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Master Logic Diagram: method for hazard and initiating event identification in process plants

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Abstract

Master Logic Diagram (MLD), a method for identifying events initiating accidents in chemical installations, is presented. MLD is a logic diagram that resembles a fault tree but without the formal mathematical properties of the latter. MLD starts with a Top Event "Loss of Containment" and decomposes it into simpler contributing events. A generic MLD has been developed which may be applied to all chemical installations storing toxic and/or flammable substances. The method is exemplified through its application to an ammonia storage facility.

Keywords: Master Logic Diagram; Hazard identification; Initiating events; Quantified risk assessment; Ammonia storage

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1. Introduction

Hazard identification is the preliminary and most important task in risk assessment of process plants. Health and safety regulations adopted in the US and the European Union, such as OSHA [1], EPA [2] and SEVESO II [3], require systematic identification of process hazards arising from normal and abnormal operation.

Several methods have been proposed in the literature for hazard identification, such as checklists, Hazard Indices (Dow and Mond), What If Analysis, Failure Modes and Effects Analysis (FMEA) and Hazard and Operability Analysis (HAZOP), described in [4,5]. HAZOP is the most widely used in the chemical process industries. It is a bottom up analysis and investigates deviations of all process variables in a plant section, their causes and consequences. Detailed description of HAZOP analysis is given by CCPS [4], Lawley [7]

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and Kletz [6]. The major drawback of HAZOP is that it is time consuming, therefore several attempts have been made for automating it by using intelligent systems, as described in [8].

This paper presents the Master Logic Diagram (MLD), a method for Hazard and Initiating event identification and its application to an ammonia storage facility. Master Logic Diagrams have been presented and applied in the past for initiating event identification of nuclear plants [9]. It is a top down analysis, providing initiating events, which may be quantified in other tasks of risk assessment, as described in [10]. Initiating events (IEs) are events that challenge the safety functions, or in general the safety designs features, of an installation and have the potential to lead to accidents. For the purposes of this paper, an accident is defined as the release of a hazardous substance to the environment. Initiating events can be events that are considered as within the design envelope of the installation and can be mitigated by a safety feature performing according to specifications, or they can be events that are considered outside the design envelope of an installation and can not be mitigated by the corresponding safety functions of the installation. An example is an earthquake and the structural characteristics of a sphere containing LPG under pressure. The design basis of the sphere could be such that it can withstand earthquakes up to a certain magnitude. Earthquakes higher than that would cause failure of the structure with certainty, while earthquakes with lower magnitude would cause failure of the structure, only if this safety function (strength of the structure) is lower than intended for some reason (deterioration, wrong material, etc.). In the latter case there would be a probability associated with the unavailability of this safety function while in the former this probability is equal to unity. Initiating events can be discrete events occurring either regularly or randomly in time or events that are constantly present. Examples of discrete events are the loss of offsite power to an installation or the loading of an empty tank with a hazardous substance. The first occurs randomly in time while the second might occur regularly as part of the normal operation of the installation. Both require a safety function to be available, namely the emergency power supply and the integrity of the tank, respectively, in order to avoid undesired developments. An example of continuous IE is the existence of a corrosive atmosphere. This event is causing the weakening of the strength of the containment (in general at random rates) causing eventually the lowering of its strength below the limit required by the normal operation of the installation. Initiating events can be generated internally to the installation (as the loss of a cooling unit) or externally (as the occurrence of strong winds).

Quantitative or qualitative risk or safety analyses require in most cases the identification of accident sequences that is sequences of events (failures and/or human actions) that result in an accident. Initiating event is the event in an accident sequence that logically precedes the others, i.e. triggers the need for certain functions and/or actions the failure or absence of which will lead to an accident. The use of IE in QRAs, as well as in qualitative analyses is part of a structured methodology, which is described in [10]. This paper presents the details of one approach for identifying IE namely the MLD technique as it has evolved in the last 10 years, and it is organized as follows: Section 2 describes the MLD technique for initiating event identification; Section 3 offers a case study of an ammonia storage facility; Section 4 compares the MLD method with two other methods; and Section 5 presents the conclusions.

2. Master Logic Diagram

The Master Logic Diagram technique is a basic approach for initiating event identification. It is a Logic Diagram that resembles a fault tree but without the formal mathematical properties of the latter. It starts with a “Top Event” which is the undesired event (like “Loss of Containment”) and it continues decomposing it into simpler contributing events in a way that the events of a certain level will in some logical combination, cause the events of the level immediately above. The development continues until a level is reached where events directly challenging the various safety functions of the plant are identified. For a chemical installation the “Top Event” of interest is the potential of release of a hazardous substance to the environment. Loss of Containment (LOC) means a discontinuity or loss of the pressure boundary between the hazardous substance and the environment, resulting in a release of hazardous substances. A generic MLD for LOC in installations handling hazardous substances is shown in Fig. 1. The development of this diagram has profited from extensive review of past accidents, from the AVRIM2 hazard assessment tool [11], and the “Generic Fault Trees” [12]. All major categories of events leading to Loss of Containment are analyzed as shown in Fig. 1. Most of the events in the last level of development in the tree describe categories of causes that alone or in some combination, result in a loss of the containment of the hazardous substance. Some of these causes can be further developed into joint events consisting of an initiating event and the failure of one or more safety functions. Examples of such event-trees are these leading to failure owing to overpressure. Other events, however, require different models (e.g. corrosion requires a multistate Markov model). An MLD, like the one in Fig. 1, is developed for each major containment (or section) of an installation and for each and every operational phase. In short an MLD is developed for each potential point of release of hazardous material. A short discussion of the MLD in Fig. 1 characterizing each of the events follows.

2.1. Master Logic Diagram for Loss of Containment

There are two major categories of events leading to Loss of Containment: those resulting in a structural failure of the containment and those resulting in containment bypassing because of an inadvertent opening of an engineered discontinuity in the containment (e.g. valves, hatches) (see Fig. 1).

Seven general ways (or direct “causes”) in which a structural failure of the containment may come about can be distinguished: (a) overpressure; (b) underpressure; (c) corrosion; (d) erosion; (e) external loading; (f) high temperature; (g) vibration.

Each of those fundamental physical processes has the potential of inducing stresses that will exceed the strength of the containment or alternatively to reduce the strength of the containment to levels low enough that cannot withstand normal stresses. Each of these causes of failure can be considered as the result of an “initiating event” coupled with the failure of one or more safety functions. The latter are combinations of engineered systems and human actions based on specific procedures aiming at preventing the initiating event from causing the failure of the containment. It is noteworthy that the frequency with which the initiating event is expected to occur can vary from extremely low values (e.g. the frequency of a large earthquake) to very high values (e.g. almost continuous operation in a corroding environment).

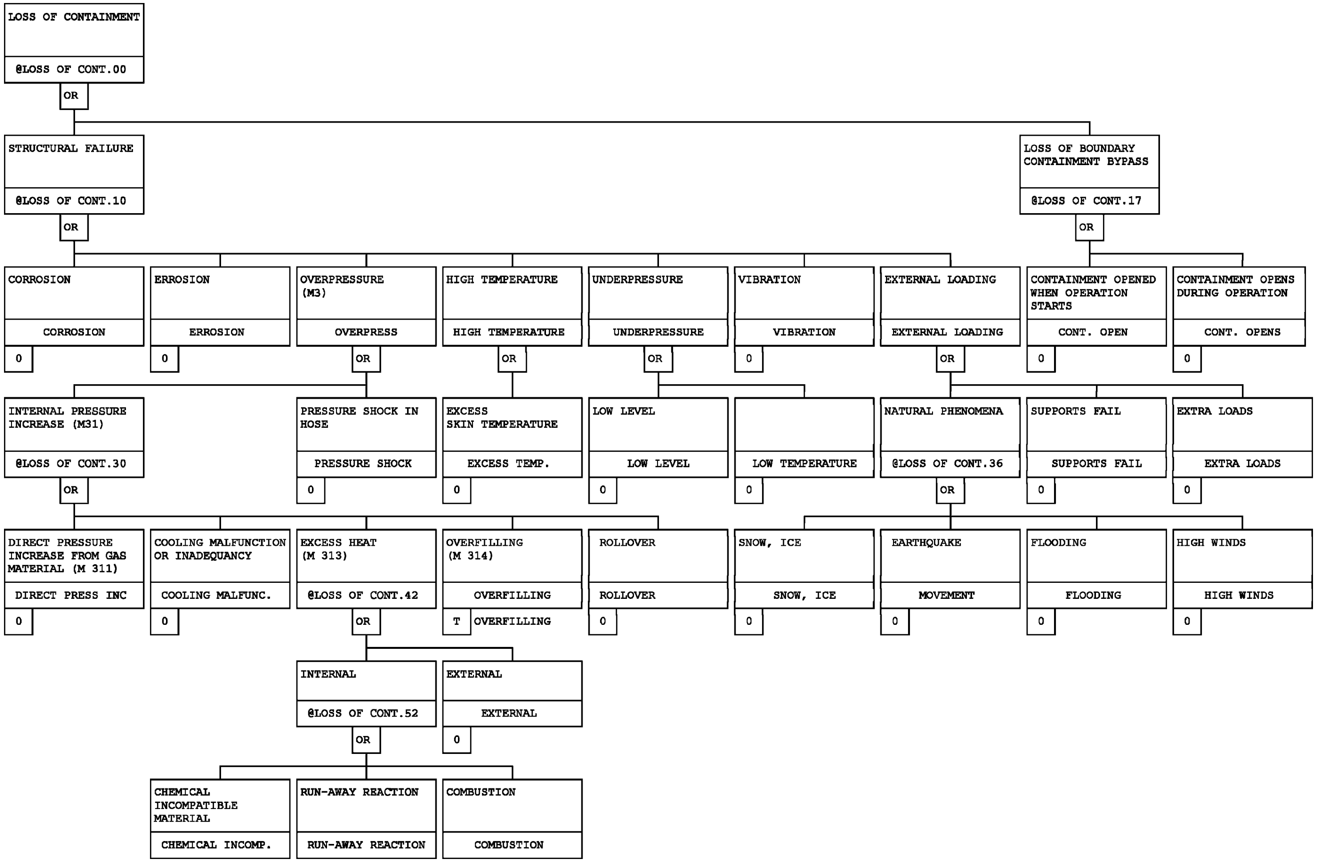


Fig. 1. Generic Master Logic Diagram.

The second major category of causes for loss of containment are those resulting in a bypass of the containment either because operations start while it is open or because the containment is opened during operations.

2.2. Direct cause of containment failure: overpressure

The second level of decomposition of the MLD in Fig. 1 follows the possibility of failure owing to overpressure. Overpressure describes the phenomenon where the internal pressure increases to such that the stresses induced on the containment overcome its strength. Overpressure may be created in the following ways: (a) internal pressure increase; (b) pressure shock.

Internal pressure increase can be further developed in a third level of decomposition. This event may occur in four ways: (a) direct pressure increase from gas material; (b) cooling malfunction; (c) excess heat; (d) overfilling; (e) rollover.

A fourth level of decomposition is possible for the cause “Excess Heat” which can be decomposed into “internally generated” and “externally generated” excess heat. The former of these two causes can be further decomposed into three contributing causes run-away reaction, combustion and chemically incompatible materials.

The generic development of the MLD for the loss of containment owing to overpressure stops at this point after having identified the following subcategories of failure causes: (a) direct pressure increase from gas material; (b) cooling malfunction; (c) chemical incompatible material; (d) run-away reaction; (e) combustion; (f) external excess heat production; (g) overfilling; (h) rollover; (i) pressure shock.

Further development of models, to identify and quantify whether one or more of these causes are possible and in what ways, requires specialization on the particular installation under analysis.

2.3. Direct cause of containment failure: underpressure

Underpressure, meaning lower internal pressure with regards to the external pressure, can lead to containment failure if the induced stress by the pressure difference becomes larger than the strength of the containment material. The result is an implosion. This direct cause can be developed into two subcategories: (a) underpressure caused by low level of liquid in the containment; or (b) underpressure caused by low temperature in the containment. Further development of the MLD requires specialization to particular systems.

2.4. Direct cause of containment failure: corrosion, erosion

Further development into subevents is not straightforward without specialization to particular system.

2.5. Direct cause of containment failure: external loading

Structural failure of containment owing to external loading occurs whenever such external loads induce stresses to the containment exceeding the strength of its material. This direct cause can be distinguished into three subcategories: (a) loading from natural phenomena; (b) failure of supports; (c) external loads on the containment. The first category can be further subdivided into four types of natural phenomena: (a) earthquakes; (b) flooding; (c) high winds; (d) snow, ice. Further development of the MLD requires a specific system.

2.6. *Direct causes of containment failure: high temperature and vibration*

No further generic development is offered to these two direct causes. A fire impinging on a vessel or tank may cause high temperature on it, while vibration might cause the failure of rotating machinery.

2.7. *Containment bypassing*

If the containment is either opened during operations (by an operator), or it remains open when operations start, these situations will lead to loss of containment. For example manual/power valves or hatches might be left open for other cause, and not closed before operations start.

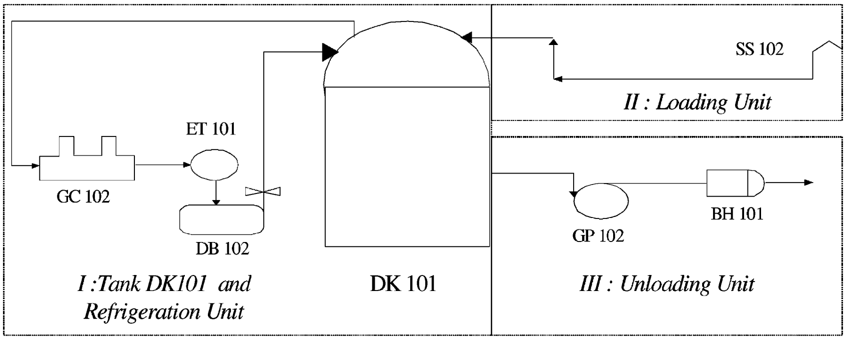
3. Case study: Master Logic Diagram for an ammonia storage facility

As a partial demonstration of the development and use of the MLD technique an ammonia storage facility is analyzed. A brief description of the installation follows, while more details are provided in [10].

3.1. *Brief description of the installation*

The reference facility stores 15,000 tones ammonia (NH_3), which is used as feedstock by a fertilizer plant. Ammonia is transported to the general site of the plant by ship. It is transferred and stored in the tank, and from the tank to its final destination (fertilizer plants) as demanded. The facility mainly consists (as shown in Fig. 2) of a storage tank (DK 101), its associated refrigeration and control systems (GC 102, ET 101, DB 102), a pipe section connecting the tank with the fertilizer plants (GP 102, BH 101) and the loading pipe section (SS 102). Ammonia is transported and stored as a refrigerated liquid at atmospheric pressure conditions (i.e. $-33\,^{\circ}\mathrm{C}$ and 1 bar.) The operation of the storage facility can be distinguished in three phases:

(a) Loading of the liquid ammonia from the ship via a specially constructed and equipped pipeline to the thermally isolated storage tank. This transfer is achieved through the use of the ship's pumps and lasts approximately 20 h for each loading cycle. There are five loading cycles each year.
(b) Storage of the ammonia in the tank, at $-33\,^{\circ}\mathrm{C}$ and 1 bar pressure, which may last for up to 1646 h (period between loading and unloading).
(c) Unloading, which is the transfer of ammonia from the storage tank to either of the two fertilizer plants by the use of three discharge pumps. This operation lasts, on average, 86 h each operational cycle.



Refrigeration Unit
GC 102: compressors
ET 101: condensers
DB 102 :separation drum

DK 101 : refrigeration tank
GP 102 unloading pumps
BH 101: heating unit
SS 102: loading arms

Fig. 2. Schematic diagram of ammonia storage plant.

3.2. MLD in the storage plant

The detailed MLD for the ammonia storage facility has been developed along the lines of the previous Section 2, for all possible sites of ammonia release and for all plant operation states (storage, loading, unloading). The basic steps for the construction of the MLDs are the following.

3.2.1. Step1: identification of critical areas

A critical area of the plant is one containing a quantity of the hazardous substance. On the basis of the extend of possible consequences (i.e. quantity to be released) the installation

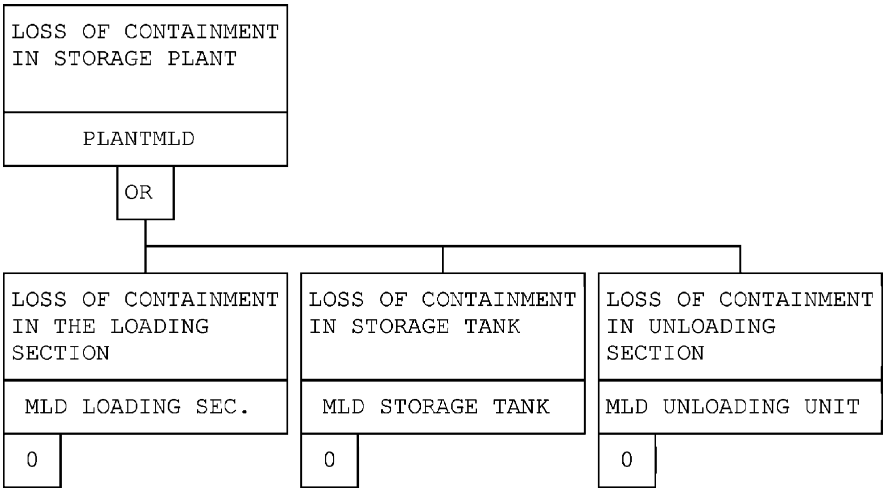


Fig. 3. Master Logic Diagram of the ammonia plant.

has been divided into three sections as follows:

(a) Tank DK 101;
(b) Loading facility;
(c) Unloading facility.

These three sections have been identified as possible sites of ammonia release. A schematic representation of the division of the ammonia storage plant in the three sections is given in Fig. 2. Following the MLD development philosophy described above, the first level of decomposition was along the three possible sites of ammonia release as shown in Fig. 3.

3.2.2. Step 2: specialization of MLD to selected critical areas

3.2.2.1. Loss of Containment in Tank DK 101. The generic MLD (Fig. 1) has been applied to the Loss of Containment in Tank DK 101. The ways the containment may fail and their significance appears in the following list:

Corrosion	Negligible contribution on the basis of frequencies
Erosion	Negligible contribution on the basis of frequencies
Internal pressure increase	Further analyzed
Rollover	Negligible
Pressure shock	Not applicable
Excess temperature	Not applicable
Underpressure	Further analyzed
Vibration	Not applicable
External loading	Further analyzed
Containment bypass	Not considered

Fig. 4 gives the MLD of the storage tank DK 101. The various ways the tank may fail namely, internal pressure increase and underpressure have been further decomposed for each plant operating state (storage, loading, unloading). An earthquake is the only natural phenomenon considered which might cause loss of containment. All the others snow, ice, flooding and high winds have been neglected, because the frequency of occurrence is very low at this particular site.

Fig. 5 shows the Master Logic Diagrams of the decomposition of internal pressure increase and Fig. 6 the MLD of the event underpressure. Internal pressure increase may occur either if there is imbalance of heat removal during the operation of the tank, or direct pressure increase from hot ammonia gas entering the tank during storage and unloading, or even overfilling during loading. Imbalance of heat removal might occur either if the refrigeration system of the tank malfunctions, or if the heat input from the environment exceeds the design basis of refrigeration capacity, owing for example to an external fire. Therefore internal pressure increase may be achieved in the following ways:

(a) Cooling malfunction during loading;
(b) Excess heat external, during loading, storage, unloading;
(c) Overfilling, during loading;
(d) Cooling malfunction, during storage and unloading;

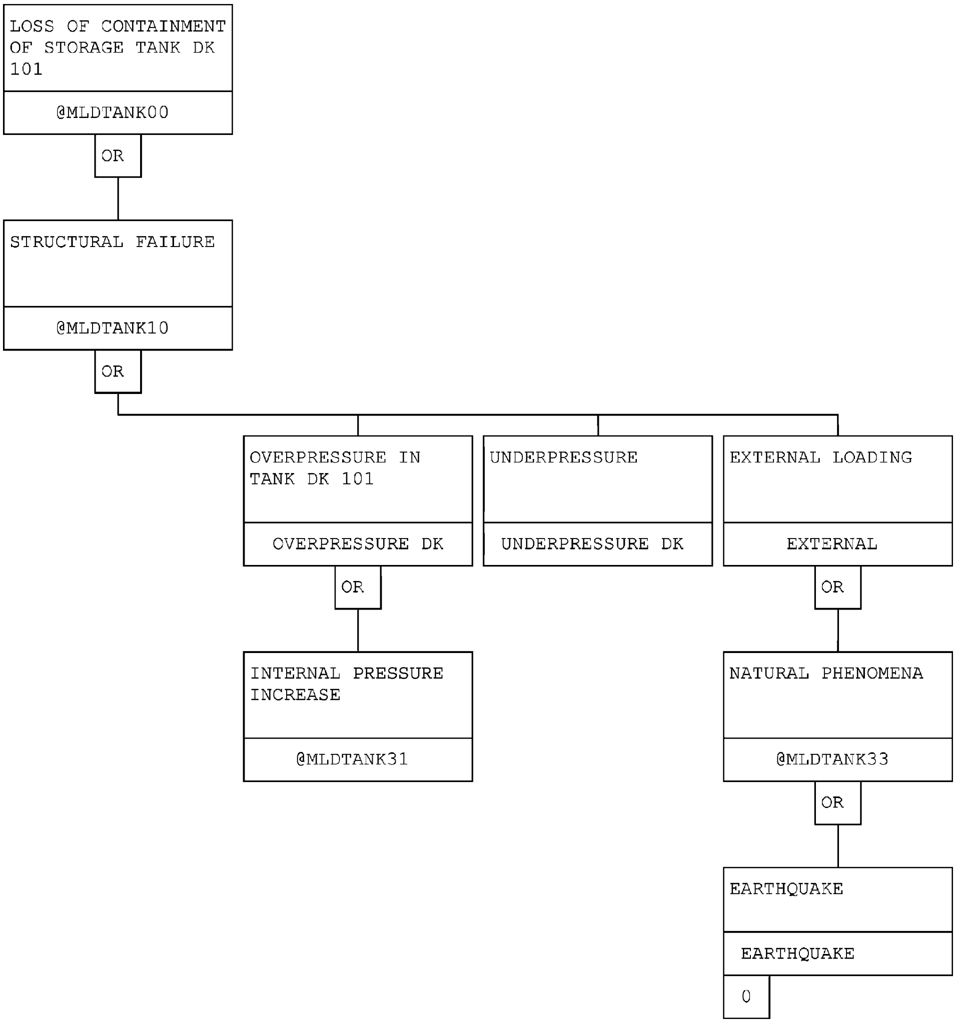


Fig. 4. Master Logic Diagram of the storage tank DK 101.

(e) Direct pressure increase, during storage and unloading;
(f) Cooling inadequacy, during loading and unloading.

Underpressure may be achieved in the following ways:

(a) Low temperature, during storage and unloading (e.g. additional compressors start);
(b) Low level during unloading.

3.2.2.2. Loss of Containment in Loading section. The generic MLD (Fig. 1) has been applied to the Loss of Containment in the Loading section. The ways the containment

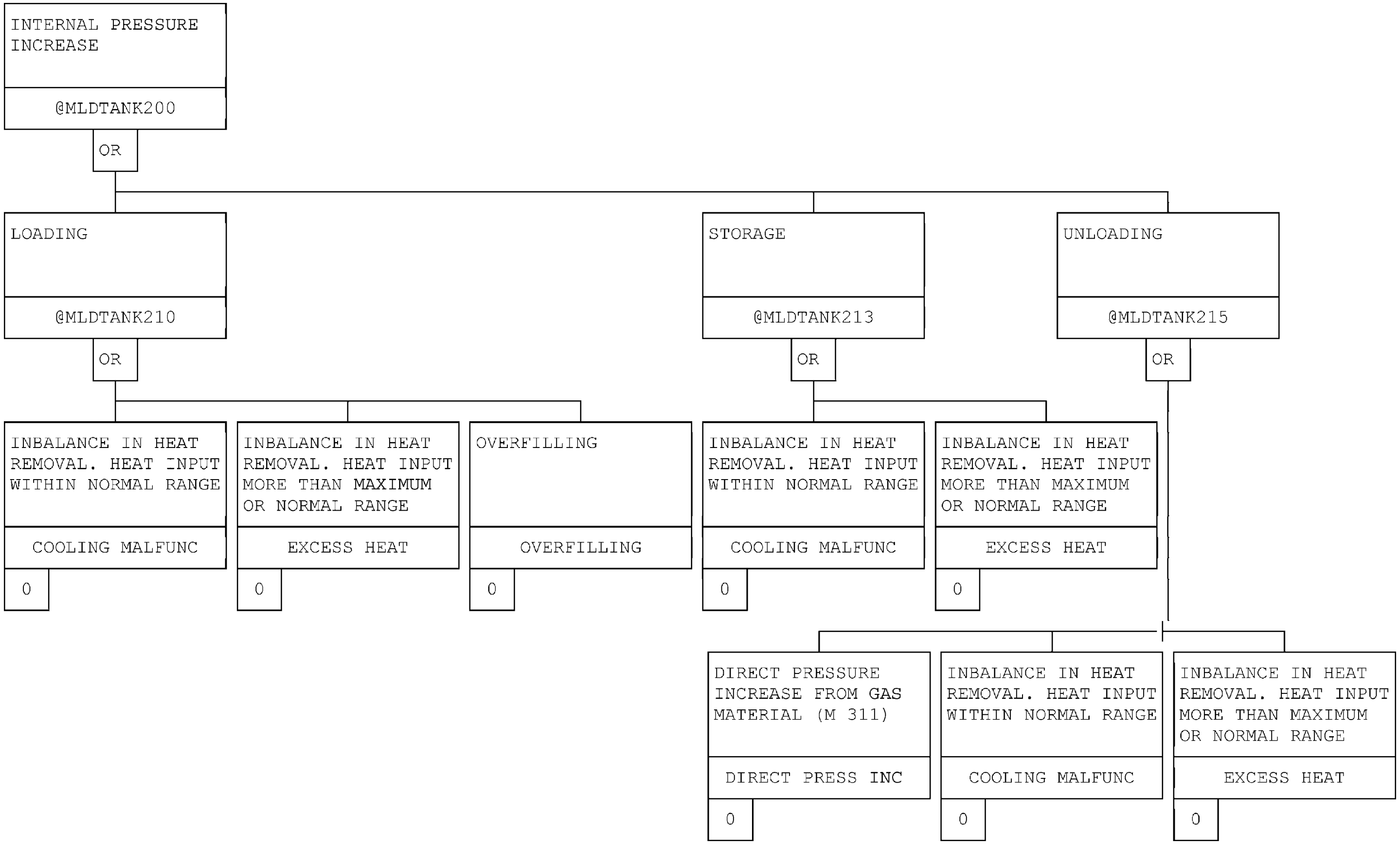


Fig. 5. Master Logic Diagram of the event “internal pressure increase”.

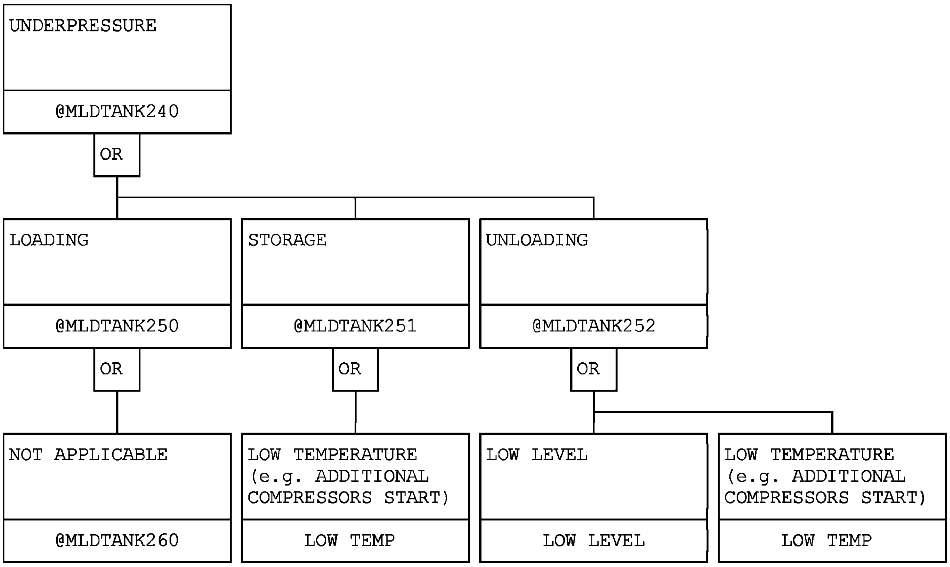


Fig. 6. Master Logic Diagram of the event “underpressure”.

may fail and their significance appears in the following list:

Corrosion	Considered (might lead to pipebreak)
Erosion	Negligible contribution on the basis of frequencies
Internal pressure increase	Not applicable
Rollover	Negligible
Pressure shock	Considered
Excess temperature	Not applicable
Underpressure	Not applicable
Vibration	Not applicable
External loading	Considered
Containment bypass	Improper disconnection of loading arm

Fig. 7 presents the Master Logic Diagram of the Loading section. The ways with which there might be a pipebreak in the loading section are corrosion, pressure shock, extra loads (movement) and high winds. High winds might cause loading arm disconnection.

3.2.2.3. Loss of Containment in Unloading section. The generic MLD (Fig. 1) has been applied to the Loss of Containment in the Unloading section. The ways the containment may fail and their significance appears in the following list.

Corrosion	Considered (might lead to pipebreak)
Erosion	Negligible contribution on the basis of frequencies
Internal pressure increase	Considered
Rollover	Negligible
Pressure shock	Not applicable

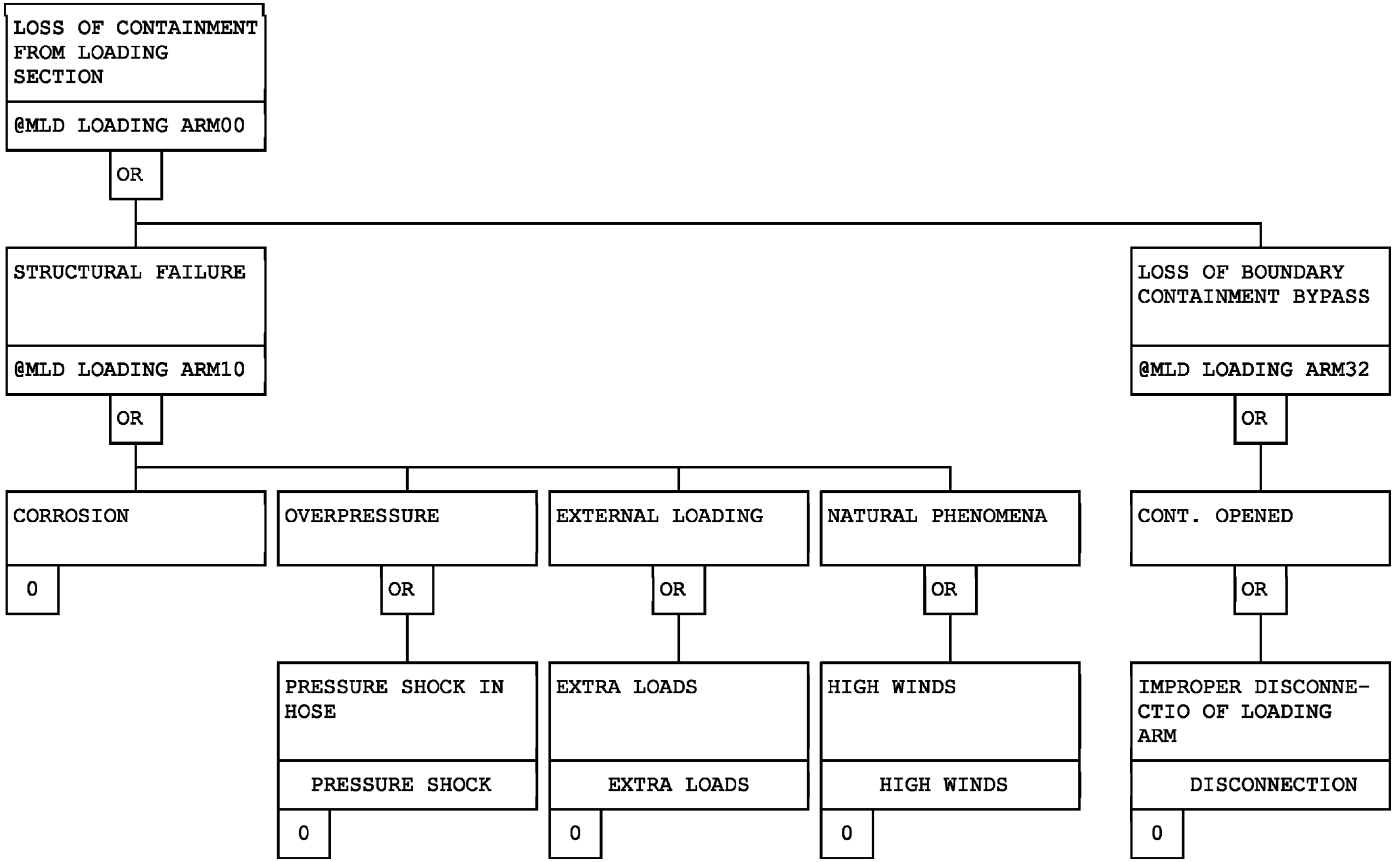


Fig. 7. Master Logic Diagram of the Loading section.

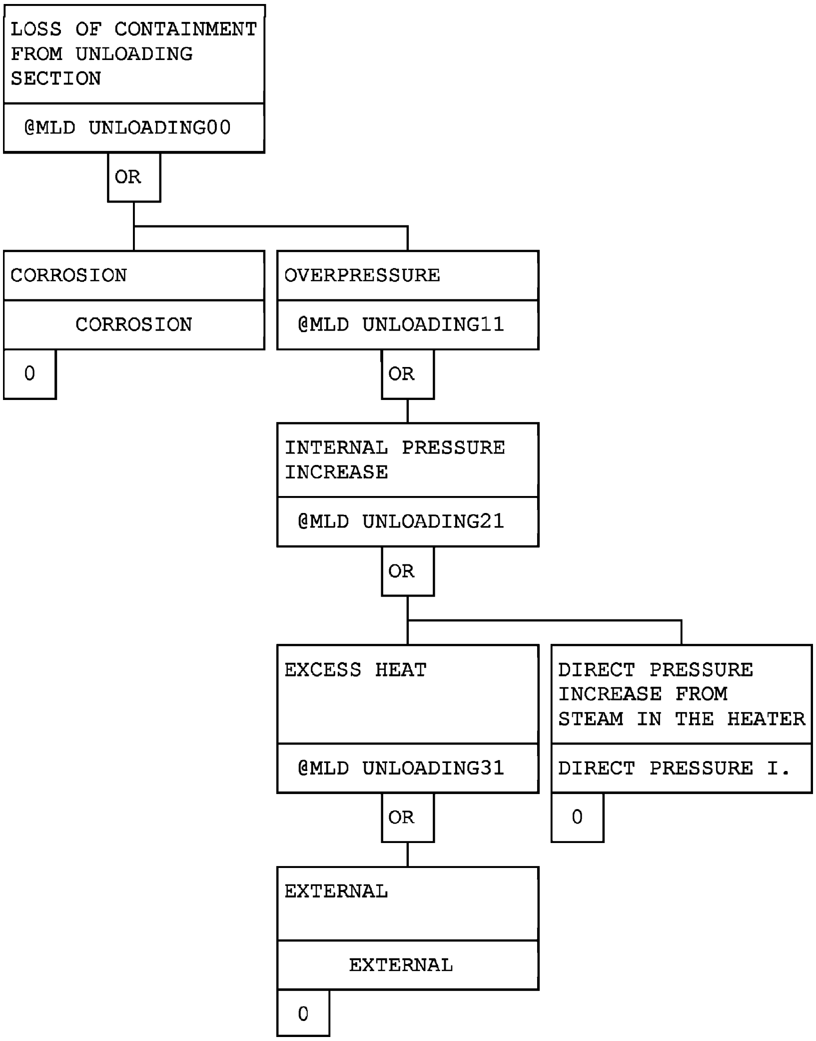


Fig. 8. Master Logic Diagram of the Unloading section.

Excess temperature	Not applicable
Underpressure	Not applicable
Vibration	Not applicable
External loading	Not applicable
Containment bypass	Not considered

Fig. 8 presents the Master Logic Diagram of the Unloading section. The ways a pipebreak in the unloading section may fail are corrosion, external heat or direct pressure increase in the heater.

The most important initiating events, which were identified with the application of the Master Logic Diagrams to the ammonia storage facility, are the following:

(1) Reduction of refrigeration capacity during loading;
(2) Hot ammonia coming from ship or sphere tank;
(3) Excess external heat;
(4) Level rise beyond safety height, or overfilling;
(5) Loss of refrigeration capacity during storage and unloading;
(6) Direct pressure increase from gas, if hot ammonia transported to the unloading unit, enters the tank by mistake;
(7) Inadvertent starting of additional compressors;
(8) Low level in tank;
(9) Earthquakes;
(10) Pipebreak in loading section, owing to corrosion, pressure shock or extra loads, high winds;
(11) Pipebreak from tank to plant (unloading section);
(12) Improper disconnection of loading arm.

4. Comparison of MLD with other hazard identification methods

Three other approaches were also used for the identification of IEs, for comparative purposes. First a search in the literature was performed identifying causes of accidents which have actually occurred in the past at ammonia storage plants and are the following, as reported in [13]: overflow, overpressure, fire, failure of loading arm, material defect, leakage and improper disconnection of loading arm. All these causes also appear in a list of initiating events identified with the MLD method, presented in Section 3.2. Overflow appears in No. 4 of the MLD list, overpressure in numbers (1, 2, 5, 6), fire in No. 3, loading arm failure, leakage and material defect in No. 10 and improper disconnection of loading arm in No. 12.

The following sections present a comparison of MLD with two other methods, namely HAZOP and AVRIM2.

4.1. Comparison of MLD and HAZOP

MLD is a deductive technique, starting from a Top Event and analyzing it down to simpler events until a level is reached where an event is identified as caused by a combination of two or more events: one of them being an initiating event and the remaining failures of safety functions. Provided that the MLD presented in Fig. 1 is “complete”, this method will guide the analyst to investigate whether such failures are possible in the particular section of the installation and if yes, all possible ways in which these failures can come about. When these findings are further analyzed and classified (e.g. with event trees and fault trees) the analysis will result in a “complete” set of event combinations that can result in the Top Event of Loss of Containment.

HAZOP on the other hand is an inductive (or bottom up) technique that starts from a detailed level of the plant (bottom), examines deviations from normal operation, the effects of these deviations and their causes. Thus an initiating event can be identified as a cause of a deviation, or as a result of a deviation. As is the case with all inductive and deductive techniques (e.g. event trees versus fault trees), HAZOP and MLD are in principle equivalent. This means that given the results of one analysis one could in principle generate the same results using the other methodology. The question is rather with which methodology an analyst feels more comfortable in the sense that it is closer to her experience and way of thinking.

The authors find more efficient the deductive approach and believe that it provides a greater degree of certainty for identifying initiating events that challenge the safety functions of the system. It is a structured approach that guides the analysis, through successive levels of simpler events, to the identification of initiating events. On the other hand, the success of a HAZOP analysis may depend on the level of detail that it starts. It might be, for example, necessary to move through several levels of causes for a particular deviation (caused by event A, which is caused by event B and so on) until an initiating event is identified. Furthermore HAZOP does not offer necessarily, a systematic way to keep track of these consecutive dependences. A final disadvantage that the authors attribute to the HAZOP analysis is that the present state-of-the art does not support identification of initiating events not directly involved with the physical or chemical processes of the installation. Such events are for example earthquakes, heavy snow falls, collision of heavy equipment with support elements or pipelines, etc.

It all boils down to the fundamental question: given that event A can be cause by a set of events $\{A_1, A_2, \ldots, A_n\}$. Does the question "what can cause event A?" help in identifying all members of the set $\{A_1, A_2, \ldots, A_n\}$? Or is it better to try to identify simpler events in the hope that all $\{A_1, A_2, \ldots, A_n\}$ will be identified and the answer to the question "what can be the consequence of A_i?" will be " Event A".

HAZOP was applied to the identification of IEs of the ammonia storage facility, as described in detail in [13] and a brief summary of this application is also presented. According to the HAZOP analysis, the plant is divided in three subsystems (see Fig. 2), which are the ammonia tank DK 101 and refrigeration unit, the loading unit and the unloading unit. Next the disturbances caused by deviations of process variables out of their normal range are analyzed. Deviations of flow, level, pressure and temperature in the three subsystems are analyzed and Table 1 presents the application of HAZOP to the ammonia storage tank. HAZOP provides the identification of event sequences which have the potential to lead to an abnormal event and a list of abnormal events which may constitute Top Events in subsequent analysis. Such a sequence is the following: high level in tank DK 101 will cause high pressure in it and additionally if both pressure relief valves fail closed, the tank will burst. (Tank rupture is a Top Event). The list of Top Events for the three subsystems of the installation is presented in Table 2. HAZOP analysis does not automatically provide a list of IEs. IEs are sometimes the cause of the considered deviation and sometimes the deviation itself. Initiating events identified by MLD such as excess external heat, reduction of refrigeration capacity, hot ammonia coming from ship or sphere tank, direct pressure increase from gas and inadvertent starting of additional compressors are causes of deviations, while level rise beyond safety height and low level in tank are deviations of process variables. Earthquake cannot easily be identified by HAZOP, since it is an external event and this method focuses to internal events.

Table 1
HAZOP analysis of storage tank DK 101

Subsystem: (1) storage tank DK 101, nodes (variable): F, L				Unit: storage plant, ref. drawing: 8108-141-101, 133-033A					
Guide	Deviation	Possible cause	Effects	Alarms		Control room actions		Notes	Top
				Optical	Acoustical	Automatic	Manual		
No	No flow of liquid ammonia into tank DK 101	No flow from Node 1 or HIC 19 fails closed; or HIC 19 gets spurious signal to close	Stop unloading				Communication between control and breasting island/ship		
–	lL low level of ammonia in DK 101	No input of ammonia and HV 04 stuck open; or HV 18 stuck open and Pumps GP 102.1.2 GP 110 continue operation	Flash evaporation of ammonia lP of ammonia in tank	LAL 10		LSL 10			
–	lP of ammonia in tank	lL low level of ammonia in tank; and Compressor GC 102 operates	llP in tank DK 101 Air intake into tank DK 101	PAL 24		VSV 18, VSV 17		Air intake, if operator does not react in time	
–	llP in tank DK 101	lL low level; and Compressor fails to stop; and VSV 17, VSV 18 fail and all inlet pipes fail blocked	Tank implosion Ammonia release	PAL 24		PSL 25	Operator stops compressor		* *
+	HL in tank DK 101	HV 04 remains closed; and HV 18 remains closed; and HIC 19 fails to close	HP in DK 101	LAH 09, LAH 10					

Table 1 (*Continued*)

+	HP in tank DK 101	hL in tank DK 101; or		PSH 25, PSHH 23	Close HIC 19	
		hT in tank DK 101; or Gas outlet blocked; or Failure of refrigeration system; or Hot ammonia coming to tank			PSH 25 actuate compressor PSV 07, 08	
+	HP in tank DK 101; and PSV 07, 08 Fail to open	hL in tank DK 101; or hT in tank DK 101; or Gas outlet blocked	Bursting of tank DK 101 Release of ammonia			* *
+	HT in tank DK 101	External fire		PSH 25, PSHH 23, TSH 23	PSH 25 actuate compressor and fire fighting system	*

Table 2
List of Top Events determined by the HAZOP analysis

(1)	Implosion of tank DK 101
(2)	Failure of tank DK 101, owing to overpressure
(3)	Mechanical failure of compression system
(4)	Level excess in drum DB 101 of the refrigeration system
(5)	Level excess in drum DB 102 of the refrigeration system
(6)	Level excess in drum DB 105 of the refrigeration system
(7)	Failure in the loop of condensers owing to overpressure
(8)	Release of ammonia through valve TIC 050 in the exchanger ET 103

4.2. *Comparison of MLD and AVRIM2*

As mentioned in the introduction the MLD technique aims at the identification of IEs that challenge safety functions of an installation and have the potential, if coupled with additional events, to lead to a LOC. Initiating events and safety functions, systems and human actions are then combined through logically consistent models (e.g. event trees + fault trees, Markov models) to provide a model of the response of an installation to possible challenges through a set of accident sequences.

AVRIM2 is a Dutch major hazard assessment and inspection tool that among other things suggests the generation of an "initiating event matrix". The columns of the matrix consist of nine "direct causes" of loss of containment. The rows of the matrix consist of parts or sections of the installation at different phases. An x in the matrix indicates that in that particular part of the installation and the corresponding operational phase it is possible to observe the direct cause of the column. The combination of a direct cause and a containment activity is called in the AVRIM2 method an initiating event [11]. Furthermore, reference [11] states that "an initiating event leads immediately to loss of containment". Consequently in the AVRIM2 terminology "initiating events" refer rather to "qualified instances of releases", that is points where the containment fails and the direct cause of such failure, rather than to events that trigger a sequence of events resulting in LOC. In this sense the AVRIM2 approach does not serve the structured and consistent approach presented in reference [10] for a qualitative and/or quantitative risk analysis.

Next, AVRIM2 offers "Generic Fault Trees" that analyze the nine direct causes for LOC presented in the "initiating event matrix" down to levels of greater detail. This decomposition proceeds down in generic terms much as it is done in the MLD. In principle the two methods can be considered as equivalent. Combination of the nine direct causes of LOC in one OR gate and then analyzing each and every direct cause with the corresponding "Generic Fault Tree" would result to a logic tree equivalent to the MLD presented in Fig. 1, albeit to a more detailed one. Here again there is, however, a difference in philosophy. In AVRIM2 the "initiating event matrix" and the associated "Generic Fault Trees" aim at presenting the reviewer with a set possible generic scenarios (equivalent to our accident sequences) to check against those presented in a specific safety study for completeness. In the opinion of the authors, the MLD approach is more systematic and self consistent for the purposes of identifying IE in the sense that the latter are used in qualitative or quantitative risk assessment following the methods and procedures presented in [10]. As an example of the difference in the philosophical approach of the two methods we offer the only example presented in [11], namely the direct cause of "containment bypass" and the corresponding generic fault tree. In [11] this direct cause is labeled as "operator error" and the corresponding generic tree is developed in terms of possible "human errors". In contrast, in the MLD setup, the analyst is guided to think what safety functions are there to guarantee containment isolation when a tank is loaded with a hazardous material (IE) and this will lead to identifying as possible causes of loss of containment, the failure of alarms and/or interlocks in addition to human errors. As a result, in the AVRIM approach a set of predetermined accident scenarios is offered to the analyst while the MLD approach guides the analyst into identifying all possible scenarios in the particular installation through the identification of initiating events.

5. Conclusions

The Master Logic Diagram technique, for initiating event identification was presented in this paper. The generic MLD, described in Section 2, may be specialized and applied to chemical plants, such as the case study of the ammonia storage plant. It is a powerful tool for initiating event identification in process plants, since it provides in a straightforward way all specific initiating events of a process plant. HAZOP provides Top Events, not initiating events and IE's can only be identified as causes of deviations or as deviations. AVRIM2 provides a list of generic scenarios against which the completeness of a safety study can be checked, whereas MLD provides a structured approach into the identification of application specific initiating events. These IEs can then be used to develop installation specific accident sequences in a way particularly suitable for qualitative and/or quantitative risk assessments.

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