Kenexis® Fault Tree

(formerly Arbor™)

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1 Introduction

1.1 About Kenexis Fault Tree

Kenexis Fault Tree is the fault tree analysis (FTA) module of the Kenexis Integrated Safety Suite (KISS). It is a browser-based, multi-user application for building fault tree models of how equipment and safeguard failures combine to produce an undesired top event, and for quantifying the probability and frequency of that event. Typical uses include Layer of Protection Analysis (LOPA) support, Safety Integrity Level (SIL) verification, spurious-trip-rate estimation, and general reliability studies.

Everything in a Kenexis Fault Tree study is expressed with three quantities:

- **Unavailability (Q)** — the probability that a component or subsystem is in a failed state at a random point in time (a dimensionless number between 0 and 1).
- **Frequency (w)** — how often a failure or event occurs, expressed per unit of the study's chosen time base (for example, per year).
- **Risk Reduction Factor (RRF)** — simply 1 ÷ Q. Kenexis Fault Tree can display results as either Q or RRF; the two are interchangeable views of the same number.

1.2 Fault Tree Basics

A fault tree is a top-down logic diagram. The undesired outcome sits at the top (the "top gate"). Beneath it, logic gates (AND, OR, voting) describe how lower-level failures must combine to cause the level above them. At the bottom are basic events — individual component failures or human errors — each characterized by a failure model. Kenexis Fault Tree evaluates the tree by finding its minimal cut sets (the smallest combinations of basic-event failures that are sufficient to cause the top event) and then rolling their contributions up through the gates. Chapter 10 documents the mathematics in full.

1.3 About Kenexis

Kenexis is an independent engineering consulting firm specializing in the integrity of instrumented safeguards and industrial networks. Kenexis applies skills in risk analysis, reliability engineering, and process engineering to help establish the design and maintenance specifications of instrumented safeguards such as safety instrumented systems (SIS), alarm systems, and fire and gas systems. The Kenexis Integrated Safety Suite is the software platform that supports this work.

2 Getting Started

2.1 Signing In

Kenexis Fault Tree runs inside KISS and requires a KISS account. Point your browser at your organization’s KISS address and sign in with your username and password, or with a configured single sign-on provider (Azure AD or Okta). Every Kenexis Fault Tree page requires authentication; if your session expires you will be returned to the sign-in screen.

2.2 The KISS Manager — Facilities and Studies

After signing in you land on the KISS Manager. Facilities are listed on the left; selecting a facility loads its studies (and any folders) on the right. Kenexis Fault Tree studies are marked with the Kenexis Fault Tree icon and the type “Arbor”. Use the toolbar above the study list to create, organize, and move studies.

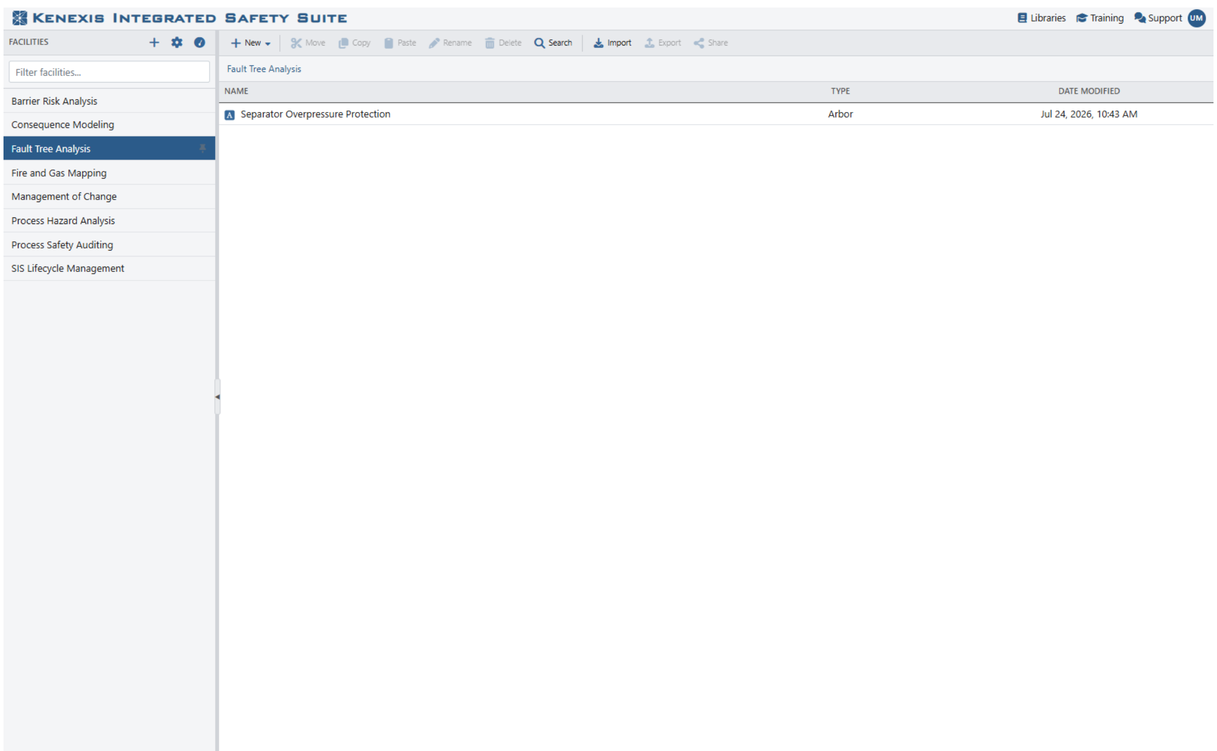


Figure 2-1. The KISS Manager. Selecting a facility lists its studies and folders; the toolbar provides New, Move, Copy, Paste, Rename, Delete, Search, Import, Export, and Share.

2.3 Creating a Kenexis Fault Tree Study

With a facility (or folder within it) selected, choose New › Arbor and give the study a name. Kenexis Fault Tree creates the study pre-seeded with a single root gate titled TOP GATE and opens it immediately. From there you build the tree downward as described in Chapter 3.

2.4 Managing Studies

The KISS Manager toolbar acts on the selected study. Buttons are enabled only when the action is permitted for your role and the facility's settings.

- **Copy / Paste / Move / Rename / Delete** — duplicate, relocate, or remove studies. Deleting is a soft delete: the study moves to the organization Recycle Bin.
- **Export** — downloads the study as a binary Kenexis Fault Tree file (".arb"), a portable format for moving a study between facilities or servers.
- **Import** — uploads a ".arb" file into the selected facility/folder. Kenexis Fault Tree recalculates the study automatically as soon as it is imported and then opens it.
- **Share** — produces an external link that opens the study directly.

2.5 The Kenexis Fault Tree Workspace

Opening a study shows the Kenexis Fault Tree workspace. A header runs across the top with the study name on the left and, on the right, a Results Out of Date badge (shown whenever the model has changed since the last calculation), the Calculate button, and the Reports menu. A read-only badge appears instead of the editing controls if you have view-only access.

Immediately below the header is the tab bar with the six workspace tabs:

Table 2-1. The six Kenexis Fault Tree workspace tabs.

Tab	What it shows
Overview	Study properties, revisions, recommendations, and inbound Kenexis SIS links (Chapter 7).
Fault Tree Diagram	The graphical tree editor — the main working surface (Chapter 3).
Gates	A sortable table of every gate and its results (Chapter 5).
Events	A sortable table of every event and its results (Chapter 5).
Event Models	A table of failure-data models with bulk-edit tools (Chapter 4).
Cut Sets	Minimal cut set results for any chosen gate (Chapter 6).

3 Building a Fault Tree

3.1 The Fault Tree Diagram Tab

The Fault Tree Diagram tab is where most work happens. It has three regions: a collapsible sidebar on the left, an editing toolbar, and the diagram canvas.

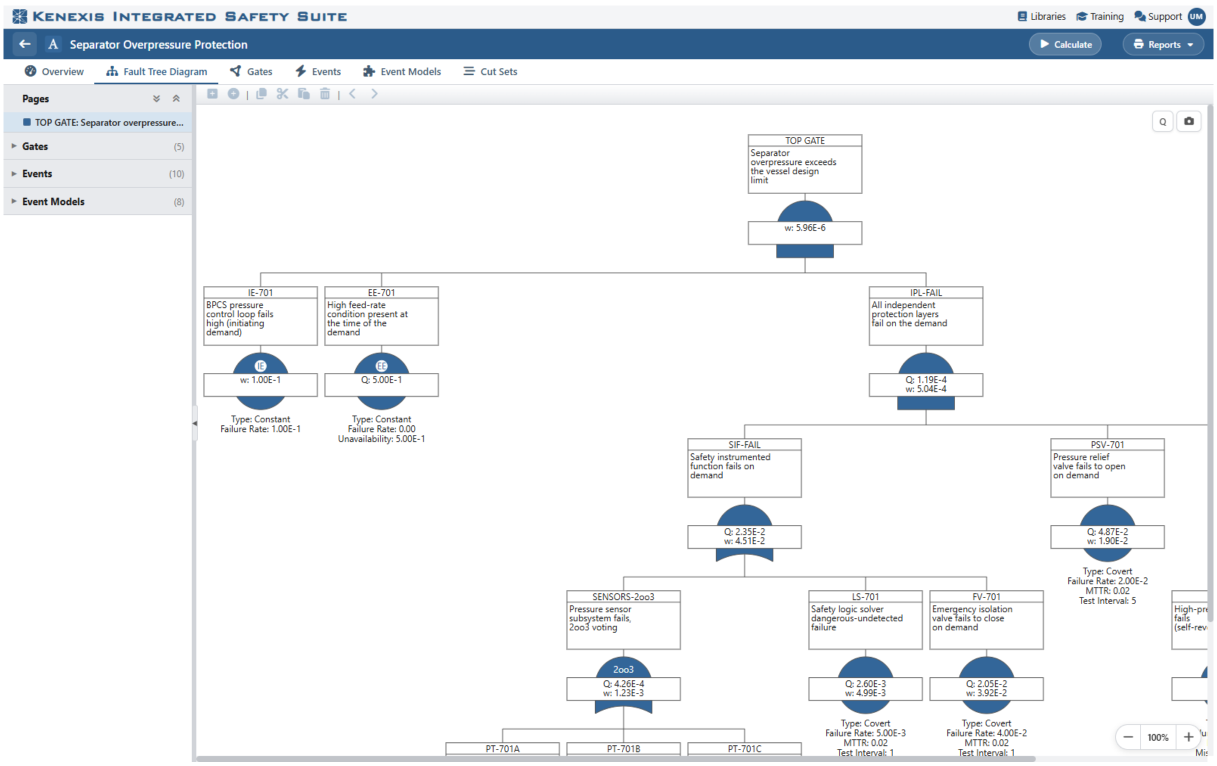


Figure 3-1. The Fault Tree Diagram tab. The sidebar (left) lists Pages, Gates, Events, and Event Models; the toolbar sits above the canvas; the tree is drawn on the canvas with each node showing its results underneath.

- **Sidebar** — four collapsible sections: Pages (the tree's page structure), and flat lists of Gates, Events, and Event Models with live counts. Click an item to select it; double-click to edit it. Drag the handle to resize the sidebar, or collapse it with the ◀ button. Your width and collapse choices are remembered between visits.
- **Toolbar** — Add Gate, Add Event | Copy, Cut, Paste, Delete | Move Left, Move Right. Add and Paste apply to a selected gate, since gates are the nodes that hold children. When a node used in more than one place is selected, Select Previous Instance / Select Next Instance buttons also appear.
- **Canvas controls** — the floating Q/RRF toggle and Save as Image button (top-right), and the zoom controls (bottom-right). Zoom also responds to the + and − keys and Ctrl+mouse-wheel; right-click-drag pans the canvas. Zoom resets to 100% each time the tree loads.

A complete tree reads top-down. In the common layer-of-protection pattern, the top event occurs only when an initiating event (left branch) coincides with the failure of the independent protection layers (right branch).

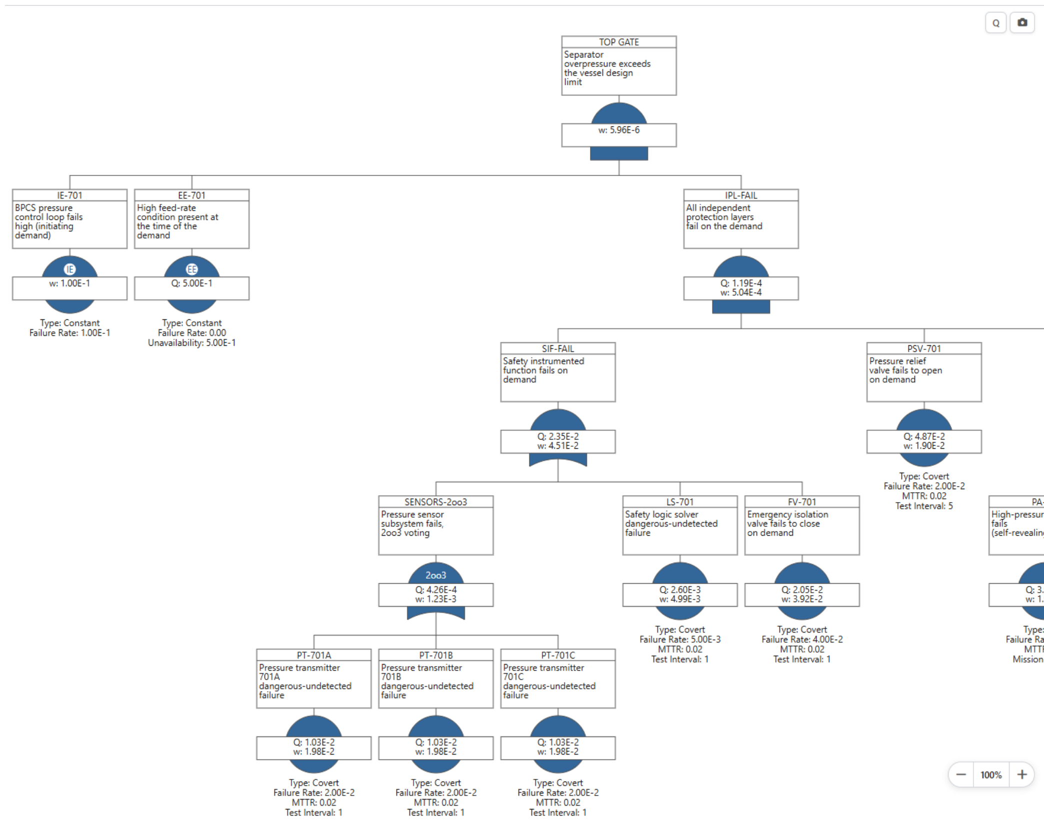


Figure 3-2. A complete fault tree. The initiating-event chain descends on the left; the protection-layer branches descend on the right.

3.2 Node Types and Symbols

Every node is either a gate (a logic operator) or an event (a leaf). The symbol Kenexis Fault Tree draws tells you the node's role at a glance.

Gate Types

Table 3-1. Gate types and the symbols Kenexis Fault Tree draws.

Type	Symbol	Meaning
Transfer	Triangle	A pass-through / page-continuation gate. It carries exactly one child's value unchanged and is also used to break a large tree across pages.
AND	Flat-bottomed gate	The output occurs only when all inputs occur. Inputs are combined into one cut set.
OR	Curved-bottom gate	The output occurs when any input occurs. Each input becomes its own cut-set branch.
VOTE	OR gate with "MooN" label	K-out-of-N voting: the output occurs when at least K of the N inputs occur. K is set in the gate dialog and shown as, for example, 2oo3.

Event Types

Table 3-2. Event types and the symbols Kenexis Fault Tree draws.

Type	Symbol	Meaning
Basic event	Circle	An event that references an event model (Chapter 4). Its Q and w come from that model.
Undeveloped event	Diamond	An event with no model assigned. It contributes Q = 0 and w = 0 — a valid placeholder for detail not yet added.
House event	House / pentagon	A boundary condition forced Always True (Q = 1) or Always False (Q = 0). Used to switch parts of the tree on or off.
Initiating event (IE)	Circle with IE badge	Carries a frequency only (its unavailability is suppressed). The starting event of an accident sequence.
Enabling event (EE)	Circle with EE badge	Carries a probability only (its frequency is suppressed). A condition that must be present for the sequence to proceed.

Initiating vs. enabling

Initiating and enabling are mutually exclusive choices. These two toggles are the hinge between the frequency world and the probability world — see sections 10.5 and 10.6 for exactly how they shape the math.

3.3 Adding, Editing, Moving, and Deleting Nodes

- **Add** — select a gate, then click Add Gate (or press W) or Add Event (or press Q). New nodes are auto-numbered “GATE n” / “EVENT n”; new gates start as Transfer gates.
- **Edit** — double-click a node on the canvas, in the sidebar, or in a grid; or select it and press Enter. This opens the node’s details dialog.
- **Move** — Move Left / Move Right (Ctrl+← / Ctrl+→) reorder a node among its siblings. To re-parent a node, use Cut and Paste (section 3.6).
- **Delete** — the Delete toolbar button or the Del key. Kenexis Fault Tree asks for confirmation and explains exactly what will happen; the root gate is always retained. If the node is used in several places, only the link to the current parent is removed and the button reads Remove.

3.4 Gate Details

The Gate dialog sets a gate’s logic and appearance.

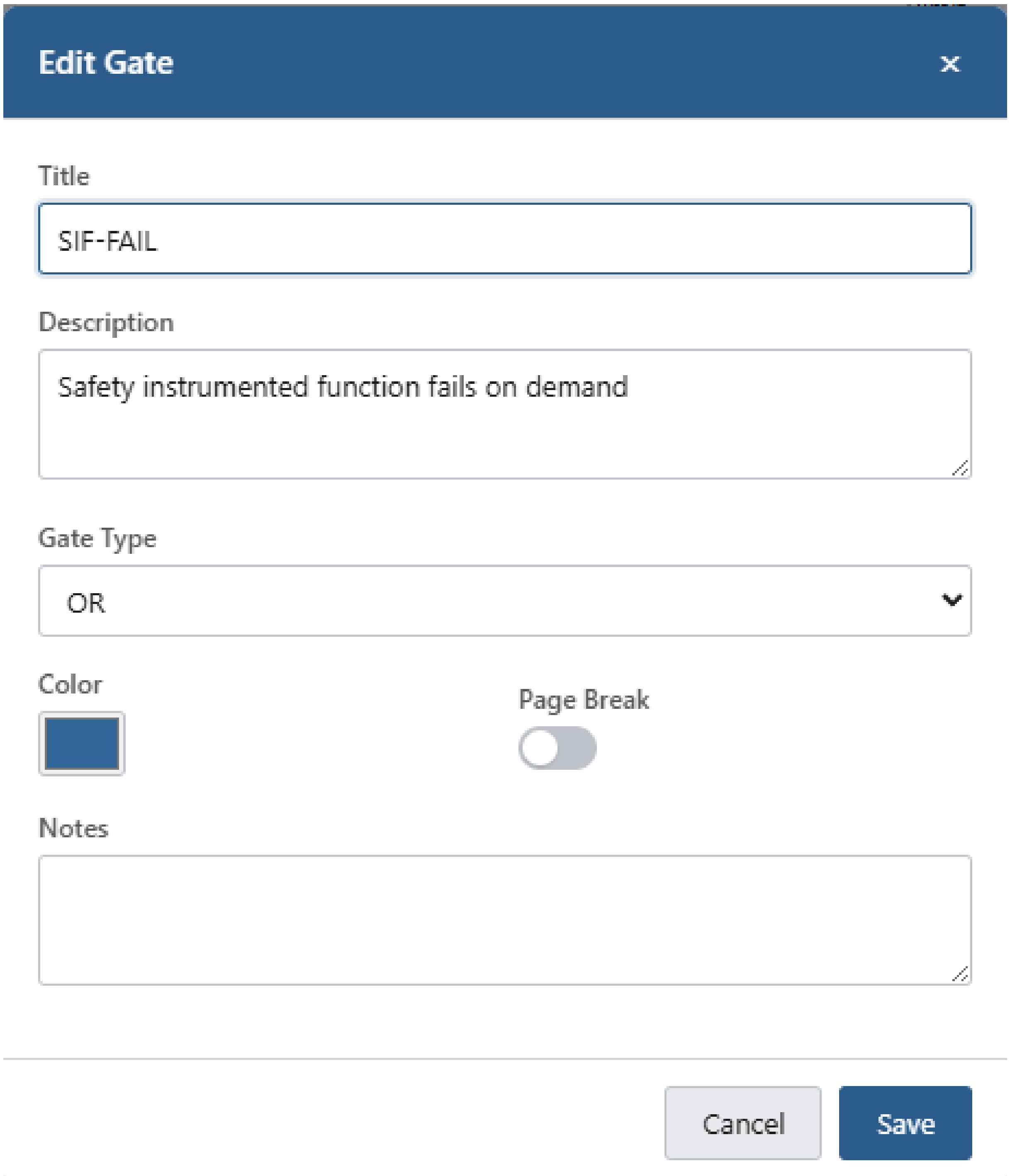


Figure 3-3. The Gate dialog, shown here for an OR gate. Fields: Title, Description, Gate Type, Color, Page Break, and Notes.

Table 3-3. Fields in the Gate dialog.

Field	Purpose
Title	Short label of up to 20 characters (auto-numbered GATE 1, GATE 2, …).
Description	Free text describing the failure the gate represents (up to 255 characters).

Field	Purpose
Gate Type	Transfer, AND, OR, or VOTE (section 3.2).
Vote (M of N)	Appears for VOTE gates: the number K of inputs that must fail, within the gate's input count.
Color	The fill color of the gate symbol (default #336699).
Page Break	When on, the gate begins a new diagram page — useful for large trees.
Notes	Longer free-text remarks.

3.5 Event Details

The Event dialog sets what an event represents and how it is quantified.

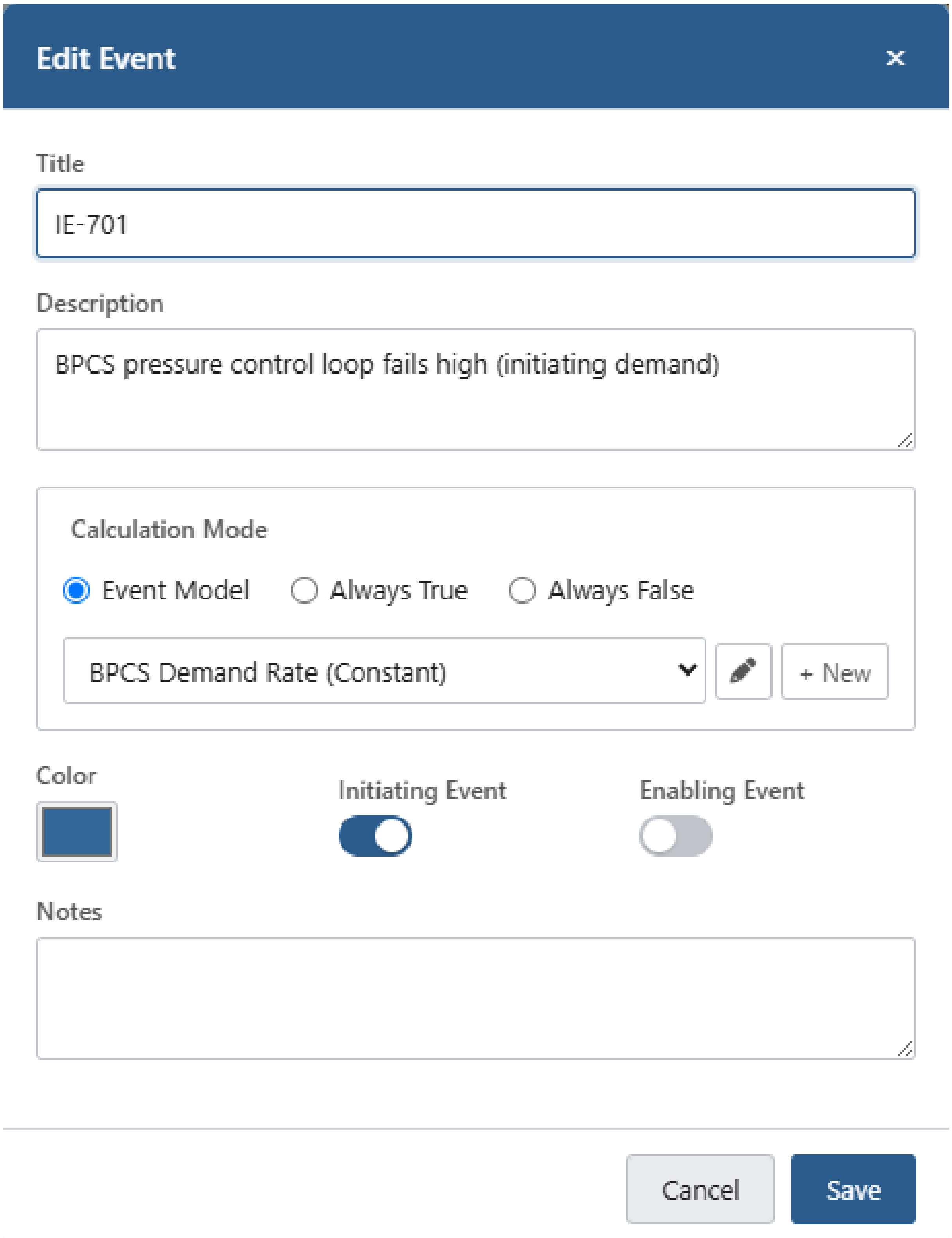


Figure 3-4. The Event dialog. The Calculation Mode is set to Event Model, and the Initiating Event toggle is on.

- **Title / Description** — the event's label (unique among events, up to 20 characters) and a longer description.
- **Calculation Mode** — choose Event Model (quantified by a model), Always True, or Always False (the two house-event modes).
- **Event Model** — in Event Model mode, pick the model that supplies the failure data. The pencil button edits the selected model in place; + New creates one.
- **Initiating Event / Enabling Event** — the mutually-exclusive toggles described in section 3.2.
- **Color / Notes** — appearance and remarks.

3.6 Nodes Used in More Than One Place

A gate or event can appear under several parents at once — the same underlying node, shared across the tree (for example, a common level transmitter feeding two different logic paths). In the grids this is shown as a Places Used count; in the diagram such a node carries a link icon and a use count.

You create shared nodes through the clipboard. After Copy, pasting onto a gate opens a Paste Reference? prompt:

- **Paste Reference** — links the same node under the new parent. Editing it anywhere changes it everywhere. Kenexis Fault Tree blocks references that would create a loop or duplicate an existing link.
- **Create New Instance** — deep-copies the node (and, for a gate, its whole subtree) as an independent new node, renumbering any colliding titles.

Cut followed by Paste moves a node's link from one parent to another (no prompt). When a shared node is selected, the Select Previous / Next Instance toolbar buttons walk you through each place it appears, switching pages as needed. Deleting a shared node only removes the one link you clicked; the node survives under its other parents.

3.7 Pages and Page Breaks

Large trees are split into pages. Any gate flagged Page Break becomes the root of a new page; below it the parent page shows a page-transfer arrow. Double-click the arrow — or click the page in the sidebar's Pages section — to move to that page. The Pages tree always lists the top gate's page as "… (Full Tree)".

3.8 Saving the Tree as an Image

The Save as Image button (camera icon, top-right of the canvas) exports the current tree as a PNG image with a white background, downloaded to your computer. For multi-page, print-ready output use the Fault Tree Diagrams report instead (Chapter 9).

4 Event Models and Failure Data

4.1 About Event Models

An event model holds the failure characteristics that quantify an event: its failure rate and, depending on type, its test interval, repair time, mission time, or a fixed unavailability. Several events can share one model, and models are managed both from the Event dialog and from the Event Models tab. Kenexis Fault Tree offers three model types, matched to how the modelled failure behaves in time.

4.2 Model Types

Constant

Use a Constant model when you want to enter an unavailability and/or a frequency directly — for example a human-error probability or an externally supplied figure. You supply the Failure Rate (which becomes the event frequency) and the Unavailability (a fixed probability between 0 and 1).

Covert

Use a Covert model for a dormant, dangerous-undetected failure that stays hidden until a periodic proof test reveals it — the usual model for safety-instrumented components. You supply the Failure Rate (λ), the Test Interval (the proof-test period), and the MTTR (mean time to restore). Kenexis Fault Tree computes the time-averaged unavailability over the test interval (section 10.2).

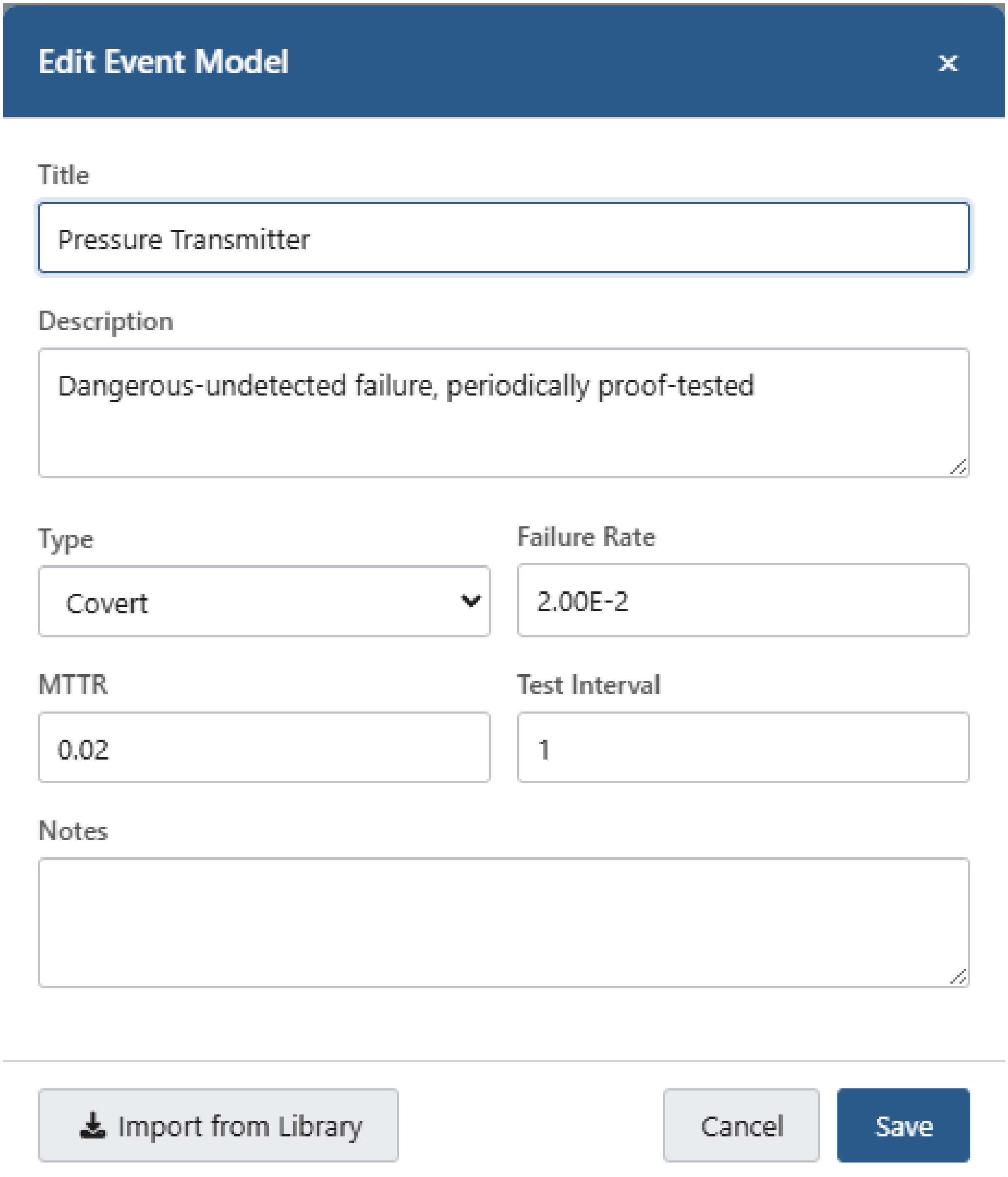


Figure 4-1. A Covert event model. Type is Covert, so the type-specific fields are MTTR and Test Interval alongside the Failure Rate.

Overt

Use an Overt model for a self-revealing failure that is detected immediately and repaired. You supply the Failure Rate (λ), the MTTR, and the Mission Time. Kenexis Fault Tree computes the steady-state unavailability λ·MTTR (section 10.2).

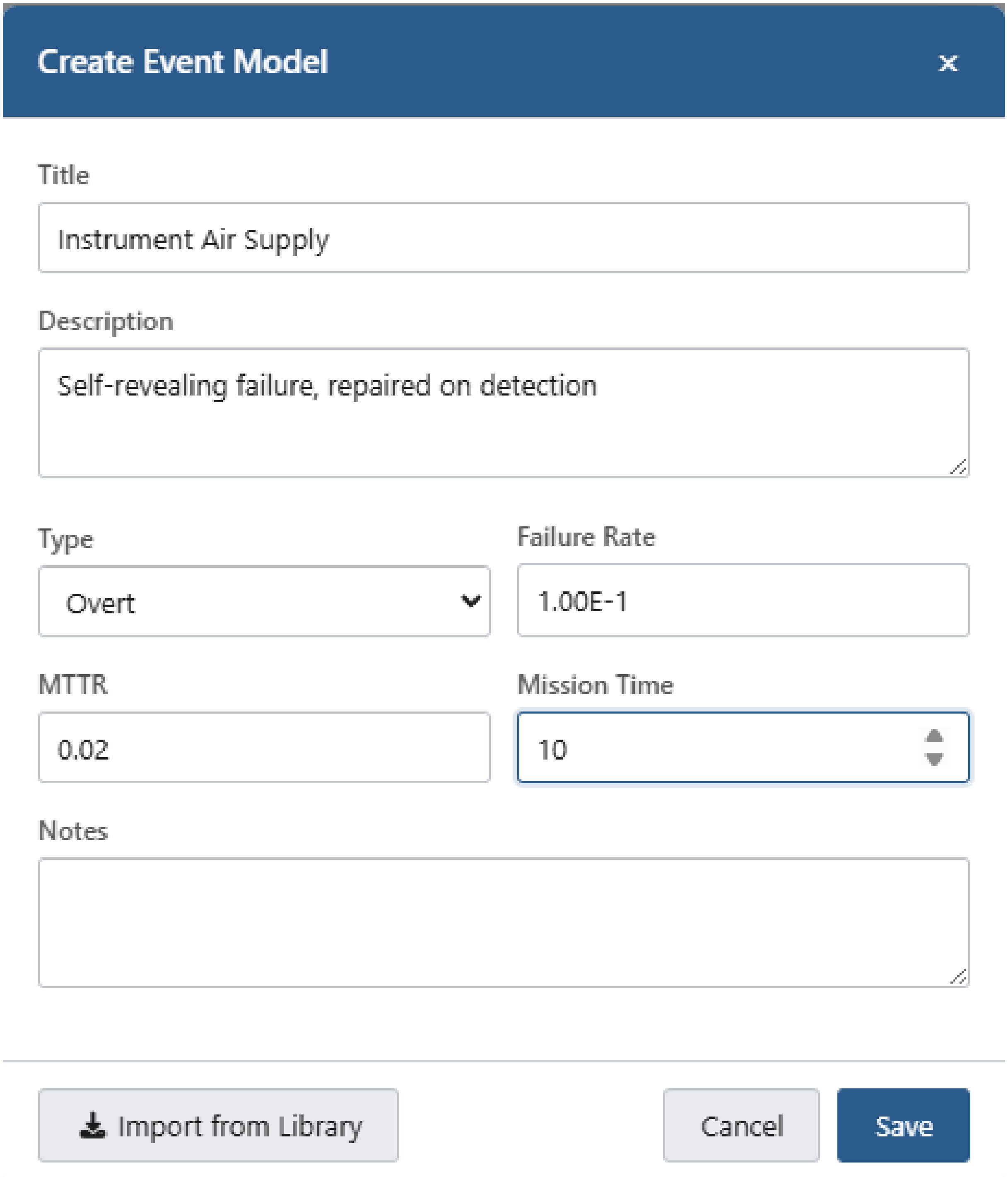


Figure 4-2. Creating an Overt event model. Selecting Overt replaces the Test Interval field with a Mission Time field (illustrative values shown).

One consistent time base

Kenexis Fault Tree is unit-agnostic. The Failure Rate, MTTR, Test Interval, and Mission Time must all be entered in the same time units, and those units must match the study's time base. The Time Units field on the Overview tab is only a label — it never converts anything (see section 10.9).

4.3 Importing Failure Data from a Library

Rather than typing failure rates by hand, you can pull them from a KISS failure-rate library. In an event-model dialog, click Import from Library.

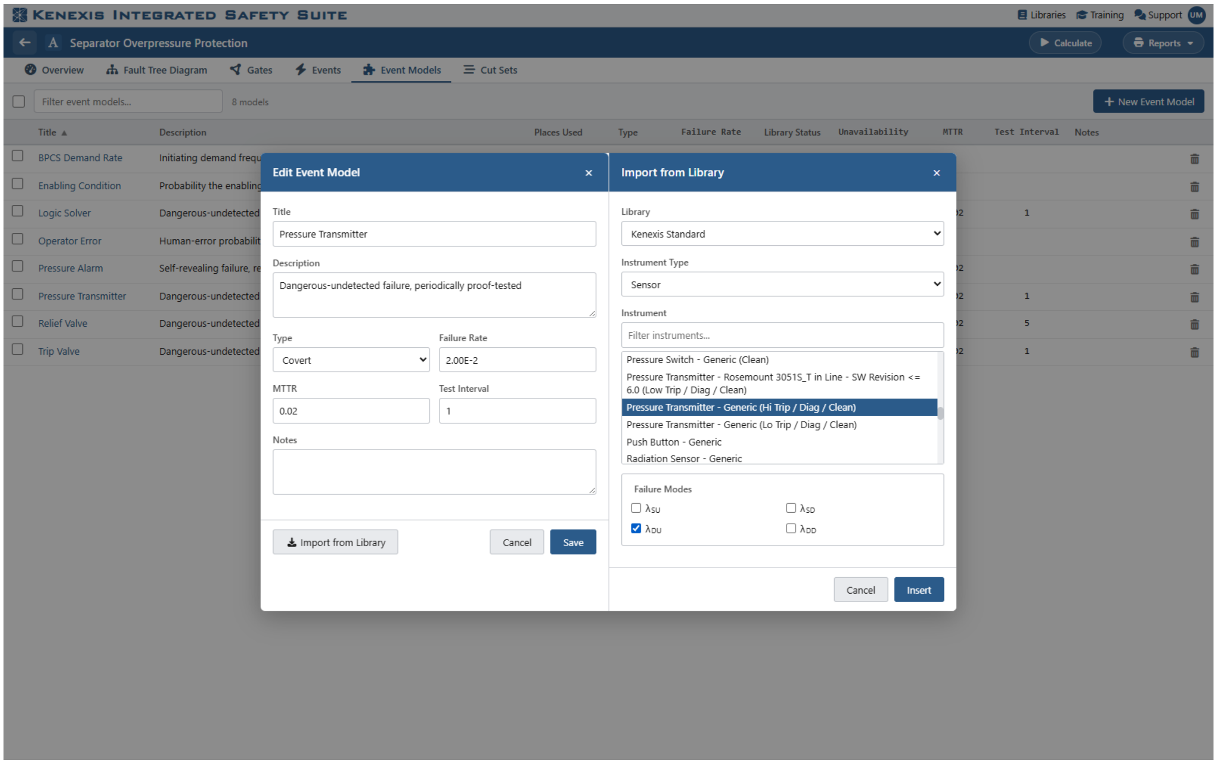


Figure 4-3. Import from Library, opened beside the event-model form. Choose the Library, the Instrument Type, and the specific Instrument, then tick the failure-mode splits (λSU, λSD, λDU, λDD) that make up the model's rate.

Choose a library (the facility's default is pre-selected), an instrument type (Process Connection, Sensor Interface, Sensor, Logic Solver, Final Element, or Final Element Interface), and a specific instrument — the filter box narrows the list. Then select at least one failure mode: λSU (safe undetected), λSD (safe detected), λDU (dangerous undetected), or λDD (dangerous detected). Insert sets the model's failure rate to the sum of the selected splits and records which library item it came from, so the model can later be checked against — and re-synced to — the library.

4.4 The Event Models Tab

The Event Models tab lists every model in the study with its type, failure rate, MTTR, test interval, unavailability, and a Library Status indicator.

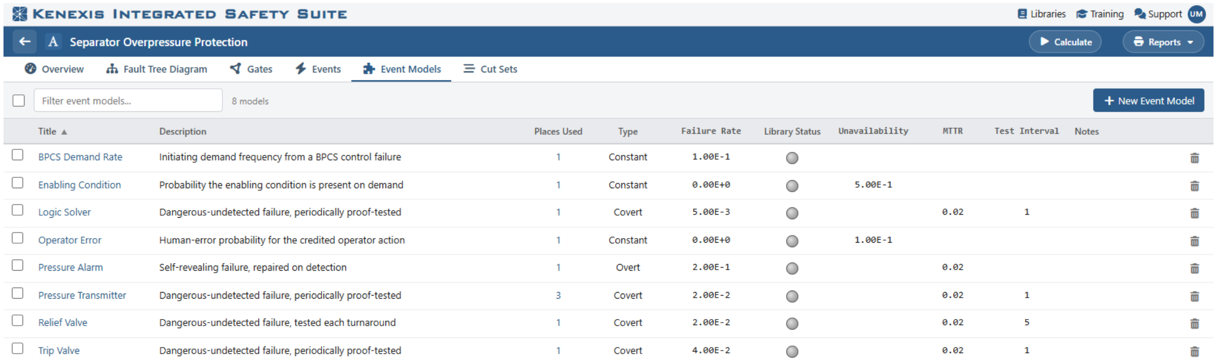


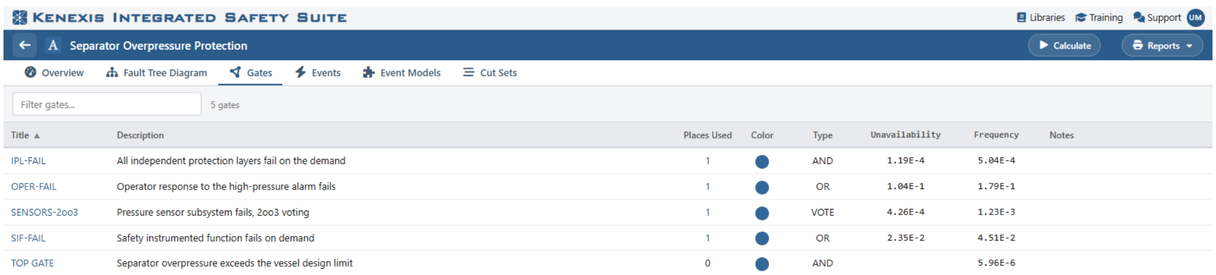
Figure 4-4. The Event Models tab. Each row shows the model type and its parameters; the Library Status dot indicates whether a model is current with, out of date against, or unlinked to a library item.

- **Library Status** — a colored dot: green (current with the library), yellow (out of date — click to open a Sync with Library dialog that compares the study rate to the current library rate), or grey (not from a library, or the library item can no longer be found).
- **Bulk operations** — tick one or more rows to reveal Update Test Interval, Update MTTR, Duplicate, and Delete. The bulk updates are ideal for sensitivity analysis — for example, changing the proof-test interval on many devices at once.
- **New Event Model** — creates a model directly, without attaching it to an event yet.

5 The Gates and Events Tables

For large trees the tabular views are often faster than the diagram for comparing results and spotting outliers. Both tables share the same behavior: a filter box (matching title, description, and notes), a live row count, click-to-sort column headers (with an ▲/▼ indicator), a clickable Places Used count that lists a node's parent gates, and a row action that opens the node's edit dialog.

5.1 The Gates Table

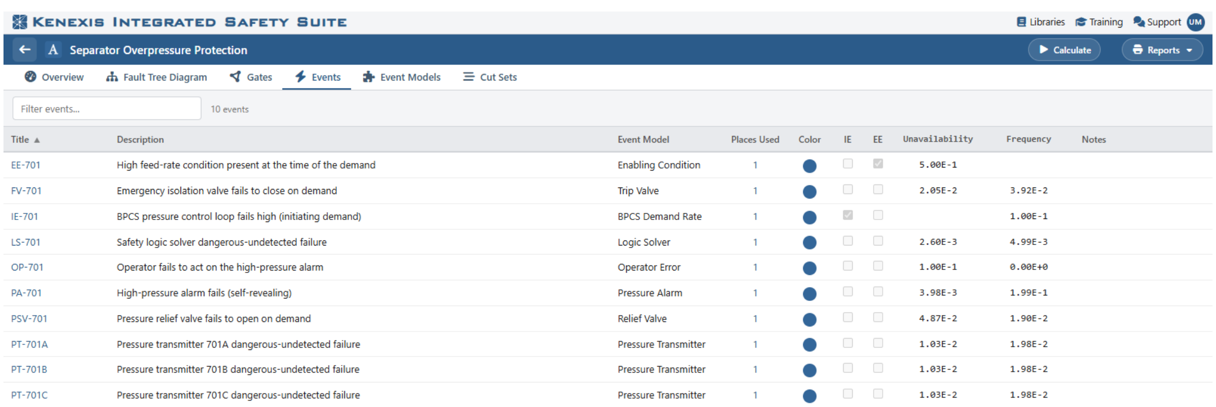


Title ▲	Description	Places Used	Color	Type	Unavailability	Frequency	Notes
IPL-FAIL	All independent protection layers fail on the demand	1	●	AND	1.19E-4	5.04E-4	
OPER-FAIL	Operator response to the high-pressure alarm fails	1	●	OR	1.04E-1	1.79E-1	
SENSORS-2oo3	Pressure sensor subsystem fails, 2oo3 voting	1	●	VOTE	4.26E-4	1.23E-3	
SIF-FAIL	Safety instrumented function fails on demand	1	●	OR	2.35E-2	4.51E-2	
TOP GATE	Separator overpressure exceeds the vessel design limit	0	●	AND		5.96E-6	

Figure 5-1. The Gates tab. Each gate shows its type, unavailability, and frequency; the Places Used column flags gates shared across multiple locations in the tree.

Columns: Title, Description, Places Used, Color, Type, Unavailability, Frequency, and Notes. Results populate when you calculate. In a frequency-driven tree, gates on the initiating-event chain show a frequency and carry their protection value in the frequency result (section 10.5 explains the math).

5.2 The Events Table



Title ▲	Description	Event Model	Places Used	Color	IE	EE	Unavailability	Frequency	Notes
EE-701	High feed-rate condition present at the time of the demand	Enabling Condition	1	●	☐	☑	5.00E-1		
FV-701	Emergency isolation valve fails to close on demand	Trip Valve	1	●	☐	☐	2.05E-2	3.92E-2	
IE-701	BPCS pressure control loop fails high (initiating demand)	BPCS Demand Rate	1	●	☑	☐		1.00E-1	
LS-701	Safety logic solver dangerous-undetected failure	Logic Solver	1	●	☐	☐	2.60E-3	4.99E-3	
OP-701	Operator fails to act on the high-pressure alarm	Operator Error	1	●	☐	☐	1.00E-1	0.00E+0	
PA-701	High-pressure alarm fails (self-revealing)	Pressure Alarm	1	●	☐	☐	3.98E-3	1.99E-1	
PSV-701	Pressure relief valve fails to open on demand	Relief Valve	1	●	☐	☐	4.87E-2	1.90E-2	
PT-701A	Pressure transmitter 701A dangerous-undetected failure	Pressure Transmitter	1	●	☐	☐	1.03E-2	1.98E-2	
PT-701B	Pressure transmitter 701B dangerous-undetected failure	Pressure Transmitter	1	●	☐	☐	1.03E-2	1.98E-2	
PT-701C	Pressure transmitter 701C dangerous-undetected failure	Pressure Transmitter	1	●	☐	☐	1.03E-2	1.98E-2	

Figure 5-2. The Events tab. Each event shows its event model, its IE / EE flags, and its results. An initiating event reports a frequency; an enabling event reports an unavailability.

Columns: Title, Description, Event Model, Places Used, Color, IE, EE, Unavailability, Frequency, and Notes. The IE and EE checkboxes are read-only here; set them in the Event dialog.

6 Running Calculations and Reviewing Results

6.1 Calculating

Click Calculate in the header (or press Ctrl+Enter) to evaluate the whole study. A progress overlay appears; calculations are usually a few seconds but there is no fixed limit on tree size. When you change anything that affects the result (add, edit, move, delete, paste, or a model change), Kenexis Fault Tree marks the results stale and shows a Results Out of Date badge until you recalculate. A single click evaluates everything.

> **One initiating event per cut set**
>
> The engine enforces one modeling rule: a single cut set holds at most one initiating event. If two initiating events meet in one cut set, Kenexis Fault Tree reports “<gate> Can Only Have One Initiating Event” so you can adjust the flags and recalculate. Two ordinary frequency-bearing events combined at an AND gate are valid — the rule applies to the initiating-event flag specifically.

6.2 Reading Results on the Diagram

After calculating, every node shows a results box beneath its symbol: an unavailability line (Q or RRF, depending on the toggle) and a frequency line (w). Initiating events and the gates above them show only a frequency.

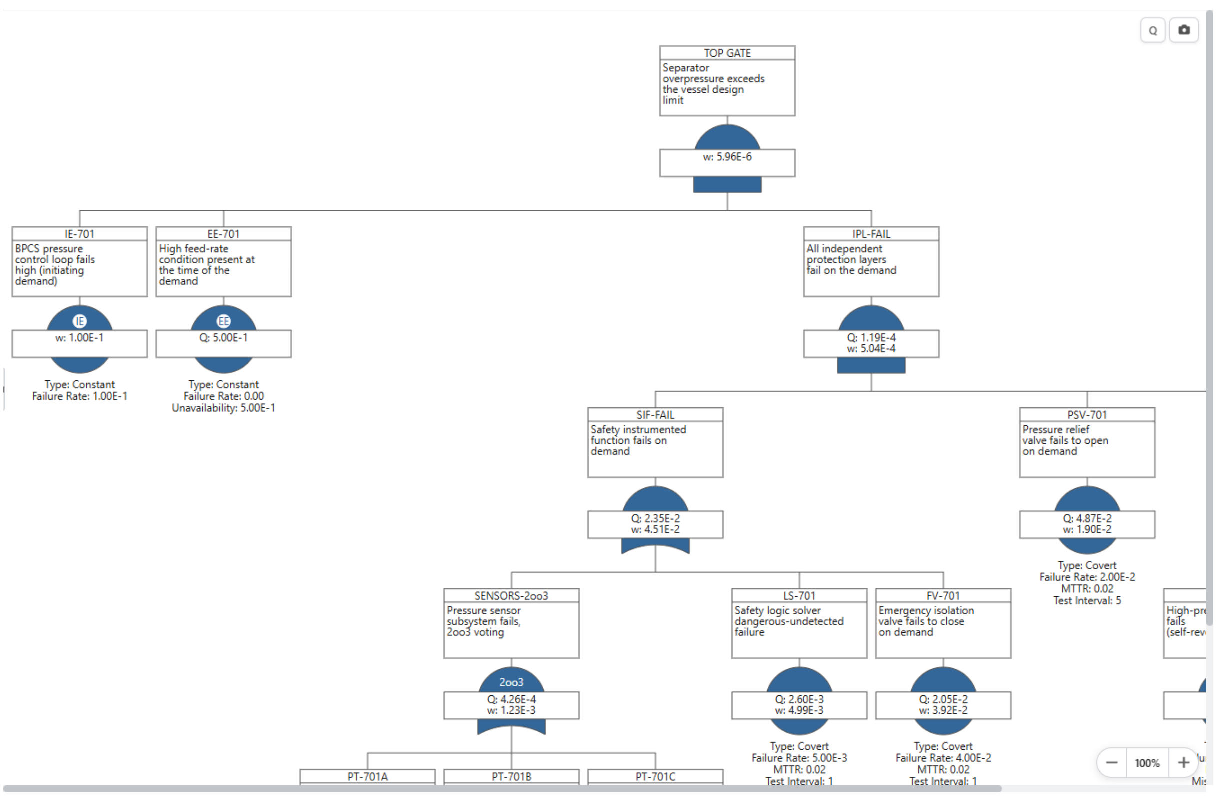


Figure 6-1. The diagram with the Q/RRF toggle set to Q. Toggling to RRF replaces each Q value with its risk reduction factor (1 ÷ Q); a Q of zero displays as RRF ➤∞. The choice is saved with the study.

The Q/RRF toggle in the top-right of the canvas switches between showing unavailability and risk reduction factor. Numbers on the diagram are formatted for readability: exact zero as 0.00, values of one or more with thousands separators, and small values in scientific notation (for example 3.46×10^{-2}).

6.3 The Cut Sets Tab

The Cut Sets tab shows the minimal cut sets for one gate at a time. Pick the gate from the Select Gate list (the top gate is offered first); the gate's overall unavailability and frequency are shown beside it.

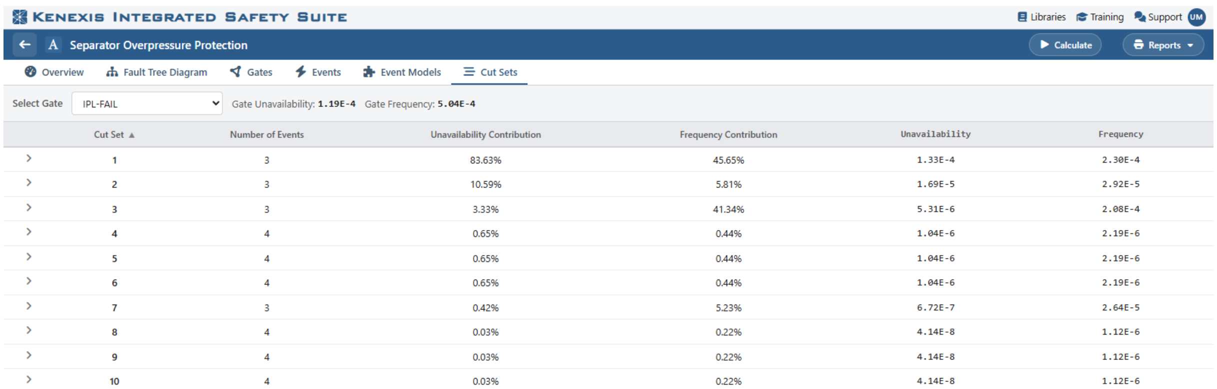


Figure 6-2. The Cut Sets tab. Columns give each cut set's event count, its unavailability and frequency contributions (normalized to total 100%), and its absolute unavailability and frequency. Every column can be sorted.

Each row is one minimal cut set. The Cut Set number is its importance rank by unavailability. The two Contribution columns are normalized so that each column totals 100%. Click a row to expand it and see the individual events in that cut set, ordered by decreasing unavailability; the event and model links open their respective dialogs.

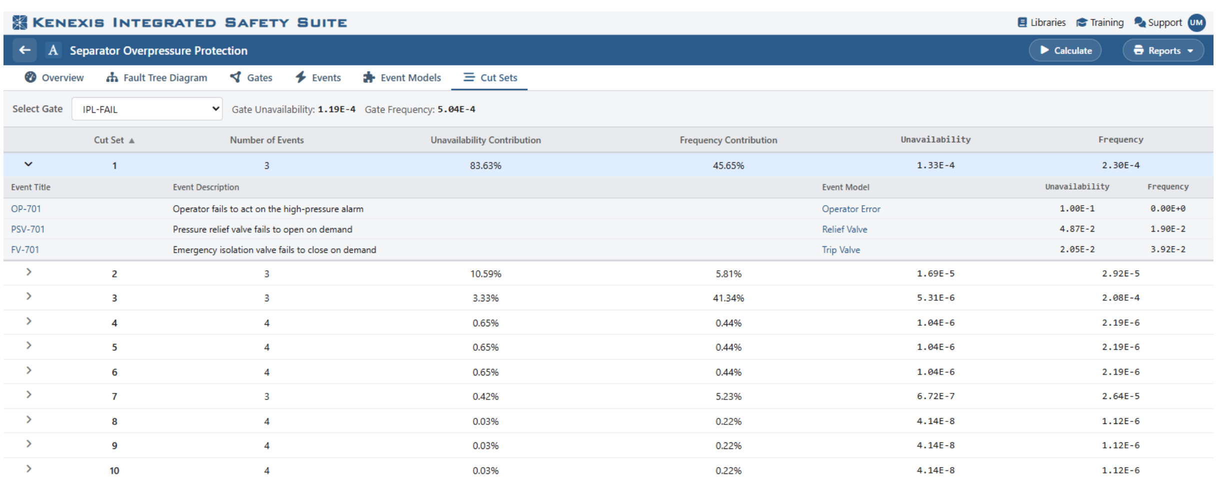


Figure 6-3. A cut set expanded to list its events. This cut set represents the simultaneous failure of several independent protection layers, listed in order of decreasing unavailability; each event's unavailability multiplies into the cut set's combined result.

Which columns to read

For a frequency-driven tree (one led by an initiating event), read the Frequency and Frequency-Contribution columns — the top gate's frequency is the meaningful result. For a probability-based (on-demand) tree, read the Unavailability columns.

6.4 Results on the Overview Tab

The Overview tab's stat strip shows the headline numbers — event/gate/model counts and the Top Gate Q and W — so you can confirm the study result without opening the diagram.

7 The Overview Tab

The Overview tab is the study's home page — its properties and its documentation records.

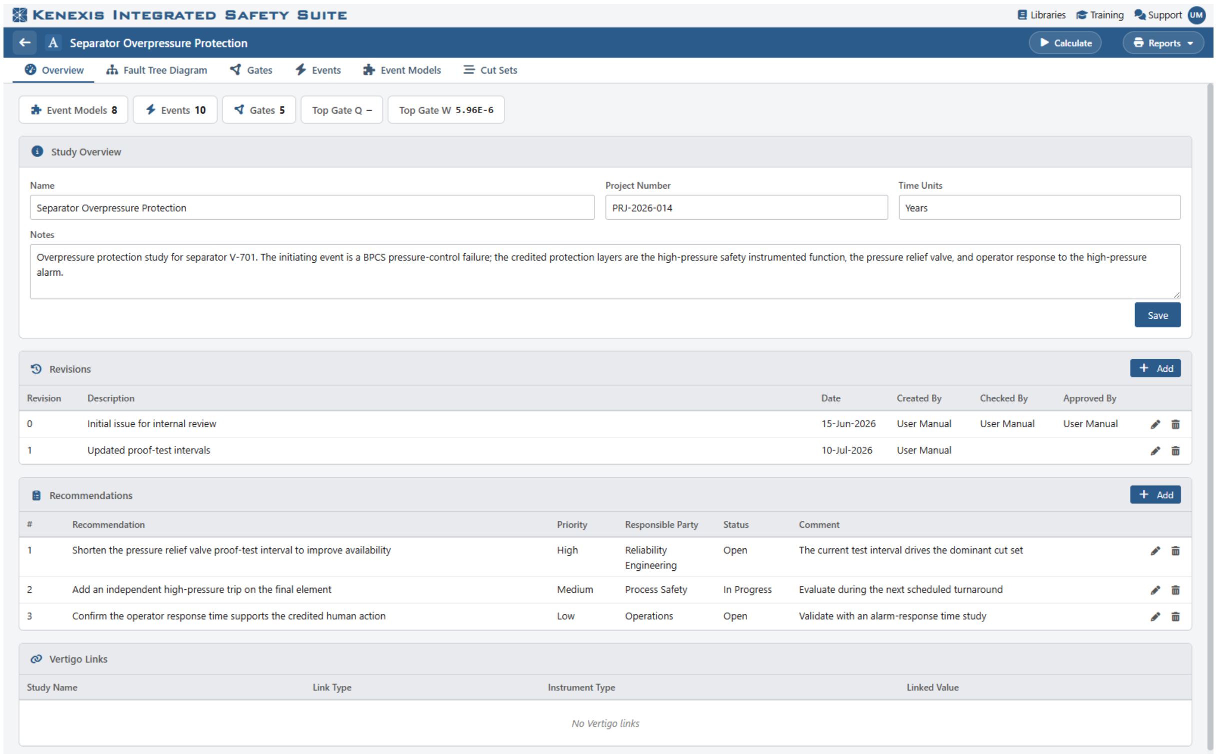


Figure 7-1. The Overview tab: the stat strip, the Study Overview properties, and the Revisions, Recommendations, and Vertigo Links sections.

7.1 Study Overview

- **Name** — the study name (required). Renaming it here also updates it everywhere it appears in KISS.
- **Project Number** — a free-text project reference for tracking purposes.
- **Time Units** — a descriptive label for the study's time base (for example, Years or Hours). Calculations use the numeric values you enter; keep them in one consistent base (section 10.8).
- **Notes** — free-text remarks. Click Save to store changes.

7.2 Revisions

The Revisions section is a change log for the study — a documented record of who made, checked, and approved each revision, so the analysis carries its own audit trail.

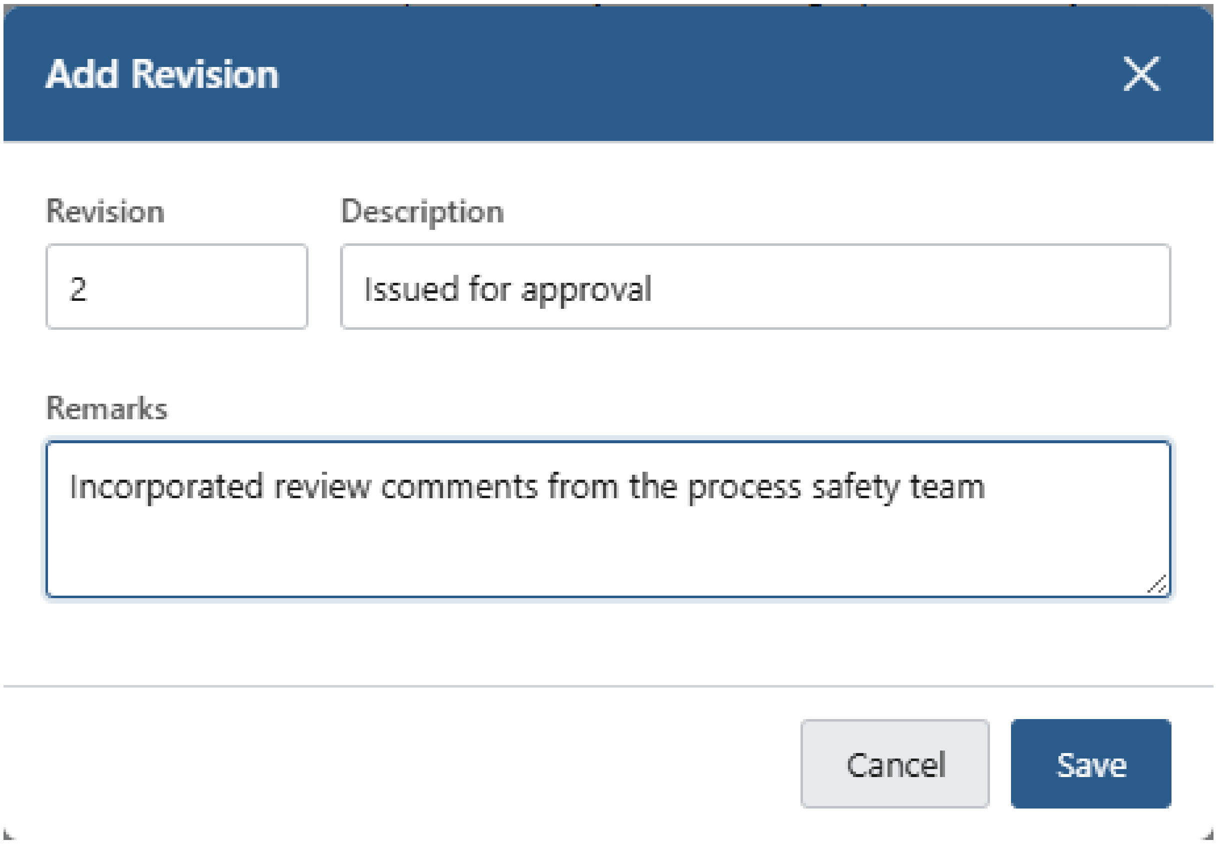


Figure 7-2. Adding a revision. A revision captures a Revision label, a Description, and Remarks; the creator's name and the date are stamped automatically.

Click Add to create a revision with a Revision label, Description, and Remarks. Editing an existing revision adds Mark as Checked and Mark as Approved buttons that stamp your name into the Checked By / Approved By columns. Revisions can be edited or deleted from the grid.

7.3 Recommendations

The Recommendations section tracks proposed design or operational changes arising from the analysis. Each recommendation has an auto-incrementing Number, a Priority (High / Medium / Low), a Responsible Party, a Status, the recommendation text, and a Comment. Recommendations can be added, edited, and deleted, and they can be exported as a report (Chapter 9).

7.4 Vertigo Links

The Vertigo Links section is a read-only list of the Kenexis SIS instrument types that draw a value from this Kenexis Fault Tree study (see Chapter 8). Each row names the Kenexis SIS study, the link type (Sensor / Logic Solver / Final Element type), the instrument type, and whether the linked value is a PFD or an STR. If nothing links to the study it reads "No Vertigo links".

8 Linking a Fault Tree to Kenexis SIS (BBM)

Kenexis Fault Tree integrates with Kenexis SIS, the KISS SIS-lifecycle module, through its Basic Building Block (BBM) mechanism. This lets a Kenexis SIS instrument type take its PFDavg or spurious-trip rate from a full Kenexis Fault Tree fault tree instead of a simple formula — useful when a subsystem is too complex for a closed-form expression.

8.1 How the Link Is Made

Links are created from the Kenexis SIS side. In Kenexis SIS, when a Sensor, Logic Solver, or Final Element type is in BBM mode, its PFDavg and STR fields each offer “Link to Fault Tree…”. A picker lets you browse to a Kenexis Fault Tree study and select it; a preview shows the study name, when it was last calculated, its root gate, and the value that will be used. Once linked, the Kenexis SIS field becomes read-only and displays the pushed value.

8.2 How Values Flow

The link is one-directional and push-based. Every time you Calculate a Kenexis Fault Tree study, Kenexis Fault Tree writes the top gate’s unavailability into the linked Kenexis SIS type’s PFD field and the top gate’s frequency into its STR field, then recalculates the affected Kenexis SIS types and their SIFs. Because the value is pushed on every recalculation, the Kenexis SIS number always reflects the Kenexis Fault Tree study’s latest calculation.

Choosing which value to link

Link a probability-based (on-demand) tree as a PFD source and a frequency-based tree as an STR source, so the pushed value matches the field it feeds. The Kenexis Fault Tree side displays inbound links on the Overview tab’s Vertigo Links list for reference.

9 Reports

The Reports menu in the header generates document and spreadsheet outputs from the study.

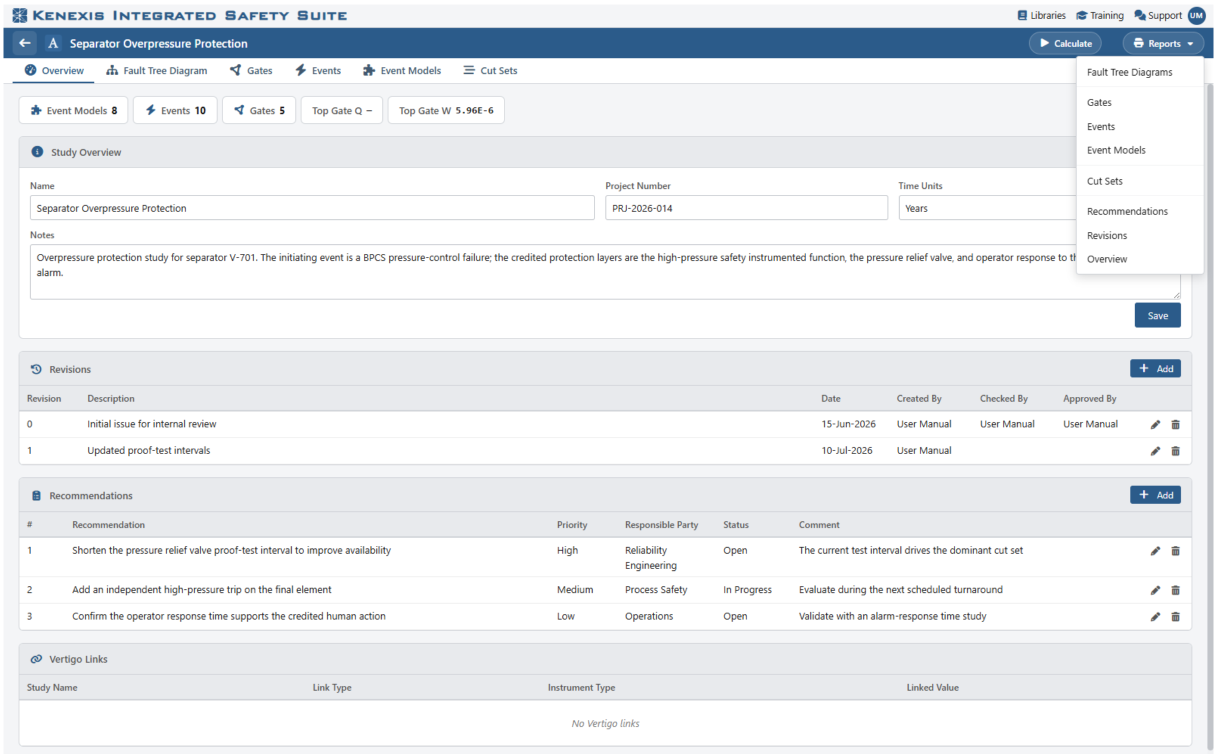


Figure 9-1. The Reports menu: Fault Tree Diagrams; Gates, Events, Event Models; Cut Sets; and Recommendations, Revisions, Overview.

9.1 Fault Tree Diagrams (Word)

Fault Tree Diagrams opens a dialog and produces a Word document (“Arbor Tree Diagrams.docx”) with a rendered image of each page of the tree.

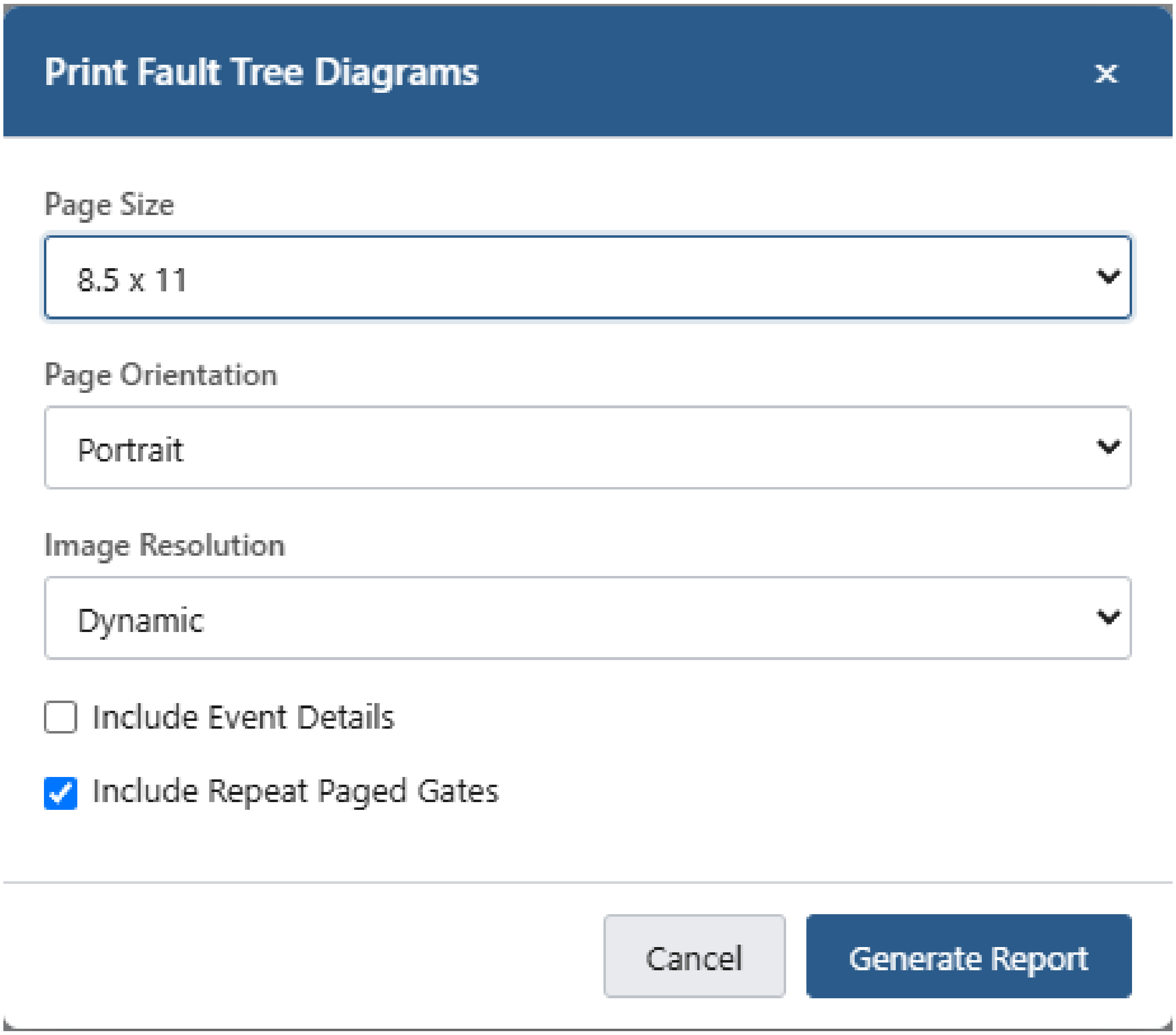


Figure 9-2. The Print Fault Tree Diagrams dialog: Page Size (8.5×11 or 11×17), Page Orientation, Image Resolution (Dynamic or Maximum), and options to include event details and repeat paged gates.

9.2 Cut Sets (Excel)

Cut Sets opens a dialog and produces an Excel workbook ("Arbor Cut Sets.xlsx") with one worksheet per gate.

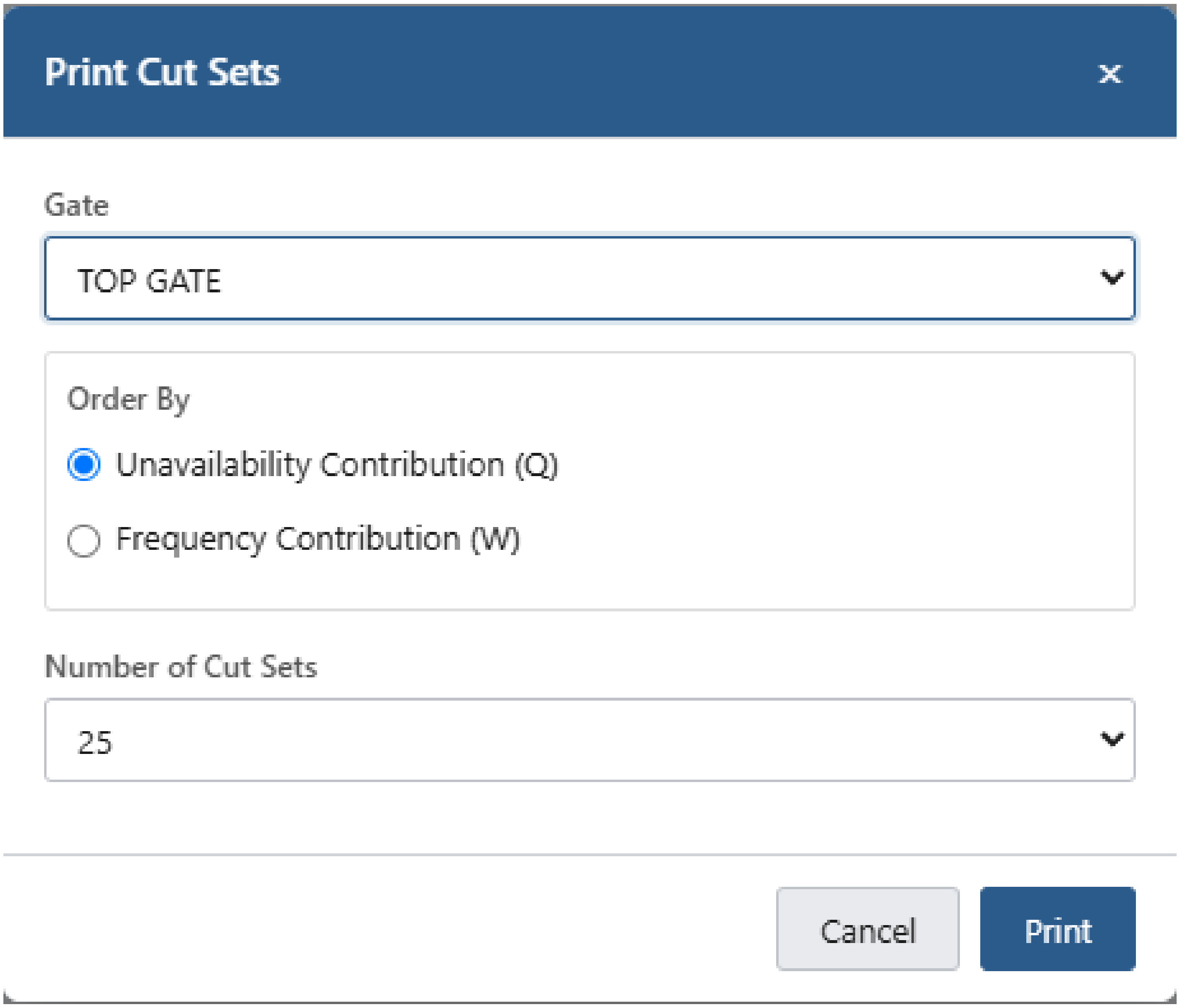


Figure 9-3. The Print Cut Sets dialog: choose the Gate, order by unavailability contribution (Q) or frequency contribution (W), and cap how many cut sets are printed (25, 50, 100, 250, or 500).

Report length

The on-screen Cut Sets tab lists every cut set. Use the Number of Cut Sets setting here to choose how many of the highest-ranked cut sets appear in the printed workbook.

9.3 Tabular Reports

The remaining menu items download an Excel workbook immediately, giving you a tabular export of that object type:

Table 9-1. The one-click tabular reports and their contents.

Report	Contents
Gates	Title, Description, Gate Type, Unavailability, Frequency, Notes.
Events	Title, Description, Event Model (or House True/False), Unavailability, Frequency, Notes.

Report	Contents
Event Models	Title, Description, Places Used, Type, Failure Rate, Unavailability, MTTR, Test Interval, Notes.
Recommendations	Number, Recommendation, Priority, Responsible Party, Status, Comment.
Revisions	Revision, Description, Remarks, Created By, Date, Checked By, Approved By.
Overview	Study name, project number, time units, notes, top-gate results, and object counts.

10 The Calculations Behind Kenexis Fault Tree

This chapter documents how Kenexis Fault Tree turns a fault tree into numbers. The formulas below are the ones the calculation engine uses, and each is followed where helpful by a small worked example.

10.1 The Three Quantities

Every event and gate resolves to an unavailability Q and a frequency w:

- **Unavailability Q** — the probability of being in a failed state at a random instant ($0 \le Q \le 1$).
- **Frequency w** — the rate of failure per unit of the study's time base.
- **Risk Reduction Factor RRF** — a display convenience equal to 1 ÷ Q; when Q = 0 it is shown as ∞.

Frequency-carrying nodes (initiating events and the gates above them) and probability-carrying nodes (enabling and basic events) are combined by the formulas in sections 10.4–10.6.

10.2 Event Model Calculations

Each event first resolves to a (Q, w) pair from its model. A house event gives Q = 1 (Always True) or Q = 0 (Always False) with no frequency; an event with no model gives Q = 0 and w = 0.

Constant

$$w = \text{failure rate}$$
$$Q = \text{unavailability, as entered}$$

Covert (dormant, periodically proof-tested)

With failure rate r, test interval τ, mean time to restore MTTR, and E = e^(−r·τ):

$$Q = \frac{r\tau - (1 - E) + r \cdot \mathrm{MTTR} \cdot (1 - E)}{r\tau + r \cdot \mathrm{MTTR} \cdot (1 - E)}$$
$$w = r \cdot (1 - Q)$$

This is the exact time-averaged unavailability of a component that fails invisibly and is only restored at each proof test (including repair time). For the common case of a short test interval and negligible repair ($r \cdot \tau \ll 1$, MTTR = 0) it reduces to the familiar approximation:

$$Q \approx \frac{\lambda\tau}{2}$$

Worked example

A Covert component with $\lambda = 1\times10^{-4}$ per year, τ = 25 years, and MTTR = 0 has $Q = \lambda\tau/2 = (1\times10^{-4} \times 25) / 2 = 1.25\times10^{-3}$.

Overt (self-revealing)

With failure rate λ, repair rate μ = 1/MTTR, and mission time T:

$$Q = \frac{\lambda}{\lambda + \mu} \cdot \left(1 - e^{-(\lambda + \mu)T}\right) \rightarrow \lambda \cdot \mathrm{MTTR}$$

$$w = \lambda \cdot (1 - Q)$$

The limit λ·MTTR applies as the mission time T grows large.

An overt failure is detected at once, so its unavailability is essentially the repair downtime fraction λ·MTTR.

10.3 Minimal Cut Sets

A cut set is any combination of failed events that is sufficient to fail the gate. A minimal cut set is one that contains no smaller cut set — remove any event from it and it no longer causes failure. Working with minimal cut sets matters: ignoring minimality double-counts and grossly overestimates the result.

Kenexis Fault Tree generates cut sets top-down (a MOCUS-style expansion), starting from the gate and substituting each gate by its inputs according to its logic:

- **AND** — the gate's inputs are merged into the same cut set (they must all fail together).
- **OR** — each input spawns a separate cut-set branch (any one failing is enough).
- **VOTE (K-of-N)** — every combination of K inputs becomes a cut set.
- **Transfer** — replaced by its single child.

The resulting sets are then minimized in two steps: sets whose contribution is negligible (both their Q and their w below one hundred-thousandth of the respective totals) are dropped, and any set that contains a smaller set is absorbed away. Cut-set generation is exhaustive; the Cut Sets report (Chapter 9) optionally limits how many rows are printed.

10.4 Cut Set Unavailability and Frequency

For a single minimal cut set, the two quantities are computed differently.

Unavailability

The unavailability of a cut set is the product of its events' unavailabilities — but with a correction for periodically-tested (Covert) components. If a cut set contains n Covert events, their combined contribution is multiplied by a factor of $2^n / (n + 1)$:

$$Q_{\text{cut set}} = P_{\text{other}} \cdot \frac{2^n \cdot P_{\text{cov}}}{n + 1}$$

P_other = product of the non-covert events' unavailabilities; P_cov = product of the n covert events' unavailabilities.

The factor corrects an averaging subtlety: for n components that are proof-tested together, the time-average of the product of their sawtooth unavailabilities is larger than the product of their individual averages. (For n = 1 the factor is 1 — no change; for n = 2 it is 1.33; for n = 3 it is 2.0.) A cut set that contains an initiating event is evaluated on frequency alone. This treatment follows Goble & Cheddie, Safety Instrumented Systems Verification, Appendix C.

Frequency

The frequency of a cut set is a plain product; the covert averaging factor applies to unavailability only. For the usual case of one initiating event guarded by protection layers:

$$w_{\text{cut set}} = f_{\text{init}} \cdot \prod Q_{\text{other events}}$$

More generally, when several events in a set carry frequencies, each contributes its frequency times the unavailabilities of the others, and those terms are summed.

> **Worked example**
>
> Consider a cut set in which an initiating event of 8 per year is guarded by three independent protection layers with unavailabilities of 4×10^{-2}, 2×10^{-2}, and 5×10^{-3}. The cut-set frequency is:
>
> ```
> w = 8 × 4×10⁻² × 2×10⁻² × 5×10⁻³ = 3.2×10⁻⁵ per year
> ```

10.5 Gate Unavailability and Frequency

Kenexis Fault Tree evaluates each gate from its full set of minimal cut sets, so that shared and repeated events are handled correctly. Events common to every cut set are first factored out, then the cut sets are combined with the Esary-Proschan equations — the standard minimal-cut-set upper bounds.

If an initiating event is common to every cut set (the LOPA pattern)

$$W_{\text{gate}} = \left(\sum f_{\text{init}}\right) \cdot Q_{\text{remaining layers}}$$

The gate carries a frequency only; its unavailability is undefined.

Otherwise (a probability-based gate)

$$Q_{\text{gate}} = 1 - \prod_{\text{cut sets}} (1 - Q_{\text{cut set}})$$

$$W_{\text{gate}} = \sum_{\text{cut sets}} w_{\text{cut set}} \cdot \prod_{\text{others}} (1 - Q)$$

Esary-Proschan minimal-cut-set bounds.

The union form $1 - \prod(1 - Q_i)$ applies to OR combinations, keeping probabilities at or below 1 and counting shared events once. A gate whose subtree contains an initiating event reports a frequency and leaves its unavailability blank, since unavailability is undefined for a frequency-driven branch.

10.6 Initiating and Enabling Events

These two flags are how a fault tree mixes frequencies and probabilities consistently:

- **Initiating event** — carries a frequency and no probability. It is the instantaneous trigger of a sequence. Because two triggers cannot occur at the same instant, a cut set may contain only one initiating event — the engine enforces this (section 6.1).
- **Enabling event** — carries a probability and no frequency. It is a condition that must be present for the sequence to proceed. Any cut set that depends on an enabling condition contributes probability, not an extra frequency.

10.7 Reconciling Gate and Cut-Set Frequencies

A natural check is to add up the frequency column in the Cut Sets tab and compare it with the gate frequency. The two relate but differ by design, for three reasons:

1. The gate value applies the covert $2^n/(n+1)$ averaging correction, while the cut-set frequency column uses a plain product.
2. The gate value applies the Esary-Proschan union bounds, which fall below a naive sum.
3. Events common to every cut set are factored out at the gate level, a step the individual rows omit.

Read the gate value as the rigorous result and the cut-set rows as a ranked breakdown of the individual contributors.

10.8 Units

Kenexis Fault Tree works in a single consistent time base. Enter every failure rate, test interval, repair time, and mission time in the same units, matching the study's base. The Time Units field on the Overview tab is a descriptive label. Choose a base — commonly years or hours — and use it throughout. When you link a study to Kenexis SIS as a spurious-trip-rate source, use an hourly base to match Kenexis SIS's per-hour rates.

10.9 Validation and Number Formatting

The engine raises one calculation message — more than one initiating event in a cut set (section 6.1). It also handles incomplete models gracefully: an event with no model contributes zero, an empty gate contributes zero, and a Transfer gate resolves through its single child. Circular references are caught as you edit — a paste that would form a loop is declined — so every calculation runs on a valid tree.

Displayed results are formatted for readability while stored at full precision. Grids and the Overview use three-significant-figure scientific notation (for example 1.23×10^{-4}); diagram nodes show exact zero as 0.00, values ≥ 1 with thousands separators, and small values in scientific notation; cut-set contribution columns are percentages that total 100%.

Appendix A Symbol Reference

Table A-1. Fault tree node symbols.

Node	Symbol	Notes
Transfer gate	Triangle	Pass-through / page continuation.
AND gate	Flat-bottomed gate	All inputs must fail.
OR gate	Curved-bottom gate	Any input fails.
VOTE gate	OR gate with MooN caption	K of N inputs must fail (e.g. 2oo3).
Basic event	Circle	Quantified by an event model.
Undeveloped event	Diamond	No model assigned; contributes zero.
House event	House / pentagon	Forced Always True (Q=1) or Always False (Q=0).
Initiating event	Circle + IE badge	Frequency only.
Enabling event	Circle + EE badge	Probability only.
Shared node	Link icon + use count	The same node used under multiple parents.

Appendix B Keyboard Shortcuts

These apply on the Fault Tree Diagram tab when no dialog is open.

Table B-1. Fault Tree Diagram keyboard shortcuts.

Key	Action
`Q`	Add an event under the selected gate
`W`	Add a gate under the selected gate
`Enter`	Open the selected node's edit dialog
`Ctrl+Enter`	Calculate the study
`Delete`	Delete the selected node (with confirmation)
`Ctrl+C / Ctrl+X / Ctrl+V`	Copy / Cut / Paste a node
`Ctrl+← / Ctrl+→`	Move the node left / right among its siblings
`+ / −`	Zoom in / out
`Esc`	Clear the selection and cancel a pending copy or cut

Appendix C Formula Quick Reference

Table C-1. Formula quick reference.

Quantity	Formula
Constant Q, w	$Q = \text{unavailability, entered,} \qquad w = \text{failure rate}$
Covert Q	$Q = \dfrac{r\tau - (1 - E) + r \cdot \text{MTTR} \cdot (1 - E)}{r\tau + r \cdot \text{MTTR} \cdot (1 - E)}$
Covert Q (small rτ)	$Q \approx \dfrac{\lambda\tau}{2}$
Overt Q	$Q = \dfrac{\lambda}{\lambda + \mu} \cdot \left(1 - e^{-(\lambda+\mu)T}\right) \rightarrow \lambda \cdot \text{MTTR}$
Event w (Covert / Overt)	$w = \lambda \cdot (1 - Q)$
Cut-set Q	$Q_{\text{cs}} = P_{\text{other}} \cdot \dfrac{2^n \cdot P_{\text{cov}}}{n + 1}$
Cut-set w (initiator)	$w_{\text{cs}} = f_{\text{init}} \cdot \prod Q_{\text{other}}$
Gate Q (Esary-Proschan)	$Q_{\text{gate}} = 1 - \prod(1 - Q_{\text{cs}})$
Gate w	$W_{\text{gate}} = \sum w_{\text{cs}} \cdot \prod(1 - Q)$
RRF	$\text{RRF} = \dfrac{1}{Q}$

End of manual.