarily a reasonable assumption for such a system that has to remove decay heat.

The period that is directly relevant to evaluate the action requirement or AOT for failure in the safety system ranges from the time the accident starts to the time of repair completion. The risk over this period, the core damage probability (CDP), can be obtained by integrating the conditional core damage frequency (CDF). If the operating risk is smaller than the shutdown risk, then the alternative of full power operation is preferable to the shutdown alternative.

Risk evaluation is based on several assumptions. In the case of a shutdown alternative, the plant is shut down directly after the failure is detected. However, some AOTs may be useful such that plants can evaluate the repairs needed and restore the operability of the failed equipment without shutting down the plant, at least for repairs that are not overly time-consuming.

Suppose three days are given as an AOT in a failure situation in the TS and that the plant personnel cannot repair the component within the AOT, and thus operators may shut down the plant three days after finding the failure. In this case, the timing of a shutdown should be considered as one of the important factors in determining the risk-effective requirement that will minimize the total risk impact associated with a given failure [13].

We can evaluate the LCO operation and shutdown risks using a typical PSA model based on fault tree and event tree models. In particular, the LCO operating risk can be easily assessed by running a computerized PSA model for full power operation after modifying the unavailability of the failed equipments appropriately. The risk assessment requires the solution of the following Eq.(1).

$$\Delta R = R_1 - R_0 \tag{1}$$

The computerized PSA model is used for quantifying the increased risk level (ΔR). The symbol R_1 is the increased risk level (CDF) with the component assumed down, or, equivalently, the component unavailability equal to 1. The notation R_0 is the reduced CDF with the component assumed up, i.e., the unavailability for test and repair equal to zero.

R_1 can be calculated by setting the component-down event to a true state in the PSA. Similarly, R_0 can be calculated by setting the component-down event to a false state in the PSA. The component down event in the PSA is the event that describes whether the component is down for repair or maintenance. If the component-down event is included in the existing minimal cut sets, then these minimal cut sets can be used to determine R_1 and R_0 provided that the minimal cut sets cover the contribution of the down event.

Quantifying the LCO shutdown risk is greatly facilitated if PSA results of a reference plant for low power and shutdown operations are available. However, the PSA is available only for a few plants and the models are not computerized in a form that can be readily usable for TS application. In this study, since CDF data in a computerized form is not available, the low power and shutdown PSA data for the Ulchin plant, which is the reference plant, are used as input data [14].

3.3 Methodology for evaluating the LCO

The basic formulas for risk-comparison measures show full power operation and shutdown operation [13]. The risk of full power operation can be expressed as the following Eq. (2).

$$r_{FP} = R_{FP} \cdot \underline{d} \quad (2)$$

where

r_{FP} = the core damage probability associated with full power operation over the downtime of the failed equipment,

R_{FP} = the increased core damage frequency associated with full power operation with the failed equipment,

$\underline{d}$ = the mean downtime.

The expected probability of core damage for the shutdown alternative can be obtained according to the following Eq. (3).

$$r_{SD} = \sum_i P_{Ini/SD} \cdot r_{SD/Ini} \quad (3)$$

where

$\sum_i P_{Ini/SD}$ = the probability that the initiating event i will occur during the transition to shutdown,

$r_{SD/Ini}$ = the conditional probability of core damage for the initiating event requiring shutdown cooling.

We can evaluate the conditional probability of core damage for the initiator according to the following Eq. (4).

$$r_{SD/Ini} = r_{SD\text{-}0/Ini} + \int_{=0}^{0} dt \cdot R_{SD/Ini}(t) \cdot P_d(t) \quad (4)$$

where

$r_{SD\text{-}0/Ini}$ = the conditional probability of core damage at the start of shutdown cooling for the initiator,

$R_{SD/Ini}(t)$ = the conditional core-damage frequency during shutdown cooling at time t for the initiator,

$P_d(t)$ = the probability that repair is not complete by time t.

Another model is proposed to design a model risk-comparison method. We can approximate the probability of core damage for the shutdown alternative by dividing the shutdown into several phases as follows:

Phase 0 : Full power operation,

Phase 1⟶2 : Power reduction from full power until the reactor becomes sub-critical,

Phase 2⟶3 : Reactor cool down subsequently from 0% power until shutdown of the cooling system,

Phase 3⟶4 : Shutdown cooling where the shutdown cooling system is used to remove decay heat.

The probability of core damage for the shutdown alternatives can be assessed by the following Eq. (5).

$$r_{SD} = R_1(1\text{-}{>}2) \cdot t_{\underline{1}} + R_1(2\text{-}{>}3) \cdot t_{\underline{re}}' + R_0(3\text{-}{>}4) \cdot t_{\underline{2}} \quad (5)$$

Also, the probability of core damage for the power operation alternatives can be evaluated by the following Eq. (6),

$$r_{FP} = R_1(0) \cdot t_{\underline{re}} + R_0(0) \cdot t_{\underline{2}} \quad (6)$$

where

$t_{\underline{re}}$ = the mean duration to component repair,

$t_{\underline{re}}'$ = the mean duration to complete component repair,

$t_{\underline{1}}$ = the mean duration from power operation to shutdown,

$t_{\underline{2}}$ = the mean duration from shutdown to power operation,

$R_1(i)$ = the core-damage frequency during phase i when components fail,

$R_0(i)$ = the core-damage frequency during phase i when components do not fail.

3.4 Full Power and Shutdown Risk

In the previous section, risk assessment formulas were introduced to compare full power operation risk with the shutdown operation risk. This section presents an analytical risk assessment model calculated with respect to time. The system dynamics methodology is also used to assess changes over time in the system's behavior. The model construction using system dynamics is therefore useful to evaluate LCOs for CANDU reactors from this step. VENSIM may contribute to realizing the modeling of system dynamics, and its effectiveness is enhanced by adding relevant variables and connecting the relevant variables.

Causal loop diagrams to evaluate full power operation risk (Risk fp in Fig.1) have been constructed as shown in Fig.1. The model to evaluate full power operation risk ($r_{FP}=R_{FP} \cdot d$) is proposed according to Eq. (2). 'Increase CDF' times 'Time' is 'Risk fp', and 'Increase CDF' is the difference between 'power operation with the failed equipment' and 'normal power operation'. The value of core damage frequency while the plant is in normal operation (normal power operation) is obtained from a computerized PSA model, KIRAP [15]. In a similar manner, the value of core damage frequency while the plant is in abnormal operation (power operation with failed equipment) is obtained from a computerized PSA model that includes the event describing whether the component is down for repair or maintenance.

The equations for the selected variables are utilized for quantifying the risk by the VENSIM code. The full power risk is estimated by multiplying an increase in CDF with respect to time. After an accident occurs, core damage frequency increases with respect to length of time. And the increase in CDF is calculated by the difference between power operation with the failed component and power operation with the working component. In the next step, a shutdown operation risk model is added to the full power operation risk. The model to describe the shutdown operation risk (Risk sd) is shown in Fig.2. The method to model the shutdown operation risk is also applied according to Eqs. (3) and Eqs. (4). The value of core damage frequency while the plant is in shutdown operation is obtained from a computerized PSA model. In the same manner as full power operation, the risk measure has a value of core damage frequency while the plant is running in an abnormal operation state. It is obtained again from a computerized PSA event model which describes the component as down for repairs or maintenance. In Table 1, human error probability is not only caused by human errors, but also by mechanical restoration failure. The detailed methods for this quantification are shown in ASEP (Accident Sequence Evaluation Program Human Reliability Analysis Procedure) [16].

The equations for the selected variables are as follows. The shutdown risk is estimated by multiplying the initial event by CDP for the initial event i requiring shutdown. And the CDP for the initial event i requiring shutdown is calculated by the sum of the CDP during shutdown cooling and CDP at the start of shutdown. And the CDP during shutdown cooling is estimated by integration of the increasing factors and the probability that repair will not be completed by time t.

Finally, a full power operation was combined with a shutdown operation to complete the risk evaluation model. This should contribute to comparing full power operation risk with shutdown operation risk when a component failure event occurs. Using Table 2, this

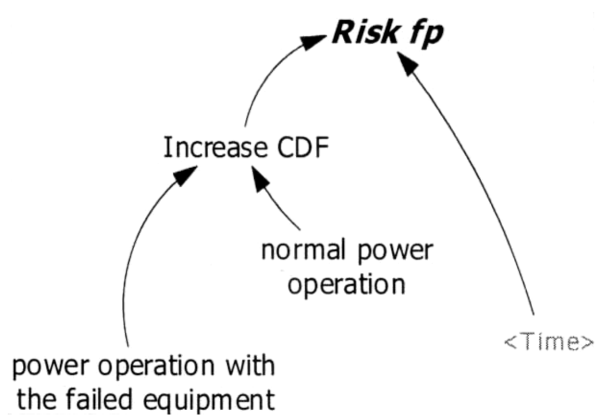

Fig. 1. Model of full power operation risk (model 1)

Table 1. Human error probabilities with respect to time

T (minutes after accident)	Probability	Error factor
1	1.0	-
10	0.5	5
20	0.1	10
30	0.01	10
60	0.001	10
1500	0.0001	30

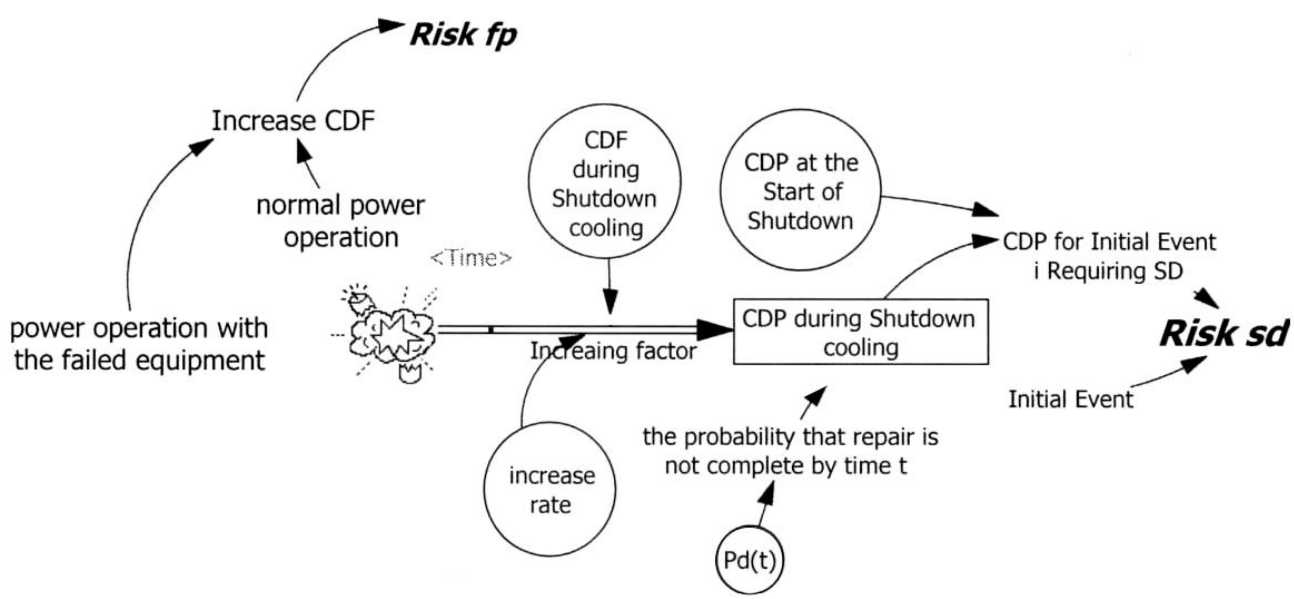

Fig. 2. Model of shutdown operation risk for LCO assessment (model 2)

model is applied to the requirement action of the LCO 3.7.5 associated with the auxiliary feed-water system. It is also used for comparing full power operation risk with shutdown operation risk using Eqs. (5) and Eqs.(6). As presented in Fig. 3, the completion time factor affecting the plant safety is added to model 2, shown in Fig. 2. By evaluating model 3 shown in Fig. 3, the AOTs in the Technical Specifications can be evaluated to produce the optimized time value.

The full power risk modeled in the causal loop diagrams has been calculated using VENSIM for selected variables. The full power operation risk is obtained by multiplying shutdown operations to the core damage frequency as well as recovery factors.

Table 2. Actions LCOs 3.7.5 in TSs of Wolsung NPP

Condition	Required Action	Completion Time
1. AFW system inoperable	Restore system to OPERABLE status.	24 hours
2. Required action and associated completion Time not met.	2.1 Be in MODE 3 **AND** 2.1 Be in MODE 4	4 hours

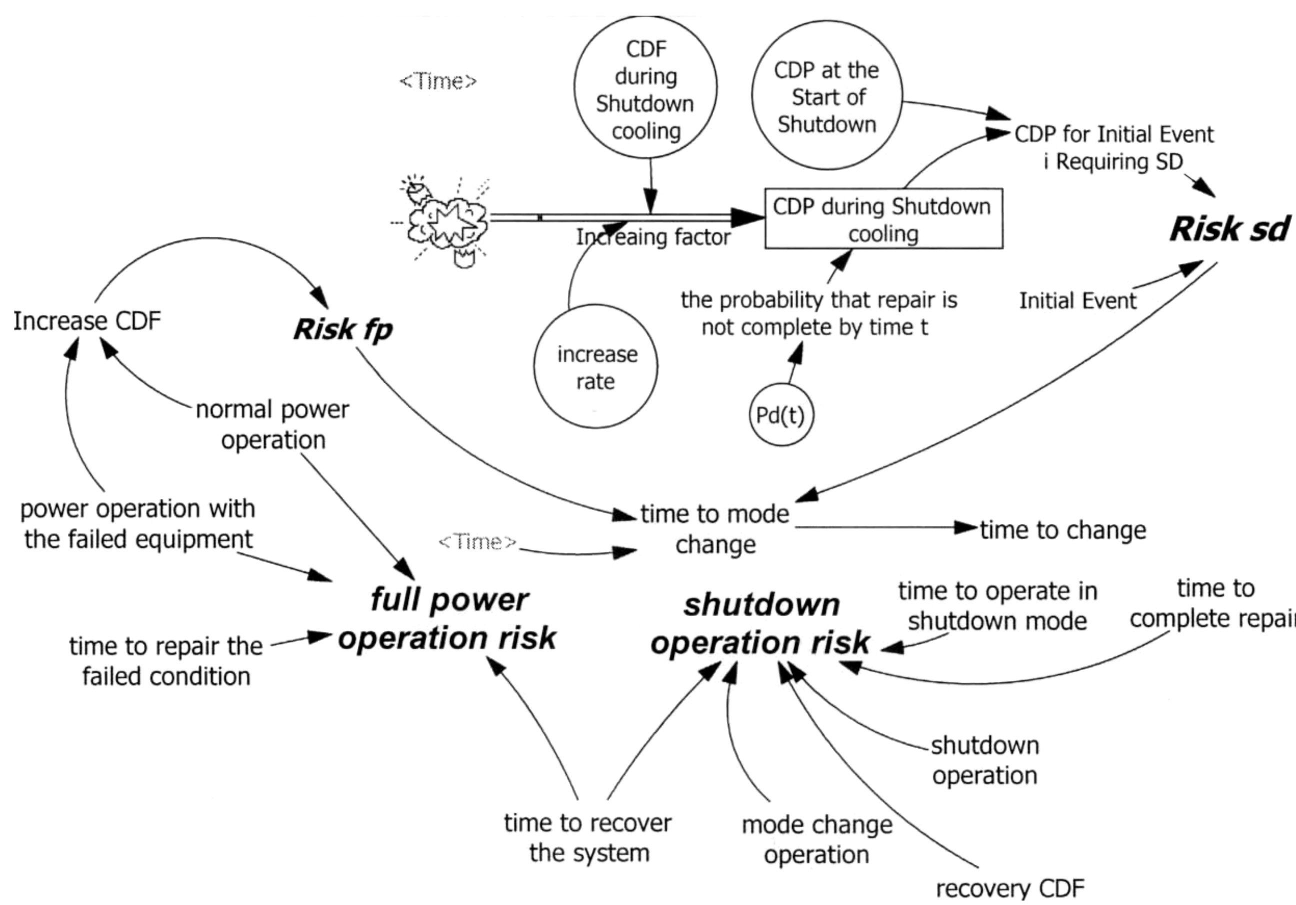

Fig. 3. Risk comparison of LCO full power and shutdown operation (model 3)

4. RESULTS

Technical Specifications for nuclear power plants define limits and conditions to assure that the plant is operated safely. Under current regulations in Korea, TSs are required as part of the Final Safety Analysis Report. TS requirements for a plant include Limiting Conditions for Operation (LCOs) to assure safety during operation. These requirements were originally based on deterministic analyses and engineering judgments. The limiting conditions for operation (LCOs) impose limitations on plant operation by requiring the status of inoperable equipment to be restored within a specific time. In this analysis, optimized LCOs are analyzed using a system dynamics model.

The CDF (Core Damage Frequency) is computed by the MCS (Minimum Cut Set), which specifies that if any basic event is removed from the set, the remaining events collectively are no longer a cut set. The basic event, which may result in core damage, can be broadly categorized into hardware failures and human errors. Since MCS contain a massive amount of data, relevant variables developed for running the model more efficiently are obtained. The values calculated by the relevant variables are returned to the system dynamics model.

Fig. 4 shows the results for LCO full power operation and shutdown risks. The measure of core damage probability, which represents the probability of the occurrence of core damage and is obtained by multiplying the core damage frequency by a time period, is used in this study.

At time zero when failure is detected, the two basic operational alternatives based on operational mode change procedures are applicable. <Risk fp> denotes the power operation state, while <Risk sd> indicates the plant shutdown state. Upon detecting failure at time zero, the LCO operating risk increases due to the increased unavailability of the initially affected system during the potential occurrence of accident scenarios.

The initial increase trend for the LCO shutdown risk is shown in Fig. 4. The results for the system's unavailability during the accidents are presented. They correspond to events occurring while the plant is brought to the shutdown mode. The initial increase in the LCO shutdown risk has two factors: First, the unreliability of the AFW Systems is needed for the change in the plant's state, or the systems has to be started up. Second, the plant vulnerability to transients is caused by the change of plant states.

At the time of the intersect point, i. e., t = 44 hr, the risk level starts to decrease with respect to time. This is due to the diminishing decay heat, which means that a lower capacity is required for the safety systems, and a longer time is available for recovery if a critical safety function is lost during the shut down cooling mission. Obtaining a lower risk level in a stable shutdown mode

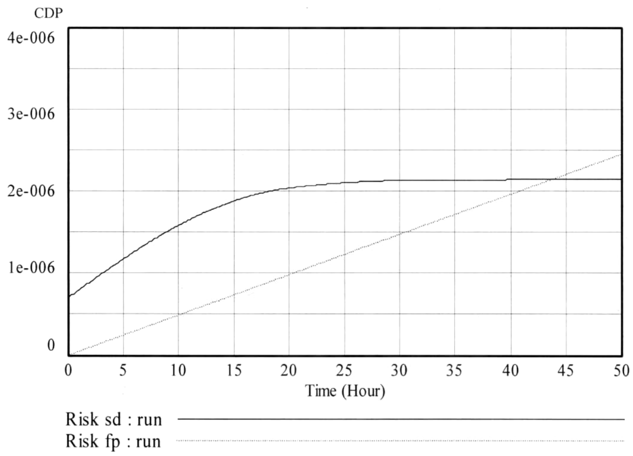

Fig. 4. Plot of LCO full power operating and shutdown risk.

by comparing the full power operation mode is the principal motivation for transferring to shutdown. Fig. 4 shows the comparison in terms of the core damage probability contributions over the repair time beginning from time zero when the failure was detected. The core damage probability for full power operation risk is smaller than that of shutdown operation risk for a certain time period, that is, when the two curves intersect, i.e., time = 44 hours. Therefore, from a risk perspective, it is more beneficial to maintain full power operation than to shut the plant down (28 hours, shown in Table 2), if the operability of the initially affected system can be restored before the intersecting time. Where the repair takes longer than the period zero to intersection time, it is advisable to shut the plant down.

A sensitivity analysis has been performed using Monte Carlo Sampling techniques with sample numbers of 10,000. The simulations employed an error factor of 3, which is used typically in PSA. The simulation results in Figs. 5 and 6 have a confidence level of 50%, 75%, 95%, and 100%, respectively.

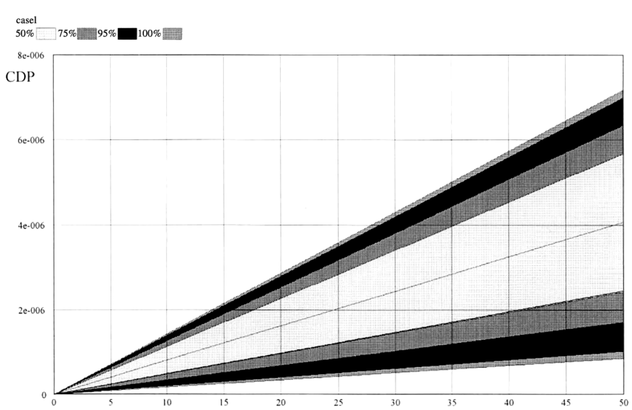

Fig. 5. Sensitivity analysis plot of LCO full power operating risk.

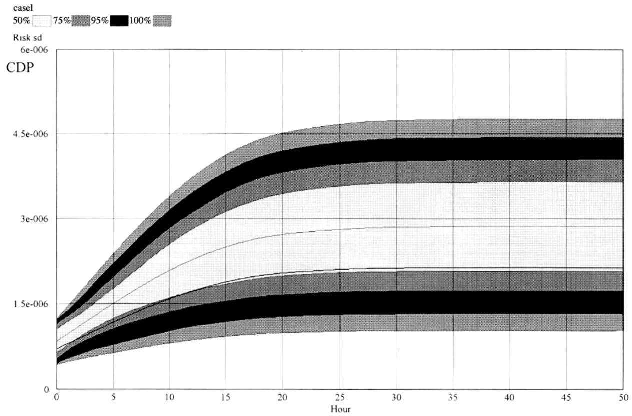

Fig. 6. Sensitivity analysis plot of LCO shutdown operating risk.

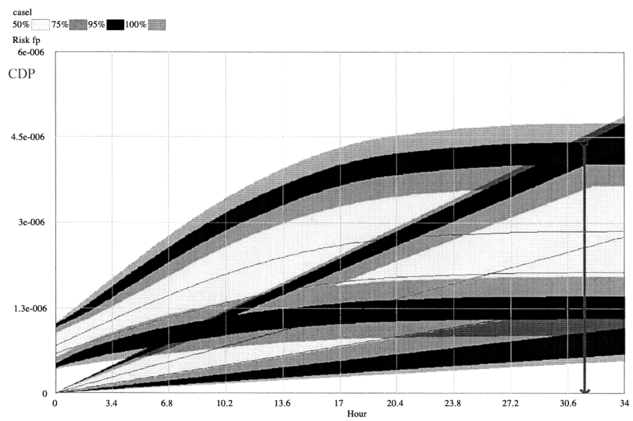

Fig. 7. Intersection point of uncertainty analysis for minimum of AOT.

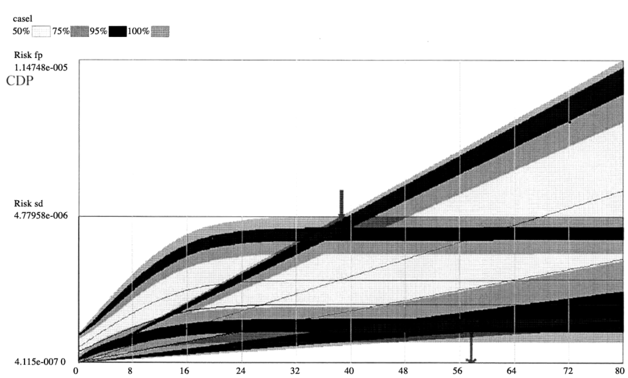

Fig. 8. Intersection point of uncertainty analysis for maximum of AOT.

Figs. 7 and 8 also represent the range of uncertainty through the intersection point, which covers a 95% confidence level. Fig. 7 shows the combined results obtained from the results of Fig. 5 and Fig. 6. This gives

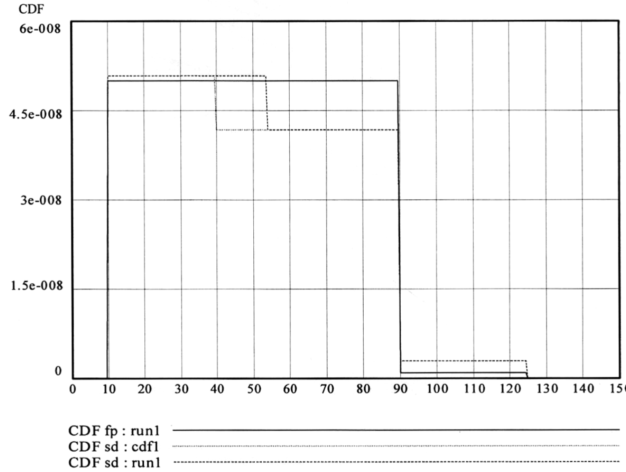

Fig. 9. Intersection point of uncertainty analysis for maximum of AOT.

us the minimum time for mode change. For example, the minimum time for mode change is 32 hr. Fig. 8 also provides information to find the maximum time for mode change (58 hr). The confidence level of 95% with regard to the optimal mode changing time therefore ranges from 32 hr to 58 hr.

When the plant is required to implement actions associated with the auxiliary feed water system according to LCO 3.7.5 of the reference plant, the dynamic risk is calculated as shown in Fig. 9. <CDF fp: run1> denotes the risk from the increasing level ranging from 10 to 90 hours caused by average repair duration (80 hours), and for full power operation when a failure event occurs [15]. <CDF sd: cdf1> represents the result when the LCO 3.7.5 completion time (24 hr) is applied. The CDF for the full power operating risk is much smaller than that of the shutdown operating risk until the time intersecting point, 40 hr. This is the time point where the two curves intersect. As the full power operating risk becomes smaller than the shutdown risk in the region ranging from 10 hr to 40 hr, the alternative of full power operation is preferable to the shutdown alternative, as shown in Fig. 9. <CDF sd: run1> shows the results obtained by applying KIRAP output and VENSIM modeling [10,13]. If the increase in completion time varies from a value of 30 hr to 44 hr, for plant safety it is necessary to ensure that full power operating risks should be maintained at a lower value than the shutdown operating risk. This study shows a plot of LCO full power operation and shutdown risks in terms of core damage probability in the case of AFWS (auxiliary feed water system) failures. Obtaining a lower risk level in a stable mode with respect to the LCO operation alternative is the principal motivation to enter full power operation or shutdown operational mode.

5. CONCLUSIONS

Changes in operation modes are evaluated quantitatively using a system dynamics method in this study. Causal loop diagrams have been developed to analyze the risk impact of LCOs for an example system, i.e., the auxiliary feed water system, of a reference nuclear power plant. The increase in core damage frequency is used as a measure of risk. System dynamics using Vensim software has been applied to assess LCOs. The method presented is generally applicable for analyzing technical specifications associated with other types of equipment and conditions, e.g., passive components and external events. Although this framework focuses on a system dynamics based method to analyze the risk impact of TS requirements, it is important to recognize that many other considerations not covered herein factor into TS change.

The time dependent method developed in this study has been shown to be very flexible in that it can be applied to assess LCOs quantitatively under any operational context of the TS in nuclear power plants. This study could contribute to establishing risk informed regulations and applications by assessing and optimizing the LCOs through application of the proposed framework.

Acknowledgement

This research was supported by the Nuclear R&D Program of MOST and iTRS (Innovative Technology Center for Radiation Safety).

REFERENCES

[1] Kim, I. S., “Improving technical specifications from a risk perspective”, *Reliability Engineering and System Safety*, 54, pp83-87, 1996.

[2] Sung, C. K., *Technical Bases for the Standard Operational Modes of CANDU*, KEPRI, 2001.

[3] *Standard Technical Specifications Westinghouse Plants USNRC*, NUREG-1431, USNRC, 1995.

[4] *WS 2/3/4 Final Safety Assessment Report*, (Rev.0), KEPCO, 1997.

[5] Georges Loiselle, Gentilly 2 Operating Policies and Principles, (Rev.6), 1997.

[6] *Bruce B Operational Safety Requirements*, Ontario Power Generation, 1999.

[7] *Standard Technical Specifications Combustion Engineering Plants*, NUREG-1432, USNRC, 1995.

[8] *Standard Technical Specifications General Electric Plants, BWR/4*, NUREG-1433, USNRC, 1995.

[9] Standard Technical Specifications General Electric Plants, BWR/6, NUREG-1434, USNRC, 1995.

[10] Son, T. W., and Chung, H. K., “System Dynamics Approach for Analyzing Dynamic Motivation Model Using VENSIM”, *Korean System Dynamics Society*, pp.61-86. 1999.

[11] Yu, J. and Ahn, N. and Jae, M., A *Quantitative Assessment of Organizational Factors Affecting Safety Using System Dynamics Model, Journal of the Korean Nuclear Society*, Vol. 36, No. 36, pp.64-72, 2004.

[12] *VENSIM reference manual version 4*, Ventana System, Inc, p3, 1999.

[13] Samanta, P. K., Kim, I. S., Mankamo, T. and Vesely, W. E., *Handbook of methods for risk-based analyses of technical specifications*. NUREG/CR-6141, Brookhaven National Laboratory, USA, 1994.

[14] Kang, D. I., *The Determination of Allowed Outage Time Using the Evaluation of Transition Risk*, KAERI/TR-1669/2000, KAERI, 2000.

[15] Kim, T. U., *The Quantitative Method of Accident Sequence Using a KIRAP*, KEARI/TR-848/97, KAERI, 1997.

[16] Alan D. Swain, *Accident Sequence Evaluation Program Human Reliability Analysis Procedure*, NUREG/CR-4772, Sandra National Laboratory, USA, 1996.