



Classification of Weld Discontinuities in Overhead Crane Girder Fabrication by Visual Detectability and Root Cause

Arda Koymen

Mechanical Project Engineer, Advanced Overhead Systems, Tampa, Florida, USA.

ORCID: 0009-0003-2749-5787

Abstract

Weld quality assurance in overhead crane girder fabrication is vulnerable when acceptance relies solely on surface evidence. This review develops a two-axis classification that links visual detectability to process-specific root causes of discontinuities in gas metal arc welding and submerged arc welding. Ten sources published from 2021 to 2025 were examined through comparative source analysis, conceptual synthesis, and typologization. The resulting taxonomy separates directly visible material-loss and profile conditions from surface-connected indications and visually unresolved internal discontinuities. Porosity and burn-through occupy different positions in this scheme. Porosity may remain hidden unless a pore intersects the surface, whereas burn-through produces immediate evidence after metal has been displaced. Their causal pathways also diverge across shielding, surface condition, flux condition, heat input, travel speed, electrode extension, plate thickness, and fit-up. The classification supports process control, inspection planning, traceable disposition, and qualified repair of continuous web-to-flange welds in crane girder production quality systems.

Keywords: Gas Metal Arc Welding, Overhead Crane Girders, Porosity, Submerged Arc Welding, Visual Inspection.

INTRODUCTION

An overhead crane girder concentrates fabrication risk in long welded connections whose local discontinuities can affect fit, load transfer, fatigue resistance, and the amount of corrective work required before shipment. The web-to-flange connection is especially demanding because it combines extended weld length with plate-thickness transitions, accumulated heat, and limited tolerance for process interruptions that propagate along the seam. A surface that appears continuous provides useful evidence within the portion of weld quality expressed at an accessible surface.

The practical distinction between porosity and burn-through exposes this boundary. A pore that opens at the surface can be identified visually. Pores within the weld metal are not visible. Burn-through produces a hole, excessive penetration, or a local loss of metal that is apparent when the relevant surface is accessible. Yet, the observation occurs after the molten pool has lost support. Treating both conditions as a single general category of weld defects obscures the distinct moments at which quality control can act.

This article aims to classify weld discontinuities relevant to

overhead crane girder fabrication by their visual detectability and process-specific root causes. Three objectives direct the inquiry. The first distinguishes discontinuities that visual inspection can identify, that can be identified only under stated access conditions, or that cannot be verified. The second maps porosity and burn-through to causal pathways in gas metal arc welding and submerged arc welding, with continuous web-to-flange welding as the governing fabrication context. The third converts the classification into a process-control and disposition logic suitable for long seams and mixed welding processes.

To the author's knowledge, recent welding reviews usually organize discontinuities by morphology, sensing technology, or process parameter. The proposed taxonomy brings together two decisions that shop quality systems must make: whether a condition can be seen and where its cause should be sought. The hypothesis is that a visual-only acceptance barrier becomes technically coherent when visually unresolved discontinuities are controlled upstream through preparation, parameter discipline, and traceable process records, and when visible material-loss conditions trigger a defined hold and qualified repair sequence.

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MATERIALS AND METHODS

The source corpus comprised ten works published between 2021 and 2025, including peer-reviewed reviews and research articles in welding, manufacturing, materials, sensing, and non-destructive evaluation, as well as one peer-reviewed technical book chapter. Publisher records and DOI metadata were screened for direct relevance to visual or in-process detectability, GMAW process variables, SAW flux and thermal behavior, porosity, penetration control, and burn-through. Sources focused on unrelated joining processes were excluded unless their inspection principle addressed the surface-to-internal detection boundary. The thematic map covered real-time GMAW sensing [1], SAW current effects [2], SAW flux reactions [3], SAW heat input and thickness-dependent thermal behavior [4], GMAW bead response to current, wire feed, and shielding gas [5], visual signatures of GMAW discontinuities [6], signal-based weld defect detection [7], ultrasonic access to internal weld condition [8], GMAW parameter and porosity mechanisms [9], and penetration control under gap variation [10]. The fabrication setting supplied by the author includes top-running bridge cranes and monorails, spans of 30 to 100 ft, capacities up to 40 tons, web plates from 1/4 to 1/2 in, flange plates from 3/8 to 7/8 in, and GMAW or automatic SAW weld lengths from 5 to 105 ft (A. Koymen, personal communication, May 2026). These values frame the scale, thickness transitions, and seam lengths considered when applying the classification.

Comparative analysis separated observation from causal inference across the selected sources. Source analysis identified the physical signal addressed by each publication and its limits. Conceptual synthesis connected surface expression to variables in the GMAW and SAW processes. Typologization then assigned each discontinuity to a detectability class and a root-cause domain. Analytical generalization converted the two axes into fabrication controls, inspection decisions, and repair disposition.

RESULTS

Visual detectability refers to the indication available to the inspector, and its scope is narrower than that of the discontinuity itself. The same type of discontinuity can appear in different visual classes. Porosity illustrates the point. A surface-breaking pore belongs to the directly observable class because it forms a visible cavity. Porosity contained below an intact weld face belongs to the visually unresolved class. The change in class occurs when the pore intersects an accessible surface, even though the metallurgical mechanism remains gas entrapment during solidification. Recent GMAW literature explicitly recognizes pores at the surface and beneath it, and associates their formation with shielding, contamination, arc behavior, and process stability [9].

Burn-through has a different observational structure. A

through-opening, a localized collapse of the molten pool, or excessive penetration, visible from an accessible face, indicates it. GMAW image studies identify burn-through through changes in the molten-pool region, including a dark opening associated with the loss of support [6]. Penetration-control research adds a geometric condition: gap variation and lateral displacement of the heat source change the molten-pool state, and an offset arc can initiate burn-through [10]. Visual inspection can recognize the resulting condition, but the visible indication records a complete loss of metal.

The boundary of visual inspection becomes clearer when optical and volumetric methods are compared. Reviews of in-process defect detection group sensing methods by the physical signals they collect, including current, voltage, sound, optical emission, images, and thermography [7]. GMAW sensing literature similarly treats seam position, arc behavior, weld-pool geometry, and process variables as different information channels [1]. Ultrasonic inspection addresses another physical volume because reflected waves can carry information from within the joint [8]. These sources converge on one consequence for classification. A sound external profile establishes only the absence of a visible surface indication within the inspector's access, lighting, cleaning, and viewing conditions. Internal pores, buried lack of fusion, and internal inclusions remain outside that conclusion.

The directly visible class contains conditions that alter accessible surface geometry. Burn-through belongs here when the opening or displaced metal is visible. Surface-connected pores, undercut, overlap, arc strikes, craters, and marked profile irregularities also enter this class. Machine-vision research is relevant because it depends on these optical differences. A GMAW defect model used molten-pool and trailing-region features to distinguish burn-through and surface pores [6]. Its success remains confined to surface and process-image evidence generated by a recognizable feature.

The conditionally visible class includes discontinuities whose classification changes with access. Incomplete penetration can be observed when the root is exposed and viewable. An enclosed root leaves the condition unresolved. A surface pore can indicate local gas entrapment while leaving the count, size, and distribution of pores beneath the face unknown. The same access rule applies to the reverse side of a web-to-flange connection. A visible backside opening supports a burn-through disposition. The lack of backside access rules out that observation, while the underlying possibility of excessive penetration remains.

Figure 1 translates those class boundaries into a two-stage decision. The first stage asks whether an accessible surface expression exists. The second assigns the likely causal review to the welding process and its records. This order keeps a visible label separate from root-cause inference and leaves an unmarked surface silent on internal soundness.

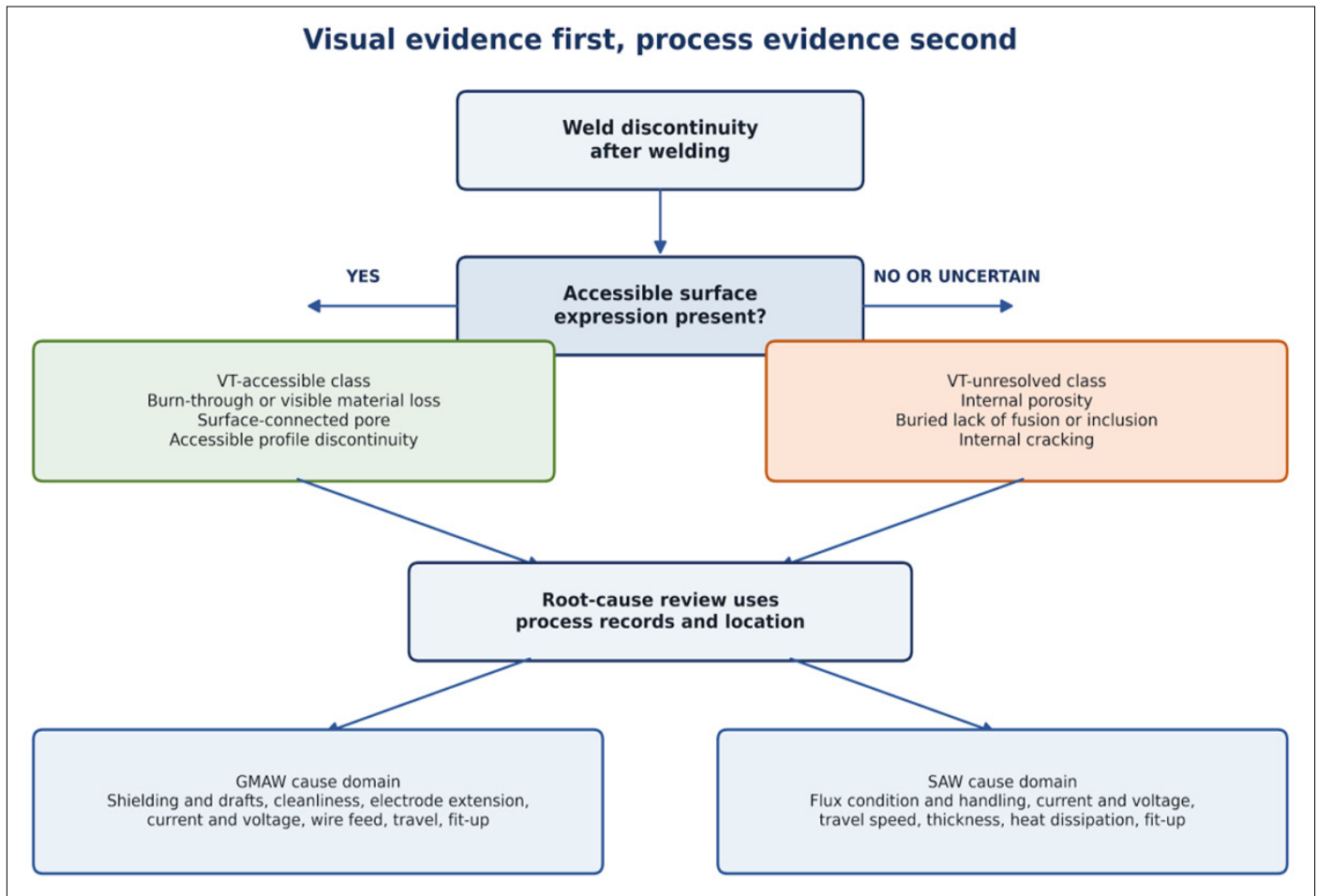


Figure 1. Two-axis classification of weld discontinuities for visual acceptance and root-cause review. Source: author's synthesis based on [3, 6, 9, 10]

A lack of surface expression characterizes the visually unresolved class. Internal porosity is its central example. Buried lack of fusion, internal slag inclusions, and internal cracking also belong here. The in situ detection review found that different signal families respond to distinct disturbances and defect states [7]. Ultrasonic work demonstrates why volumetric information requires a signal that travels through the material [8]. For a shop that relies on visual acceptance, the classification leaves the inspection scope unchanged. It identifies the discontinuity classes that must be constrained through the welding process before the finished surface is judged.

For GMAW porosity, the causal path begins with gas protection and surface condition. The shielding gas isolates the molten pool from atmospheric contamination, and inadequate coverage permits gases to enter the pool and remain trapped as the metal solidifies [9]. Drafts in a fabrication bay, damaged or obstructed gas-delivery components, inappropriate flow, excessive nozzle distance, or unstable torch position can disturb that protection. Rust, mill scale, moisture, oil, and other contaminants can serve as additional gas sources or interfere with fusion. Electrode extension changes resistive heating and the energy delivered to the workpiece, so that uncontrolled stickout can alter penetration and pool behavior even with a nominally unchanged machine setting [9].

Current, wire feed, arc voltage, travel speed, and shielding-gas composition form a coupled group. Experimental work on GMAW bead formation found that current, filler feed, and gas composition affected bead geometry and distortion [5]. The review of real-time GMAW sensing explains why nominal settings alone are insufficient: actual welding conditions deviate from their target values due to fit-up variation, seam position, material condition, and equipment behavior [1]. Consequently, porosity prevention requires confirmation of gas delivery and surface preparation at the weld location, followed by stable parameter execution. A final visual check identifies open pores after shielding loss or contamination has already acted on the liquid metal.

SAW porosity follows another protection mechanism. Granular flux covers the arc and molten pool. Its chemical and gas-phase behavior controls oxygen transfer, hydrogen pickup, and reactions at the slag-metal interface [3]. Moisture exposure matters because water vapor changes the hydrogen-bearing gas environment above the pool. Flux condition, storage, handling, recovery, and reuse belong to root-cause review when porosity appears in an SAW seam. Surface cleaning remains relevant. The flux blanket removes the GMAW-specific draft pathway from the cause review.

SAW thermal behavior depends on current, voltage, travel speed, and plate thickness. The first three variables set energy delivery and weld geometry, while thickness changes heat dissipation away from the weld [4]. A current-intensity study on SAW also found systematic changes in penetration, weld geometry, microstructure, and mechanical response as the current changed [2]. These findings matter for a continuous web-to-flange weld because the web can begin at 1/4 in while the flange is thicker. The thinner component has less section available to absorb and conduct the local thermal cycle. The cause review must join the machine settings with the thickness pair and actual fit-up at the location of the indication.

Burn-through is governed most directly by the balance among heat input, pool support, and joint geometry. The GMAW imaging study treats it as a distinct state of the molten pool [6]. Penetration-control experiments show that gap width, the position of the wire relative to the gap center, weaving width, and travel speed can move the process toward excessive penetration [10]. This evidence separates burn-through from porosity at the causal level. Shielding failure can generate pores while joint support remains intact. Burn-through can occur under adequate shielding when energy density, speed, thickness, and fit-up combine to remove the support beneath the pool.

The same balance applies to automatic SAW, with process-specific emphasis. Continuous operation promotes repeatability when travel speed, wire delivery, current, voltage, flux coverage, and joint position remain stable. It can also carry an unsuitable setting along an extended seam. Published SAW work identifies current, voltage, travel speed, plate thickness, and thermal cycle as central to bead and heat-affected-zone formation [4]. A separate study demonstrates that current changes penetration and weld response [2]. In the crane-girder context, a thin web joined continuously to a thicker flange creates a plausible location for burn-through when a local gap or edge condition combines with excessive penetration. This statement concerns process risk and leaves the connection weld type unspecified.

Comparison across the detection and process literature produces a consistent asymmetry. Optical systems recognize burn-through and surface pores once they create image features [6]. Real-time sensing can detect deviations in arc, pool, sound, or electrical behavior before a finished seam is accepted [1,7]. GMAW parameter research locates porosity risk in shielding and contamination and locates penetration risk in energy, electrode position, and fit-up [5,9,10]. SAW studies relocate the protection question to flux behavior and preserve the thermal question across current, voltage, speed, and thickness [2-4]. The classification requires two labels for every indication: an observation label that states what visual

inspection can establish, and a cause label that directs the review to the relevant process variables.

The resulting taxonomy places visible burn-through in the high-detectability, late-intervention quadrant. Surface porosity occupies the high-detectability portion of a discontinuity family that can also extend into the visually unresolved quadrant. Internal porosity occupies the low-detectability, prevention-dependent quadrant. This arrangement assigns separate control responses to the two frequently encountered conditions. Burn-through calls for an immediate production hold, disposition of material loss, and a review of thermal and geometric stability. Porosity calls for visible-indication disposition plus review of shielding or flux condition, cleanliness, and process consistency. An unmarked face remains silent on internal soundness.

DISCUSSION

The proposed classification changes the role assigned to visual inspection. Visual examination remains the barrier to acceptance for surface condition, accessible profile, and visible material loss. Internal weld quality is governed upstream by the stability and traceability of the process that produced the seam. This division provides the inspector with a defensible statement: the accessible surface meets the visual acceptance criteria, and the process record confirms that the controls associated with visually unresolved discontinuities remained in effect.

Implementation begins before arc initiation. The job packet should identify the assigned welding process, qualified procedure, base-material thickness pair, weld location, applicable parameter range, preparation requirements, and hold points for fit-up and cleanliness. The continuous web-to-flange weld should be segmented in the record by machine setup, consumable lot, flux lot (where applicable), start and stop points, and any interruptions. A single undifferentiated completion mark is inadequate for a seam extending tens of feet because local changes in gap, thickness, edge condition, or equipment behavior can alter the causal picture.

For GMAW, the pre-weld record should confirm cleaned edges, unobstructed gas delivery, nozzle condition, gas selection, draft control, contact-tip-to-work distance, wire condition, and fit-up. During welding, current, voltage, wire feed, travel behavior, and interruptions should remain linked to the affected seam segment. For SAW, the corresponding controls are flux identification and condition, storage and handling status, the disposition of recovered flux, wire feed, flux coverage, travel alignment, current, voltage, speed, thickness transition, fit-up, and start-stop practice. These records provide a defined path for root-cause review when the finished surface contains an indication.

Table 1 converts the detectability classes into shop decisions.

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Table 1. Decision logic for porosity and burn-through under visual weld acceptance

Accessible observation	Detectability class	Immediate disposition	Root-cause record to open
Through-opening, local metal loss, or excessive penetration	Directly visible when the affected face is accessible	Hold the seam segment, mark the location, and start material-loss disposition	Current, voltage, travel speed, gap, alignment, thickness pair, and pool-support conditions
One or more surface-connected pores	Visible expression of a family that may extend below the surface	Mark the indication, apply acceptance criteria, and review the adjacent seam segment	GMAW gas protection, drafts, cleanliness, nozzle and stickout, or SAW flux condition and surface preparation
No visible indication on a cleaned accessible face	Internal discontinuities remain outside the visual conclusion	State surface acceptance only and confirm completion of required process controls	Procedure assignment, consumable traceability, parameter record, interruptions, fit-up release, and protection controls
Prepared cavity and completed repair zone	Repair verification at two separate stages	Examine after removal, reweld to the qualified procedure, blend locally, and reinspect	Original indication, removal method, cavity examination, repair procedure, welder or machine, and release record

The table prevents two common reasoning errors. A visible pore gives an incomplete map of porosity within the weld, and an unmarked surface leaves the question of internal porosity open. Burn-through receives a different path because its visible evidence establishes local material loss or excessive penetration. In both cases, the observation initiates disposition, and the process record organizes the causal investigation.

Repair control follows disposition. A rejectable area should be marked, isolated, and assigned to an approved repair route. Depositing metal over an unresolved indication leaves the removal of the discontinuity unverified. The affected material is removed by an approved mechanical or thermal method, the prepared cavity is examined, and rewelding is performed in accordance with a qualified welding procedure. Final grinding blends the repaired zone into the adjacent weld profile while preserving the required weld section. Reinspection then applies the acceptance method specified for the repaired area and preserves the link between the original indication, removal, rewelding, and release.

The control sequence also needs feedback. Recurring GMAW pores should be addressed by reopening gas delivery, shop airflow, surface condition, torch position, and electrode extension. Recurring SAW porosity should prompt a review of flux conditions and recovery, wire delivery, parameter stability, and surface preparation. Burn-through clustered at thickness transitions or fit-up changes should trigger review of the applicable WPS range and setup instructions. This feedback keeps repairing an exceptional production event.

Table 2 maps the sequence to both welding processes while preserving distinct protection mechanisms.

Table 2. Process-control responsibilities for GMAW and automatic SAW on continuous web-to-flange welds

Control stage	GMAW	Automatic SAW	QA record
Preparation	Clean and dry edges, fit-up release, draft assessment, and wire condition	Clean and dry edges, fit-up release, thickness transition, flux readiness	Seam ID, location, thickness pair, preparation release, process assignment
Protection setup	Gas type and delivery, hose and nozzle condition, contact-tip-to-work distance	Flux identity, storage and handling status, recovered-flux disposition, coverage	Consumable lot, protection check, equipment status, authorized WPS
Parameter setup	Current, voltage, wire feed, travel behavior, torch position, fit-up response	Current, voltage, wire feed, travel speed, head alignment, flux feed	Approved range, actual setup, operator or machine, start point
Execution	Observe arc stability, shielding continuity, surface condition, and interruptions	Observe travel alignment, flux coverage, bead formation, and interruptions	Segment record, stop-start locations, deviations, adjustments, and affected length
Visual acceptance	Clean and examine the fully accessible surface, mark open pores and profile conditions	Remove slag and examine the full accessible surface, mark pores and penetration conditions	Inspector, access conditions, indication location, acceptance decision
Disposition and repair	Remove the discontinuity, examine the cavity, and reweld to the qualified WPS; blend locally.	Remove the discontinuity, examine the cavity, and reweld to the qualified WPS; restore the local profile.	Nonconformance, removal, cavity check, repair execution, reinspection, release

The comparison identifies the point at which a shared checklist becomes unsafe. Cleanliness, fit-up, parameter authorization, seam traceability, and repair documentation apply to both processes. Gas shielding and electrode extension are part of GMAW control. Flux condition and coverage are part of SAW control. Thermal balance crosses both columns, although automatic SAW places greater emphasis on sustained settings over long weld lengths. One form can govern the workflow if its process-specific fields remain separate.

Visual inspection should occur at multiple points in the production process. Fit-up and cleaned edges are inspected before welding. The operator or designated inspector observes arc stability, travel alignment, flux coverage, or gas protection, and abnormal pool behavior during execution. The completed seam is cleaned sufficiently for surface examination, then checked along its full accessible length with repair locations identified by position. This sequence moves some quality decisions to the time when their causes can still be corrected, and the affected seam remains limited.

The taxonomy has limits. Visual class depends on access, surface condition, lighting, viewing angle, and the geometry exposed to the inspector. Root-cause assignment remains probabilistic until process records, the removed cavity, and the repair examination support it. A discontinuity name alone is insufficient for code acceptance. Size, distribution, location, service category, and the governing fabrication standard control whether an observed discontinuity is rejectable. The taxonomy organizes inspection and investigation, while acceptance criteria and the qualified welding procedure retain governing authority.

For overhead crane girders, the main value lies in the connection between seam length and local traceability. Automatic SAW may produce a highly uniform weld over a long distance, yet a localized gap, edge contaminant, flux disturbance, or thickness transition can still create a local departure. GMAW offers flexibility for shorter regions and modifications, with greater exposure to gas-delivery and torch position variations. A quality record that locates each interruption and repair by seam segment gives engineering and QA enough context to decide whether the condition is isolated or process-driven.

CONCLUSION

Weld discontinuities in overhead crane girder fabrication are classified as directly visible, conditionally visible, or visually unresolved. Burn-through is directly visible when the material loss or excessive penetration reaches an accessible surface. Porosity changes class according to whether a pore intersects that surface. A clean weld face supports only a surface acceptance decision and leaves internal porosity or other discontinuities.

The root-cause classification distinguishes GMAW gas

protection, cleanliness, electrode extension, electrical settings, travel, and fit-up from SAW flux condition, flux handling, current, voltage, travel speed, thickness-dependent heat dissipation, and fit-up. Continuous automatic SAW at a web-to-flange connection requires special attention, as a thinner web and a local gap reduce molten-pool support.

The combined classification supports a traceable workflow from preparation and process assignment through execution, visual acceptance, disposition, qualified removal and rewelding, blending of the repair zone, and reinspection. The hypothesis is supported. A visual-only acceptance barrier becomes technically coherent when its limits are stated, and visually unresolved discontinuities are governed by upstream process controls. Burn-through and porosity then receive distinct responses that match their detectability and causal pathways.

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