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Development of chemical accident database: Considerations, accident trend analysis and suggestions

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Abstract−Traditionally, regulations, standards, codes and management systems were established after major accidents such as Seveso Directive by Seveso accident, Italy, in 1976, etc. Also, several chemical material and process accident databases were developed and implicated in the world. In this paper, we introduce a set of recently developed databases, such as eMARS (EC), HSEES (USA) and PEC-SAFER (Japan), and describe current development of a chemical accident tracking system in Korea. Especially, we intensively focused on general classification codes, simplified and effective database structure, user friendly interface and intuitional searching methods. Additionally, the chemical accident trends were analyzed by using third grade of accident casualties and property's loss. Finally, suggestions for applicability improvement of database are proposed. To improve the management and operability of hazardous materials and chemical processes, the systemic approaches are essential using accident database. The developed database and suggested issues in this study can perform an important function in the chemical industries.

Key words: Chemical Accident, Database, Statistical Analysis, Lessons from Accidents

INTRODUCTION

A milestone in the history of process safety was the 1974 Flixborough explosion in the United Kingdom that caused twenty-eight deaths, eighty-nine injuries and one hundred million dollars of loss. Following the Flixborough explosion, interest in safety increased not only within industries, but also in governments, international organizations and the general public [1]. This increased interest in the safety of chemicals and the process industry eventually led the UK government to enact the Health and Safety at Work Act in 1974. Then, the Seveso accident occurred in Italy, 1976. It led to the development of Seveso Directive I (82/501/EC) to be promulgated in 1982 for the consideration of industrial major hazards. Several regulations, codes and standards continued to be legislated in the following decades. For example, the Seveso Directive was revised to the Seveso Directive II (96/82/EC) in 1996, and 2003/105/EC due to the occurrence of significant chemical accidents in Europe. A few regulations related to chemical accidents are listed in Table 1 [2-4].

Chemical accidents work as one of the sources for enhancement in management of chemicals and chemical process in relevant industries. To learn from experience, international organizations such as EU (European Union) and OECD (Organization for Economic Cooperation and Development) are sharing accident information, investigation reports and prevention activities by the chemical accident database, formal discussion, etc. The management systems for chemical accidents have been used as a tool for policy making, system improvement and release of information. Therefore, development of the effective chemical accident database management techniques

Table 1. Regulations related to chemical accidents

Accident	Regulations
Flixborough explosion, UK, 1974	Health and Safety at Work Act, 1974
Seveso Directive, Italy, 1976	Seveso Directive I, EC, 1982 The Control of Major Accidents Hazards Regulations (CIMAH), UK, 1984 Seveso Directive II, EC, 1996 Control of Major Accident Hazards (COMAH) , UK, 1999
Bhopal accident, 1984	Emergency Planning and Community Right-to-Know Act (EPCRA), USA, 1986 Rotterdam Convention on Harmful Chemicals & Pesticides, 1998
Khian Sea waste disposal incident, 1986	Basel Convention, 1994
Philips explosion, Texas, USA, 1989	CFR 1910.119; PSM, USA, 1993

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by the relevant information and systematic process methods are necessary for preventing similar accidents [1].

Chemical accident databases can improve information sharing. In Europe, the Major Accident Reporting System (MARS) was established to handle information pertaining to major accidents submitted to the EU by its member states in accordance with the provisions of the Seveso II Directive. On the other hand, the Process Safety Incident Database (PSID) was developed by the U.S. in 1997 to disseminate accidents and information on near misses in chemical and petroleum industries by Center for Chemical Process Safety (CCPS), AIChE in collaboration with Exxon via the Incident Reporting and Analysis System (IRAS). The Japanese Science and Technology Agency (JST) has developed the Relational Information System for Chemical Accidents Database (RISCAD) in collaboration with Japanese National Institute of Advanced Industrial Science and Technology (AIST). Chemical Accident Tracking System (CATS) has been developed by the Center for Chemical Safety Management, National Institution of Environmental Research in Korea [2].

In this paper, we introduce recent activities with respect to the chemical accident database and their usage in the industries and governing agencies. Then, the description of the construction of chemical accident database, including considerations and troubleshoots to improve the performance of our new designed system of the accident DB, will be provided. Also, statistical analysis is performed based on the three grades of accidents (near miss, incident and accident) to identify chemical accident trends. Finally, a management system for adequate application of the database is going to be suggested.

1. Recent Notable Databases

Many chemical accident databases have already been developed by international organizations and nations. MARS (EU), RISCAD (Japan), and PSID (USA) are well known, with several works, reports and papers describing them. In fact, our previous paper compared their differences, advantages and disadvantages [5]. In this regard, we will introduce the following recent databases that are less well known: eMARS, HSEES and PEC-SAFER.

1-1. eMARS

As mentioned in the introduction, the EU developed MARS and uses it for information sharing according to Seveso Directive II. Recently, the Major Accident Hazard Bureau (MAHB) established new strategies for applying MARS. They developed eMARS based on the internet interface. It can be accessed via http://emars.jrc.ec.europa.eu/. MAHB focused on the simplification of system and information open to the public as follows.

• Simplification of reporting and searching functions by use of a single MARS report form and internet application (reduction from over 200 fields of MARS 4.2 down to 60 fields)

• Wide dissemination of information through a password-protected internet site for authorities and a publicly available site for the general public

• Easy searching

• Easy reporting through a password-protected internet site

• Simplification of the structure of MARS and separation of "confidential" from non-confidential information

1-2. Hazardous Substances Emergency Events Surveillance (HSEES)

The hazardous substance emergency events surveillance (HSEES) was established in 1989 by the Agency for Toxic Substances and Disease Registry (ATSDR) in USA. In an attempt to describe the morbidity and mortality experienced by employees, first responders, and the general public that result from hazardous substances emergencies, a surveillance system has been developed which is currently implemented in 15 states: Alabama, Colorado, Iowa, Louisiana, Minnesota, Mississippi, Missouri, New Jersey, New York, North Carolina, Oregon, Texas, Utah, Washington, and Wisconsin. The components of the surveillance system consist of data collection, data management, data analysis, and regular dissemination of reports to promote strategies to reduce morbidity and mortality.

For consistency in data collection and ease of analysis, ATSDR created a web-based data entry system around January 1, 2000. The web-based application provides an easy way to enter data for qualifying acute releases into a centralized computer database. The detailed information and searching of HSEES database can be accessed via http://www.atsdr.cdc.gov/hs/hsees/. Also, The ATSDR published annual accident reports that contain analysis of the database [7].

1-3. PEC-SAFER in Japan

The Japanese Ministry of Economy, Trade and Industry announced an interim report for industrial accident inspection in 2003. In this report, the main idea suggested improving safety and security in the petrochemical industries. It recommended safety education, sharing of accident information and management system as major means to improve safety. It took three years to develop PEC-SAFER, starting from 2005. The main purpose of the PEC-SAFER is to store data about safety activities, which consist of near miss, accident information, safety education materials, process safety and construction management. The database can be accessed by internet interface. The detailed information and searching of PEC-Safer database can be accessed via http://safer.pecj.or.jp/. It is only serviced in Japanese.

PEC-SAFER contains near miss and accident information including explanation of accident, equipment, cause of accident (direct, indirect), cause of accident propagation, prevention method, lessons, and comments of expert. A total of 285 cases of near miss and 250 cases of accident are listed in the database.

2. Development of Database and Tool

For the development of chemical accident tracking system in Korea, we proposed classification codes of chemical accidents and developed a simplified prototype of system in our recent works. Also, at the initial stage of research, 2115 cases of chemical accident data in Korea over the last 20 years have been gathered and classified accordingly [6]. As mentioned earlier, the existing databases have disadvantages such as different classification codes and type of collected accidents (major pollution accident, environment accident, etc.), scope of accident (industry type, fixed facility, transportation, accident materials and cause and propagation of accident) and less user friendly interface. Meanwhile, the eMARS has recently been revised to improve user friendliness in the interface.

In this paper, we intensively focused on describing our development in the aspect of general classification codes, simplified and effective database structure, user friendly interface and intuitional searching methods.

2-1. General Classification Codes

The classification codes consist of 12 upper, 66 middle and 365 lower codes. They benchmarked similar codes such as those from MARS, RISCAD, and NRC. Also, to improve generality of codes,

Table 2. Summary of the classification codes by time table of accident

Time table	Contents (Upper codes)
Accident situation	Industry (1), Facility (2), Weather information (3), Location (12)
Detail information	Cause (4), Activity (5), Involved materials (6)
Damage of accident	Damage (8), Affected area (9)
Countermeasure	Early action (10), Late Action (11)

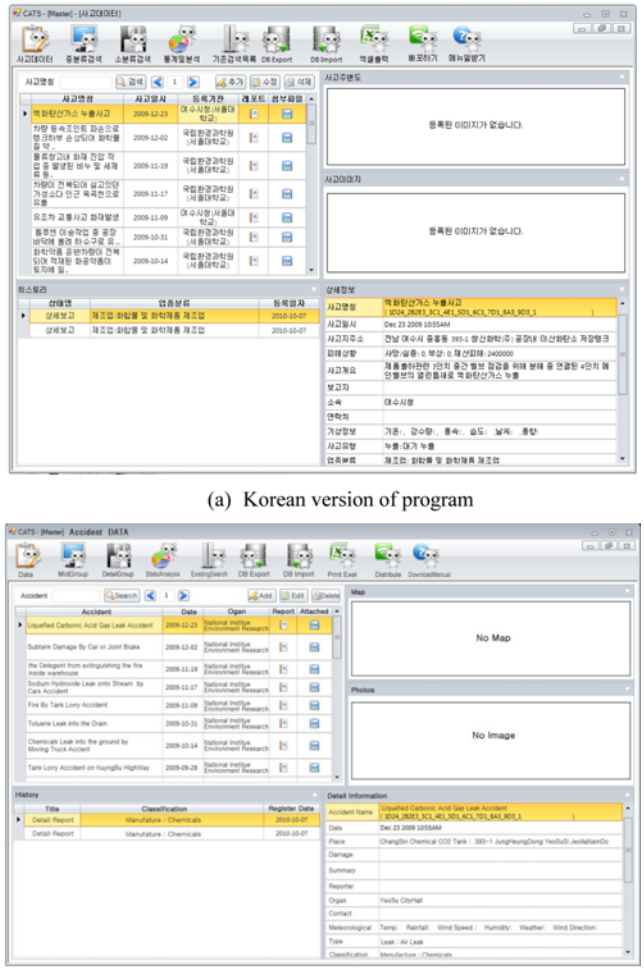
311 events in National Institute of Environmental Research (NIER), Korea were applied. Classification with selected events resulted in the revision of codes and update to increase the accuracy and data coverage capacity. The classification codes are divided into four categories as listed in Table 2. It expresses the procedure of accident reporting and investigation. The detailed information is described in our recent paper [6].

2-2. User Friendly Interface

It is difficult to use reporting, searching and analysis interface of existing databases. For example, the RISCAD database has too many input data that are intended to be entered manually. Also, the searching tools need support for advanced query such as conditional searches. It requires experts who are individuals of sense or know classification codes.

In CATS, the user interface and operating modules consist of five parts. They are data input module, list up module, data searching module and data statistics/analysis module, as shown in Fig. 1. Here, the detailed specifications and information of each module are described in our previous paper [6]. It was made for Koreans, but it can be easily translated into English, as shown in Fig. 1(b), because it follows the standard format in international accident databases.

To improve the every-day use environment of user friendly interface, a user test and survey were carried out targeting 12 experts in universities, governments and industries. The result of the survey is presented in Table 3. These suggestions for improvement of the database were reflected to the current developed of our system. Truly, the user friendly interface test needs more user tests for the public. Since the current version of the database has considered the intuitional searching method, it also improves user performance.



(a) Korean version of program

(b) English version of program

Fig. 1. Interface of developed program.

2-3. Simplified and Effective Database Structure

To improve its operation, the database was developed by using the entity relationship diagram as shown in Fig. 2. Table 4 lists con-

Table 3. The result of user interface test and survey

	Questions	Excellent	Very good	Good	Not bad	Bad	Suggestions solutions
DB list module	Function of detail view and report print	2	7	2	0	1	Visualization of hierarchical accident information modification of interface of system
	Editing of reported data	3	6	2	0	1	No. of accident list expression of No. of accident by classification code
Searching module	Accident search	2	5	3	1	1	Help function required added
	Statistical analysis and graphics based on the searched results	3	5	2		2	Variety of expression of charts add function of DB export data to excel
Statistical analysis	Statistical analysis and graphics	1	6	3	1	1	Download statistical data add function of DB export data to excel
Data input	Accident information input	1	7	3	0	1	Accident image modification of interface of system (add accident image and accident map image)

Table 4. Contents of entity relationship diagram

Name of entity	Contents	Description
Department	Information of department	Name and code of department
LoginInfo	Information of log-in ID	Log in ID, password, etc.
CatsSCode	Lower classification codes	ID, lower classification codes, related high class codes (middle, upper)
CatsMCode	Middle classification codes	ID, middle classification codes, related high class codes (upper)
CatsLCode	Upper classification codes	ID, upper classification codes
AccidentsMSDS	Involved material information	CAS No., accident ID
AccidentInfo	Detail information	ID, name of accident, date, address, damage, reporter, update date, phone number, weather information, etc.
AccidentsCats	Given classification codes by accidents	Accident ID, Code ID
MSDS	MSDS (CAS No.)	ID, CAS No., name, etc.
UserInfo	User information	Log-in ID, name, phone number, address, e-mail, etc.
ZipCode	Information of address	ID, address classification codes
AccidentFile	Attached files, reference	ID, accident ID, files, etc.

tents of the entity relationship diagram. In software engineering, an entity relationship model (ERM) is an abstract and conceptual representation of data. Entity-relationship modeling is a database modeling method used to produce a type of conceptual schema or semantic data model of a system and its requirements in a top-down fashion [8]. Using this entity relationship diagram, the database searching and statistical analysis can be done easily.

2-4. Intuitional Searching Method

As mentioned above, the existing database and tools require many conditions and several steps to search information of accidents or statistical analysis. To avoid such complexities, we developed two types of search engines. They are word matching and code matching engine, like the advanced search in Google. The word matching engine was introduced in our last paper [2]. Here, we introduce code matching engine by "AND" and "OR" query expressions. Users select items among classification codes and add them to search conditions. Then, search conditions comprise a searching table for the data parsing. Also, an individual data set is categorized by classification codes (upper classes, middle classes). Finally, the merged data are presented as a chart or table and are exported to a statistical

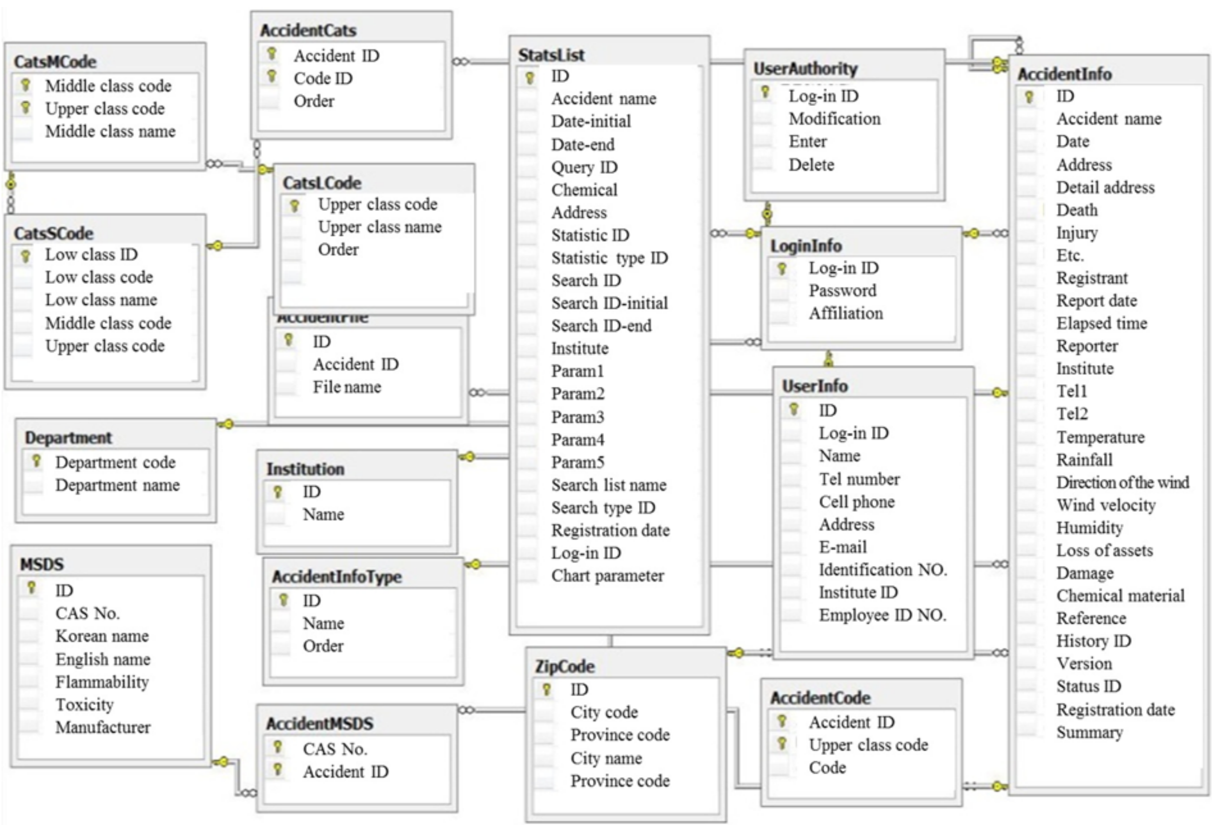


Fig. 2. Entity relationship diagram of developed accident database.

Table 5. Chemical accident trends in detail between 2000 and 2007

Type	Equipment	1st Grade		2nd Grade		3rd Grade	
Fire	Transportation	6	27.3%	6	27.3%	10	45.5%
	Tank	13	20.0%	25	38.5%	27	41.5%
	Heat exchanger	5	27.8%	2	11.1%	11	61.1%
	Separator	0	0.0%	4	57.1%	3	42.9%
	Pipe	2	12.5%	3	18.8%	11	68.8%
	Reactor	3	33.3%	3	33.3%	3	33.3%
	Etc	6	16.7%	15	41.7%	15	41.7%
	Total	35	20.2%	58	33.5%	80	46.2%
Explosion	Transportation	1	11.1%	3	33.3%	5	55.6%
	Tank	2	4.8%	26	61.9%	14	33.3%
	Heat exchanger	0	0.0%	2	50.0%	2	50.0%
	Separator	1	50.0%	1	50.0%	0	0.0%
	Pipe	0	0.0%	5	62.5%	3	37.5%
	Reactor	1	14.3%	4	57.1%	2	28.6%
	Etc	2	20.0%	5	50.0%	3	30.0%
	Total	7	8.5%	46	56.1%	29	35.4%
Release	Transportation	0	0.0%	5	8.5%	54	91.5%
	Tank	3	10.7%	4	14.3%	21	75.0%
	Heat exchanger	0	0.0%	0	0.0%	1	100.0%
	Separator	0	0.0%	0	0.0%	1	100.0%
	Pipe	2	5.3%	6	15.8%	30	78.9%
	Reactor	0	0.0%	1	100.0%	0	0.0%
	Etc	1	16.7%	1	16.7%	4	66.7%
	Total	6	4.5%	17	12.7%	111	82.8%

program (e.g., Excel).

To improve a user's usage, frequently visited items are listed in the statistical analysis. Examples include most frequently used chemicals in 10 years, number of events, loss from damage, death, and injuries according to upper classification codes. Also, a user's search condition can be stored in database and reused with or without modification.

3. Chemical Accident Trends Analysis

Several regulations, standards, codes and protocols were established and revised as results of serious accidents in the world as mentioned earlier. In addition, research and investigation reports are announced; results of the paper led to improved safety of chemical industries by developing a database of accidents, new risk assessment methods, safety reviews, best practices and education. Here, one of the methods is an analysis of chemical accident trends. In various studies, it has been demonstrated that there is a relationship between the numbers of near misses, minor incidents and major accidents. This is also shown in the Bird and Germain Pyramid [9].

To study chemical accident trends, Park et al. [10] suggested three grades of accidents according to casualties and property loss. The first grade accident is defined as an incident causing more than 5 deaths, or 10 serios injuries, or property loss worth 500 million won ($500,000). The second grade accident is defined as one causing between 1 and 4 deaths, or 2 and 9 injuries, or 100 and 500 million won ($100,000~$500,000) property's loss. Any other incidents causing less damage to people or property are defined as third-grade accidents [10].

Not enough material for statistical analysis has been collected yet, especially up to the 1980's. Most of data have been missing since the chemical accident reporting system had not been working well in Korea. To study accident trends based on the Park's three grades, we used an accident database from 2000 to 2007, which consists of 389 cases.

Most of the results show similar relationship as in the Bird and Germain Pyramid, except the case of explosion as detailed in Table 5. Especially, second-grade accidents have most frequently occurred in tanks, pipes, and reactors. Also, most of the release accidents are third-grade accidents. In addition, the transportation in equipment categories makes up more than 50 percent. Furthermore, release accidents took up few histories in first-grade accidents because the environmental effects are not considered as damage loss. Lastly, we can know that car accidents for the transportation of chemicals in the urban and rural sites are frequent, which is more than half of the transportation-release accidents.

4. Suggestions for Improved Applicability of Accident Database

International organizations (e.g., OECD, UNDP) of developed countries managed chemical accidents using database systems. In addition, they have systemic procedures for chemical accident investigation, collecting and distributing chemical accidents. For example, MARS gathered accident data including near misses and major accidents from OECD member nations based on the Seveso Directive II. All data were progressively reviewed for redistribution. Recently, MARS started to be serviced by the internet. RISCAD, which is operated by Research Institute of Science for Safety and Sustainability (RISS) in AIST of Japan, gathers data from media and accident reports. It provides information based on the internet. However, they did not use accident data for suggestion of policies or recommendations. In the USA, the Chemical Safety and Hazard Investigation Board was organized to investigate chemical accidents. They have completed 64 cases and ongoing 17 cases since 1990. CSB (Chemical Safety Board) operates as an independent organization. They issue recommendations against government organizations.

Therefore, to improve applicability of the database, several issues need to be considered and developed by combined efforts of government, universities and industries. Especially, the following three issues need to be resolved.

Accident investigation committee: For effective accident investigations and recommendations, an independent committee needs to be organized. Actually, several government agencies have made accident investigations and then shared the results. However, the scope was different and the results did not gather well. It is hard to effectively analyze accidents in the current manner. The committee is essential.

Expansion of database including near miss: Accidents and major accidents happen after several times of near misses in industries. Also, the analysis of near miss is essential to find an underlying cause of accidents.

Regular update of chemical accidents and distribution of dataset: The key point of database is regular updates to maintain new records. In order to keep it fresh, the manager of the database needs to gather and update frequently. One of the methods is upgrading database system based on the internet like eMARS.

Above three issues are essential for timely database maintenance and effective management of chemical accidents.

CONCLUSION

Several regulations, standards, codes and protocols were established as a result of serious accidents in the world. Also, a chemical accident database, new risk assessment method, safety review, best practice and education are suggested to improve safety, management system and operability in chemical industries. Especially, several chemical accident databases were developed by international organizations and countries, such as MARS (EC), RISCAD (Japan) and PSID (USA), etc. As discussed in this paper, several databases were recently upgraded from standalone system to internet based system and integrated with several safety databases (education, safety activities, chemical properties, and management of process, etc.).

The current status of the accident database in Korea is the result of development for three years using 20 years of chemical accident data. In this paper, we focused on the considerations and troubleshooting to improve performance and to handle matters relevant to the accident database. To enhance the database's usage and efficiency, the database needs to consider general classification codes, simplified and effective database structure, user friendly interface and intuitional searching methods.

The statistical analysis is performed to understand accident trends in process industries using third grade of accident classification using casualties and property loss. As a result, we know that explosion accidents and chemical material release accidents have different trends compared to the well-known accident pattern. The middle level of accidents frequently occurs because the explosion and hazardous material release is more severe when it occurs. This result justifies the regulations and safety system for hazardous materials and chemical processes.

Finally, in this paper, we suggest three issues for applicability improvement of the database. It is an organization of chemical accident investigation committee, expansion of database and regular update of chemical accidents and distribution of dataset. To improve management and operability of hazardous materials and chemical processes, systemic approaches are essential in using the chemical accidents database. The developed database and suggested issues in this study can perform an important function in the chemical industries and support improving their sustainability.

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