

# Qualification Program for Electrofusion Fittings



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## Abstract

Ensuring the integrity of new installations is a critical component of an overall pipeline safety and integrity management system. A methodology has been developed for the acquisition phase of the pipeline lifecycle that identifies all threats, the primary mitigations that can be applied to those threats and the detailed components that need to be included in the mitigations to ensure effectiveness. An example is provided outlining how the methodology can be applied to the development of a comprehensive qualification program for electrofusion fittings.

## Gas Pipeline Safety and Integrity

Pipeline safety and integrity management involves addressing the full lifecycle risks of a pipeline. As the future risk profile of a buried pipeline asset is largely set when the asset is installed, the acquisition phase (to use the terminology of the PAS-55 and ISO 55000 Asset Management standards) plays a critical role in the overall safety and integrity management process.

As in DIMP or TIMP programs, proper risk assessment plays a crucial role in being able to optimally manage risk and, hence, pipeline safety and integrity in the acquisition phase. Whereas the risk assessed in DIMP and TIMP is focused on assets already in existence, the risk assessment process for the acquisition phase looks at predicting future risk for a yet-to-be installed asset. While the same basic risk modeling framework can be applied, this distinction necessitates a somewhat different approach to risk assessment and risk management than that applied to existing assets. This paper details the approach developed by JANA for managing pipeline safety and integrity during the acquisition phase for the specific case of electrofusion fittings and outlines how the process can be applied to develop a comprehensive electrofusion fitting qualification program.

## Electrofusion Fittings

Electrofusion fittings are seeing increased use in gas distribution pipelines. While electrofusion (EF) joints can be highly reliable, quality components and installation techniques are necessary for ensuring the long-term integrity of the joints. The Plastic Pipe Database Committee (PPDC) has identified infant mortality failures in electrofusion joints<sup>1</sup>. Similarly, a comprehensive study of electrofusion joints in the UK<sup>2</sup> found that 20% of field joints sampled failed in destructive testing. The primary causes of failure in this study were identified as:

- Inadequate clamping or misalignment: 34%
- Contamination: 29%
- Poor scraping: 26%
- Other: 11%

<sup>1</sup> Plastic Piping Data Collection Initiative Status Report, December 2014.

<sup>2</sup> UK WIR Report Ref No 10/WM/08/43, "Leakage from PE Pipe Systems", 2011

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To ensure pipeline safety and integrity these failures, and any other potential sources of risk for electrofusion fittings, need to be addressed.

## Developing a Comprehensive Qualification Program

Proper qualification programs, including proper installation procedures and operator training best practices, can significantly mitigate these potential failures and ensure other potential issues are not introduced into the pipeline. The challenge, however, is ensuring that the qualification program that is developed is comprehensive and will be effective in preserving the safety and integrity of future installations. An approach to developing such a comprehensive program is detailed below, based on the JANAcquire55™ process.

This process involves developing Fault Trees to assess all potential threats to future safety and integrity of to-be-installed assets. At the top level of the Fault Trees are all the higher level threats (such as faulty design, manufacturing issues, installation issues, etc.). These identify the key areas where risk can potentially be introduced into the pipeline. For each of these, the fault trees are expanded to identify all potential root causes that could lead to the higher level threat. The overall Fault Tree is then used to conduct a gap analysis based on assessing the risks and current mitigations, identifying potential mitigations to address the gaps and, from analysis of the risk reduction benefits of the potential mitigations, an developing an implementation plan. The form of the implementation plan will depend on the specific asset being addressed and the specific mitigations (in the example for electrofusion fittings provided below, the development of an overall Qualification Program is examined). An iterative process is applied to address the highest return risk reduction opportunities first.

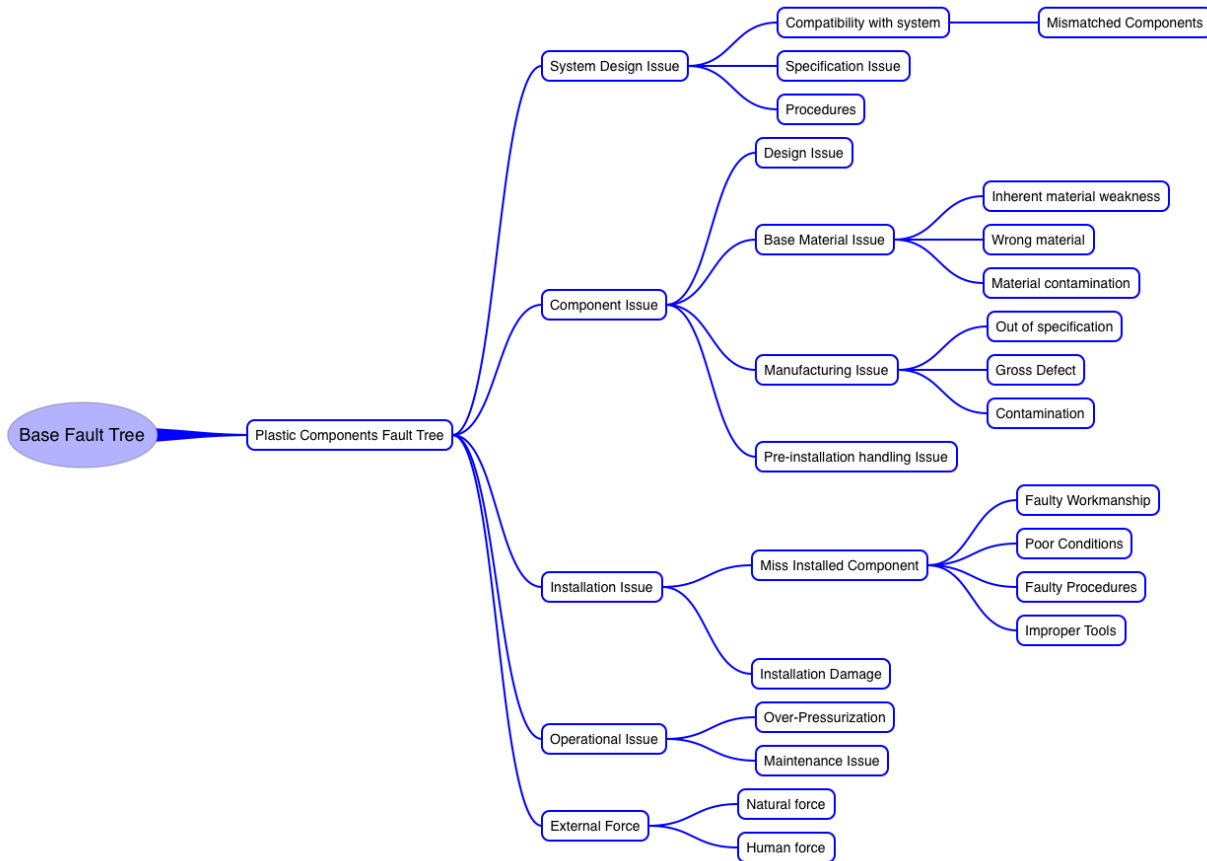
In its full implementation, the higher level branches identify the key areas to be addressed (e.g. installation error), the primary mitigations (e.g. operator training, field inspections, etc.) and the detailed root causes. Existing and potential mitigations address the details of the implementation plans (e.g. the specific details to be addressed in operator training and qualification programs). With comprehensive Fault Trees, the process ensures that all potential threats, both those known to exist in current installations and those currently not seen but that could potentially lead to significant future issues, are appropriately mitigated.

In applying the process to electrofusion fittings, a Base Fault Tree (BFT) for plastic components was used (see **Figure 1** for high level summary of the Base Fault Tree) as the starting point of the full Fault Tree development process. By using a library of BFTs developed for like components, which share many of the same threats, root causes and potential mitigations, the overall process is expedited. A group of SMEs (Subject Matter Experts) was then assembled, including manufactures, installers, failure analysis experts, etc., to develop a comprehensive overall Fault Tree for electrofusion fittings.

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Figure 1: Base Fault Tree for Plastic Components



A portion of the full Fault Tree for electrofusion fittings, focused on weld failure as the higher level event, is shown in **Figure 2** and **Figure 3**.

# Qualification Program for Electrofusion Fittings



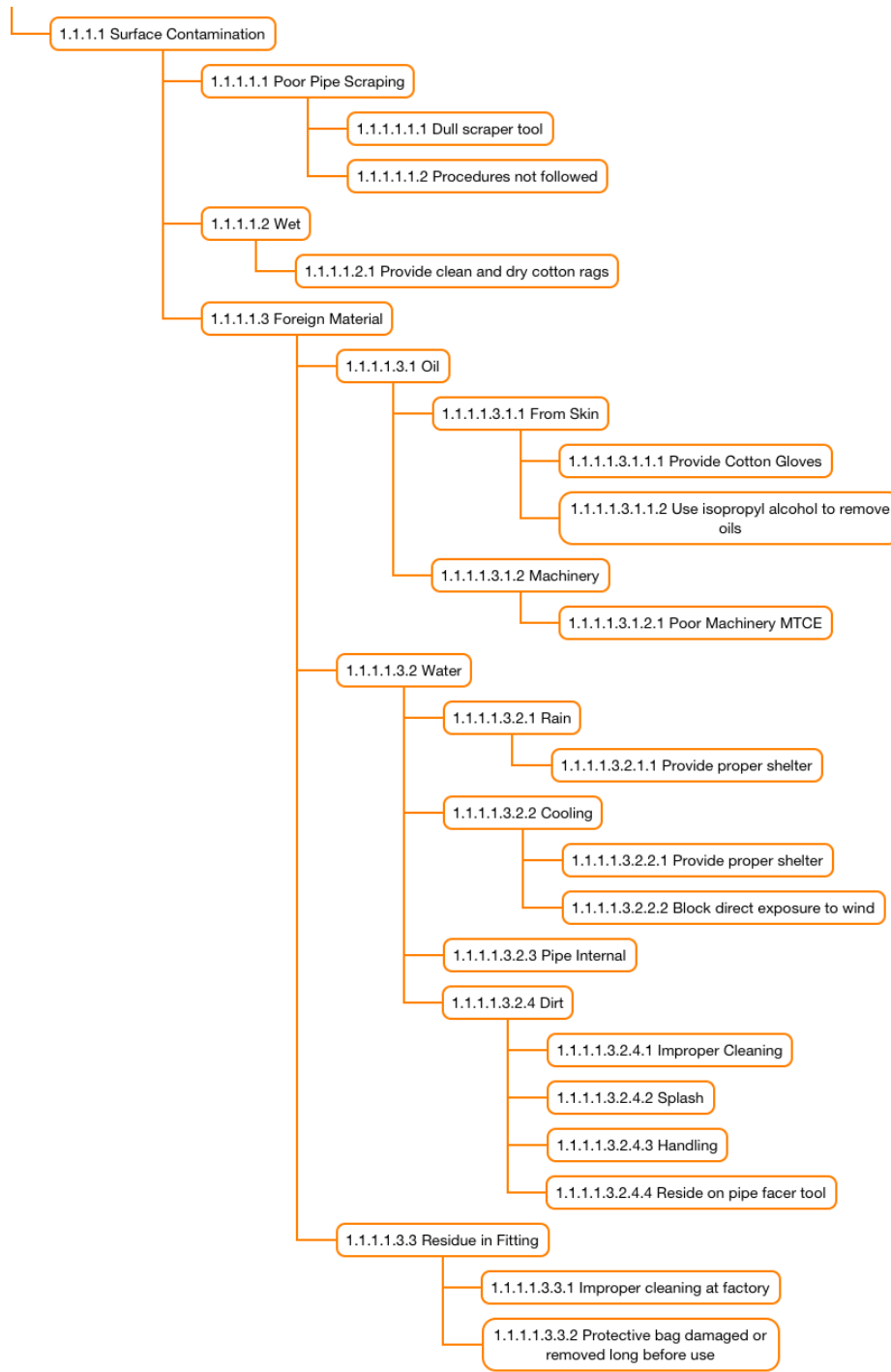
Figure 2: High-Level Fault Tree for Contaminated Electrofusion Weld



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Figure 3: Fault Tree for Contaminated Electrofusion Weld – Surface Contamination Branch



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A complete Fault Tree of this type, encompassing all possible failure paths and root causes, is typically quite involved. For a comprehensive Qualification Program, the Fault tree should contain all potential threats and sub-threats to a high level of granularity. As is shown in **Figure 3**, the Fault Tree may be very detailed; this figure shows only a single sub-branch under the failure of fusion weld branch as laid out in **Figure 2**. JANA has developed a library of such Fault Tree for the primary pipeline components in a gas distribution system to facilitate implementation of the process.

Once the overall Fault Tree is developed and assessed, the branches are typically rearranged under the primary threat areas (e.g. installation issues) to facilitate conducting the gap analysis and assessing the potential mitigations. The gap analysis assesses the risk for each threat by applying a standardized risk modeling approach to assess the probability of the threat occurring and the potential consequences based on:

$$\text{PofF} = \text{exposure} \times (1 - \text{mitigation}) \times (1 - \text{resistance}) \quad (1)$$

where:

- Exposure is an event which, in the absence of any mitigation, can result in failure if insufficient resistance exists
- Mitigation is the effectiveness of all activities designed to stop the exposure (a number between 0 and 1 representing the probability of the mitigation stopping the exposure, 1 representing 100% effectiveness)
- Resistance is a measure or estimate of the ability of the component to absorb the exposure force without failure once the exposure reaches the component (a number between 0 and 1 representing the probability of the component to resist failure)

The overall PofF is aggregated from the probabilities of each root cause branch. PofF is typically described in terms of events/mile/year or events/component/year, providing an absolute (as opposed to relative) estimate of the probability of failure.

And:

$$\text{CofF} = (\text{Hazard Zone Size}) \times (\text{Receptor Density}) \quad (2)$$

CofF is calculated for each specific threat or exposure type. CofF is typically described in terms of \$/incident. Again, an absolute—as opposed to relative—estimate is provided.

For a component like electrofusion fittings—where there exists some installation history—RCA (root cause analysis) reports, historical performance data, interviews with field personal and SMEs, audits of procedures, etc. are drawn upon to develop quantitative estimates of the risk. The process also implicitly considers potential risks that have not yet been observed in the field but could potentially lead to significant safety and integrity issues (e.g. an improperly

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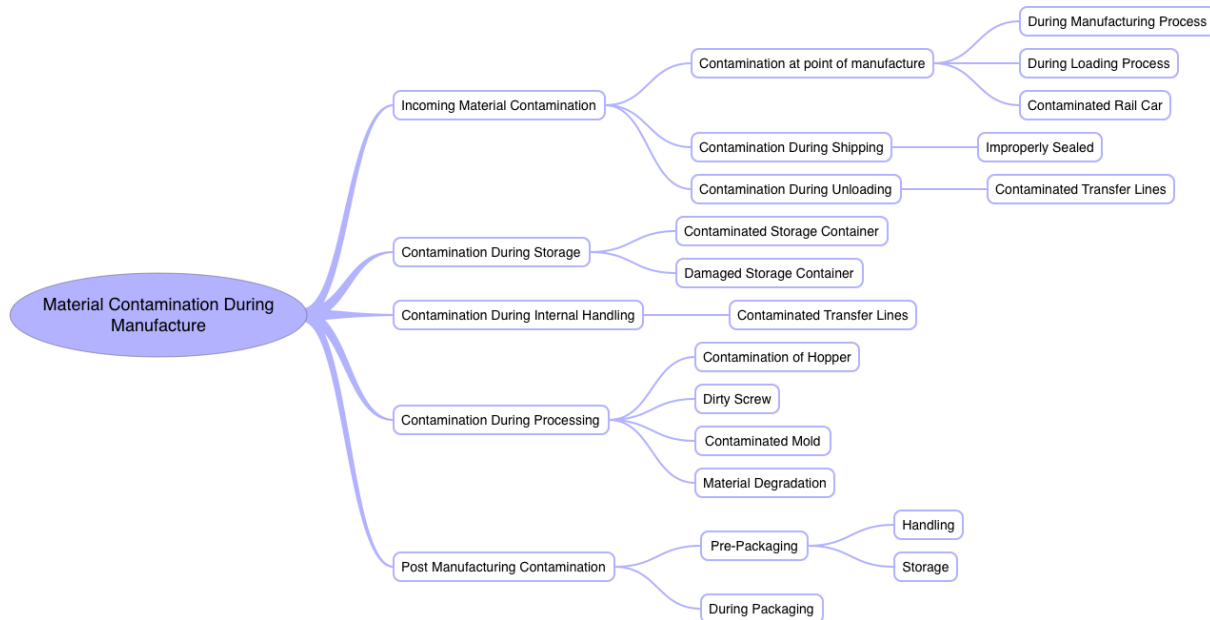
verified design change by the manufacturer that could lead to issues in all potential installations that may not manifest as field failures for several years, allowing for installation of a large number of defective components).

From this process the highest risks for electrofusion fittings are identified for the particular operator and a Qualification Program is developed. The specific higher risk areas will depend on the specific operator's existing practices. In general for electrofusion fittings, however, higher risk areas are typically seen in qualification of the design and manufacturing process, the qualification of handling and installation procedures and the qualification of installers and inspectors (consistent with the primary reported causes of field failures discussed previously).

## Using the Detailed Fault Tree to Develop a Qualification Program

By way of example, the methodology is outlined through the process of developing a Qualification Program for the design and manufacturing of electrofusion fittings. Based on the overall risk assessment and gap analysis and the operator's specific field history, it was determined that sufficient risk was present in the controls in place around the design and manufacturing process to warrant mitigating these risks. Starting with the overall full Fault Tree, all identified potential threats related to design and manufacturing root causes (including interacting threats) were aggregated to develop an overall Design and Manufacturing Fault Tree. An example branch of the Fault Tree for potential contamination during the manufacturing process is shown in Figure 4.

Figure 4: Fault Tree for Contamination during Manufacturing Process



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Current mitigations were identified and assessed to develop a Design and Manufacturing Risk Assessment. A gap analysis was then conducted to identify the effectiveness of current mitigations and further potential mitigations. It was identified that limited current mitigations were in place. From these assessments, a detailed implementation plan was developed that included specific mitigations broken out by where in the product lifecycle they could be applied (e.g. design, manufacturing, procurement, receiving and storage, etc.).

For example, technical audit guidelines for quality assessment of electrofusion fitting manufacturers were developed, along with an audit template and an auditor training program. An excerpt from the audit template for part of the audit of incoming material quality control is provided in Figure 5.

Figure 5: Excerpt from Supplier Qualification Audit Template

Incoming Material Quality Control	Complies			Comments/ Auditor Notes
	Yes	No	N/A	
Resin Supplier Quality Certificate reviewed vs Spec and Purchase Order?				
Certificate lot #/seals compared to rail car or truck?				
All rail compartments sampled for QC work?				
Resin QC Tests:				
Density (ASTM D792/D1505)				
Melt FR (ASTM D1238): 2.16 & 21.6kg				
OIT (ASTM D3350/D3895)				
Masterbatch Supplier Quality Certificate reviewed vs. spec and PO?				
Masterbatch QC Tests:				
Density (ASTM D792/D1505)				
Melt FR (ASTM D1238): 2.16 & 21.6kg				
OIT (ASTM D3350/D3895)				
Ash (ASTM D5630)				
Are there action levels established for the above measurements?				
Control charts established and up to date?				
All test equipment and standards calibrated with NIST traceable reference standards and calibrations in date?				
Copies of all current ASTM and/or internal test procedures readily available?				
Review effectiveness of system for handling non-conforming product.				
Assess system for material lot sign-off and release authority.				
Assess controls regarding product transfer to molding machines.				
Assess lab personnel training records and authorization.				



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The specific items in the audit guidelines, audit template and auditor training program were developed based on all the identified potential root causes from the fault tree, ensuring a comprehensive Qualification Program as it address all potential threats in a systematic way. The results of the Qualification Program are fed back into the risk model to update the risk assessment.

Through application to the full Fault Tree for electrofusion fittings, including design, manufacturing, storage and handling, installation, inspection, etc., an overall comprehensive Qualification Program was developed. The result is a clear picture of current risks in the acquisition phase for electrofusion fittings, the existing mitigations and their effectiveness, the greatest risk reduction opportunities and the detailed required mitigations for these risks.

## Conclusions

Ensuring the integrity of new installations is a critical component of an overall pipeline safety and integrity management system. A methodology has been developed for the acquisition phase of the pipelines lifecycle based on a structured Fault Tree process that identifies all threats, the primary mitigations that can be applied to those threats and the detailed components that need to be included in the mitigations to ensure effectiveness. By applying the process to the full Fault Tree for electrofusion fittings a clear picture of current risks in the acquisition phase for electrofusion fittings, the existing mitigations and their effectiveness, the greatest risk reduction opportunities and the detailed required mitigations for these risks is developed, enabling the operator to take appropriate action to ensure the future safety and integrity of electrofusion fitting installations.