

Safety-critical human factors issues derived from analysis of the TEPCO Fukushima Daiichi accident investigation reports

SAKUDA Hiroshi¹, and TAKEUCHI Michiru²

1. Institute of Nuclear Safety Systems, Inc., 64 Sata Mihama-cho Fukui Pref., 919-1205 Japan (sakuda@inss.co.jp)

2. Institute of Nuclear Safety Systems, Inc., 64 Sata Mihama-cho Fukui Pref., 919-1205 Japan (currently Institute of Elderly Housing Sciences, 5-5-15 Nishinakajima Yodogawa-ku Osaka, 532-0011 Japan (mtakeuchi@keiyuu-kai.or.jp))

Abstract: The Fukushima Daiichi nuclear power plant accident on March 11, 2011 had a large impact both in and outside Japan, and is not yet concluded. After Tokyo Electric Power Co.'s (TEPCO's) Fukushima accident, electric power suppliers have taken measures to respond in the event that the same state of emergency occurs - deploying mobile generators, temporary pumps and hoses, and training employees in the use of this equipment. However, it is not only the "hard" problems including the design of equipment, but the "soft" problems such as organization and safety culture that have been highlighted as key contributors in this accident. Although a number of organizations have undertaken factor analysis of the accident and proposed issues to be reviewed and measures to be taken, a systematic overview about electric power suppliers' organization and safety culture has not yet been undertaken.

This study is based on three major reports: the report by the national Diet of Japan Fukushima Nuclear Accident Independent Investigation Commission (the Diet report), the report by the Investigation Committee on the Accident at Fukushima Nuclear Power Stations of Tokyo Electric Power Company (Government report), and the report by the non-government committee supported by the Rebuild Japan Initiative Foundation (Non-government report). From these reports, the sections relevant to electric power suppliers' organization and safety culture were extracted. These sections were arranged to correspond with the prerequisites for the ideal organization, and 30 issues to be reviewed by electric power suppliers were extracted using brainstorming methods.

It is expected that the identified issues will become a reference for every organization concerned to work on preventive measures hereafter.

Keyword: nuclear; TEPCO Fukushima accident; human factors

1 Introduction

On March 11, 2011 the Fukushima Daiichi nuclear power plant (NPP) of Tokyo Electric Power Company, Inc. (TEPCO) suffered severe damage from the Great East Japan Earthquake and the ensuing tsunami. The subsequent nuclear accident (TEPCO Fukushima accident) seriously impacted on the local area.

The total amount of radioactive material released into the atmosphere from the Fukushima Daiichi NPP is (to date) about 900 PBq iodine equivalent, and about 1/6 of the 5200PBq released in the Chernobyl NPP accident^[1]. About 78,000 residents in the Access Restricted Area within a radius of 20km from the NPP have been evacuated. In the evacuation zone of areas with a possible annual cumulative dose of 20mSv or higher in the area beyond the 20-km zone, about 10,010 persons have been evacuated, while in the emergency evacuation zone outside the Deliberate

Evacuation Area and the zone where indoor evacuation directives were canceled 20 to 30 km from the NPP, about 58,510 persons were evacuated, making the total 146,520 persons^[2] (as of August 29, 2011). Even now, many residents are obliged to live as refugees. The corresponding area of contaminated land which may cause a space dose of 5 or more mSv per year and 20 mSv is estimated to be 1,778 km² and 515 km², respectively^[3]. This contamination diffuses to the extensive area of not only Fukushima Prefecture but across a large part of Eastern Japan. The problem of radioactive contamination causes many people, including children, anxiety over the potential health impacts. Moreover, it has caused extensive damage to the producers of agricultural, livestock and marine products; and caused anxiety among the consumers of those products.

Regarding the TEPCO Fukushima accident which caused such an unprecedented disaster, three

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organizations - the national Diet, the government, and a non-government organization - each investigated and issued reports. (An outline of these reports is shown in Table 1.) Besides these, TEPCO itself and several international organizations also submitted investigation reports and proposed various kinds of measures for improvement.

Utility companies contend with pursuing hard measures based on the knowledge acquired from this accident. The approaches have much in common at the general level although it is apparent that the specific content of proposals change with the type of plant (PWR, BWR), and the specific electric company. For example:

- (1) Regarding the total loss of AC power, the power supply by means of air cooled emergency generators *etc.* and (2) loss of ultimate heat sink, provision of sea water cooling by deployment of portable type engine drive seawater pumps, and (3) the submergence of important equipment, implementation of measures against flooding by means of waterproofing seal construction on buildings and doors. Moreover, the structure for persons to operate the additionally deployed equipment appropriately - manuals, and training, *etc.* are reinforced.

As mentioned above, although the utility companies are advancing measures to improve the hardware side in response to the TEPCO Fukushima accident, it is pointed out in each report that this accident was not

only a problem of hardware but also a problem of the soft side of the operation, such as organizational aspects and safety culture of TEPCO.

The reports have areas where they share a common view, and other areas where they may differ. To contribute to the examination of measures to prevent recurrence, it is thought necessary to extract and arrange issues from these reports to be reviewed systematically around the organization and safety culture of utility companies.

2 Purpose of the study

The purpose of this study is to analyze the accident investigation reports about the TEPCO Fukushima accident by three main organizations: the national Diet, the government, and a non-government organization. Next it is to derive issues to be reviewed systematically about the organization and safety culture of utility companies. It is expected that the derived issues to be reviewed will become a reference when a concerned organization examines measures to prevent recurrence.

3 Methods

The accident investigation reports applicable to this analysis were the official report of The Fukushima Nuclear Accident Independent Investigation Commission reported by the Diet^[4] (the Diet report) , the report of the Investigation Committee on the Accident at Fukushima Nuclear Power Stations of

Table 1 Reports by the 3 committees of the Fukushima nuclear accident investigation (general outline)

	The Diet report	Government report (Interim)	Government report (Final)	Non-government report
Name	The official report of The Fukushima Nuclear Accident Independent Investigation Commission	Investigation Committee on the Accident at Fukushima Nuclear Power Stations of Tokyo Electric Power Company Interim Report	Investigation Committee on the Accident at Fukushima Nuclear Power Stations of Tokyo Electric Power Company Final Report	Investigation and verification report of Independent Investigation Commission on the Fukushima Daiichi Nuclear Accident
Issued	July 5, 2012	December 26, 2011	July 23, 2012	February 28, 2012
Members	Chairman: Kiyoshi Kurokawa No. of members: 9 persons	Chairman: Yotaro Hatanaka No. of members: 9 persons		Chairman: Koichi Kitazawa No. of members: 5 persons
Investigation policy	To investigate the causes of the accident, and the causes of the damage sustained from the accident. To investigate and verify the emergency response and the history of nuclear policies. To recommend measures based on the findings of the above investigations.	To make policy recommendations on measures to prevent further spread of the damage caused by the accident and a recurrence of similar accidents in the future. This is done by conducting a multifaceted investigation to determine the causes of the accident and the causes that contributed to the damage inflicted by the accident.		To verify the responsibility of the government and TEPCO by making truth, independence, and the world into a motto.

Tokyo Electric Power Company reported by the government (the Interim^[5] government report, and Final^[6] government report), and the investigation and verification report of the Independent Investigation Commission on the Fukushima Daiichi Nuclear Accident^[7] (non-government report). The accident investigation report made by TEPCO^[8] (made public on June 20, 2012) was utilized for comprehending the facts. Authors (1) extracted and (2) arranged the sections which are relevant to the organization and safety culture of utility companies, and then (3) derived issues to be reviewed from them. Hereinafter, these are explained in full detail.

3.1 Extraction of relevant sections

For the Diet report and the government report, relevant sections were extracted from the discussion on the issues to be reviewed and the measures to be taken. For the non-government report, since the issues to be reviewed and the measures to be taken are contained in various sections of the report, relevant sections were extracted by means of keyword retrieval from the electronic file. The keywords utilized were: “problem”, “issue”, “appropriate”, “sufficient”, “point out” (“pointed out”), “necessary”, “should”, “presume”, “guess,” “cause”, “remote cause”, “factor”, “culture”, “view”, “constitution”, and “thinking”. (Specifically refer to Table 2.)

Moreover, from the extracts, the items relevant to the organization and safety culture of utility companies were selected, as well as items indirectly relevant.

3.2 Arrangement of relevant sections

In order to arrange the extracted contents and classify them by similarity of content, the framework^[9] of "nine prerequisites for the ideal organization" was adopted. This framework was developed by reviewing (as referred to in the KJ method) the research on organizations with regard to: safety culture, high reliability organizations, resilient organizations, leadership in safety-critical organizations. This framework was thought to be the most appropriate as a classification system.

The nine prerequisites are, (1) The organization provides systematic resources and infrastructure to ensure safety. (2) The organization has a sharable vision. (3) Management attaches importance to safety. (4) Employees openly communicate issues and share

wide-ranging information with each other. (5) Adjustments and improvements are made as the organization’s situation changes. (6) Learning activities from mistakes and failures are performed. (7) Management creates a positive work environment and promotes good relations in the workplace. (8) Workers have good relations in the workplace. (9) Employees have all the necessary requirements to undertake their own functions, and act conservatively. The extracted sections were classified and arranged by their contents into the nine prerequisites. Since each section may have two or more meanings, in this case, they were subdivided. Here, each subsection is called a "file."

Table 2 Extraction of sections relevant to the organization and the safety culture of the utilities

The Diet report	The section where the problems are pointed out in the Executive Summary
Government report (Interim)	The section where the problems are pointed out in VII. Observations and Proposals Regarding Problems Identified through Investigations and Inquiries to Date and IV. Accident response at TEPCO's Fukushima Dai-ichi NPS
Government report (Final)	The section where the problems are pointed out in Executive Summary of the Final Report
Non-government report	The sections retrieved by keywords in the main text. Keyword: problem; issue; appropriate; sufficient; point out; (pointed out); necessary; should; presume; guess; cause; remote cause; factor; culture; view; constitution; thinking

3.3 Derivation of issues to be reviewed

The files arranged according to the nine prerequisites for the ideal organization were grouped by their similarity. If there were causal relationship between groups, they were connected by drawing an arrowed line. Moreover, in the case where the content of a file was related to the "background factor" which caused a problem, a dotted enclosure frame and dotted arrow line were drawn. Finally, every group was given a name expressing the contents inside the group. This name serves as an "issue to be reviewed" This derivation work was done using a brainstorming method.

4 Results

4.1 Results of extraction of relevant sections

The sections, which were relevant to the organization and safety culture of utility companies, were extracted

from the contents of the above reports. 21 sections were extracted from the Diet report, 36 from the government report (Interim and Final), and 60 from the non-government report, for a total of 117 extracts. An example is shown in Fig. 1.

Report	No. of referred place	Description
Diet	1	The fundamental causes of the accident already existed prior to March 11, 2011 (3.11). According to the investigation of the Commission, as of 3.11, the Fukushima Daiichi Nuclear Power Plant was presumably in a vulnerable condition, incapable of withstanding an earthquake and tsunami. Tokyo Electric Power Company (TEPCO) as the nuclear operator, the Nuclear Safety Commission (NSC) and the Nuclear and Industrial Safety Agency (NISA), as the regulatory authorities, and the Ministry of Economy, Trade and Industry (METI), as the government body promoting nuclear power, all failed to correctly prepare and implement the most basic safety requirements, such as assessments of the probability of damage by earthquakes and tsunamis, countermeasures toward preparing for a severe accident caused by natural disasters, and safety measures for the public in case of a large release of radiation.
Diet	2	In 2006, NSC revised the old guidelines for anti-seismic standards, while NISA requested the nuclear power operators in Japan to carry out the Seismic Safety Assessment (anti-seismic backcheck) as new guidelines. TEPCO notified NISA that the deadline for their final report on the anti-seismic backcheck would be June 2009. However, the anti-seismic backcheck did not proceed, and within the company, it was postponed to January 2016. Although TEPCO and NISA were aware of the need for structural reinforcement in order to conform to new guidelines, no part of the required reinforcements had been implemented on Units 1 through 3 at the time of the accident. After the accident, TEPCO claimed that there was no significant damage to Unit 5 according to a visual survey, but this did not mean that there had been no damage caused by the earthquake to Units 1 through 3.
Diet	21	Concerning the rise in pressure in the containment vessel at Unit 3 at 08:00 on March 14, TEPCO records state that it did not make this public because it had received instructions from NISA to stop issuing press releases. However, according to the Kantei, it had merely instructed TEPCO to at least inform the Kantei (official residence) when issuing a press release. For TEPCO to act according to instructions from the Kantei and the supervising authorities may be considered sensible. However, it transpired that the company apparently was placing higher importance on its public appearances vis-à-vis the government than transparency of information in a situation where residents in the vicinity and other people were being placed in danger.

Fig.1 An example of extraction result (the Diet report).

4.2 Results of classification of extracted sections

Regarding the content of the 117 extracts described in section 4.1, the text that expresses the meaning directly was marked, and was named a "file". As a result, 140 files were able to be extracted from 117 sections. An example is shown in Fig. 2.

4.3 Results of derivation of issues to be reviewed

The 140 files extracted as described in section 4.2 were classified according to the nine prerequisites for the ideal organization, and Table 3 was obtained as a result. For the classifications: (2) The organization has a sharable vision, (7) Management creates a positive work environment and promotes good relations in the workplace, and (8) Workers have good relations in the workplace, no file fell into these prerequisites. During the stage of classifying the files, since there were files which could not be settled into any of the nine prerequisites, the category (10) "The relations, communication, and information sharing between stakeholders, are good." was added to the classification axes.

Next, with four researchers' cooperation,

brainstorming was performed and the classified files of similar content were grouped. If necessary, in the process of grouping, the file was subdivided.

For example, as for the prerequisite "(1) The organization provides systematic resources and infrastructure to ensure safety.", every file was sorted into four groups. The files listed below are one of these groups.

Report	No.	Description
Diet	15	How the accident developed and an overall review • In the chaos following the destruction wrought by the tsunami, workers were hindered greatly in their response efforts. The problems from the loss of control room functions, lighting and communications, and the struggle to deliver equipment and materials through the debris-strewn and damaged roads in the plant and continuous aftershocks were, all in all, far beyond what the workers had foreseen. The response manuals, with detailed measures against severe accidents, were not up to date, and manuals including that of the isolation condenser (IC) were not sufficiently prepared in advance to cover circumstances such as this accident. Emergency drills and the training of operators and workers had not been sufficiently prioritized. Documents outlining the venting procedures were incomplete. These were all symptom of TEPCO's institutional problems. • This accident revealed a number of issues relating to measures against severe accidents that had previously not been seriously considered; this should include redundancy, diversity and independence in measures against a massive disaster, the interaction of multiple units or adjacent nuclear power plants, and preparation against simultaneous multiple accidents.

File	↓	File	↓
The response manuals, with detailed measures against severe accidents, were not up to date, and manuals including that of the isolation condenser (IC) were not sufficiently prepared in advance to cover circumstances such as this accident. Emergency drills and the training of operators and workers had not been sufficiently prioritized.		This accident revealed a number of issues relating to measures against severe accidents; this should include redundancy, diversity and independence in measures against a massive disaster, the interaction of multiple units or adjacent nuclear power plants, and preparation against simultaneous multiple accidents.	

Fig.2 An example of results of file extraction (the Diet report).

Table 3 Results of classification

(1) The organization provides systematic resources and infrastructure to ensure safety.	7	16	13	36
(2) The organization has a sharable vision.	0	0	0	0
(3) Management attaches importance to safety.	9	2	2	13
(4) Employees openly communicate issues and share wide-ranging information with each other.	4	6	13	23
(5) Adjustments and improvements are made as the organization's situation changes.	2	0	2	4
(6) Learning activities from mistakes and failures are performed.	1	2	6	9
(7) Management creates a positive work environment and promotes good relations in the workplace.	0	0	0	0
(8) Workers have good relations in the workplace.	0	0	0	0
(9) Employees have all the necessary requirements to undertake their own functions, and act conservatively	1	11	2	14
(10) The relation, communication, and information sharing between stakeholders, are good	11	4	26	41
Total	35	41	64	140

[Diet-14]

- External events such as earthquakes and tsunamis were not postulated.

[Gov.Final-3]

- External events such as earthquakes and tsunamis were not viewed as targets for specific consideration.
- The PSA for external events established prior to the Fukushima nuclear accident was only the seismic PSA and was still limited as a means.
- Periodic Safety Review (PSR) failed to offer opportunities for improving severe accident measures.
- The early introduction of the PSA had not been considered due to factors such as work on seismic back checks.

[Gov.Final-4]

- Nuclear utilities should actively utilize currently available methods in their analyses of such external events.

[Gov.Final-5]

- External events should be identified by comprehensive safety analysis, and appropriate measures (severe accident management) against such vulnerability should be examined and placed in shape.

[Gov.Final-18]

- An institutional framework is needed to ensure continued in-depth examination of “residual risks” or “remaining issues” without leaving them behind.

[Gov.Final-21]

- Scientific knowledge of earthquakes is not sufficient yet. The latest research results should be continually incorporated in disaster preparedness.

[Non-Gov.-52]

- The safety assessment of the whole of plant was insufficient.
- The probabilistic safety assessment for incidents arising as a result of external events was delayed because its methods were not well established.
- The frequency of unplanned outage was low, and as a result the myth of safety was originated.

[Non-Gov.-53]

- An examination of “residual risk ” of tsunami

- The accumulated scientific knowledge of tsunamis is far smaller than that of earthquakes.

After examining above eight files, this group was named “(1) Reviews of external events and residual risks”. Other groups were examined and named, and issues to be reviewed were derived. The result is shown in Fig.3 – Fig.9. Let us point out that the contents of some files are omitted for the readability of the figures.

Issues to be reviewed were derived as below.

[(1) The organization provides systematic resources and infrastructure to ensure safety.]

- (1) Reviews of external events and residual risks
- (2) To improve the management culture giving priority to costs
- (3) To assume the occurrence of events of low probability
- (4) Thoroughgoing measures against severe accidents

[(3) Management attaches importance to safety.]

- (5) To create the organization’s posture to safety precedence
- (6) Appropriate cognition concerning the risk of earthquake and tsunami
- (7) To put importance on cost efficiency and effects on existing reactors and lawsuits, rather than safety (background factor)

[(4) Employees openly communicate issues and share wide-ranging information with each other.]

- (8) Thorough information disclosure
- (9) To strengthen individual competence to deal with an emergency
- (10) Studies of what an organization should be to function in an emergency

[(5) Adjustments and improvements are made as the organization’s situation changes.]

- (11) Definite implementation of seismic measures
- (12) Continuous revision of tsunami countermeasures

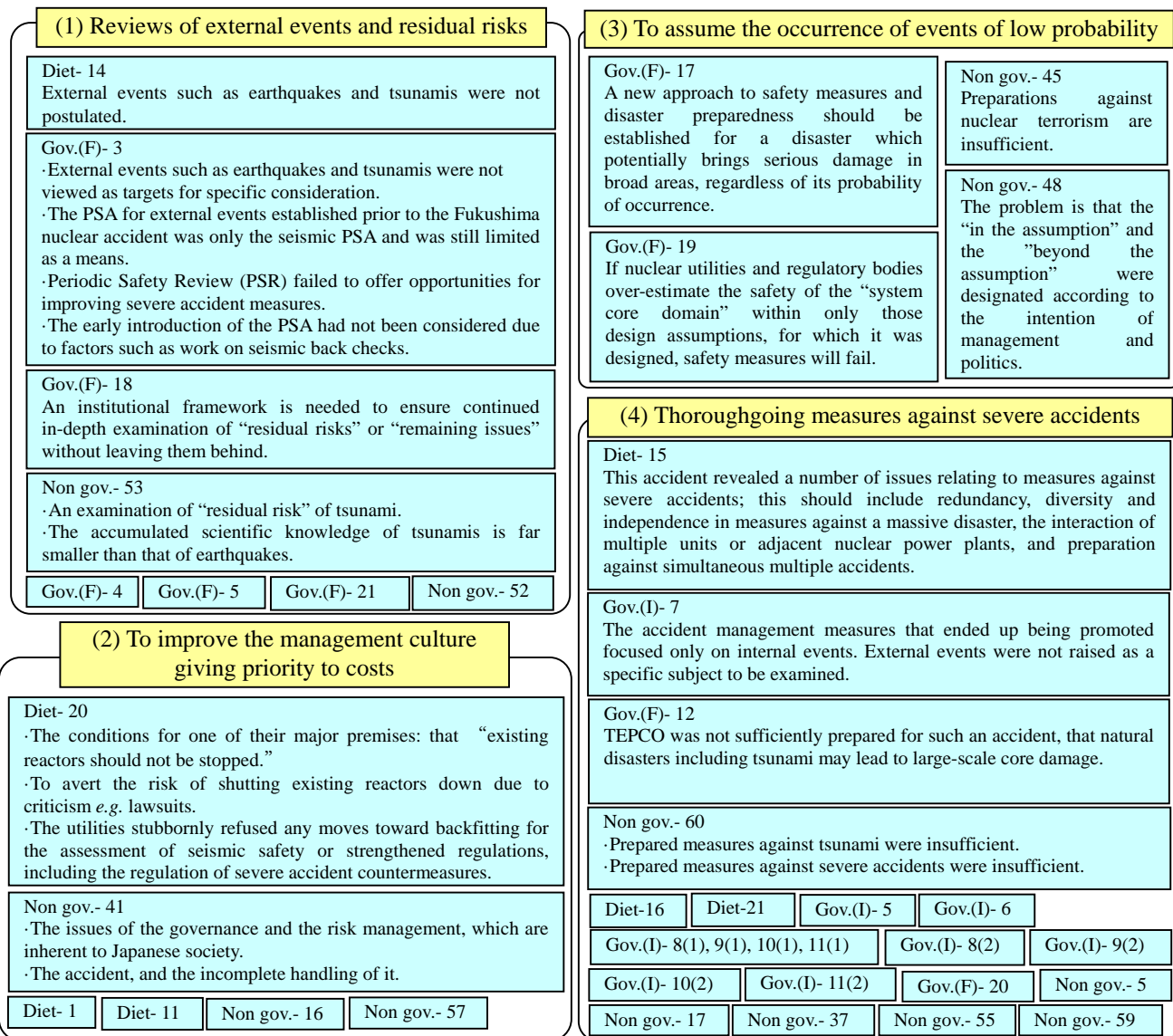


Fig.3 Extraction of issues to be reviewed.

[(1) The organization provides systematic resources and infrastructure to ensure safety.]

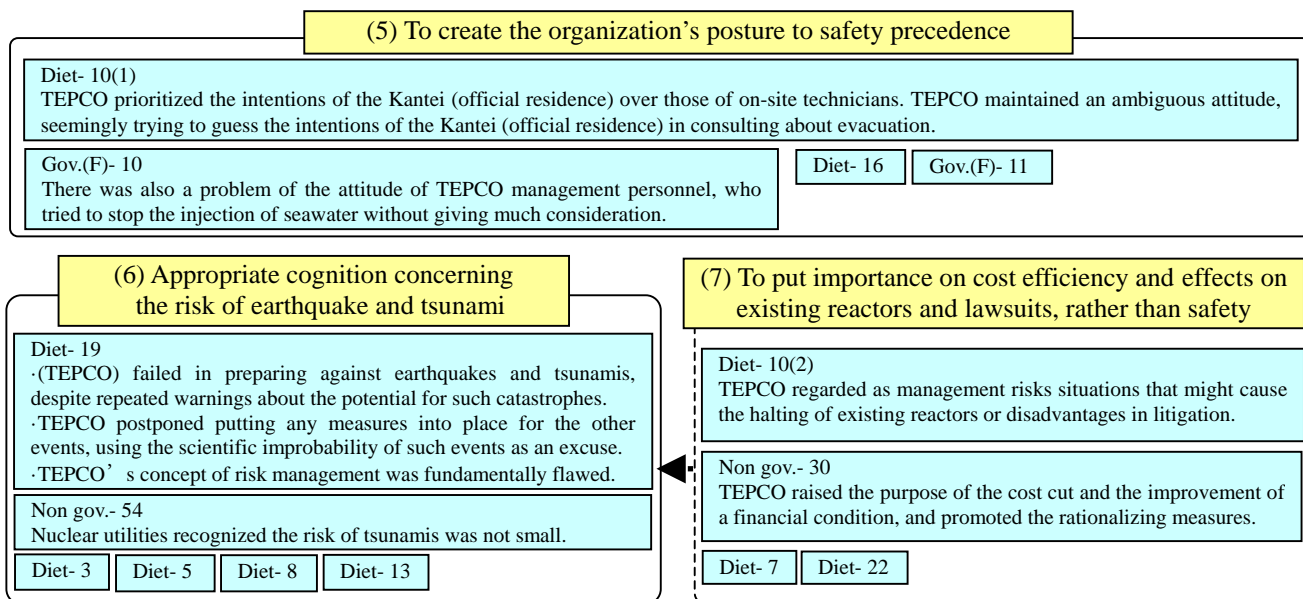


Fig.4 Extraction of issues to be reviewed. [(3) Management attaches importance to safety]

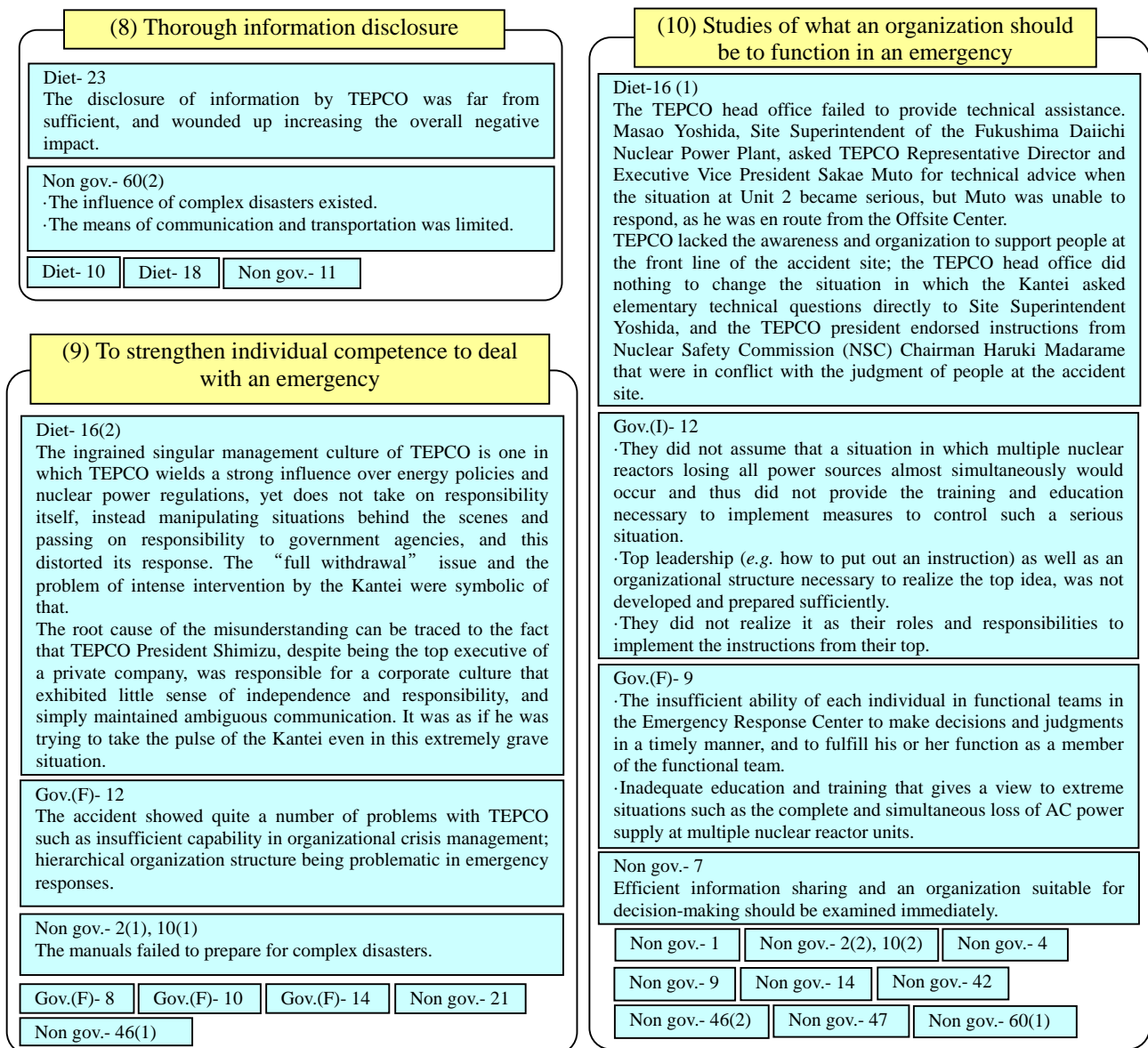


Fig. 5 Extraction of issues to be reviewed.

[(4) Employees openly communicate issues and share wide-ranging information with each other.]

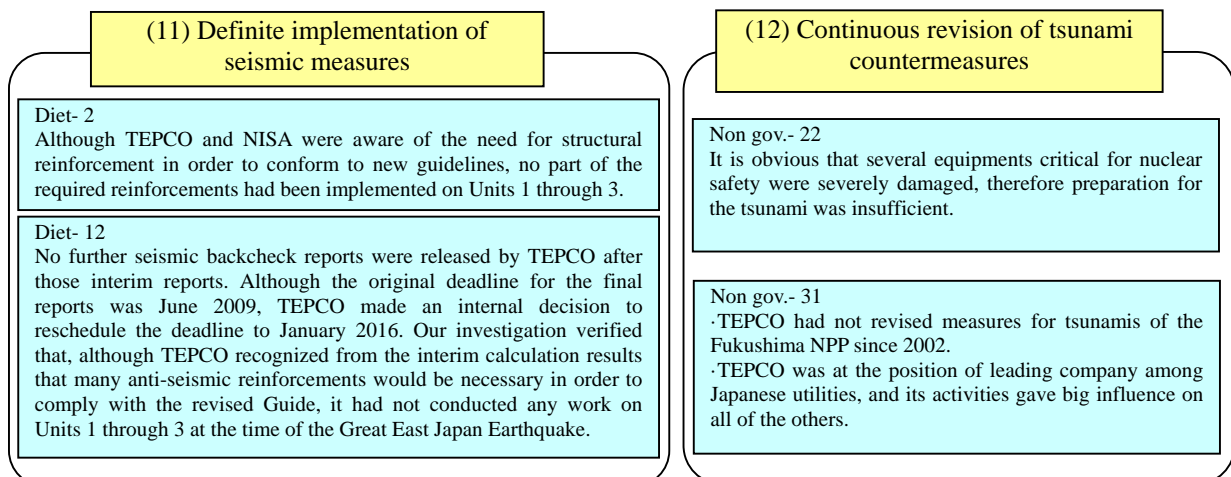


Fig. 6 Extraction of issues to be reviewed.

[(5) Adjustments and improvements are made as the organization’s situation changes.]

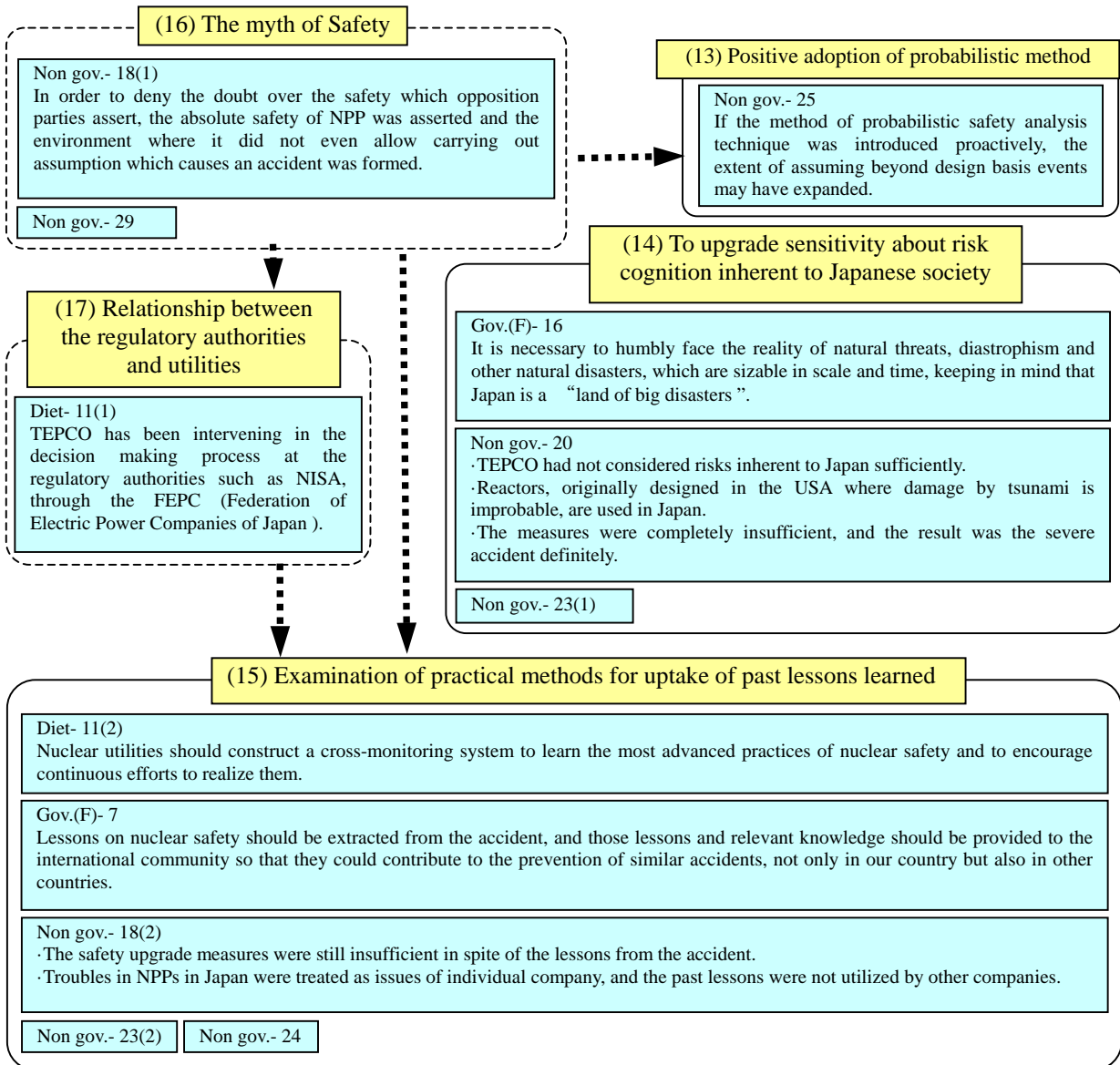


Fig. 7 Extraction of issues to be reviewed.

[(6) Learning activities from mistakes and failures are performed.]

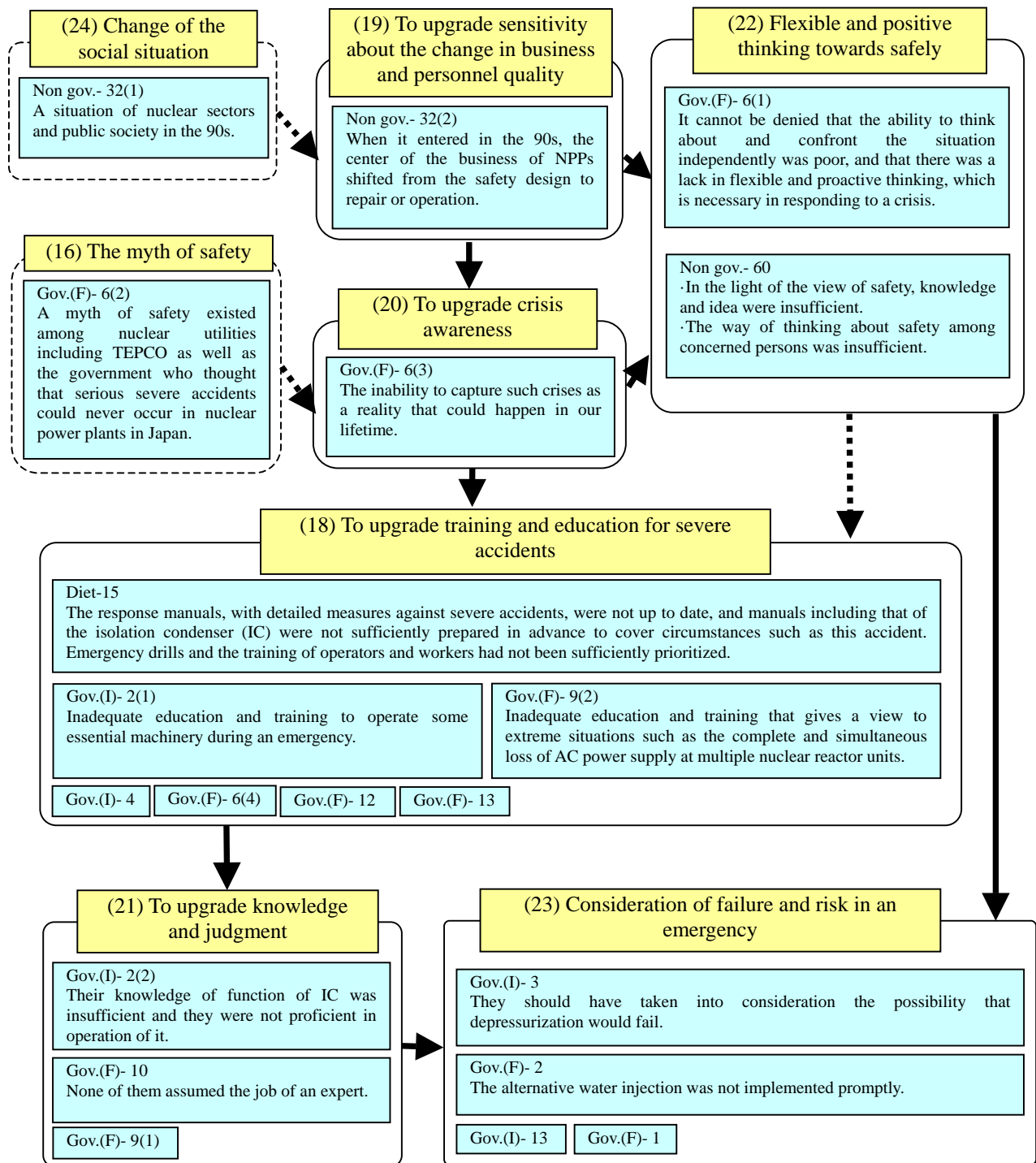


Fig. 8 Extraction of issues to be reviewed.

[(9) Employees have all the necessary requirements to undertake their own functions, and act conservatively.]

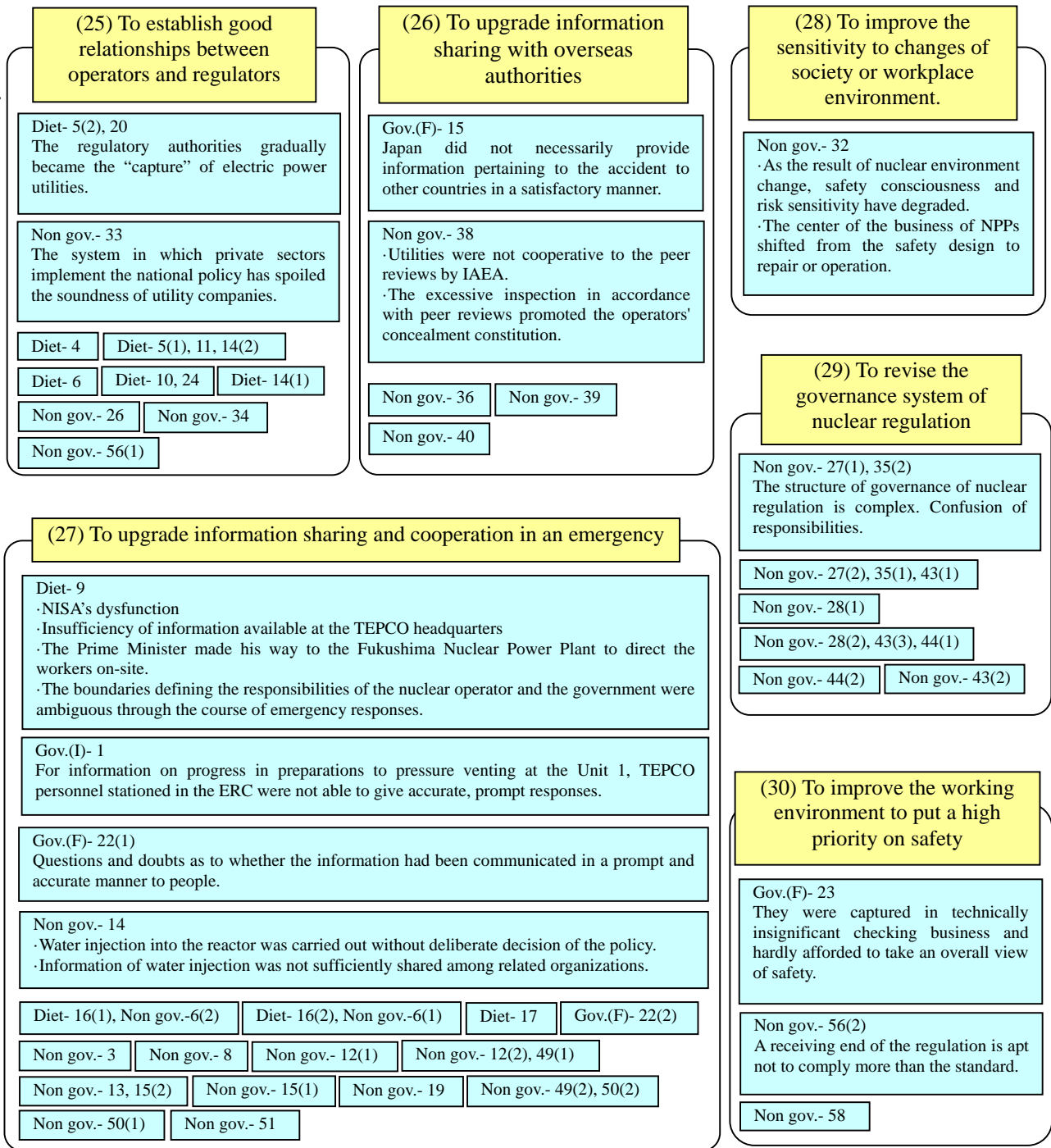


Fig. 9 Extraction of issues to be reviewed.
 [(10) The relation, communication, and information sharing between stakeholders, are good.]

[(6) Learning activities from mistakes and failures are performed.]

- (13) Positive adoption of probabilistic method
- (14) To upgrade sensitivity about risk cognition inherent to Japanese society
- (15) Examination of practical methods for uptake of past lessons learned
- (16) The myth of safety (background factor)
- (17) Relationship between the regulatory authorities and utilities (background factor)

[(9) Employees have all the necessary requirements to undertake their own functions, and act conservatively.]

- (18) To upgrade training and education for severe accidents
- (19) To upgrade sensitivity about the change in business and personnel quality
- (20) To upgrade crisis awareness
- (21) To upgrade knowledge and judgment
- (22) Flexible and positive thinking towards safely
- (23) Consideration of failure and risk in an emergency
- (24) Change of the social situation (background factor)

[(10) The relation, communication, and information sharing between stakeholders, are good.]

- (25) To establish good relationships between operators and regulators
- (26) To upgrade information sharing with overseas authorities
- (27) To upgrade information sharing and cooperation in an emergency
- (28) To improve the sensitivity to changes of society or workplace environment.
- (29) To revise the governance system of nuclear regulation
- (30) To improve the working environment to put a high priority on safety

Among these, 4 issues, *i.e.* (7) To put importance on cost efficiency and effects on existing reactors and lawsuits, rather than safety, (16) The myth of safety, (17) Relationship between the regulatory authorities and utilities, (24) Change of the social situation, were positioned as “background factors”. A background factor means that these issues are more fundamental factors, broadly-based or underlying organizational

cultural issues and tend to cause effects on other issues but do not obviously lie in the direct chain of causality. For example, “the myth of safety” has an inverse effect on the relevant persons’ consciousness and actions to upgrade safety which would otherwise be taken with a greater level of concern. Moreover, such a background factor is difficult to be solved inside an organization in isolation as it may also relate to the general social culture.

5 Conclusion

30 issues were extracted associated with the organization and safety culture of utility companies by analyzing reports issued by three organizations, *i.e.* the Diet, the government and a specific non-government organization. Authors avoided evaluating the appropriateness of the contents of every report, and simply accepted the description as it is. Although the contents have the possibility to be changed hereafter, it is still thought instructive for concerned organizations to examine these appropriate measures.

In the course of arranging the contents of accident investigation reports into nine prerequisites of ideal organizations, no file was extracted related to the classification axes: (2) The organization has a sharable vision, (7) Management creates a positive work environment and promotes good relations in the workplace, and (8) Workers have good relations in the workplace. This means that in the stage of classifying the files, no file was relevant to these prerequisites. However the contents of these files are considered background factors that may be detected by deep examination of the workplace. It is presumed that there is the possibility that they were not captured adequately in the accident investigations. They are important matters for an ideal organization and should be taken into consideration for the upgrade of the safety culture of an organization, therefore it is expected that further investigations will ascertain these matters.

Besides these, the files which did not fit into the nine prerequisites were put in the additional prerequisite, *i.e.* “The relationship, communication and information sharing among stakeholders are good”. The TEPCO Fukushima accident is not just an issue inside a single organization in the nuclear sector, many stakeholders,

e.g. the national government, local governments, local residents, electric power utilities, plant makers, subsidiary companies and mass media are related to each other, therefore there are thought to be many files suitable to this prerequisite. Conversely, in previous organizational research, studies of the relationship among stakeholders (*e.g.* regulatory authority, local nuclear site residents, nuclear industry organizations, and other companies) were scarce or unavailable, therefore it is thought to be an important research agenda. Revealing the need for organizational research to extend beyond the boundaries of the organization itself is one of the key contributions of this study.

In this study, the keyword retrieval method was adopted only in the non-government report, but this approach can possibly extract new classification axes and issues to be reviewed by applying it in other accident reports domestically and globally. This issue will be studied in future.

The issues that were extracted in this study are expected to be used as references for each relevant organization to consider as improvement measures in the future. At this time, it is thought difficult to infer the meaning definitively from their names only. Therefore, it is necessary to consider Fig.3 to Fig.9 simultaneously and confirm the meaning. This time, the descriptions relevant to organization and the safety culture of electric utility companies were classified and arranged, and the issues were extracted from them. However, the severe accident of this time can not be cleared up solely by electric utilities. The additional prerequisite "The relationship, communication and information sharing among stakeholders are good" is therefore important, and an examination of the measures through collaboration with stakeholders is now essential.

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