The role of Individual and Societal Risk in the ALARP demonstration for Pipelines

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The use of risk assessment is well established in the pipeline industry. Quantified risk assessment (QRA) has been used for many years as part of the design process and during operations, in connection with land use planning and assessing the impact of code infringements of onshore pipelines. International codes and standards include a requirement for periodic review of the pipeline location classification and to ensure that risks are appropriately managed. This includes demonstration that the pipeline risk is as low as is reasonably practicable (ALARP). Risk assessment approaches range from fully qualitative to fully quantitative. Risk assessment using quantitative methods is required in a number of standards (for example IGEM/TD1 and PD 8010-3) for formal ALARP assessment.

Detailed guidance on how pipeline QRA should be carried out is provided in pipeline codes, such as IGEM/TD/2 and PD 8010-3. This guidance emphasises the use of societal risk in the form of a FN curve (cumulative frequency, *F*, of accidents causing *N* or more casualties). Individual risk is used for land use planning in setting consultation zones and making decisions on proposed developments. Pipeline QRA, using individual and societal risk results, is used in the demonstration of ALARP, where comparison is made of the cost benefit of alternative risk reduction measures.

The purpose of this paper is to review the role of individual and societal risk in determining the benefit associated with implementing particular risk reduction measures. A case study is presented to illustrate how the principles of cost benefit analysis have been applied to determine the required risk reduction measures at a sensitive development location on a liquefied petroleum gas (LPG) pipeline route.

Keywords: Systems, Safety, Engineering

Introduction

Ensuring public and worker safety is the primary responsibility for operators of pipelines and other facilities. This duty is formalised under the general regulatory requirement to ensure that risks of failure have been reduced to a broadly acceptable level or at least to as low as is reasonably practicable (ALARP), if in the tolerable risk region. Quantified Risk Assessment (QRA) is used to analyse the risk of a safety hazard to an individual and the overall impacted population i.e. societal risk. The results of the analysis are used to assess if the risk is acceptable or if further risk reduction measures are needed. Where further action is required, Cost benefit analysis (CBA) is performed to evaluate whether the risk is ALARP, by demonstrating if the action to reduce the risk is grossly disproportionate in cost to the reduction in risk achieved.

This paper presents discussion on the use of individual and societal risk in QRA. A case study is presented to illustrate the decision making process regarding implementation of risk reduction measures, which is based on the results of pipeline QRA and CBA. Two types of risk reduction measures are considered, one that reduces the frequency of the hazardous event and another control measure that reduces the consequences of the event.

Quantified Risk Assessment

QRA is typically used to satisfy specific regulatory requirements for the management of pipeline safety. Guidance on the use of risk assessment during the design and operation of pipelines is provided in standards such as IGEM/TD/1, PD 8010-3 and AS 2885.3. A QRA includes the analysis of the frequency and consequences of a hazard and the associated individual and societal risk.

Individual Risk

Individual risk is defined as a measure of the frequency with which an individual at a specified location is expected to sustain a specified level of harm from the realisation of specific hazards. Individual risk criteria have been published by the UK Health and Safety Executive (HSE), for example in the guidance ‘Reducing Risks, Protecting People’, or alternatively companies can adopt their own criteria.

Societal Risk

Societal risk is defined as a measure of the relationship between the frequency of an accident and the number of fatalities that will result from the accident. Societal risk is often displayed graphically in the form of the cumulative frequency, F, (usually per year) of accidents causing N or more fatalities. Criteria for assessing societal risk in terms of FN curves are presented in IGEM/TD/2 and PD 8010-3.

Use of Individual and Societal Risk in Pipeline QRA

Societal risk is generally used to determine the measure of acceptability of pipeline risk, as the hazards associated with pipelines tend to be high consequence, low frequency events where significant numbers of people may be at risk in a single event. It is noted that at the design stage, pipelines may be routed away from populated areas or suitably protected, based on the results of risk assessment. During pipeline operation, population densities close to the pipeline may have increased over time, thereby requiring risks to be reassessed to ensure that they remain ALARP.

Individual risk is primarily used in conjunction with the HSE requirement on the provision of land use planning advice for major accident hazard facilities and pipelines. It should be noted that the use of 'local societal risk' by the HSE in connection to land use planning was the subject of a public consultation by the HSE followed by the publication of a technical issues document (Research Report RR703). To date, there has been no decision by the government in support of 'local societal risk' by the HSE in the context of land use planning.

HSE guidance for assessing overall risks and undertaking an ALARP assessment is also available in the context of Control of Major Accident Hazards (COMAH) SPC/Permissioning/37. Such guidance can be equally applied to pipelines. In particular, SPC/Permissioning/37 makes it clear that the adoption of relevant good practice will meet the 'All Measures Necessary' requirement under COMAH when the societal risk can be shown to be in the acceptable risk region. This approach is consistent with that given in the pipeline standards IGEM/TD/2 and PD 8010-3. It is noted that SPC/Permissioning/37 includes the requirement to consider both societal and individual risk.

Case Study

The following sections describe a case study to illustrate the use of individual and societal risk in pipeline QRA.

A liquefied petroleum gas (LPG) pipeline is routed predominantly through residential areas. However, a 200 m long section passes through an area of increased population, which includes sensitive developments such as a pre-school centre, a school, and a proposed integrated child care centre development. The pipeline operator required a QRA to assess the safety risks and aid the decision making on the risk reduction measures to be implemented in the locations of the sensitive populations.

The key pipeline details are presented in Table 1.

Parameter	**Value / Description**
Diameter	4 inch
Wall Thickness	6.02 mm
Grade	API 5L Grade A
Pipe Type	Seamless
Maximum Allowable Operating Pressure	27.56 bar
Operating Pressure	20.68 bar
Construction Date	1961
Pipeline Length	4.54 km

Table 1: Pipeline Design and Operating Data

It is noted that the full assessment includes analysis of a number of different failure scenarios, population occupancy scenarios and risk reduction measures. However, for illustrative purposes, the results from the case study presented in the following sections are based on the threat posed by third party mechanical activity with failure modelled using a small and large leak (using a 90% and 10% frequency split, respectively). Risk reduction by implementing concrete slabbing plus marker tape and the provision of remotely actuated pipeline isolation valves is considered.

Individual Risk Results

The calculated individual risk of fatality per annum from pipeline mechanical damage due to third party activity is shown in the form of a pipeline risk transect, as presented in Figure 1. The individual risk has been calculated for both indoor and outdoor occupancy, assuming 100% occupancy in each case.

The maximum individual risk has been calculated to be 5.58 x 10^{-6} per annum, based on outdoor occupancy (see Figure 1). The selected risk acceptability criteria for the pipeline, based on local tolerability criteria provided by the operator, are as follows:

Intolerable risk – 1 x 10^{-5} per annum

Broadly acceptable risk – 1 x 10^{-7} per annum

Based on the above data, it is concluded that the individual risk lies towards the top of the ALARP risk region and thus consideration of further risk reduction measures is required.

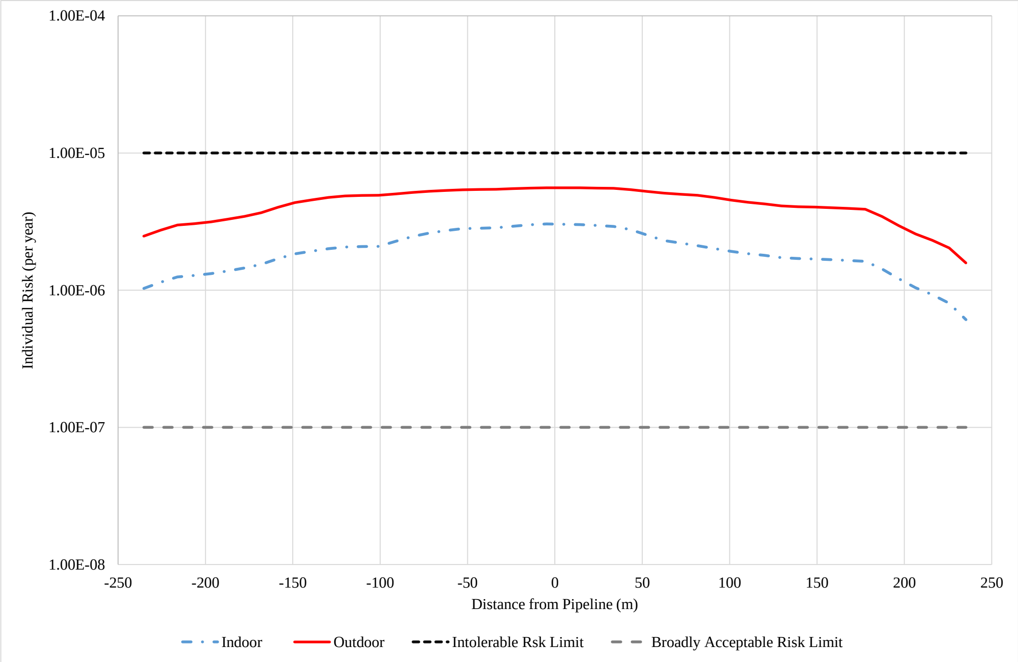

Figure 1: Pipeline Individual Risk Transect

Societal Risk Results

The calculated societal risk for the identified sensitive populations, estimated day and night time populations of 1530 and 1052 respectively (with an assumed 0.33:0.67 split between day and night respectively), is presented in Figure 2.

The maximum and minimum criterion shown on Figure 2 are set in accordance with the guidance given in PD 8010-3. The unacceptable region, the maximum criterion line on the FN curve, presented in PD 8010-3 was developed based on an approach advocated by the HSE. The minimum criterion line on the FN curve for broadly acceptable risk is set as two orders of magnitude below the maximum. It is noted that the PD 810-3 curve for societal risk is applicable to 1 km of pipeline. Therefore, the criterion lines have been adjusted by a factor of two for use in this case study, as the site specific pipeline interaction distance is approximately 500 m (based on the length of the development plus twice the calculated maximum hazard range).

Based on the data in Figure 2, it is concluded that the societal risk for the sensitive populations lies in the tolerable if ALARP risk region and thus consideration of further risk reduction measures is required.

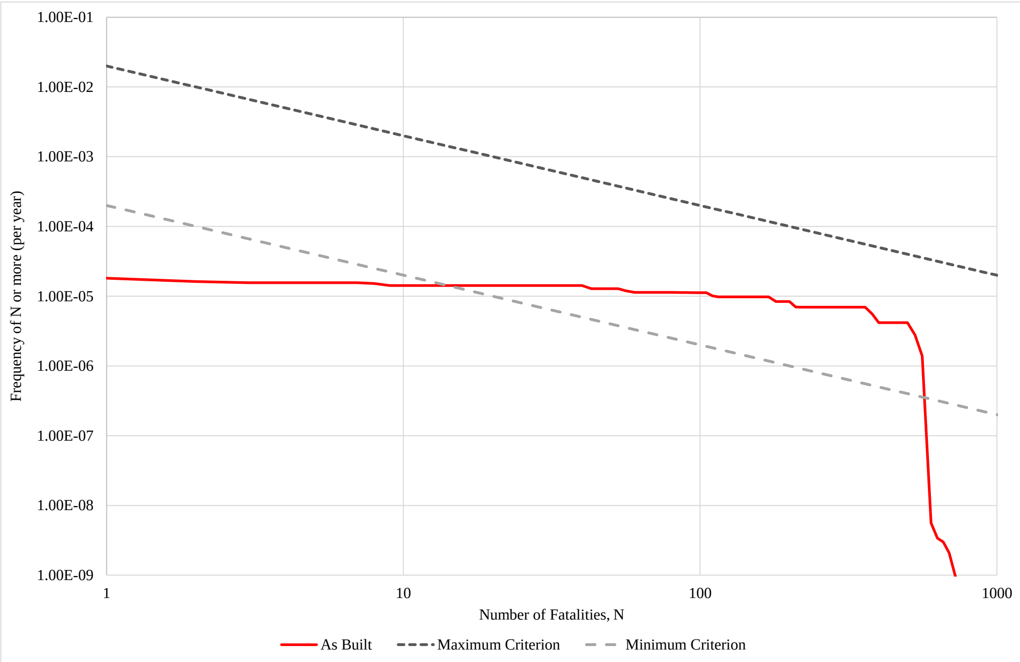

Figure 2: Pipeline Societal Risk

Cost Benefit Analysis Results

The principal of CBA when applied to pipeline risk assessment is to determine the balance between the benefit of the risk reduction measures against the cost of implementation. This is calculated using the estimated number of fatalities averted, expressed as a monetary value, and the cost of the risk reduction measure with a suitable gross disproportion factor. To estimate the number of fatalities per annum averted by implementation of the control measure, both the individual and societal risk results are used.

Individual and Societal Risk Results with Risk Reduction Implemented

The impact of installing slabbing plus marker tape has been assessed by applying a risk reduction factor of 0.125 to the pipeline failure frequency, in accordance with the guidance issued in IGEM/TD/2. This reduces the calculated individual risk of fatality to 6.98 x 10^{-7} per annum; however, this risk is still above the broadly acceptable risk level of 1 x 10^{-7} per annum.

For the individual risk case, the predicted number of fatalities averted can be determined from the individual risk value and the associated population exposed to that risk level. In this case, the predicted number of fatalities averted is 5.81 x 10^{-3} per annum.

The societal risk results accounting for the installation of slabbing plus marker tape are presented in Figure 3.

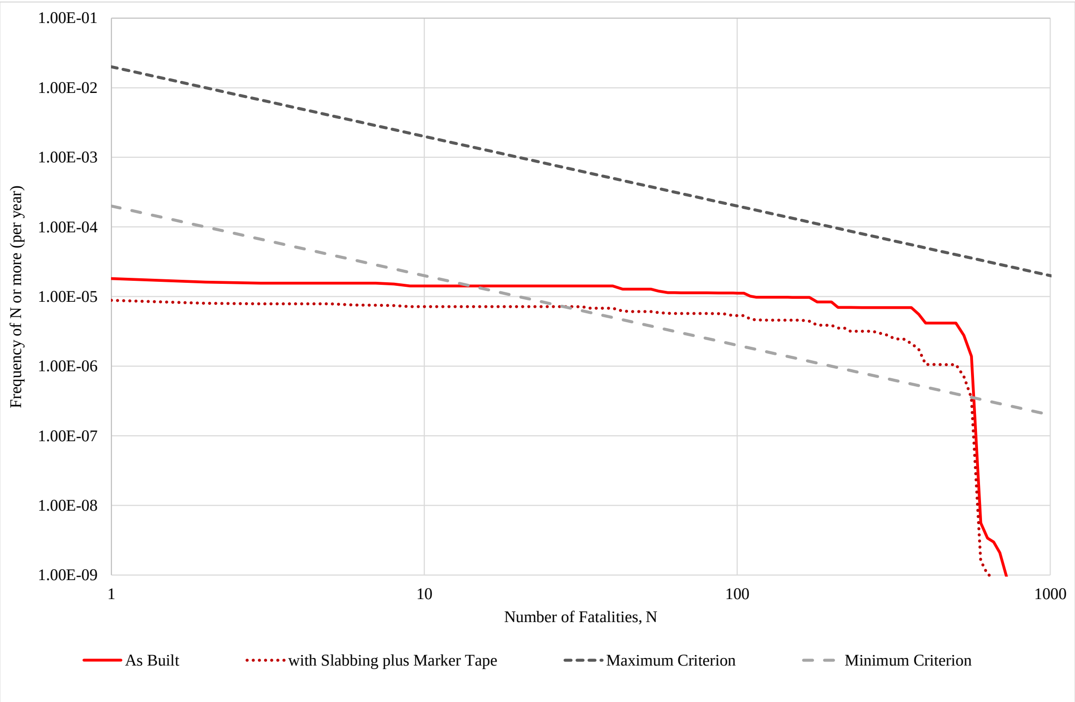

Figure 3: Societal Risk (with Slabbing plus Marker Tape)

As shown in Figure 3, although the societal risk has been substantially reduced, a significant part of the FN curve still lies within the tolerable risk region. Therefore, further cost benefit analysis is needed to demonstrate whether the risks are ALARP.

Implementation of slabbing plus marker tape reduces the frequency of an event associated with third party mechanical activity. Another approach to lowering risk is to reduce the consequences of failure. Consequence analysis indicates that for this pipeline the largest hazard ranges are associated with pool fire scenarios. The pipeline has a leak detection system which alerts the control room personnel who then activate the emergency shutdown (ESD) system (which includes stopping the export pump and closing the battery limit isolation valve). This process is assumed to take 10 mins. A control measure that has been considered comprises automatic ESD activation (in this case within 1 minute) plus installation of remotely actuated pipeline isolation valves either side of the sensitive populations. The main impact of implementing such a measure is to reduce the maximum size of the pool fire and hence lower the number of calculated fatalities. An additional impact, is that the site specific pipeline interaction distance will be reduced which will in in turn affect the positioning of the societal risk criterion lines as the PD 810-3 curve for societal risk is applicable to 1 km of pipeline. In this case the case specific pipeline interaction distance is reduced from 500 m to 440 m. Therefore the criterion lines have been adjusted by this ratio. Figure 4 presents the societal risk results implementing slabbing plus marker tape and the additional remotely actuated pipeline isolation valves.

Figure 4 shows that the FN curve has been reduced further; however, part of the FN curve still lies within the tolerable risk region. Therefore, further cost benefit analysis is needed to demonstrate whether the risks are ALARP.

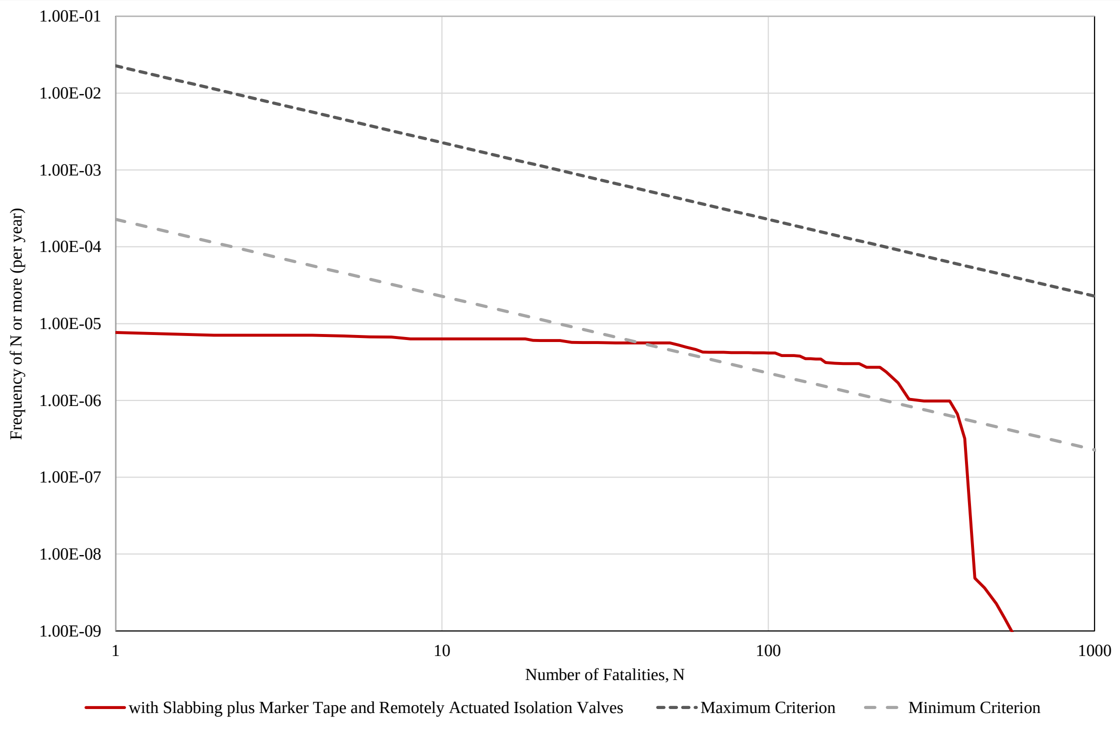

Figure 4: Societal Risk (with Slabbing plus Marker Tape and Remotely Actuated Isolation Values)

It is also noted that the impact of implementing this additional control measure will also reduce the calculated individual risk of fatality in the far field but has little or no impact on individual risk closer to the pipeline. In this case, the cost benefit analysis using societal risk is more useful in demonstrating whether the risks are ALARP.

Cost Benefit Calculation

The cost benefit calculation uses the number of fatalities averted per annum, the remaining operational life of the pipeline and the monetary value of averting a fatality.

In the case of societal risk, the average number of fatalities averted can be determined from the sum of the FN pairs, also known as the Expectation Value. In the case of implementation of slabbing and marker tape, the predicted average number of fatalities averted is 2.41 x 10^{-3} per annum. Incorporating the additional remotely actuated pipeline isolation valves reduces the average number of fatalities averted value by a further 6.53 x 10^{-4} per annum.

The cost benefit calculation compares the cost of implementing the risk reduction measure against the risk benefit:

Cost Benefit Ratio = Cost of Risk Reduction Measure / Benefit of Fatalities Averted

The resulting cost benefit ratio is then compared with a gross disproportion factor. This gross disproportion factor is generally a value of between 1 and 10 dependant on level of risk (based on SPC/Permissioning/37). If the cost benefit ratio is less than or equal to the gross disproportion factor, then implementation of the risk reduction measure is justified.

The cost benefit ratio, incorporating the slabbing plus marker tape cost estimate of £200,000 for the risk reduction measure is 1.92 and 4.15, using individual and societal risk respectively. Accounting for the additional installation of the remotely actuated pipeline isolation valves, which increases the cost estimate by £150,000, the cost benefit ratio is 11.5, based on the societal risk results. If a gross disproportion factor of 10 is applied, based on the level of risk and the sensitivity of the populations, then installation of the slabbing plus marker tape is justified on the basis of both the individual risk and societal risk results. However, the installation of the additional remotely actuated pipeline isolation valves is not justified.

Case Study Conclusions

The results of the cost benefit analysis show that the installation of slabbing plus marker tape is justified at the location of the sensitive developments along the pipeline route, based on the individual and societal risk results respectively. However, the individual and societal risk levels calculated with this risk reduction measure is still within the tolerable risk region. When the additional risk control measure of installing pipeline isolation valves is considered, the cost benefit analysis estimated the cost of the risk reduction measure is disproportionate to the risk reduction. However, to justify the risks at this location are ALARP, consideration of further risk reduction measures, such as increased depth of cover or replacement of the pipeline with an increased impact resistant design, are required.

Discussion

Both societal risk and individual risk should be evaluated to show that the risk is in the broadly acceptable risk region and if not then that risk should be shown to be ALARP. The case study presented, considered both individual and societal risk and risk reduction measures which impacted the frequency and consequences of failure. The results of the cost benefit analysis show that the risk reduction measure of slabbing plus marker tape is justified, based on both the individual and societal risk results. However, the risk reduction measure of remotely actuated pipeline isolation valves is not justified, based on societal risk results. It should be noted that this case study is based on the implementation of slabbing plus marker tape. There are additional risks related to the installation of this risk reduction measure and these risks also need to be assessed as part of the overall ALARP demonstration. It is not necessarily the case that these installation risks need to be assessed using QRA and cost benefit analysis. Use of other qualitative or semi quantitative techniques may be more appropriate.

While the benefits of using societal risk in the case of pipeline risk assessment are well established, in the UK there is no regulatory guidance on the criteria for acceptable societal risk levels, only for individual risk. To date, the HSE takes account of 'local societal risk' in its provision of land use planning advice, with such decisions undertaken as a combination of individual risk and the nature of the development including its sensitivity and the number of people involved. However, the HSE do propose that the risk from an accident causing the death of 50 people or more should be regarded as intolerable if the associated frequency is more than one in five thousand per annum. Although, to construct an FN curve requires assumptions regarding the tolerability of other combinations of FN pairs. Acceptable levels of societal risk are presented in pipeline codes such as IGEM/TD/1 and PD 8010-3, the criterion applicable to 1.6 km and 1 km of pipeline, respectively. It is noted that when using these societal risk criterion, account must be taken of the length of the assessed pipeline section.

Individual risk calculations also have their limitations including the absence of any universal consensus on the limits for tolerable and broadly acceptable risk. The UK HSE have produced guidance but companies are free to use their own criteria.

Concluding Remarks

Individual and societal risk are both important inputs to safety related hazard risk assessment. For most pipeline operators, societal risk will be the dominant consideration as pipeline hazards tend to be high consequence which may impact the public. Whilst there is no regulatory guidance on the criteria for acceptable societal risk levels, pipeline codes provide acceptable risk criteria and guidance on the use of societal risk in QRA.

The learnings from pipeline risk assessment, as discussed and illustrated in the case study presented, can be equally applied to facilities such as COMAH sites when making the required ALARP demonstration.

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