Exploring Trends and Patterns in International Event Reporting

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ABSTRACT

Various international systems were developed for event reporting that enable exchange of operational experience (OE) to improve the safety of nuclear power plants. This paper presents a review of event reports from the International Atomic Energy Agency (IAEA) International Reporting System (IRS) database, focusing on trends and recurring themes relevant to nuclear plant operation and maintenance. Drawing from reported events, the study applies frequency analysis, temporal trending, event grouping, and causal node mapping to explore common causes, safety relevance and significance, interdependencies across systems, plant states, and operational contexts. The approach includes descriptive metrics related to reactor trips, equipment performance degradation and human performance, as well as visual tools that highlight potential relationships between technical, procedural, and human factors. The analysis is structured to allow multiple patterns to emerge - such as persistent vulnerabilities or patterns that cut across systems, causes, or organizational factors. While specific conclusions will depend on the data, the paper aims to contribute to more structured and transferable use of OE information and provide a foundation for developing consistent trending approaches across the industry to be able to achieve higher level of nuclear safety.

Keywords: *Operational experience (OE), Event reporting, International Reporting System (IRS), Nuclear safety trending*

1 INTRODUCTION

Operating experience feedback is one of the basic ways in which the nuclear industry prevents recurrence of safety significant events. An event occurring at one nuclear power plant can reveal a vulnerability that may also exist elsewhere, even when the detailed design, operating condition or event sequence is not the same. For this reason, event reporting systems should not be viewed only as archives of individual occurrences, but also as sources of lessons for operation, maintenance, engineering and organizational learning.

The International Reporting System for Operating Experience (IRS) is a joint IAEA and OECD/NEA system used for exchanging safety-related operating experience from nuclear power plants. Its purpose is to support the sharing of lessons learned from events and, by doing so, reduce the probability that similar events will occur at other plants.

A practical difficulty in using IRS information for trending is that the reports are narrative and plant-specific. Events are not always described with the same terminology, level of detail or causal structure. This means that direct comparison between reports is difficult unless the information is first brought into a common analytical structure. In this review, this was done by applying structured coding to the selected IRS reports and then looking for recurring contributor and plant-control patterns across the sample.

The goal of the study was to determine how often similar or partly similar patterns appeared in the reviewed reports, and which of those patterns were most relevant to nuclear power plant operation and maintenance.

2 DATASET DEVELOPMENT

To support the review, a structured dataset was developed from IRS event reports received by the IAEA in the last five years. The intent was to make the reports comparable while still retaining the main engineering meaning of each event. For each report, the reviewers identified what happened, which structures, systems and components were involved, how the condition was detected, how the plant responded, what consequences occurred or could have occurred, and what corrective actions were reported.

A coding structure was then applied to the reports. The main fields included event family, plant state, detection context, affected SSCs, equipment type, failure mode, cause category, safety function affected or challenged, human involvement, corrective action type, and operating experience relevance.

The resulting dataset provided a consistent basis for comparing the events, identifying recurring affected systems and causes, reviewing operational consequences, and examining how the use of operating experience was reflected in the reports.

3 CONSEQUENCE FOOTPRINT OF THE REVIEWED EVENTS

Before discussing recurring causes and contributing factors, the reviewed reports were first examined in terms of their direct operational consequence. This was done to provide context for the subsequent analysis and to distinguish between events that mainly represented degraded plant conditions and events that resulted in an immediate plant response, such as a reactor trip or shutdown.

The 159 reviewed reports cover events from 2021 to 2025, with the majority of reports falling between 2021 and 2024 (see Figure 1). The number of reviewed reports was relatively similar across these four years, ranging from 35 to 45 reports per year. Since only one report from 2025 was included, this year was not considered suitable for trend interpretation.

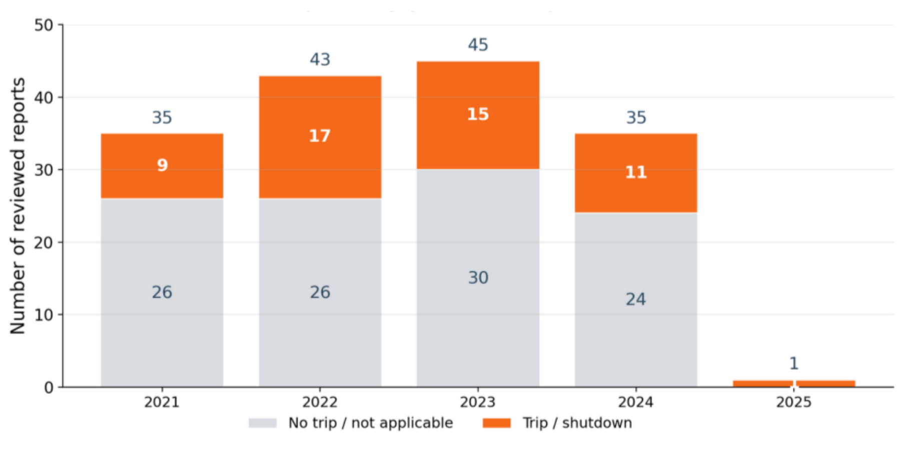

Figure 1: Reviewed reports by year and trip/shutdown outcome

A reactor trip, scram, or manual shutdown was identified in 53 reports, representing approximately one third of the reviewed events. This indicates that a substantial part of the dataset had a direct operational impact, and did not consist only of latent deficiencies or minor equipment findings. At the same time, the absence of a reactor trip does not mean that an event was without importance. Several reports described degraded equipment, unavailable systems, failed tests, or conditions that could have become more significant under different plant conditions.

The way in which events were detected also provides useful context (Figure 2). A number of reports were identified through testing, inspection, quality assurance activities, alarms, automatic protection actions or operator monitoring. With this in mind, the reviewed events should not be understood only as failures of equipment or personnel. They also demonstrate the role of plant barriers that detect, interrupt, or limit the consequences of degraded conditions. In several cases, the event became visible only when a test, alarm or operational response challenged the assumed equipment condition or system readiness.

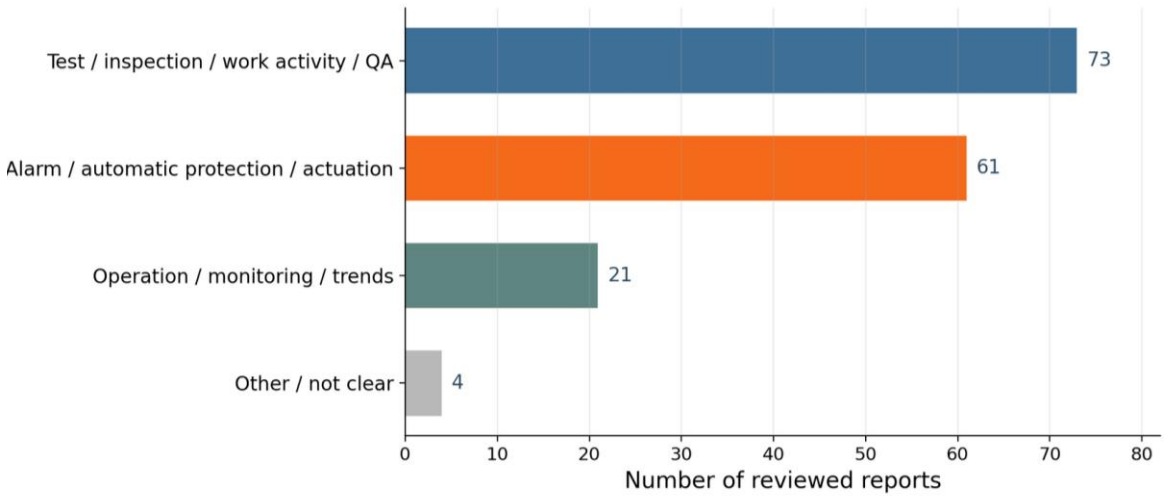

Figure 2: How reviewed events were detected

For this reason, the consequence footprint was used mainly as a framing step for the rest of the analysis. Reactor trips and shutdowns identify the events with immediate operational effects, while the detection context shows where weaknesses became visible. The following sections therefore focus not only on the consequence that occurred, but also on the combinations of technical, procedural, maintenance, design and human-performance factors that allowed the consequence to develop.

4 TECHNICAL EVENT FAMILIES

The reviewed reports were grouped into broad technical event families in order to identify which types of plant problems appeared most often and which were most often associated with direct operational consequences (Figure 3). These families were not treated as mutually exclusive categories. In a number of reports, more than one technical family was relevant, for example when equipment degradation was accompanied by design or configuration issues.

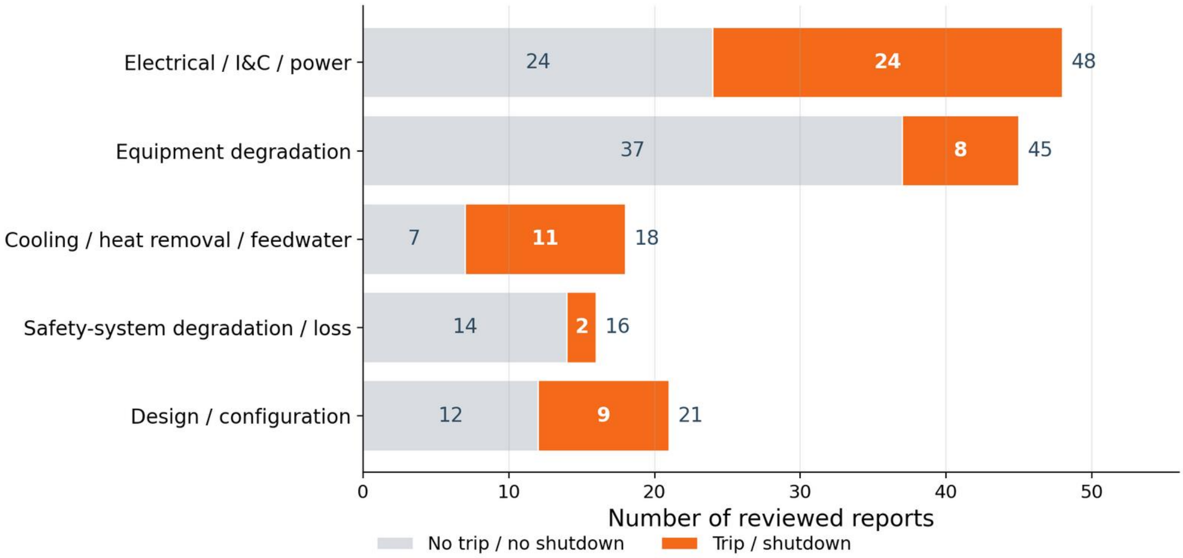

Figure 3: Technical event families and trip/shutdown outcome

The most frequent technical family was electrical, instrumentation and control, and power-supply related events. This group appeared in 48 reports and was associated with 24 reactor trips or shutdowns. It is therefore the clearest example of a technical family that was both frequent in the reviewed dataset and strongly connected with immediate plant impact. The events in this group generally involved failures or disturbances in electrical supply, control logic, instrumentation signals, protection systems, or related support equipment.

Equipment degradation was also common and appeared in 45 reports. However, only 8 of these reports involved a reactor trip or shutdown. This gives the category a different type of operational importance. Degradation events were often important because they revealed weakened equipment condition, failed tests, leakage, reduced reliability, or loss of margin, and not necessarily because they immediately forced the plant to trip.

Cooling, heat-removal and feedwater-related events were less frequent, appearing in 18 reports, but 11 of them involved a reactor trip or shutdown. This indicates a relatively high direct operational footprint.

Safety-system degradation or loss was identified in 16 reports, with 2 of them associated with a reactor trip or shutdown. These cases were mainly related to degraded readiness, reduced availability, failed surveillance, or impaired safety function rather than immediate plant shutdown.

Design and configuration issues appeared in 21 reports, including 9 reports with a reactor trip or shutdown. This group is important because it shows that some technical events were shaped by latent plant conditions, such as equipment configuration, design assumptions or modification quality.

Overall, the technical family review shows that the operational footprint of an event family cannot be assessed only by its frequency. Electrical and I&C-related events were both frequent and trip-relevant, while equipment degradation was frequent but often appeared as a latent condition. Cooling and feedwater events were less numerous but more likely to produce an immediate plant response. Safety-system degradation was less trip-dominant, but important for system readiness. This supports the need to review IRS events not only by outcome, but also by the technical pathways through which plant vulnerabilities become visible.

5 PLANT-CONTROL WEAKNESSES

An important finding of the review was that many events were not related only to the immediate technical problem, but also to weaknesses in plant controls that should normally prevent, detect or limit such problems. Three control areas appeared repeatedly across the reviewed reports: procedures, maintenance, and design or configuration control (Figure 4).

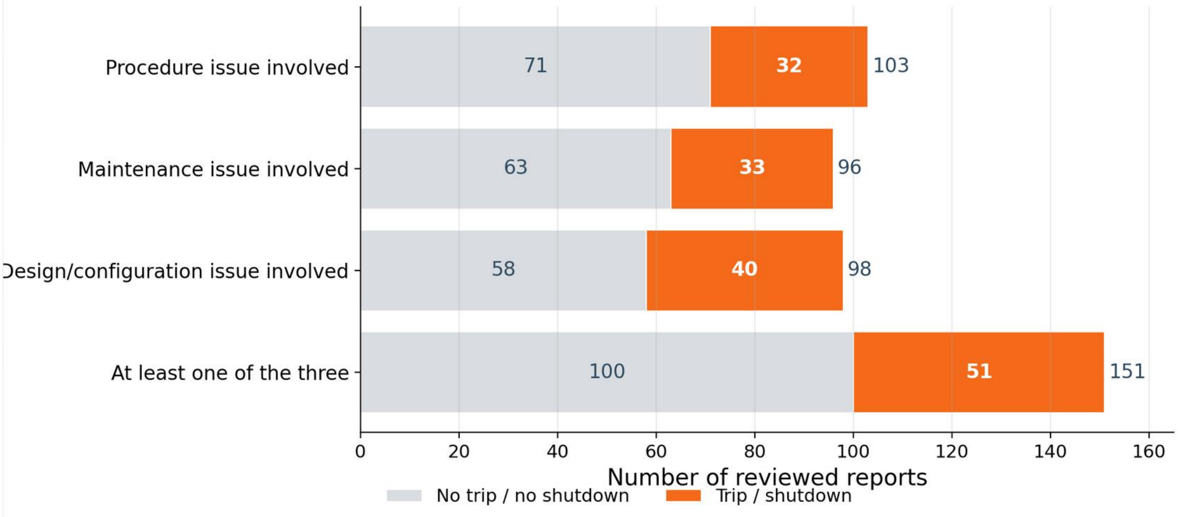

Figure 4: Plant-control issue frequency and trip/shutdown outcome

Procedure issues were identified in 103 of the 159 reviewed reports. Maintenance issues were identified in 96 reports, and design/configuration issues in 98 reports. At least one of these three control areas was involved in 151 reports. This means that only a small number of reviewed events fell outside these categories.

The same pattern was visible in events with direct operational impact. Procedure issues were present in 32 trip or shutdown cases, maintenance issues in 33, and design/configuration issues in 40. The largest trip/shutdown footprint was therefore associated with design/configuration issues. This does not mean that design alone caused these events, but it does show that many of them had an engineering or configuration dimension in the background, such as equipment set-up, modification quality, protection logic, or design assumptions.

The overlap between the three control areas is more important than the individual counts (Figure 5). The reviewed reports were often not simple one-category events. Only 11 reports were coded as procedure-only, 3 as maintenance-only, and 25 as design/configuration-only. By contrast, 39 reports involved procedure and maintenance together, 20 involved maintenance and design/configuration together, and 19 involved procedure and design/configuration together. A further 34 reports involved all three areas at the same time.

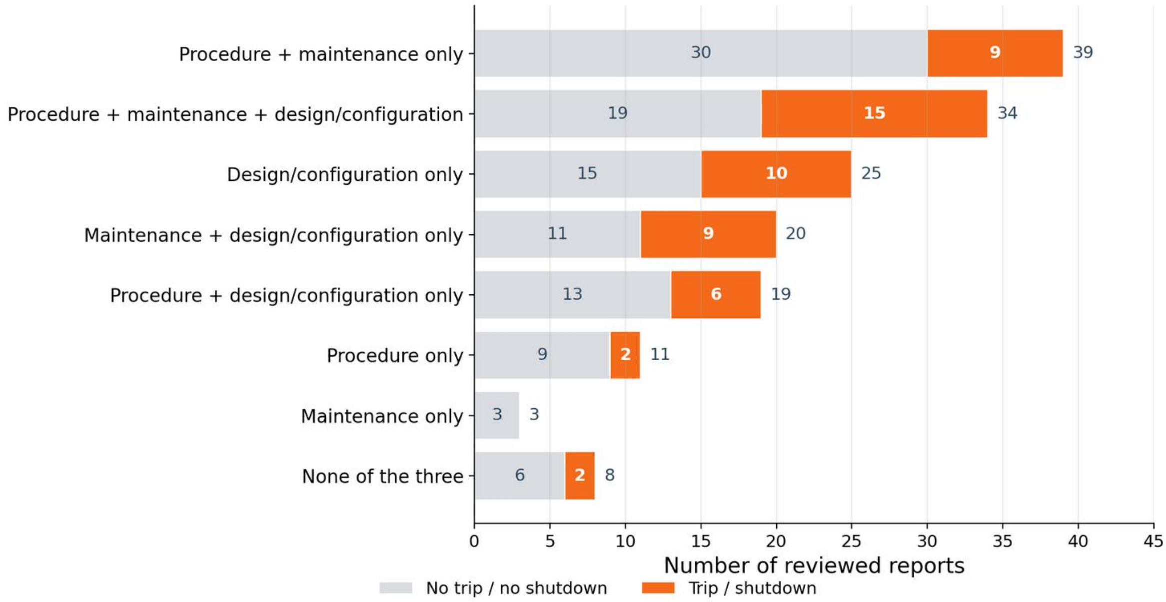

Figure 5: Plant-control issue overlap and trip/shutdown outcome

This indicates that many events cannot be understood well as isolated procedural errors, isolated maintenance failures, or isolated design problems. In many cases, the event developed through a combination of weak controls. A maintenance activity may have depended on unclear instructions. A procedural weakness may have been made worse by plant configuration or design assumptions. A design/configuration issue may only have become visible during testing, maintenance, or abnormal operation. The overlap is therefore important because it points to the limitations of single-track corrective action.

Overall, this part of the review indicates that most of the reviewed IRS reports were not single-cause events. They are better described as combinations of technical failure and incomplete plant controls. For that reason, corrective actions focused only on the most visible problem may be too narrow. When a report points to a maintenance problem, it may still require review of procedures, configuration control, or engineering assumptions. Likewise, a procedure revision alone may not be sufficient if the underlying problem also involved maintenance practice or plant design.

6 HUMAN INVOLVEMENT

Human performance was reviewed separately because it appeared in the reports in more than one way. In some events, human action was part of the immediate event sequence, such as incorrect manipulation, incomplete verification, inadequate response to an alarm, weak risk recognition, or non-adherence to a work instruction. In other events, the human contribution was more latent and appeared through engineering judgement, procedure quality, configuration control, maintenance planning, supplier oversight, or the interpretation of operating experience.

For this reason, human performance was not treated as a synonym for “operator error.” The review considered human contribution at different points in the event chain, including control-room operation, field work, maintenance execution, engineering decisions, and recovery actions.

In the detailed human-performance review, human action was identified as contributing to the event in 69 of the 159 reports. These 69 reports were grouped according to where the human contribution entered the event chain. Three groups were used: operator or operations-related contribution, maintainer/technician or work-execution contribution, and engineering, analysis or design contribution.

As shown in Figure 6, the largest group was associated with maintainer, technician or work-execution activities, with 33 cases. Operator or operations-related contribution was identified in 18 cases, and engineering, analysis, design or programme-level contribution was also identified in 18 cases. This distribution shows that the human-performance population was not dominated by direct control-room error. A large part of the events instead involved field execution, work planning, verification, maintenance quality, temporary configuration control, contractor work, or earlier engineering and programme-level decisions.

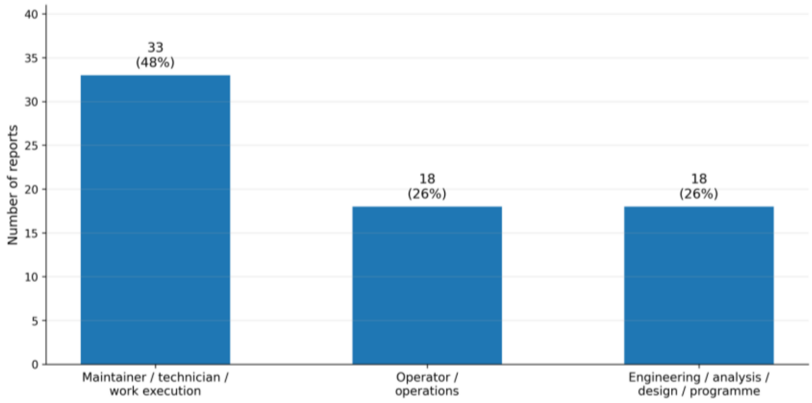

Figure 6: Human Performance Related Reports by Contribution Category

The same distinction is useful when considering operational impact. To keep this part of the analysis focused, the consequence review was limited to events that resulted in a reactor trip or shutdown. As shown in Figure 7, within the 69 human-performance-related reports, 20 resulted in either a reactor trip/scram or a shutdown. This included 17 reactor trips/scrams and 3 non-trip shutdown cases. The remaining 49 human-performance-related events did not result in a trip or shutdown.

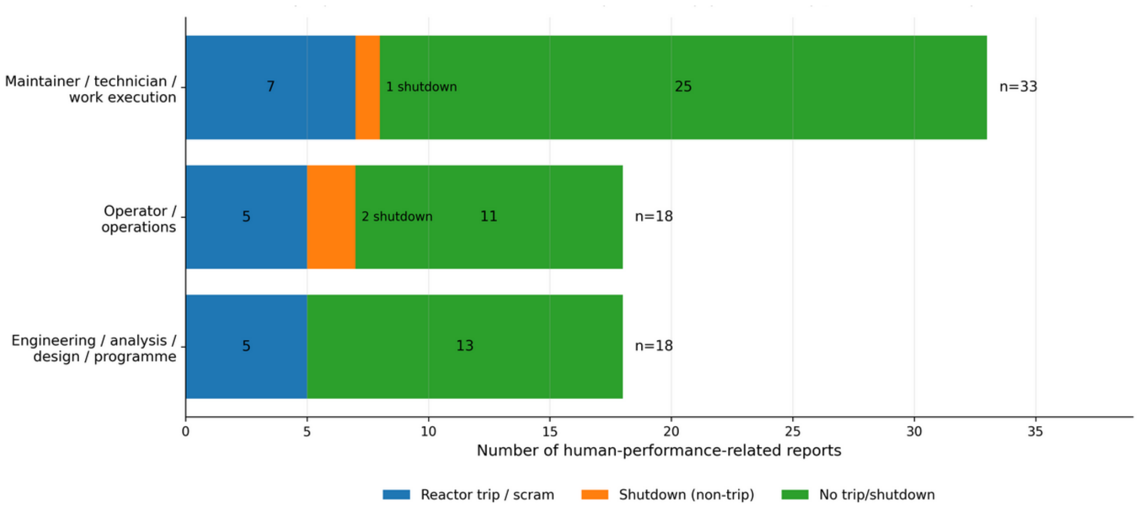

Figure 7: Trip/shutdown outcomes within human-performance-related reports

To further examine these patterns, the human-performance cases were also reviewed against the types of barriers that were weak or missing. This is shown in Figure 8 as a barrier matrix. The figure should not be read as a set of exclusive categories, because a single event could involve more than one weak barrier. Instead, it shows how often each barrier type appeared within each human-contribution mode.

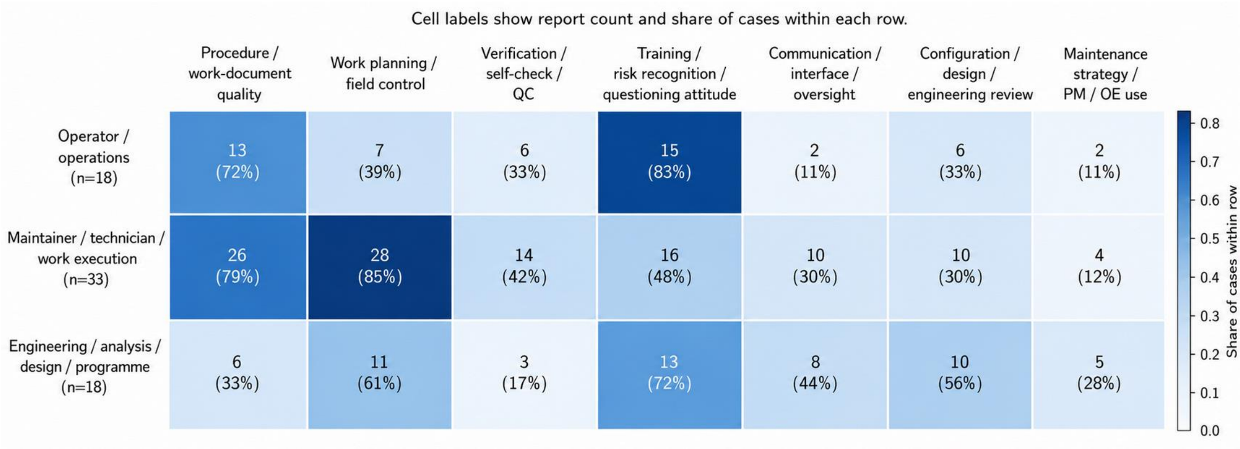

Figure 8: Barrier weaknesses associated with human-performance-related events

7 USE OF OPERATING EXPERIENCE

One part of the review considered how operating experience was involved in the reported events. The aim was not only to identify whether similar events had occurred before, but also to examine whether earlier knowledge had been translated into effective plant action. Operating experience was interpreted broadly. It included formal industry or vendor information, previous events at the same plant or fleet, corrective actions from earlier problems, factory or commissioning observations, and local warning signs such as repeated alarms, defects, troubleshooting history, or similar minor events.

Out of the 159 reviewed IRS reports, 46 reports contained evidence that relevant prior knowledge was available before the event, but was missed, delayed, incompletely implemented, or weakly applied. These cases were not treated simply as examples of "ignored operating experience." In many cases, the plant or organization had some awareness of the issue. The more important question was whether that knowledge was converted into effective preventive action.

To make this clearer, the 46 reports were grouped according to the main point where the use of operating experience appeared to weaken (Figure 9). The largest group involved cases where prior knowledge was not adequately translated into plant controls. This included cases where operating experience was not fully incorporated into preventive maintenance, inspection scope, maintenance documentation, calibration activities, work packages, monitoring practices, or operator barriers. This group accounted for 16 of the 46 cases.

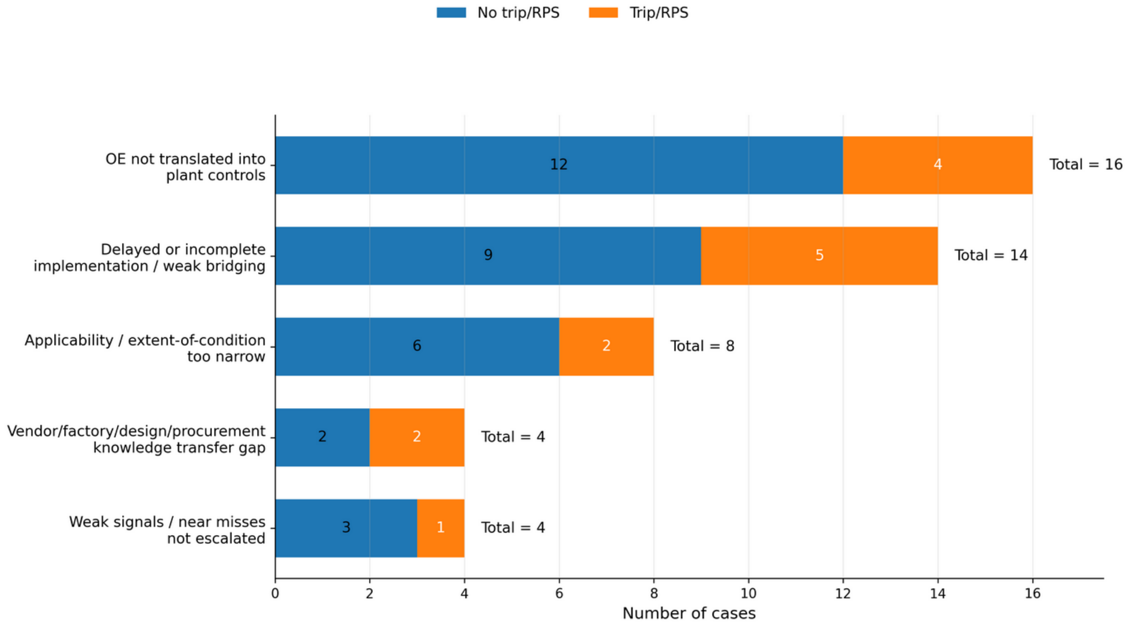

Figure 9: OPEX implementation weaknesses and trip/shutdown outcomes

A second group involved delayed or incomplete implementation, including weak interim controls before permanent action was completed. These were cases where a corrective action, modification, recommendation, or preventive-maintenance change was known or planned, but was not completed in time, was only partly implemented, or was not supported by sufficient temporary measures. This group accounted for 14 cases.

Another group involved weak applicability or extent-of-condition judgement. In these cases, prior experience was available, but the affected equipment population, common-cause potential, local design difference, or transferability of the lesson was underestimated. This group accounted for 8 cases. These cases differ from a simple failure to find operating experience. The issue was more often that the earlier experience was considered too narrow, too plant-specific, or already bounded, even though the vulnerability was actually broader.

Four cases involved weak transfer of vendor, factory-test, design, procurement, or technical try-out information. In these events, useful knowledge existed before installation, commissioning, procurement, or wider implementation, but was not fully carried through into plant controls. Another four cases involved weak signals that were not escalated strongly enough. These included repeated local symptoms, previous anomalies, similar minor events, or troubleshooting information that did not result in a stronger corrective-action response.

The pattern suggests that the practical challenge in operating experience is not only whether prior information exists. The more important issue is whether that information is recognized as applicable, acted on in time, and embedded into plant processes strongly enough to prevent recurrence. In practical terms, operating experience has value only when it is converted into a plant control, such as a maintenance task, inspection scope, procedure change, design modification, training point, monitoring activity, or verification requirement.

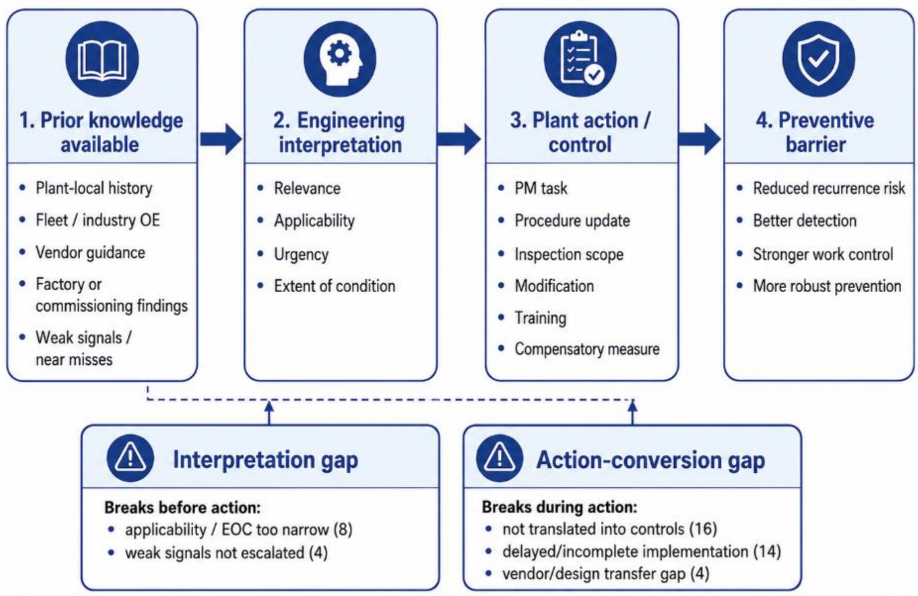

Figure 10: OPEX implementation chain

8 CONCLUSION

The review of 159 IRS reports showed that reported nuclear plant events are rarely explained well by a single technical failure. Although many events started with equipment degradation, electrical or I&C faults, feedwater disturbances, or other technical problems, the event narratives often also included procedure weaknesses, maintenance or work-control issues, design/configuration vulnerabilities, and incomplete use of earlier operating experience. This was especially visible in the overlap between procedure, maintenance, and design/configuration issues, which appeared in the large majority of reviewed reports.

The analysis also showed that operating experience is most useful when it is treated as a conversion process. The important question is not only whether previous information existed, but whether it was recognized as applicable and translated into durable plant controls, such as maintenance tasks, inspections, procedures, design changes, training, configuration checks, or interim compensatory measures. Several reviewed events indicate that relevant information was available before the event, but was not fully converted into preventive action.

The present review was limited to a selected IRS report set. Expanding the dataset would provide a broader and more stable basis for identifying trends, especially for less frequent event types. Similar structured reviews of other sources, such as NRC event reports, could open additional lines of analysis. These could include topics such as commercial-grade item dedication, counterfeit, fraudulent and suspect items, supplier oversight, equipment qualification, and component-specific degradation patterns.

Overall, the review supports the need for a systematic approach to operating experience. Useful information exists both in plant-specific history and in wider industry reporting systems, but industry-level information is often too broad to be applied directly without interpretation. To become useful, it has to be screened against the actual plant design, equipment population, maintenance practices, procedures, suppliers, operating history, and known vulnerabilities of a specific facility. Effective use of operating experience therefore requires both industry-level collection and plant-specific interpretation. The value is created when external lessons are screened for applicability and converted into plant controls that can be verified in maintenance, engineering, operations, procurement, and corrective-action programmes.

REFERENCES

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