<Technical Note>

TASK TYPES AND ERROR TYPES INVOLVED IN THE HUMAN-RELATED UNPLANNED REACTOR TRIP EVENTS

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In this paper, the contribution of task types and error types involved in the human-related unplanned reactor trip events that have occurred between 1986 and 2006 in Korean nuclear power plants are analysed in order to establish a strategy for reducing the human-related unplanned reactor trips. Classification systems for the task types, error modes, and cognitive functions are developed or adopted from the currently available taxonomies, and the relevant information is extracted from the event reports or judged on the basis of an event description. According to the analyses from this study, the contributions of the task types are as follows: corrective maintenance (25.7%), planned maintenance (22.8%), planned operation (19.8%), periodic preventive maintenance (14.9%), response to a transient (9.9%), and design/manufacturing/installation (6.9%). According to the analysis of the error modes, error modes such as control failure (22.2%), wrong object (18.5%), omission (14.8%), wrong action (11.1%), and inadequate (8.3%) take up about 75% of the total unplanned trip events. The analysis of the cognitive functions involved in the events indicated that the planning function had the highest contribution (46.7%) to the human actions leading to unplanned reactor trips. This analysis concludes that in order to significantly reduce human-induced or human-related unplanned reactor trips, an aide system (in support of maintenance personnel) for evaluating possible (negative) impacts of planned actions or erroneous actions as well as an appropriate human error prediction technique, should be developed.

KEYWORDS : Unplanned Reactor Trips, Human-Related Unplanned Reactor Trips, Human-Induced Unplanned Reactor Trips, Human Error, Error Mode, Cognitive Function

1. INTRODUCTION

The periodic or non-periodic test and maintenance activities in nuclear power plants (NPPs) are essential for stable power production and the sustainment of the plant safety. However, due to NPP system complexity and human limitation in cognition and action, these activities may also have the potential to induce unwanted and unanticipated reactor trip events and may render critical systems unavailable.

Several studies have been conducted in the arena of maintenance human factors. James Reason emphasized the importance of maintenance-related human errors as well as human errors in responding to emergency situations [1]. Dhillon addressed the research status on human errors in test and maintenance tasks in several industries including nuclear power plants, aviation, and chemical processing plants, etc. [2]. Seminara and Parson reviewed the status of human factors engineering research in the domain of power plant maintenance [3]. Pyy analyzed the types of common cause failures in maintenance-related tasks in nuclear power plants [4], and Toriizuka presented a work improvement method using performance shaping factors in industrial plant maintenance tasks [5].

This paper is concerned with human errors in test and maintenance activities of NPPs that have the potential for inducing unplanned reactor trips. The Korean regulatory organization for nuclear and radiological systems, Korea Institute of Nuclear Safety (KINS), provides a list of the major events, including unplanned reactor trips and unplanned initiations of safety systems that have occurred in Korean nuclear power plants, on a public website, the Operational Performance Information System (OPIS), http://opis.kins.re.kr [6]. According to OPIS, about 23% of the events that occurred during 2002 ~ 2006 were caused by human error. More recently, during 2004 ~ 2005, the contribution of human error to the unplanned reactor trip events has grown to about 34%, a significant increase.

Interest in analyzing and reducing the human-induced or human-related unplanned reactor trip events has been increasing gradually in response to the increased number of human-induced unplanned reactor trip events. In response to this interest, and in an attempt to establish a strategy for reducing these human-related unplanned reactor trips, this report analyses the overall task types and error types contributing to the human-induced or human-related unplanned reactor trip events between 1986 and 2006. The analysis items presented in this paper include the task types (or types of activity), and the error modes and cognitive functions involved in the human-related unplanned reactor trip events. We note that analysis of the causes and context involving the so-called MTO (man, technology, and organization) factors and latent conditions that lead to human errors are important considerations in the effective management of human error [7, 8]. A root cause analysis method, or HuRAM for short (Human-related Root cause Analysis Method), was developed and used to identify important root causes leading to human-related unplanned reactor trips [9].

With the exception of the root cause analysis, this paper presents some insights, garnered from the analysis of task types and error types, on how to possibly reduce human-related unplanned reactor trip events. Classification systems for the task types, error modes, and cognitive functions are developed or adopted from the currently available taxonomies in order to extract those kinds of information from the event reports. The decision of an appropriate type among various ones is made by the analysts by adhering to the definitions of the classification schemes.

2. STATUS OF HUMAN-RELATED UNPLANNED REACTOR TRIPS IN KOREA

Task and error-type analysis was performed on the incident reports for the unplanned reactor trip events between 1986 and 2006. These reports are provided by the OPIS website [6]. The latter provides detailed and/or summarized event reports in chronological order, event classification according to initiating event location (i.e., primary-system related or secondary-system related), and primary cause divided into the four categories of human, mechanical, instrumental, and electrical-related. The primary cause contributing to the occurrence of an event is usually determined by analyst judgment. The human-induced and human-related unplanned reactor trip events are extracted from the total reported events and organized according to their primary causes and related systems as seen in Table 1.

Of the 101 human-related unplanned reactor trip events that occurred between 1986 and 2006, 33% were associated with the primary system. The remainder was all "secondary-system" events. The events classified as a "human-cause" take up 73%. The remaining human-related trip events were mechanical, instrumental, and electrical in nature. The presence of these latter events is indicative of latent human factors.

3. TASK TYPES INVOLVED IN HUMAN-RELATED UNPLANNED REACTOR TRIPS

Human actions involved in the human-related unplanned reactor trips are classified into task (or activity) types which serve as categorized groups of plant personnel's activities requested during non-emergency situations in nuclear power plants. Seven task types considered in this study are: *planned maintenance, periodic preventive maintenance, predictive maintenance, corrective maintenance, planned operation, response to a transient, and design-implementation-manufacturing-installation.* The classification of the task types and their definitions are provided in Table 2. Of these, *planned maintenance, periodic preventive maintenance, predictive maintenance, and corrective maintenance* are plant maintenance activities introduced in the administrative standard operating procedure (SOP) of the YGN 3&4

Table 1. Overview of the Human-Related Unplanned Reactor Trip Events (During 1986~2006)

The Primary Cause	The number of events related to the primary system	The number of events related to the secondary system	The number of events by cause category
Human	26	48	74 (73%)
Mechanical	2	10	12 (12%)
Instrumental	4	5	9 (9%)
Electrical	1	5	6 (6%)
Sum	33 (33%)	68 (67%)	101 (100%)

Table 2. Taxonomy of the Task Types and their Definitions

Task Types		Definition
Preventive maintenance	Planned maintenance	All the activities, such as equipment inspection, checking, and maintenance, carried out on a pre-planned maintenance schedule during the plant overhaul or the reactor refueling period
	Periodic preventive maintenance	All the activities, such as oiling, cleaning, test, adjustment, calibration, inspection, filter replacement, carried out on a periodic maintenance schedule
	Predictive maintenance	All the activities that predict the possibility of equipment fault through the measurement or analysis of vibration, acoustics, lubrication oil, non-destruction, infrared, off-normal state, and maintain the equipments/items prior to an actual fault
Corrective maintenance		The unscheduled maintenance activities to return faulted equipments/items to a state of normal operability
Planned operation		The plant operation activities, such as plant startup, power ascending, power descending, and system operation, requested on a pre-planned schedule to achieve a purpose or goal in plant normal condition
Response to a transient		All the operator activities carried out in response to a plant transient that might occur during plant normal state or other activities such as test or maintenance
Design/implementation/ manufacturing/installation		All the activities related to design, implementation, manufacturing, and installation of plant systems or components

NPPs [10]. *Planned operation, response to a transient, and design-implementation-manufacturing-installation*' are additional task types considered to classify the human actions involved in the unplanned reactor trip events.

The human actions involved in the unplanned reactor trip events were analyzed according to the classification system for the task types. The results are given in Table 3. No human-related unplanned reactor trip events were found for the human actions during *predictive maintenance.* The sub-task types, such as *testing, calibration, and maintenance*, as well as the basic task types of *planned maintenance, periodic preventive maintenance, and corrective maintenance* are shown in Table 3.

The results indicate that *corrective maintenance, planned maintenance, and periodic preventive maintenance* activities contribute a large portion to the unplanned reactor trips common to the primary system and the secondary systems, and that the contribution of *planned operation* and *response to a transient* to the unplanned reactor trips for the events related to the secondary system is relatively high in comparison to the events related to the primary system. This is due in part because the plant response of the secondary system by a plant operation is more sensitive than for the primary system. Identification of specific tasks involved in the *planned operation* and *response to a transient* activities indicates that about 70% of the *planned operation* events and about 90% of the *response to a transient* events in the secondary-system related events are directly related to failure of a steam generator level control or a feedwater control at around 20% of a normal power.

According to the analysis of the sub-task types such as test, calibration, and maintenance, the calibration task shows a relative low frequency over all the task types. In the case of *planned maintenance*, the test and maintenance tasks take up a much larger proportion of the events, and in the case of *periodic preventive maintenance* and *corrective maintenance*, the test task and the maintenance task have the single largest contribution to the unplanned reactor trips for each task type, respectively.

4. ERROR TYPES INVOLVED IN HUMAN-RELATED UNPLANNED REACTOR TRIPS

Cognitive functions and error modes for the human actions involved in the human-related unplanned reactor trip events were analyzed as error types. Cognitive

Table 3. Classification of the Human-Related Unplanned Reactor Trip Events by Task Types

Task type	The number of events related to the primary system	Percentage of events related to the primary system	The number of events related to the secondary system	Percentage of events related to the secondary system	Sum	Percentage of the sum
Planned maintenance	**9**	**8.9%**	**14**	**13.9%**	**23**	**22.8%**
- test	4		5		9	
- calibration	2		0		2	
- maintenance	3		9		12	
Periodic preventive maintenance	**7**	**6.9%**	**8**	**7.9%**	**15**	**14.9%**
- test	5		6		11	
- calibration	1		0		1	
- maintenance	1		2		3	
Corrective maintenance	**12**	**11.9%**	**14**	**13.9%**	**26**	**25.7%**
- calibration	2		0		2	
- maintenance	10		14		24	
Planned operation	**4**	**4.0%**	**16**	**15.8%**	**20**	**19.8%**
Response to a transient	**0**	**0.0%**	**10**	**9.9%**	**10**	**9.9%**
Design/manufacturing/installation	**1**	**1.0%**	**6**	**5.9%**	**7**	**6.9%**
Sum	33	32.7%	68	67.3%	101	100.0%

function analysis aims to identify the major cognitive functions that contributed to human errors intervened in the unplanned reactor trip events, and error mode analysis aims to analyze the profile of the externally observable forms of human errors.

4.1 Cognitive Functions

The following four cognitive functions, which are the basic elements of the Hollnagel's Simple Model of Cognition (SMoC) [7], are adopted in this study.

- Observation function
- Interpretation function
- Planning function
- Execution function

Definitions for these four cognitive functions are provided in Table 4.

The results of the analysis of the cognitive functions for 101 human-related unplanned reactor trip events are given in Table 5. The *planning* function had the highest contribution (as much as 46.7%) of all the relevant cognitive functions. Its contribution is followed by the *observation* function (23.4%), the *execution* function (17.8%), and the *interpretation* function (10.3%). If we

Table 4. Taxonomy of the Cognitive Functions and their Definitions (*Adapted from [7]*)

Cognitive function	Definition
Observation function	The cognitive function relevant to the recognition of a signal or an event, or the identification of an object
Interpretation function	The cognitive function relevant to the identification of system states, or the diagnosis of plant situations
Planning function	The cognitive function relevant to setting out a sequence of actions, or making a decision
Execution function	The physical execution of a planned sequence of actions
Unclear	The cognitive functions involved in the event under analysis are not clear.

examine the cause of the human erroneous actions, most of the events in which a major cognitive function was classified as the *planning* function occurred because plant personnel did not recognise the negative effects of the planned sequences of the test or maintenance tasks on a plant system. In particular, it is noted that about 52% (14 events of 27) of the events during the *corrective maintenance* activities are related to a failure of the *planning* function.

The results of the cognitive function analysis for the events related to the primary system are shown in Table 6. The contribution of each cognitive function is as follows: the *planning* function (47.1%), the *observation* function (23.5%), the *interpretation* function (14.7%), and the *execution* function (11.8%). For the *corrective maintenance*, the *planning* function takes up 67% (8 events of 12) of the events.

The results of the cognitive function analysis for the events related to the secondary system are provided in Table 7. The contributions of the cognitive functions are the *planning* function (46.6%), the *observation* function (23.3%), the *execution* function (20.5%), and the *interpretation* function (8.2%). The task types where the *planning* function takes up a large portion of the events are the *planned operation* (65%; 11 events of 17), the *response to a transient* (64%; 7 events of 11), and the *corrective maintenance* (40%; 6 events of 15). The reason why the *planning* function has a high contribution

Table 5. Results of the Cognitive Function Analysis for the Total Human-Related Unplanned Reactor Trip Events

Task type \ Cognitive function	Observation	Interpretation	Planning	Execution	Unclear	Sum
Planned maintenance	4	5	8	8	0	25
Periodic preventive maintenance	7	0	5	3	1	16
Corrective maintenance	7	2	**14**	3	1	27
Planned operation	4	2	13	2	0	21
Response to a transient	0	2	7	2	0	11
Design/manufacturing/installation	3	0	3	1	0	7
Sum	25	11	**50**	19	2	107
Percentage of the Sum	23.4	10.3	**46.7**	17.8	1.9	100

Table 6. Results of the Cognitive Function Analysis for the Human-Related Unplanned Reactor Trip Events Related to the Primary System

Task type \ Cognitive function	Observation	Interpretation	Planning	Execution	Unclear	Sum
Planned maintenance	2	3	4	1	0	10
Periodic preventive maintenance	3	0	1	2	1	7
Corrective maintenance	2	1	**8**	1	0	12
Planned operation	1	1	2	0	0	4
Response to a transient	0	0	0	0	0	0
Design/manufacturing/installation	0	0	1	0	0	1
Sum	8	5	**16**	4	1	34
Percentage of the Sum	23.5	14.7	**47.1**	11.8	2.9	100

Table 7. Results of the Cognitive Function Analysis for the Human-Related Unplanned Reactor Trip Events Related to the Secondary System

Task type \ Cognitive function	Observation	Interpretation	Planning	Execution	Unclear	Sum
Planned maintenance	2	2	4	7	0	15
Periodic preventive maintenance	4	0	4	1	0	9
Corrective maintenance	**5**	1	**6**	2	1	15
Planned operation	3	1	**11**	2	0	17
Response to a transient	0	2	7	2	0	11
Design/manufacturing/installation	3	0	2	1	0	6
Sum	17	6	**34**	15	1	73
Percentage of the Sum	23.3	8.2	**46.6**	20.5	1.4	100.0

to the failure of the *planned operation* and *response to a transient* is that the failure to control the steam generator water level, which has been assigned a *planning* function problem, has the single highest contribution (about 70%) to the failure of *planned operation and response to a transient.*

4.2 Error Modes

The classification system used for the error mode analysis is based on the taxonomy of error modes of Hollnagel's CREAM [7]. Ten of the twenty-two error modes of CREAM were identified in this analysis. Four additional error modes, such as *control failure, inadequate,*

Table 8. Taxonomy of the Error Modes and their Definitions (*Adapted Partly from [7]*)

Error mode	Definition
Control failure	Failure to control a plant dynamic variable
Wrong action	An extraneous action is carried out
Wrong object	An action is taken on an object other than the required one
Omission	A total or part of the required actions is not carried out
Inadequate	The level of adequacy for a maintenance action is less than perfection, even though a right action is performed on a right object
Reversal	The order of the required work sequence is reversed
Too early	An action is taken too early before the required point of time
Too late	An action is taken too late behind the required point of time
Too much	Too much force or effort is taken than required
Too little	Insufficient force or effort is taken than required
Too fast	Action is performed too quickly than required
Too slow	Action is performed too slowly than required
Wrong input	Wrong information or digit other than the required one is entered
Miscalibration	Wrong calibration on the instrumentation and control equipment or device is carried out
Unclear	The error mode for the event under analysis is not clear.

miscalibration, and *wrong input* were also resulting in a total of fourteen error modes adddressed in this study. The *control failure* mode is used for the failure to control a dynamic plant variable. It can, in fact, can be viewed as a failure mode resulting from other error modes such as *action at an inappropriate time*. However, the latter error mode is used for event for which an accurate error mode is difficult to pinpoint in the event of a failure to control a dynamic variable. The taxonomy and definitions of the error mdoes used in this study are given in Table 8.

The results of the error mode analysis for the events related to the primary and secondary systems are provided in Table 9 and Table 10, respectively. A combined table of the error modes from both systems related events is not presented here because the distribution of the error mode contributions in a combined result is dominated by the one of the secondary-system related events. Error modes such as *omission* (23.5%), *wrong object* (23.5%), and *wrong action* (17.6%) take up 64.6% of the total error modes for the events related to the primary system. Error modes such as *control failure* (28.8%), *wrong object* (16.4%), *omission* (11.0%), and *inadequate* (9.6%) takes up 66% of the secondary-system related error modes. The reason why the *control failure* mode takes up a large portion of the total error modes is that the *failure to control the steam generator feedwater* during planned operation and *response to a transient* contributes to the unplanned reactor trips by about 27% of the secondary system events.

5. DISCUSSION ON THE VALIDITY OF THE RESULTS

Validity or reliability of the classified task types, error modes and cognitive functions involved in the human-related unplanned reactor trip events are the focus of this section. The discussion is solely based on the authors' experience in determining the most appropriate types of tasks and actions of the operators or the maintenance personnel involved in the events.

The analysis was, for the most part, conducted by an analyst through discussions with another reviewer. Difficulties in drawing conclusions about the reliability and consistency of the results between analysts were resultant. Therefore, we want to discuss the validity of *our* results from the viewpoint of clarity (or ambiguity)

Table 9. Results of the Error Mode Analysis for the Human-Related Unplanned Reactor Trip Events Related to the Primary System

Error mode	Planned maintenance	Periodic preventive maintenance	Corrective maintenance	Planned operation	Response to a transient	Design/ manufacturing/ installation	**Sum**	**Percentage (%)**
control failure	1	0	0	2	0	0	3	**8.8%**
wrong action	0	2	4	0	0	0	6	**17.6%**
wrong object	1	3	4	0	0	0	8	**23.5%**
omission	2	2	3	1	0	0	8	**23.5%**
inadequate	2	0	0	0	0	0	2	5.9%
reversal	0	0	0	0	0	0	0	0.0%
too early	2	0	0	0	0	0	2	5.9%
too late	0	0	0	0	0	0	0	0.0%
too much	0	0	0	0	0	0	0	0.0%
too little	0	0	0	0	0	0	0	0.0%
too fast	0	0	0	0	0	0	0	0.0%
too slow	0	0	0	0	0	0	0	0.0%
wrong input	0	0	1	0	0	1	2	5.9%
miscalibration	2	0	0	1	0	0	3	**8.8%**
unclear	0	0	0	0	0	0	0	0.0%
Sum	10	7	12	4	0	1	34	100%

Table 10. Results of the Error Mode Analysis for the Human-Related Unplanned Reactor Trip Events Related to the Secondary System

Error mode	Planned maintenance	Periodic preventive maintenance	Corrective maintenance	Planned operation	Response to a transient	Design/ manufacturing/ installation	**Sum**	**Percentage (%)**
control failure	1	1	0	11	8	0	21	**28.8%**
wrong action	2	3	1	1	0	1	8	8.2%
wrong object	2	1	5	2	0	2	12	**16.4%**
omission	1	1	3	0	0	1	6	**11.0%**
inadequate	4	0	1	0	0	2	7	**9.6%**
reversal	0	1	0	0	0	0	1	1.4%
too early	1	0	0	1	0	0	2	2.7%
too late	1	0	0	1	1	0	3	4.1%
too much	1	0	0	0	0	0	1	1.4%
too little	1	1	2	1	1	0	6	8.2%
too fast	0	1	2	0	1	0	4	5.5%
too slow	0	0	0	0	0	0	0	0.0%
wrong input	1	0	0	0	0	0	1	1.4%
miscalibration	0	0	0	0	0	0	0	0.0%
unclear	0	0	1	0	0	0	1	1.4%
Sum	15	9	15	17	11	6	73	100%

in the type-determination of events.

Task-type determination was relatively easy task as the event report describes the type of activity directly or indirectly. We estimate that more than 90% of the events lend themselves well to the determination of a task type. The remaining events (about 10%) task types could be deduced with moderate certainty. The situation for determining error modes is much the same as for the task types since most of the event reports describe the actions of the operators or the maintenance personnel specifically, such as "omitted a step from a procedure", "acted on a neighboring object", or "wrongly touched an irrelevant object adjacent to a workspace". We estimate that around 10-20% of the events has an ambiguity problem in terms of determining an appropriate error mode involved in human actions due to a rough description of the action involved.

As for the cognitive functions, the most influential, one major cognitive function that led to a manifestation of an external error mode was determined to see the statistical distribution of the major cognitive function involved in a human erroneous action. Identification of major cognitive functions that contribute to an erroneous action may require a deliberate (subjective) judgment of an analyst from the description of the human actions involving the sequence of events under analysis. For some events, determination of the most influential cognitive function seemed ambiguous because the cognitive functions involved in an event are closely interrelated with each other. About 20% of the events were estimated to have such ambiguities due to a poor description of an event progression or an inherent coupled-nature of the cognitive functions. The determination of a major cognitive function for the *observation* and the *execution* functions seems to be relatively straightforward. A more deliberate judgement is required for the events in which the *interpretation* and *planning* functions are closely interrelated. For such events, we tried to stick to the definition of each cognitive function, i.e., whether the problem is more on the plant personnel's identification of system states or diagnosis of plant situations, or on planning on how to respond to a given situation or how to take actions to correct a problematic situation on the basis that they made a correct situation assessment.

6. CONCLUSION

The major findings and insights for reducing human-related unplanned reactor trips obtained from the analysis of the task types and error types for the human-related unplanned reactor trip events are summarised as follows:

- The number of human-related unplanned reactor trip events that were caused by the secondary system (67%) is double the number of those caused by the primary system (33%). Therefore, a strategy/method for reducing human-related unplanned reactor trips needs to both focus more on the secondary-system related human actions or activities and to reflect their inherent characteristics.
- According to the results of the contribution of the task types to the total human-related unplanned reactor trip events, all the task types are considered to be non-negligible for reducing human-related unplanned reactor trips. In addition, special attention needs to be paid to *corrective maintenance* as this task takes up the highest contribution to unplanned reactor trips. The potential for committing errors during a corrective maintenance seems to be higher than the other activities since corrective maintenance activities are, in most cases, performed under temporarily composed work plans or procedures and/or under less experienced work environments. Therefore, a strategy/method for reducing human-related unplanned reactor trips should consider the inherent characteristics of corrective maintenance activities.
- Beside a corrective maintenance, it should be noted that *planned operation* and *response to a transient* have a much higher contribution to the secondary-system related unplanned reactor trips than to the primary-system related ones, and most of the events are related to "failure of a steam generator level control or feedwater control at around 20% of a normal power". Therefore, in order to significantly reduce the human-related unplanned reactor trip events, a method for enhancing a stable control of steam generator water level should be devised.
- According to the analysis of the cognitive functions for the total human-related unplanned reactor trip events, the *planning* function has the highest contribution (as much as 46.7%) of all the cognitive functions involved; in particular, about 52% of the events during the *corrective maintenance* activities are related to the *planning* function. The reason why this function takes up the single largest portion of the unplanned reactor trip events is that plant personnel frequently perform test or maintenance tasks without knowing or recognising the negative effects (i.e., inducing unexpected transients or a signal generation leading to a reactor trip) of planned tasks on the plant system. Therefore, a strategy/method for reducing human-related unplanned reactor trips should consider an aid system to help maintenance personnel in evaluating the possible effects of a planned sequence of a test or maintenance task on the other parts of a plant.
- According to the analysis of the error modes for the total human-related unplanned reactor trip events, representative error modes in association with test and maintenance activities are *wrong object, omission, wrong action, and inadequate.* Therefore, a strategy/method for reducing human-related unplanned reactor trips should consider a method for a human error prediction with special attention to these four representative error modes

Through the analysis of human-related unplanned reactor trip events, it is realized that the following aspects should be supported in order to significantly reduce the human-induced or human-related unplanned reactor trips. In addition to conventional human engineering approaches such as improvements of man-machine interfaces, maintenance procedures, and level of training and education, they are:

- An aid system for evaluating the possible (negative) effects of planned sequences of maintenance tasks on the plant system (a system impact evaluation system),
- Provision of important objects and actions that might lead to an unplanned reactor trip, when performing a maintenance task, by the combined use of a human error prediction technique and an aid for system impact evaluation.

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