THE METHODOLOGIES USED IN FRANCE FOR DEMONSTRATING RISK CONTROL OF MAJOR ACCIDENT: A HERITAGE OF ARAMIS PROJECT ?

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Abstract

French regulations regarding risk prevention and risk management were mainly reinforced by the law, introduced on July 30, 2003, which defines both prevention measures and repair conditions for the damage caused by industrial and natural disasters. Since then, regulations have been made considerably tighter and the entire approach towards risk assessment has changed.

This law has developed very interesting tools for risk assessment and risk management (some of which are unique worldwide) and has initiated the use of frequency and probability in the French system. Better information to the public, stronger regulations, new methodology for safety reports, over-hauling of land-use planning and improved accident analysis are some of the mainstays of the law.

Regarding the introduction of frequencies and probabilities, as operators in France are free to choose the methodology of probability assessment, it is interesting to review the different methodologies used by operators, with their advantages and disadvantages.

Some of these methodologies are based on the ARAMIS project which has defined a methodology for risk assessment.

This article aims to present major different methodologies used by operators.

Keywords: probability, land-use planning, frequency, safety barrier, risk assessment, bow-tie, major accident

1. Introduction

Co-funded under the 5^{th} EC Framework Programme, ARAMIS ("Accidental Risk Assessment Methodology for IndustrieS") was a three-years project that started in January 2002. ARAMIS overall objective was to build up a new "Accidental Risk Assessment Methodology for IndustrieS" that combines the strengths of both deterministic and risk-based approaches, and aimed at becoming a supportive tool to speed up the harmonised implementation of SEVESO II Directive in Europe [1].

This project took place in a particular context in France after the AZF accident (on September 21, 2001, in Toulouse). Discussions were carried out at various levels (competent authorities, local authorities, industry, experts…) to elaborate solutions aimed at improving the prevention and management of risks generated by hazardous industrial sites. A new law was introduced on July 30, 2003, which defines both prevention measures and repair conditions for damage caused by industrial and natural disasters [2].

The entire approach towards risk assessment has changed. Before 2003, risk assessment was based on the worst-case scenario. It was a deterministic approach. The law of July 30, 2003 now requires that the risk analysis, made in the context of the safety report, takes into account the probability of occurrence, the kinetic and the gravity of potential accidents [3]. It specifies precisely and objectively the conditions under which an industrial site can be operated in a build environment. The assessment takes into account reducing the risks at the source, by cutting down the hazard (i.e reducing the quantity of used / stored dangerous substances…), or reducing the probabilities of occurrence of the potential accidents and limiting the consequences through organizational and technical safety measures. Nevertheless, it should be noted that the French regulation does not make compulsory a specific risk assessment methodology, as long as the operator justifies his or her choice.

The location of AZF factory in a very urbanized environment, which suffered catastrophic damages, strongly marked the minds and revealed the limits of land-use planning tools that existed until then. All these tools were intended to avoid aggravating the existing situations by preventing the increase of land use around industrial sites. It was necessary to go further by adopting a policy of gradual reabsorption of excessive promiscuity between hazardous installations and inhabited areas. The Technological Risk Prevention Plan (PPRT) is one of the flag-ship measures of the law of July 30, 2003. The aim of the PPRT is to protect people by acting on the existing urbanization and also by controlling the future land-use planning in the vicinity of the existing top-tier Seveso establishments.

Among the different features of the ARAMIS project, this paper focuses on those that have inspired some aspects of the regulation and that are currently commonly used in France for demonstrating risk control of major accident in the new regulation framework, especially:

- the use of bow-tie diagrams for the identification of the major accidents scenarios;
- the assessment of the probability of occurrence of dangerous phenomena, taking into account the efficiency and reliability of the safety barriers;
- the demonstration of risk control based on the combination of gravity and probability of occurrence of the accidental scenarios;
- and the interest of decisions taken by local authorities to reduce the global risk level by reducing the surrounding vulnerability (whereas the plant operator only can act on the potential hazard or risk of the installation).

The regulatory approach currently in force in France on which this article is based was wraped-up in 2010 in a regulatory guideline (circulaire du 10 mai 2010 [4]).

2. Identification of the major accident hazards using bow-ties

The identification of major accident hazards likely to occur on an industrial site is the first step of the risk analysis. This work is made possible by the methodology MIMAH (Methodology for the Identification of Major Accident Hazards) developed in the ARAMIS project.
The methodology is based mainly on the use of bow-tie diagrams (Fig. 1), centred on a critical event and composed of a fault tree on the left and an event tree on the right. Initiating events include human errors such as a mistake in a filing procedure, technical failures as the failure of a control sensor, external aggressions such as an impact of a vehicle… A critical event is generally defined as a loss of containment or a loss of physical integrity. Then, central event leads to several dangerous phenomena such as BLEVE, boil-over, pool fire, toxic cloud dispersion…
Safety systems, technical or organisational, can be placed on the different branches of the bow-tie. Safety barriers may operate for prevention (before the central event) or for protection (after the central event).

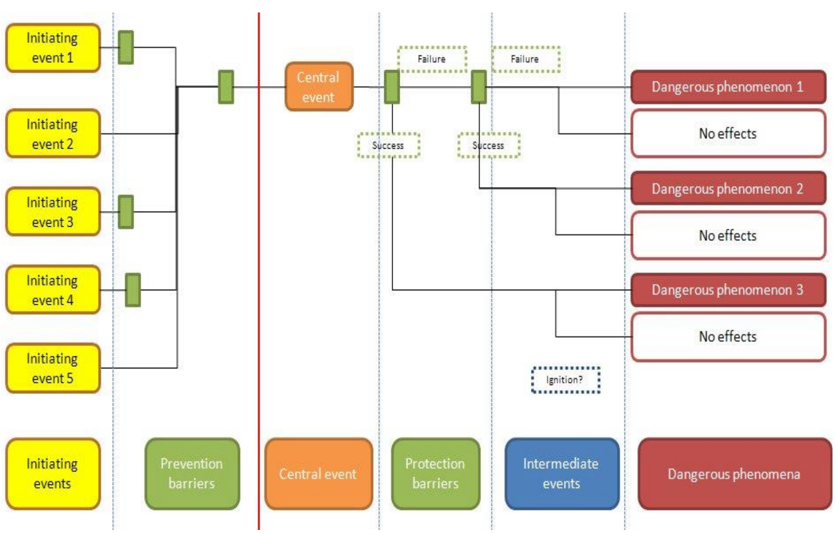


Fig.1: An example of a bow-tie diagram

The bow-tie concept is gaining in popularity and is believed to offer a good overview of the different accident scenarios considered. All causes and consequences are clearly identified on the bow-ties.
In the safety report, this tool is often used to describe more precisely the major accidents having consequences beyond the limits of the industrial site. It is used as a complementary tool to other risk analysis methodologies, like Preliminary Risk analysis, HAZOP… (methods based on the use of tables). The use of bow tie allows for a more complete analysis of every incident / accident that can happen.

3. Evaluation of the probability of dangerous phenomena

Classical risk analysis methods propose to assess the probability of major accident. But, during the ARAMIS project, this calculation of the probability was shown not to be an easy task. An inventory of the probabilistic data sources was carried out. It showed that very generic frequency ranges are usually used in these data sources, both for critical events and causes. These generic figures have to be considered very cautiously; indeed, they may have been averaged from different kinds of plants and substances, the safety systems are not clearly identified in figures and the global level of safety of the considered plants is unknown. Eventually, the use of generic figures does not underline the efforts made by the industrialists on their specific site both in prevention and mitigation, and in their safety management system.

An alternative method was also proposed, which really takes into account the safety barriers implemented on the industrial site [5]. Indeed, the ARAMIS project proposes the assessment of the frequency of the accident scenarios starting from the original frequency of occurrence of the deep causes and by reducing it taking into account the probability of failure of the safety functions identified on each scenario. An evaluation of the barriers is performed to validate that they are relevant for the expected safety function and to assess their probability of failure.
The calculations of the safety functions probabilities of failure are carried out according to the principles derived from the Safety Integrity Level concept (SIL) introduced by IEC 61508 [6] and IEC 61511 standards [7] (extended to all active barriers) and according to the known reliability of the safety barriers.

In order to be considered, a safety barrier (technical or human) has to meet the following requirements. It has to be:

- independent: the safety barrier must be independent of the causal events of the scenario and independent of other safety barriers (or in case of dependence with other safety barriers it must be taken into account when assessing the reliability);
- effective: able to fulfil the safety function that it was chosen for, in its usage context, for a period of process operation;
- with a response time in accordance with the kinetic of the scenario;
- testable;
- covered by preventive maintenance designed to guarantee that performance levels are maintained over time.

These developments were the basis of a methodology described in the Ω 10 and Ω 20 reports (INERIS 2005 and 2006) (see Fig. 2). The assessment is based on the evaluation of each component of the barrier with regards to three criteria: effectiveness (Eff), response time (RT) and level of confidence (LC). The level of confidence is then converted into a “risk reduction factor” (RR). The risk reduction factor represents the amount by which the presence of a given barrier would divide the frequency of a given scenario. For example, if a scenario (defined as the sequence of events initiated by an initiating event and leading to a given hazardous phenomenon) has an initial frequency of 10^{-1} occurrence per year, adding a safety barrier with a risk reduction factor of 10 to prevent its occurrence would result in a frequency of the final hazardous phenomenon of 10^{-2}/year. In order to assess the risk reduction factor of the whole barrier, an aggregation of the data related to its components is realised. The assessment of each component is guided by a questioning process as described in the Ω 10 and Ω 20 reports.

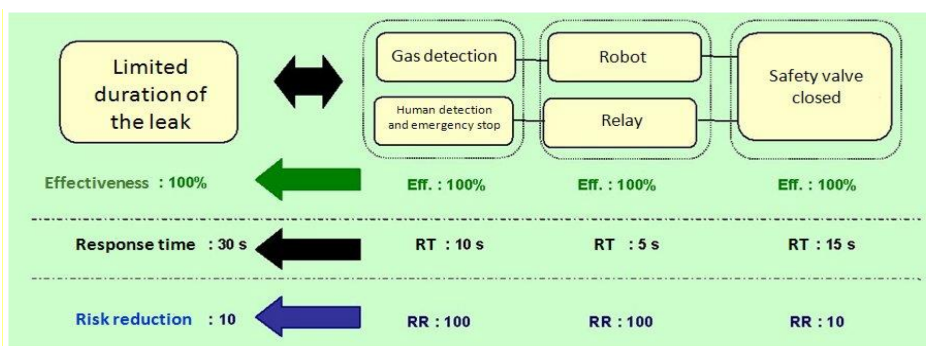


Fig. 2: An example of the assessment of a barrier according to the Ω 10 methodology

The safety management has a strong influence on the capacity to control the risk, and hence for the evaluation of barriers performance. The approach in ARAMIS consists in devising a process-oriented audit protocol focusing on the activities relating to the life cycle of the safety barriers including design, installation, use, maintenance and improvement activities.

As operators are free to choose the methodology to be used in the safety report for assessing the occurrence probability of a dangerous phenomenon, the methodologies can be very different. Since 2005, two main methodologies have been used for major accident probability assessment:

- Quantitative evaluation "from initiating events to dangerous phenomena" (as proposed by the ARAMIS project);
- Quantitative evaluation "from the central event to dangerous phenomena".

This later methodology uses generic frequencies for central events that are independent from the actual implementation of prevention safety barriers. Only the control or protection safety barriers, which become active after a central event has occurred are taken into account.
These two methodologies are approximately equally used. Their principle is presented in figure 3.

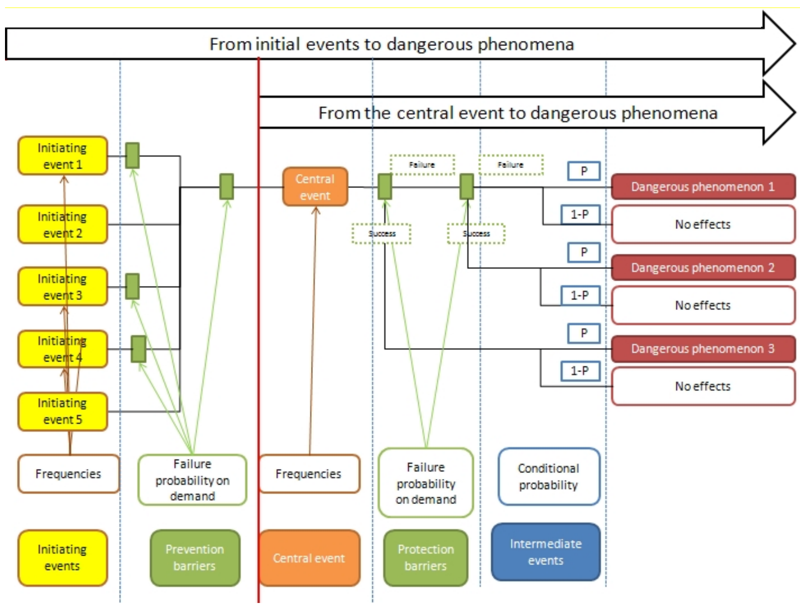


Fig. 3: The two mains methodologies used in France
for the assessment of dangerous phenomena occurrence probability

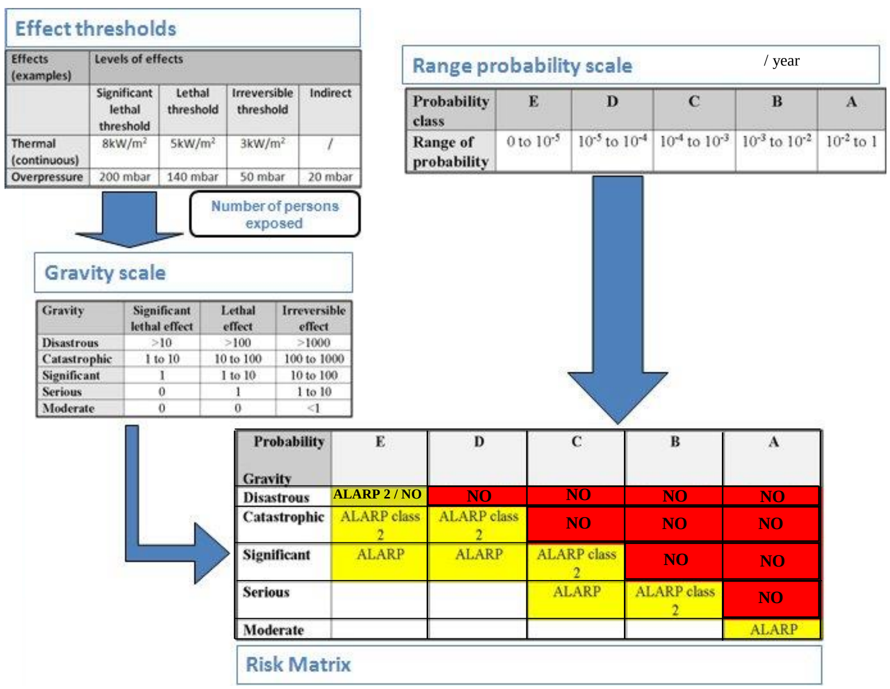
5. Demonstration of risk control and acceptability

The risk analysis has the purpose to demonstrate that the industrial site has a good level of risk control. This risk control is built on the reduction of the frequency of occurrence of the major dangerous phenomena taking into account the safety barriers, so that the dangerous phenomena are finally assessed with an acceptable combination of gravity of their consequences and frequency of occurrence. The consequences are defined by combining the intensity of the hazardous phenomenon (i.e. distance to regulatory effect thresholds) with the potentially impacted population.
The dangerous phenomena are then ranked according to their classes of probability and consequences in a risk matrix where acceptable risk levels are defined by regulation. This approach is interesting because it encourages the plant operators improving the management of risks by defining clear risk reduction targets. It takes into account the existing risk reduction measures, and provides recommendation for additional safety measures in case some scenarios have insufficient risk control.

The concept of risk matrix, as promoted in the ARAMIS project, was adopted by the French government, which has indeed developed a risk matrix for assessing the societal acceptability of the risk generated by a Seveso establishment. The input data are the probabilities of major accidents and the number of people potentially exposed to their consequences.

The matrix (see Fig. 4) defines three levels of accidental risk:

- Acceptable (in white on the matrix): the risk is acceptable because both its consequences and probability are low;
- ALARP (As Low As Reasonably Practicable, in yellow): the risk has to be reduced in order to become "as low as reasonably practicable";
  The operator has to add additional safety measures in order to reduce the risk as low as possible, given an acceptable cost/effectiveness ratio.
- Unacceptable (in red): the risk is too high;
  The safety must be improved in order to reduce the gravity or the probability and, as a matter of fact, move the accident to the yellow zone. If accidents still remain in the red zone in spite of an improvement of the safety, the establishment is liable to be closed.



Effects (examples)	Levels of effects			
	Significant lethal threshold	Lethal threshold	Irreversible threshold	Indirect
Thermal (continuous)	8kW/m²	5kW/m²	3kW/m²	/
Overpressure	200 mbar	140 mbar	50 mbar	20 mbar

Probability class	E	D	C	B	A
Range of probability	0 to 10^{-5}	10^{-5} to 10^{-4}	10^{-4} to 10^{-3}	10^{-3} to 10^{-2}	10^{-2} to 1

Gravity	Significant lethal effect	Lethal effect	Irreversible effect
Disastrous	>10	>100	>1000
Catastrophic	1 to 10	10 to 100	100 to 1000
Significant	1	1 to 10	10 to 100
Serious	0	1	1 to 10
Moderate	0	0	<1

Probability / Gravity	E	D	C	B	A
Disastrous	ALARP 2 / NO	NO	NO	NO	NO
Catastrophic	ALARP class 2	ALARP class 2	NO	NO	NO
Significant	ALARP	ALARP	ALARP class 2	NO	NO
Serious			ALARP	ALARP class 2	NO
Moderate					ALARP

Fig. 4: A simplified risk matrix and its input data: effects thresholds, gravity and probabilities.

6. Vulnerability mapping and land-use planning

An innovative attempt from AMARIS project is to address the vulnerability of the environment independently of the hazardous site. On a given spot of the environment, the vulnerability is thus characterised by the number of potential targets (human, environmental or material) and their relative vulnerability to different phenomena. The global vulnerability is a linear combination of each target vulnerability to each type of effects for the various types of impacts (overpressure, thermal radiation, gas toxicity or liquid pollution). The ARAMIS project also showed the value of using GIS for mapping vulnerable areas.

These elements contributed to the discussions around the creation of PPRT, new tool for the land-use planning introduced by the law of July 30, 2003.

The most important stages of PPRT are the following:

- Determination of the *aléa*[1] by combining the probability of a dangerous phenomenon and the potential intensity of its effects. Aléas are calculated for each point of the territory and for each type of effects (thermal, overpressure and toxic effects);
- Analysis of the stakes in the vicinity of the establishment. The types of construction and public buildings are distinguished;
- Cross-reference of the *aléas* and the stakes, allowing to draw a zoning map.

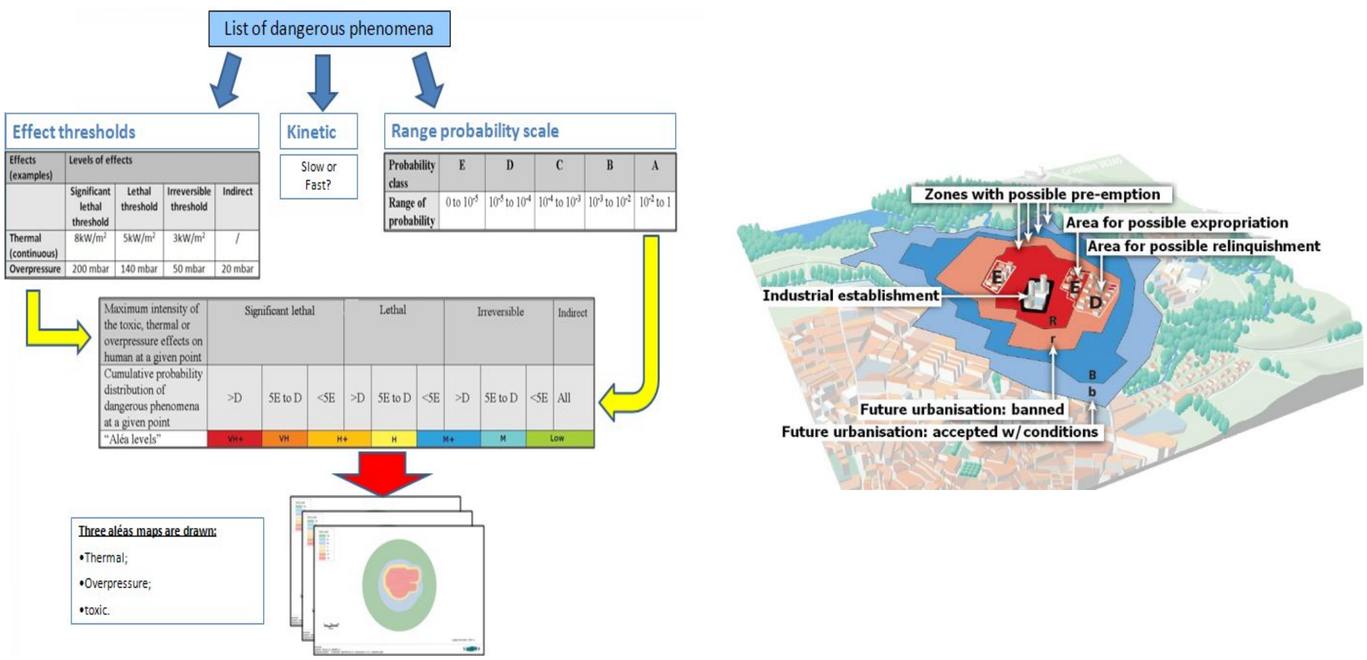


Fig. 5: Simplistic scheme presenting the elaboration process of a PPRT

When the PPRT is finalized, it delineates a risk exposure perimeter, at the heart of which regulated zones are established. These zones can be either:

- "ban zones", within which future constructions are banned. Inside this zone, areas can be defined for expropriation or relinquishments;
- or "limitation zones", within which protective measures on the future or existing buildings can be compulsory.

7. Conclusion

The law of July 30, 2003 has introduced the use of probabilities and frequencies into the French legislation and regulations regarding industrial risks. The risk analysis, at the heart of the safety report, has now to take into account the probability of occurrence, along with the kinetic and the gravity of the potential accidents. Combined with the gravity of potential accidents, the probability is used to assess, using a regulatory risk matrix, the acceptability of an industrial establishment in its environment and the demonstration of risk control. Then, for land-use planning, probabilities and intensities of hazardous phenomena are used for the calculation of the *aléas*. Combined with an analysis of the stakes, they are used for the elaboration of the PPRT, which constitutes the basis for land-use planning decision, including the possibility to reduce existing land use if the risk cannot be further reduced at the source.
To respond to these changes concerning the identification, assessment and prevention of risks, the results of the ARAMIS project have been very useful.

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[1] *Aléa*: Probability that a dangerous phenomenon creates effects of a given intensity, and over a determined period of time at a given point of the territory.

Points are still open to discussion and questions:

- The authorities and the operators have faced some difficulties in this new context for safety report elaboration requiring the quantification of the probability of occurrence of major accidents, due to the lack of available data. Uncertainties exist for the calculation of these probabilities. To overcome this difficulty, some operators have put in place feedback analysis on their initiating events, on the failure of their barriers to obtain probability values closer to the experience of their installations, and thus to take them into account during the upcoming revisions of the safety reports.
- It can be noted that the gravity of major accidents is currently evaluated in the safety reports exclusively by taking into account the human consequences outside site (exposed persons). It might also be interesting to integrate the assessment of environmental consequences of major accidents into the risk assessment process.
- There is an advantage to having a P/G risk matrix setting national criteria for risk acceptability, as it helps the authorities to prioritize actions to be requested from the operator to reduce risk and hence promotes a homogeneous treatment on French territory. Yet it turns sometimes difficult to apply the ALARP principle, as the assessment of what is "reasonably practicable" may be different between the operators and the authorities in charge of enforcing the regulation. Differences have even been observed between regional offices of the national authorities. And setting the limit of what can be imposed to the plant operator is difficult, when the risk exists of closing the industrial site for economic reasons.
- Although the interest of the PPRT in evident, in order to avoid the recurrence of accidents with major consequences, the introduction of this new tool is felt unfavorably at local level and for the large public. The elaboration procedure is long and difficult to implement, as it involves many actors. The dissatisfaction is also due to the measures resulting from the PPRT that directly impact the local residents and economic activities (expropriation / relinquishment, reinforcement of building structure…). Actions are still under way to promote the effective implementation of the PPRTs.

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