Kenexis® Bowtie

Quantitative Bowtie Analysis

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1 Introduction

1.1 About Kenexis Bowtie

Kenexis Bowtie is the quantitative bowtie module of the Kenexis Integrated Safety Suite (KISS). It is a browser-based, multi-user application for building bowtie diagrams — the barrier-centered picture of how a hazard is released and how its outcomes are controlled — and for putting numbers to them. A Kenexis Bowtie study shows, on one page, what can cause a loss of control, what happens if control is lost, which barriers stand in the way, and how often each outcome is expected.

The quantitative treatment is the point of difference. A qualitative bowtie records that barriers exist; Kenexis Bowtie also carries a frequency for every cause and a probability of failure on demand for every barrier, and propagates them through the diagram to a frequency for each consequence. That frequency is then compared against the tolerance criteria your organization has defined, so each outcome carries a clear tolerable or intolerable verdict. Chapter 11 documents the mathematics in full.

1.2 The Bowtie Model

A bowtie is read from left to right, and takes its name from its shape. The knot in the middle is the top event — the moment control of the hazard is lost. Everything to the left explains how the top event comes about; everything to the right explains what follows from it.

Table 1-1. The six elements of a bowtie.

Element	What it represents
Top event	The loss of control at the center of the study, such as a loss of containment. Every cause leads to it and every consequence flows from it.
Cause	A credible way the top event can occur, sometimes called a threat. Each cause carries the frequency at which it would produce the top event if nothing stood in its way.
Consequence	An outcome that can follow the top event, such as a fire or an environmental release.
Barrier	A safeguard that interrupts the sequence. On the left it is preventive, reducing how often a cause reaches the top event; on the right it is mitigative, reducing how often the top event reaches a consequence. Each barrier carries a probability of failure on demand.
Escalation factor	A condition that undermines a barrier — the reason a barrier might not work when called upon. Kenexis Bowtie calls this a degradation factor.
Escalation factor control	A measure that manages an escalation factor. Kenexis Bowtie calls this a degradation control.

Kenexis Bowtie draws all six element types on a single canvas, so the whole argument — hazard, barriers, and outcomes — stays visible while you work.

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, bringing hazard analysis, fault tree analysis, safety integrity verification, consequence modeling, and bowtie analysis together in one place so that the results of one study can inform another. Kenexis Bowtie is the module that draws these threads together into a single barrier-centered picture of a hazard.

2 Getting Started

2.1 Signing In

Kenexis Bowtie 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 such as Azure AD or Okta. Every Kenexis Bowtie page requires authentication; if your session expires you are returned to the sign-in screen.

2.2 The KISS Project Manager

After signing in you land on the KISS Project Manager. Facilities are listed on the left; selecting a facility loads its studies, and any folders, on the right. Kenexis Bowtie studies are marked with the Kenexis Bowtie icon and the type "Bowtie". The toolbar above the study list acts on whatever is selected.

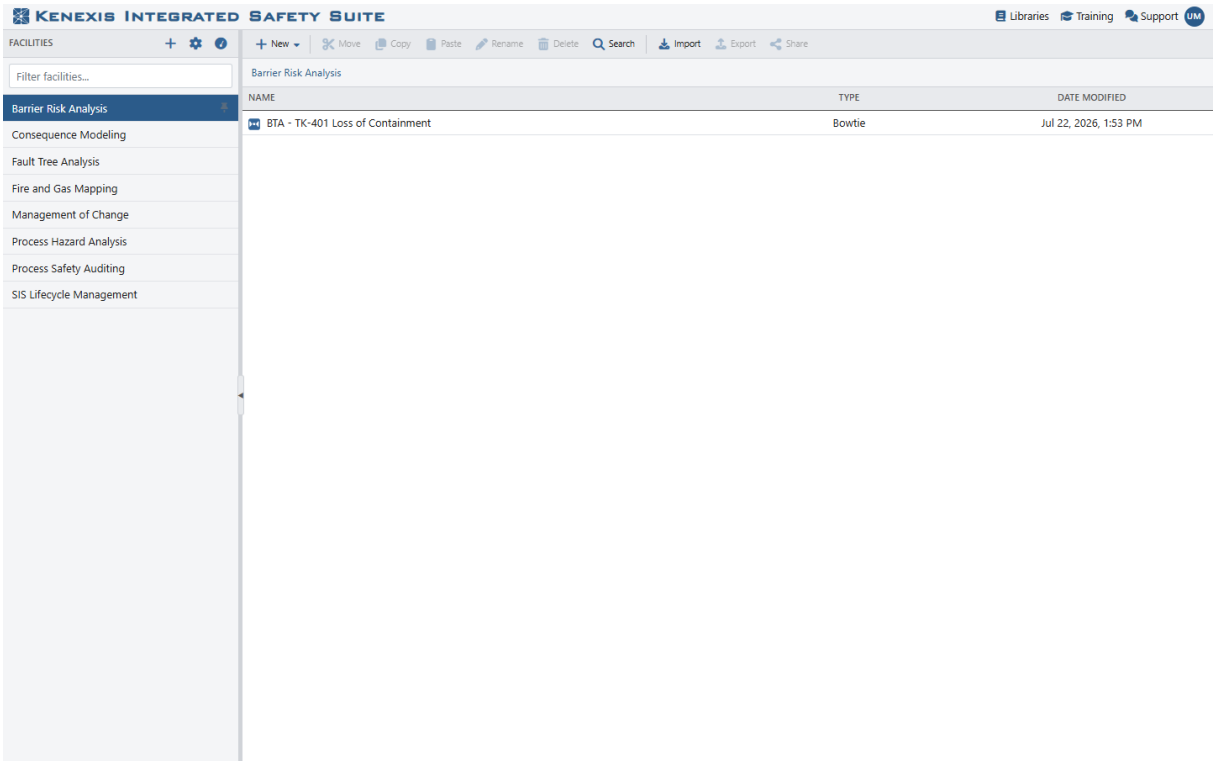


Figure 2-1. The KISS Project Manager. Selecting a facility lists its studies; the toolbar provides New, Move, Copy, Paste, Rename, Delete, Search, Import, Export, and Share.

2.3 Creating a Study

With a facility, or a folder inside it, selected, choose New › Bowtie and give the study a name.

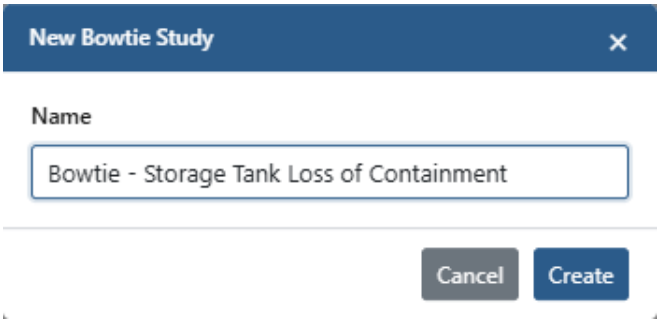


Figure 2-2. The New Bowtie Study dialog.

Kenexis Bowtie creates the study ready to work in: one bowtie diagram with a top event, one cause, and one consequence, all waiting to be renamed and given values. The study opens as soon as it is created.

2.4 Managing Studies

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

- **Copy / Paste / Move / Rename** — duplicate a study, relocate it, or change its name. A pasted copy carries the whole study with it: every diagram, cause, consequence, barrier, escalation factor, consequence type, recommendation, and revision.
- **Delete** — removes the study from the list. This is a soft delete: the study moves to the organization Recycle Bin, from which an administrator can restore it.
- **Export** — downloads the entire study as an Excel workbook, one sheet per kind of record. Appendix A lists the sheets.
- **Import** — uploads a previously exported workbook into the selected facility or folder as a new study, then opens it.
- **Share** — produces an external link that opens the study directly.

Export and import make a faithful pair

An exported workbook re-imports as an exact copy — the same causes, barriers, severity selections, and calculated frequencies. Give every barrier a Tag before exporting: the workbook links barriers to causes and consequences by Tag, so a tagged barrier travels with all of its links.

2.5 The Kenexis Bowtie Workspace

Opening a study shows the Kenexis Bowtie workspace. A header runs across the top with a Back button, the study name, and on the right the Reports menu and the Settings button. A Read Only badge appears there instead of the editing controls when you have view-only access to the study. The same badge appears when every concurrent-user license seat for Kenexis Bowtie is in use: you open the study read-only, and a notice below the header names the colleagues holding the seats. Reopen the study once a seat is free to edit it.

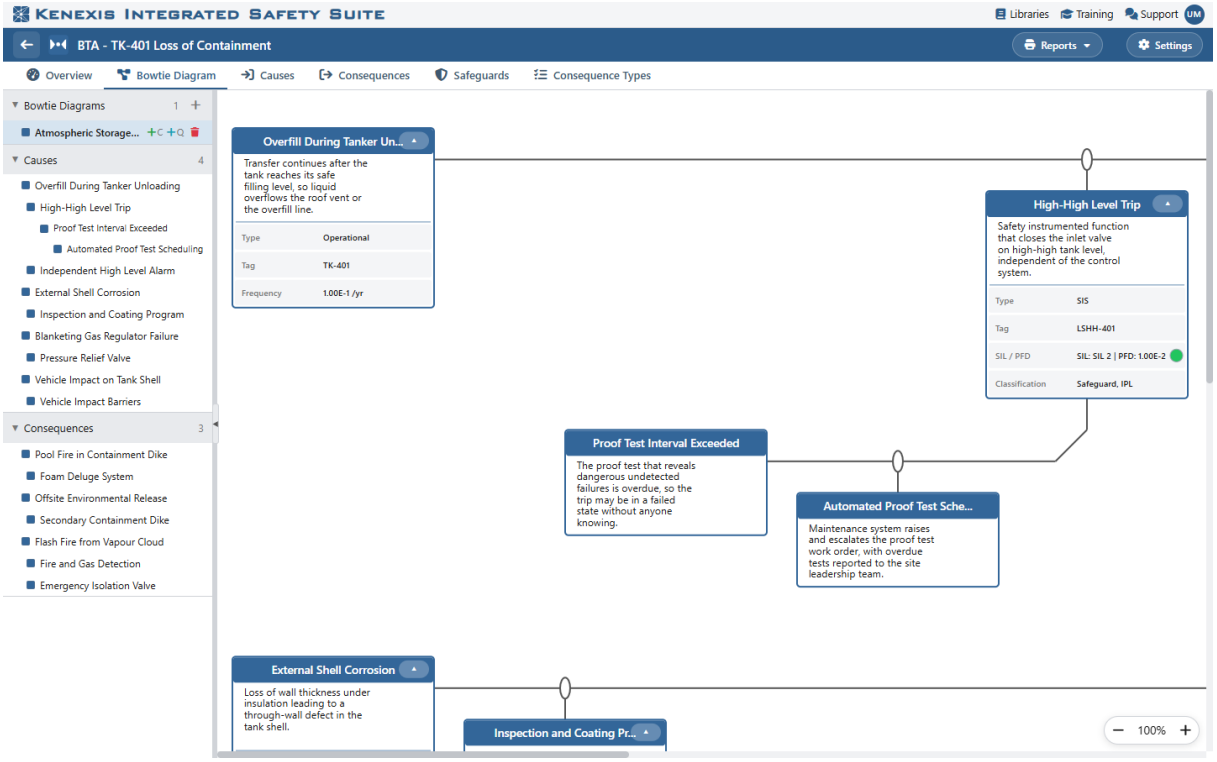


Figure 2-3. The Kenexis Bowtie workspace. The element tree occupies the sidebar on the left; the diagram canvas fills the remainder of the window.

Immediately below the header is the tab bar with the six workspace tabs. A study opens on the Bowtie Diagram tab.

Table 2-1. The six Kenexis Bowtie workspace tabs.

Tab	What it shows
Overview	Study properties, revisions, and recommendations (Chapter 8).
Bowtie Diagram	The graphical bowtie editor — the main working surface (Chapter 3).
Causes	A sortable table of every cause and its results (Chapter 4).
Consequences	A sortable table of every consequence and its results (Chapter 5).
Safeguards	A sortable table of every barrier in the study (Chapter 6).
Consequence Types	The risk categories and severity levels that define tolerability (Chapter 7).

3 Building a Bowtie Diagram

3.1 The Bowtie Diagram Tab

The Bowtie Diagram tab is where most work happens. It has two regions: a collapsible element tree on the left and the diagram canvas on the right. Everything in the study is created, edited, reordered, and deleted from the tree; the canvas shows the result.

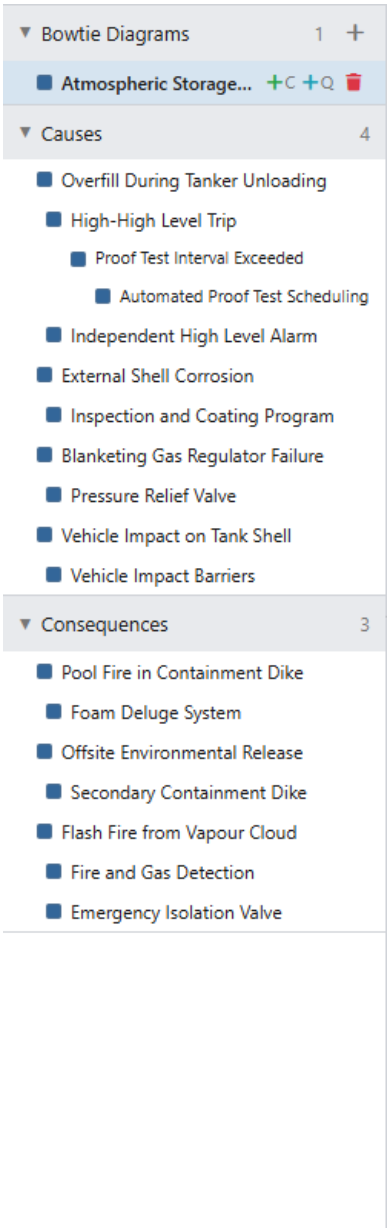


Figure 3-1. The element tree. Bowtie Diagrams, Causes, and Consequences each form a section with a live count; barriers nest under the cause or consequence they protect, and escalation factors nest under their barrier.

Hovering over a row reveals the actions available for that element. The buttons differ by row type:

Table 3-1. Element tree hover actions by row type.

Row	Actions revealed on hover
Bowtie diagram	Add Cause, Add Consequence, Move Up, Move Down, Delete Diagram.
Cause or consequence	Add Safeguard, Link Safeguard, Move Up, Move Down, Delete.
Barrier	Add Degradation Factor, Toggle Degradation Factors, reorder along the chain, Unlink.
Escalation factor	Add Control, Move Up, Move Down, Delete.

The Bowtie Diagrams section header carries a + button that adds another bowtie to the same study, so several top events can be analyzed side by side. A new diagram joins the bottom of the list and opens straight away.

The list keeps the order you give it. Move Up and Move Down on the selected diagram change its place, and the study keeps that order for everyone; the Causes and Consequences reports and the Excel export follow it too. Once a study has two or more diagrams, a Sort A–Z button joins the + button in the section header: after you confirm, it puts the whole list in name order, comparing numbers by value so that Bowtie 2 comes before Bowtie 10.

Drag the handle between the tree and the canvas to resize the tree, or collapse it with the chevron button; your width and collapse choices are remembered between visits.

3.2 Adding Elements

Select a bowtie diagram in the tree to reveal its two add buttons, then build outwards from the top event:

- **Add Cause** — adds a cause on the left of the diagram.
- **Add Consequence** — adds a consequence on the right.
- **Add Safeguard** — on a cause or a consequence, adds a barrier to that element's chain. A barrier added from a cause is preventive; one added from a consequence is mitigative.
- **Link Safeguard** — attaches a barrier that already exists elsewhere in the study, so one barrier can protect several causes or consequences (section 6.4).

New elements are created immediately with a placeholder name and no values. Open one by double-clicking it — in the tree or on the canvas — and give it a title, a tag, and its number. Move Up and Move Down reorder an element among its siblings, which controls the order it is drawn in.

Give every barrier its probability of failure on demand

Kenexis Bowtie reports a frequency once every value it depends on is present. A barrier is created without a probability of failure on demand, so fill that field in as soon as you add the barrier and the results along that branch will appear straight away. Section 11.9 explains exactly which results depend on which inputs.

3.3 A Completed Diagram

A finished bowtie reads outward from the center. The top event sits in the middle as a circle, with the hazard description above it. Causes run down the left, each on its own horizontal line, with its preventive barriers strung along that line between the cause and the top event. Consequences run down the right, each with its mitigative barriers between the top event and the outcome. The frequency badge on every line shows the result of the calculation at that point. Each box shows its title on a single line; a title longer than the box ends in an ellipsis (...), and hovering over the title bar shows it in full.

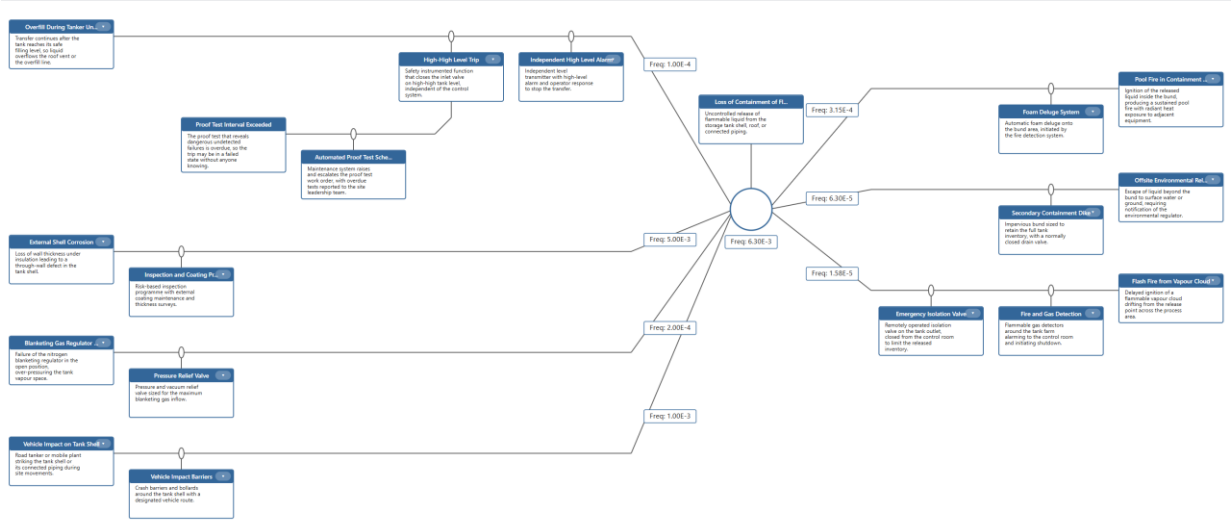


Figure 3-2. A completed bowtie. Causes and their preventive barriers occupy the left half; consequences and their mitigative barriers occupy the right. The frequency badges show the mitigated frequency of each cause, the top event frequency at the center, and the frequency of each consequence.

3.4 Element Detail Rows

Each cause, consequence, and barrier box carries a small chevron in its title bar that expands a detail panel beneath the description. The panel restates the element's stored values as labeled rows, so the numbers behind the diagram can be read without opening any dialog. Expand All Details, on the canvas controls, opens every panel at once.

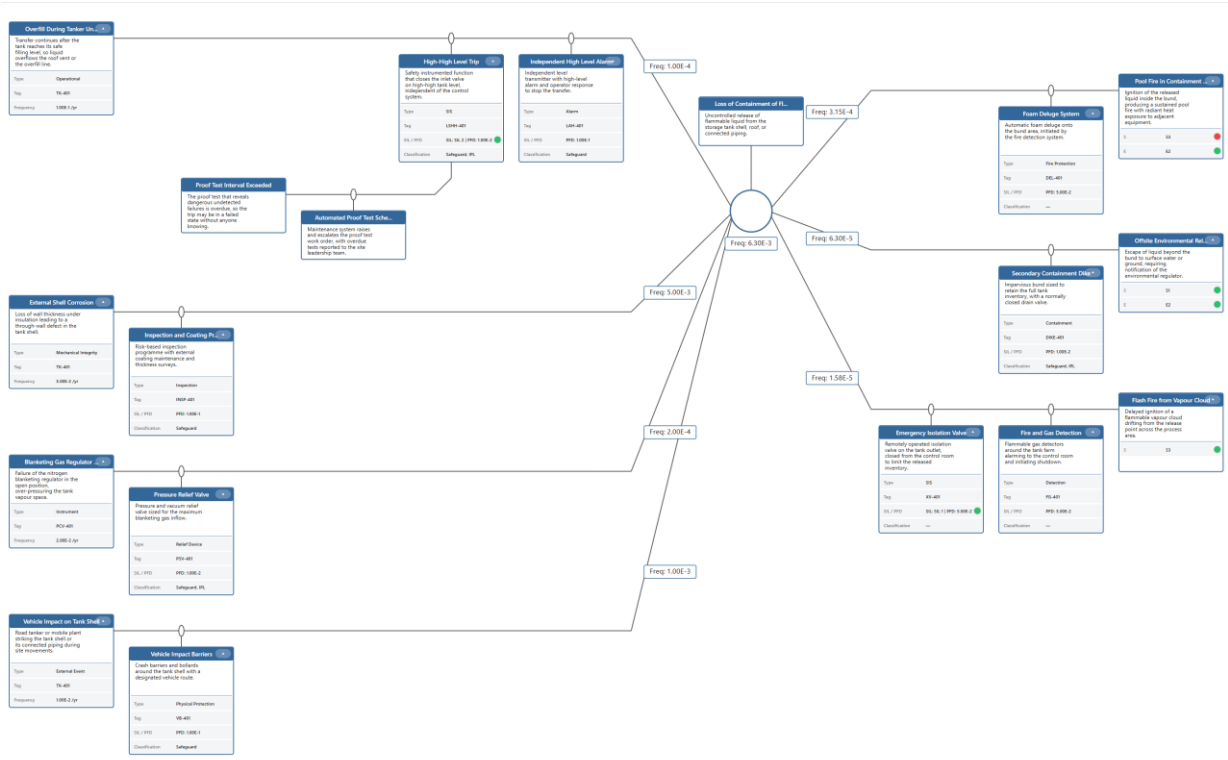


Figure 3-3. The same bowtie with all detail rows expanded. Causes show Type, Tag, and Frequency; barriers show Type, Tag, SIL and PFD, and Classification; consequences show one row per consequence type with the selected severity.

Which rows appear is entirely up to you — the Diagram Detail Fields section of the Settings dialog turns each row on or off independently (Chapter 10). Two kinds of row also carry a colored indicator dot, described in sections 7.5 and 11.8.

3.5 Compact View

Compact view redraws the diagram with narrower boxes and without the frequency badges or detail panels, fitting a large study into far less space. It is the view to use when the shape of the argument matters more than the numbers — reviewing barrier coverage in a workshop, for example.

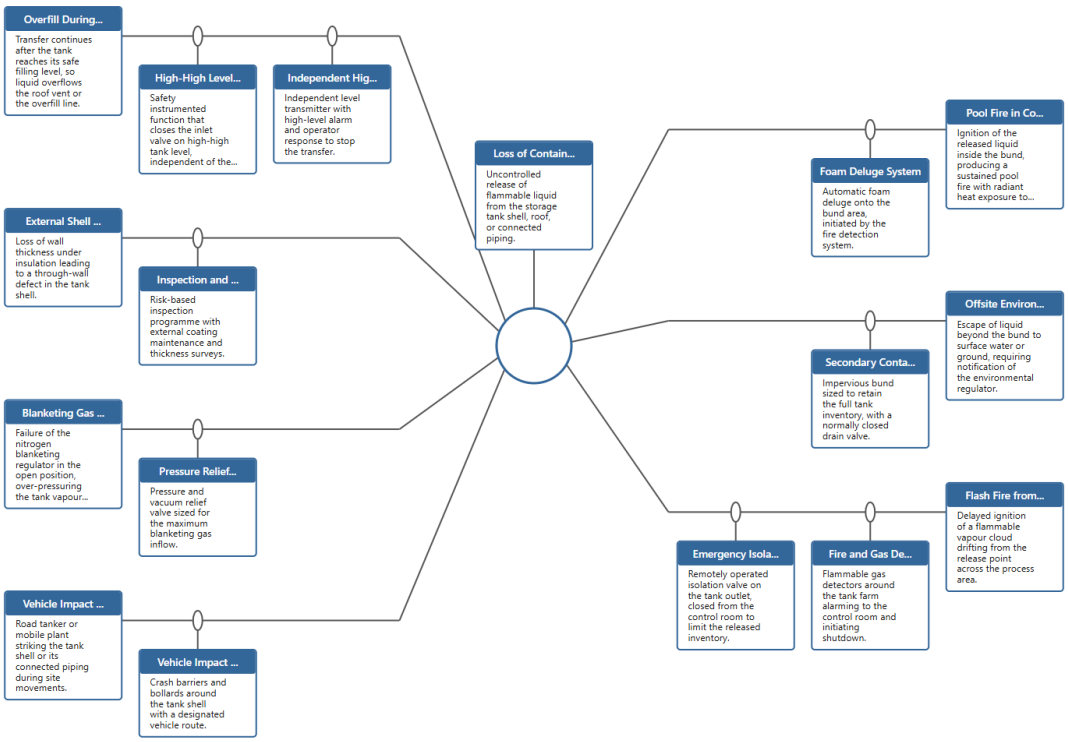


Figure 3-4. The same bowtie in compact view. Narrower boxes bring the whole diagram into a single screen.

3.6 Navigating the Canvas

The zoom controls sit at the bottom-right of the canvas: − and + step the zoom in tenths, and the percentage button between them returns the view to 100%. Holding Ctrl while turning the mouse wheel zooms in the same steps. To pan, hold the right mouse button and drag; the canvas also has ordinary scrollbars. Zoom ranges from 20% to 300%.

3.7 Saving the Diagram as an Image

The camera button on the canvas controls exports the current diagram as a PNG image on a white background, downloaded to your computer, which is convenient for pasting a single bowtie into a report or a presentation. For a print-ready document containing every bowtie in the study, use the Bowtie Diagram report instead (Chapter 9).

4 Causes

4.1 About Causes

A cause is a credible route to the top event. Its Frequency is the rate at which that route would deliver the top event with no preventive barrier in place — the demand rate on the barriers that follow it. Frequencies are normally expressed per year, and are typically drawn from site incident history, generic process industry failure data, or a fault tree analysis carried out in Kenexis Fault Tree.

4.2 Cause Details

Double-click a cause, in the tree, on the canvas, or in the Causes table, to open its dialog.

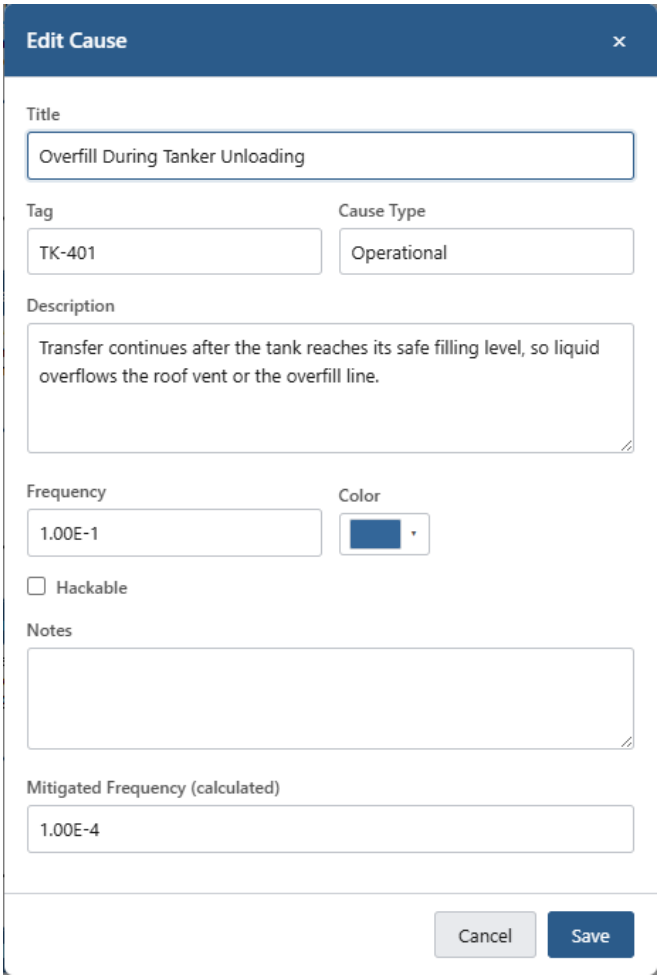


Figure 4-1. The Cause dialog. Mitigated Frequency at the foot of the dialog is calculated by Kenexis Bowtie and cannot be typed into.

Table 4-1. Fields in the Cause dialog.

Field	Purpose
Title	The cause's name, up to 50 characters.
Tag	A reference to the equipment or drawing the cause relates to.
Cause Type	A free-text classification, such as a mechanical, instrument, or external-event category. Use the same wording across a study so the Causes table can be sorted by it.
Description	Free text explaining the failure sequence the cause represents.
Frequency	How often the cause occurs, in events per unit time. Accepts either plain decimals or scientific notation, and is redisplayed in scientific notation.
Color	The fill color of the cause box and its title bar. The swatch picker offers a standard palette, the colors already used in this study, and your recent choices; Custom… opens a full color picker. Every color field in the study works the same way.
Hackable	Marks the cause as one that a cyber attack could bring about, for use in security-informed studies.
Notes	Longer free-text remarks.
Mitigated Frequency	Calculated. The frequency remaining after the cause's preventive barriers are credited (section 11.3).

4.3 The Causes Table

The Causes tab lists every cause in the study with both its entered and its calculated frequency. Click a column header to sort by it, and click again to reverse the order; the filter box narrows the list by title, description, tag, type, or top event. Double-click a row to edit that cause.

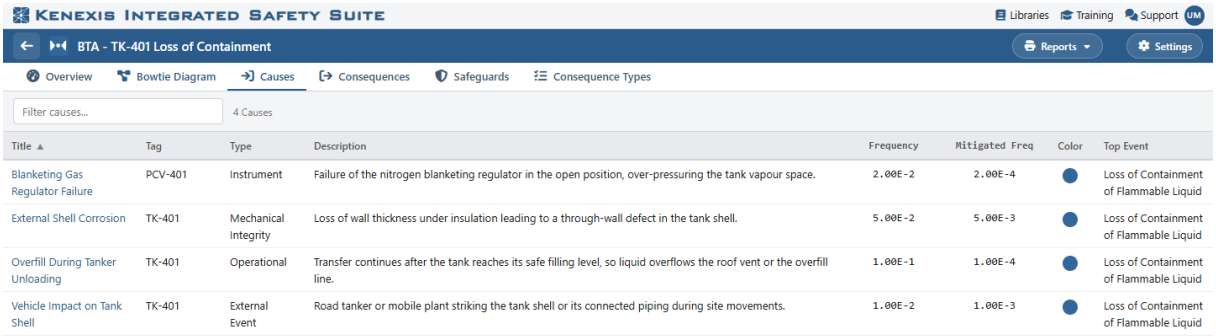


Figure 4-2. The Causes tab. Frequency is the value entered on each cause; Mitigated Freq is the result after its preventive barriers are applied.

5 Consequences

5.1 About Consequences

A consequence is an outcome that can follow the top event. Where a cause carries a frequency you supply, a consequence receives its frequency from the calculation: the top event frequency reduced by whichever mitigative barriers stand between the top event and that outcome. What you supply instead is the severity of the outcome, chosen against the consequence types described in Chapter 7, which is what makes the calculated frequency meaningful.

5.2 Consequence Details

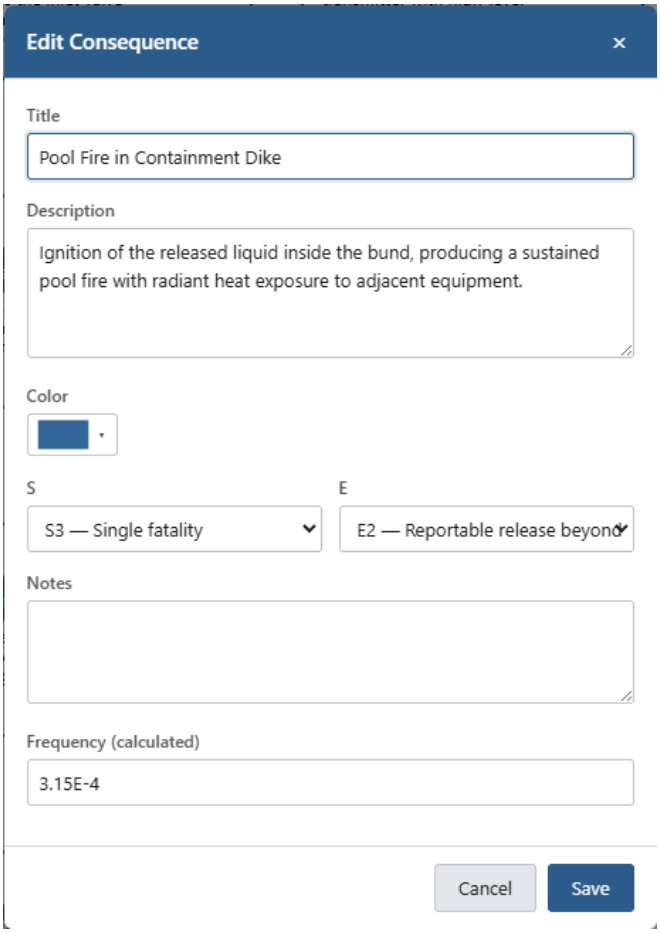


Figure 5-1. The Consequence dialog. One severity list appears for each consequence type defined in the study; Frequency at the foot is calculated.

Table 5-1. Fields in the Consequence dialog.

Field	Purpose
Title	The consequence's name, up to 50 characters.
Description	Free text describing the outcome and its extent.

Field	Purpose
Color	The fill color of the consequence box.
Severity lists	One list per consequence type, labeled with that type's code. Choose the severity level this outcome represents for that category, or leave it as — None —. The lists appear once consequence types have been defined (Chapter 7).
Notes	Longer free-text remarks.
Frequency	Calculated. How often this outcome is expected, after its mitigative barriers are credited (section 11.5).

5.3 The Consequences Table

The Consequences tab lists every consequence with its calculated frequency and its selected severity in each category. The table gains one column per consequence type, headed with that type's code, so a study with safety and environmental categories shows a column for each.

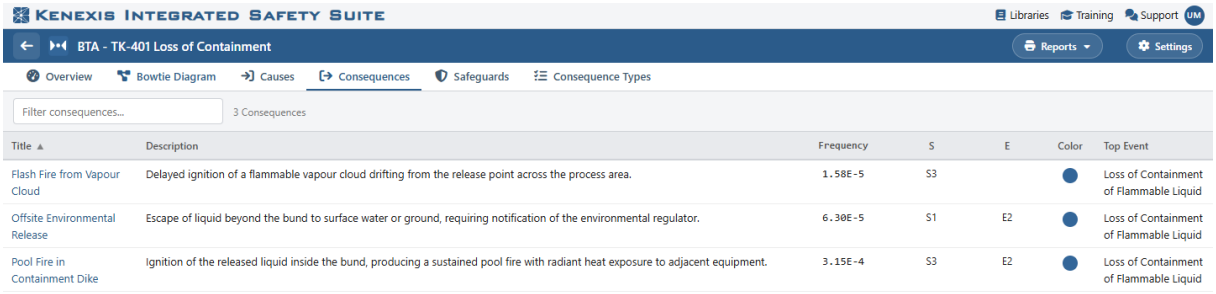


Figure 5-2. The Consequences tab. The columns after Frequency are the study's consequence types, each showing the severity selected for that outcome.

6 Barriers

6.1 About Barriers

A barrier — a safeguard, in the software's own wording — is anything that interrupts the sequence between a cause and the top event, or between the top event and a consequence. Its single quantitative property is its probability of failure on demand: the probability that it fails to perform when the sequence calls upon it. A barrier with a probability of failure on demand of one in a hundred lets one demand in a hundred through, so it divides the frequency reaching it by one hundred.

Barriers belong to the study rather than to any one cause, and are attached to the causes and consequences they protect. That attachment is what gives them their place in the diagram and their effect on the arithmetic.

6.2 Barrier Details

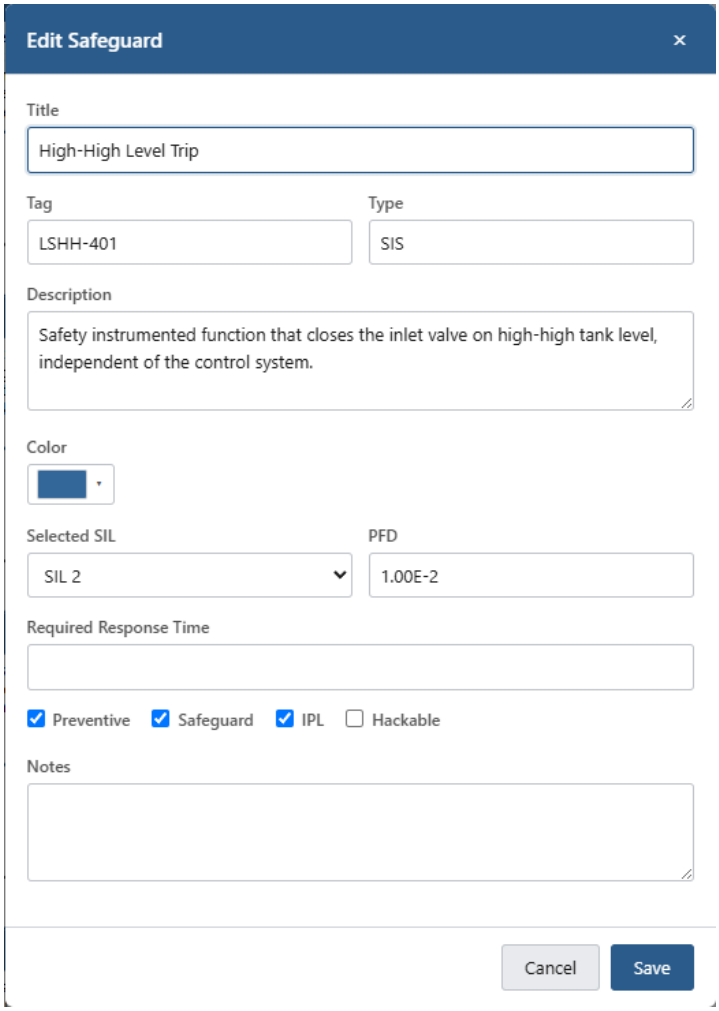


Figure 6-1. The Safeguard dialog. Selected SIL and PFD are independent entries; the four checkboxes classify the barrier.

Table 6-1. Fields in the Safeguard dialog.

Field	Purpose
Title	The barrier's name, unique within the study, up to 50 characters.
Tag	The instrument or equipment tag. Tags identify barriers when a study is exported and re-imported, so tag every barrier.
Type	A free-text classification such as an instrumented, relief, inspection, or physical-protection category.
Description	Free text describing what the barrier does and how it acts.
Color	The fill color of the barrier box.
Selected SIL	The safety integrity level claimed for the barrier: SIL 1 to SIL 4, or — None —. Used for the achievement indicator described in section 11.8.
PFD	The probability of failure on demand, entered as a decimal or in scientific notation. This is the value that enters the calculation.
Required Response Time	Free text recording how quickly the barrier must act to be effective.
Preventive	Marks the barrier as acting before the top event.
Safeguard	Marks the element as a credited safeguard.
IPL	Marks the barrier as an independent protection layer.
Hackable	Marks the barrier as one a cyber attack could defeat.
Notes	Longer free-text remarks.

Classification and credit

The Preventive, Safeguard, IPL, and Hackable checkboxes classify a barrier for reporting and review. The arithmetic is driven by the attachments and the PFD values: every barrier attached to a cause or consequence, and carrying a probability of failure on demand, contributes to that element's result. Attach the barriers you intend to take credit for, and record the rest as text in the study notes.

6.3 Preventive and Mitigative Barriers

Which side of the bowtie a barrier sits on is decided by what you attach it to. A barrier attached to a cause is preventive: it reduces how often that cause reaches the top event, and Kenexis Bowtie pre-ticks its Preventive and Safeguard boxes. A barrier attached to a consequence is mitigative: it reduces how often the top event produces that outcome. The same barrier can be attached on both sides when it genuinely acts twice, in which case it is credited on each side.

6.4 Reusing a Barrier

One barrier often protects against several causes — a single trip system may stand in the way of three different routes to the same top event. Rather than recreating it, use Link Safeguard on the second and subsequent causes and pick the existing barrier from the list.

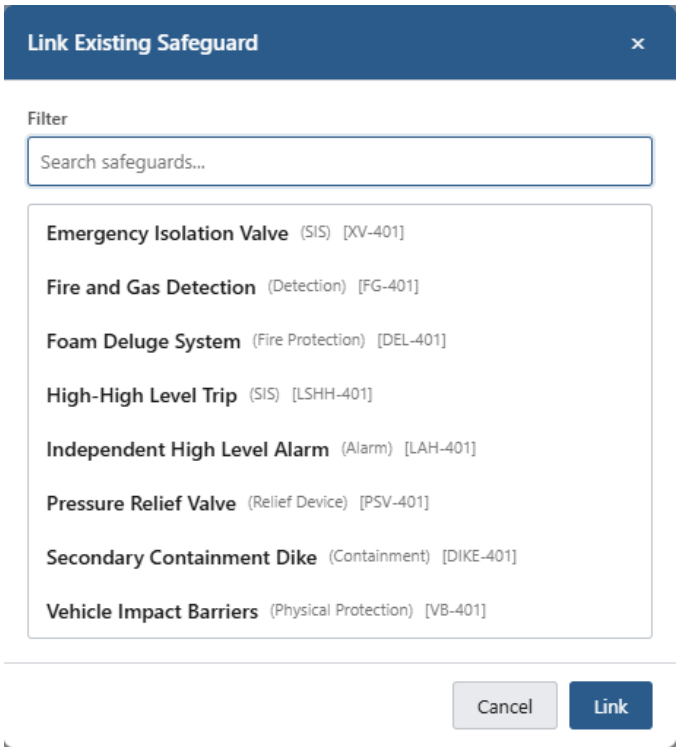
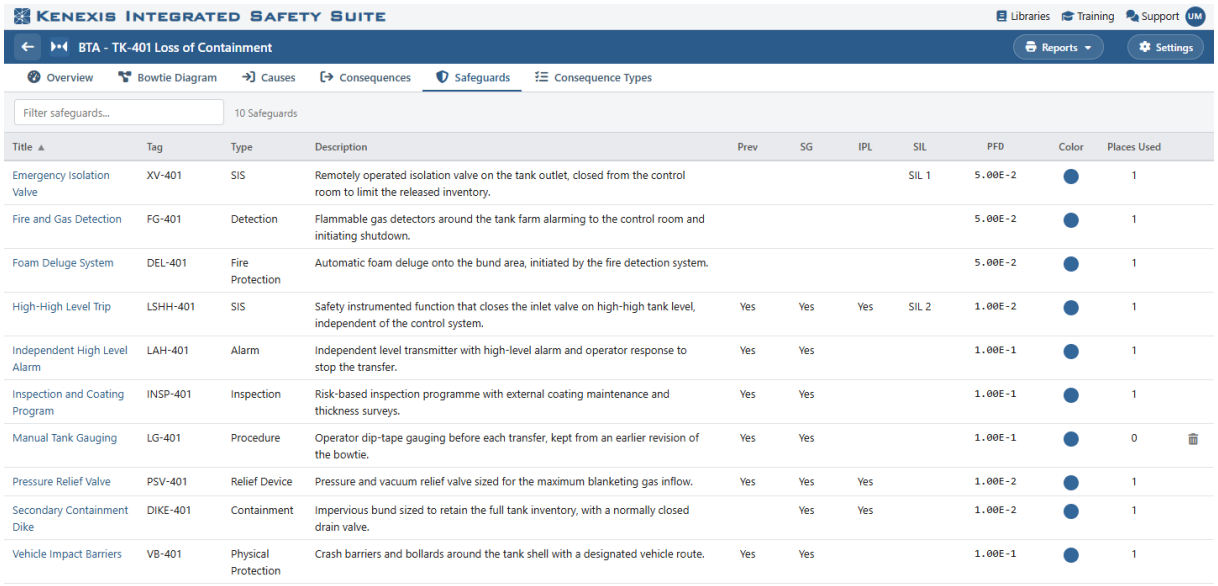


Figure 6-2. The Link Existing Safeguard dialog. The filter box searches by title, tag, and type; barriers already attached to this element are omitted from the list.

A linked barrier is one barrier in several places, not a copy: editing it anywhere updates it everywhere, and it appears once in the Safeguards table with its probability of failure on demand credited on each element it is attached to. The Unlink action on a row detaches the barrier from that one element. The barrier itself stays in the study, listed in the Safeguards table and in the Link Safeguard list, ready to be attached elsewhere.

6.5 The Safeguards Table

The Safeguards tab lists every barrier in the study once, whatever number of causes and consequences it protects. The Prev, SG, and IPL columns show the classification checkboxes, SIL and PFD show the two quantitative entries side by side, and Places Used counts the causes and consequences the barrier is attached to, which makes the table a convenient review of the barrier set as a whole.



Title	Tag	Type	Description	Prev	SG	IPL	SIL	PFD	Color	Places Used
Emergency Isolation Valve	XV-401	SIS	Remotely operated isolation valve on the tank outlet, closed from the control room to limit the released inventory.				SIL 1	5.00E-2		1
Fire and Gas Detection	FG-401	Detection	Flammable gas detectors around the tank farm alarming to the control room and initiating shutdown.					5.00E-2		1
Foam Deluge System	DEL-401	Fire Protection	Automatic foam deluge onto the bund area, initiated by the fire detection system.					5.00E-2		1
High-High Level Trip	LSHH-401	SIS	Safety instrumented function that closes the inlet valve on high-high tank level, independent of the control system.	Yes	Yes	Yes	SIL 2	1.00E-2		1
Independent High Level Alarm	LAH-401	Alarm	Independent level transmitter with high-level alarm and operator response to stop the transfer.	Yes	Yes			1.00E-1		1
Inspection and Coating Program	INSP-401	Inspection	Risk-based inspection programme with external coating maintenance and thickness surveys.	Yes	Yes			1.00E-1		1
Manual Tank Gauging	LG-401	Procedure	Operator dip-tape gauging before each transfer, kept from an earlier revision of the bowtie.	Yes	Yes			1.00E-1		0
Pressure Relief Valve	PSV-401	Relief Device	Pressure and vacuum relief valve sized for the maximum blanketing gas inflow.	Yes	Yes	Yes		1.00E-2		1
Secondary Containment Dike	DIKE-401	Containment	Impervious bund sized to retain the full tank inventory, with a normally closed drain valve.		Yes	Yes		1.00E-2		1
Vehicle Impact Barriers	VB-401	Physical Protection	Crash barriers and bollards around the tank shell with a designated vehicle route.	Yes	Yes			1.00E-1		1

Figure 6-3. The Safeguards tab, listing each barrier once with its classification, claimed SIL, probability of failure on demand, and the number of places it is used.

A Places Used count above 0 is a link. Clicking it opens a list of every cause and consequence the barrier is attached to, with the bowtie diagram each one belongs to, in the same order as the diagram list and the diagram itself: causes first, then consequences. Clicking a row closes the list and opens that bowtie diagram on the Bowtie Diagram tab, so a barrier shared across several diagrams can be traced to each place it is credited.

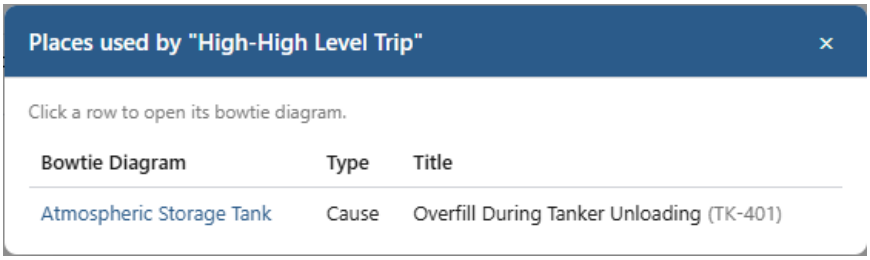


Figure 6-4. The places a barrier is used, listing each cause and consequence with its bowtie diagram.

A barrier whose Places Used is 0 is attached to no cause or consequence, usually because it was unlinked or because the element that carried it was deleted. It takes no part in the calculation and stays available in the Link Safeguard list. When it is no longer needed, the delete button at the end of its row removes it, together with any escalation factors and controls recorded on it, after a confirmation. The button appears on unused barriers only; to retire a barrier that is still in use, unlink it from each element first.

6.6 Escalation Factors and Their Controls

A barrier is credited on the assumption that it will work. An escalation factor records a condition that undermines that assumption — an overdue proof test, a bypass left in place, a corrosive service the

barrier was not selected for. Kenexis Bowtie calls these degradation factors, and each can carry its own controls: the measures that keep the escalation factor in check.

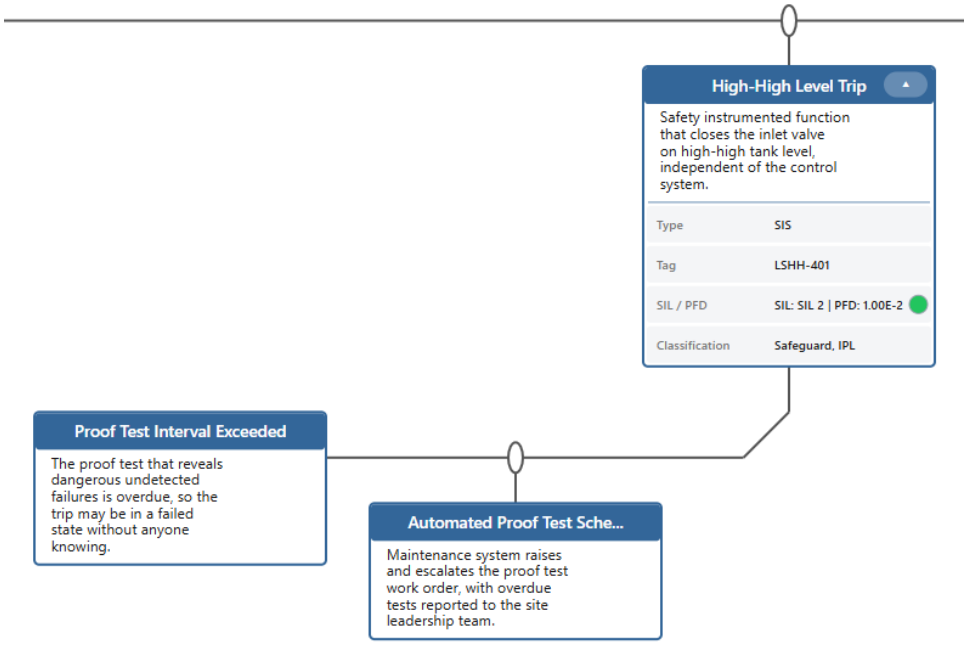


Figure 6-5. An escalation factor and its control, drawn beneath the barrier they relate to.

Add an escalation factor from the barrier's row in the tree, then add controls to the factor from its own row. Both carry a title, a description, and a color. They document the conditions attached to a barrier and the management response to them, and they appear in the diagram and in the exported workbook; the barrier's credited probability of failure on demand remains the value you entered on the barrier itself. Where an escalation factor is serious enough to change that value, revise the probability of failure on demand and record the reason in the barrier's notes.

Escalation factors are hidden on the canvas until you ask for them. The layers button on the canvas controls shows and hides every escalation factor in the diagram at once, and each barrier row in the tree has its own toggle.

7 Consequence Types and Tolerability Criteria

7.1 About Consequence Types

A calculated consequence frequency answers “how often”. Consequence types answer “is that acceptable”. A consequence type is a category of harm — safety, environmental, asset, reputation — and within each type you define the severity levels your organization recognizes, from minor up to catastrophic. Each severity level carries a Tolerable Maximum Event Likelihood, or TMEL: the highest frequency at which an outcome of that severity is considered tolerable.

Together these express the same judgement a corporate risk matrix expresses. A risk matrix pairs a severity with a likelihood band and reads a color out of a grid; Kenexis Bowtie pairs the severity you select with the frequency it has calculated and compares the two directly, which keeps the full precision of the calculated result. Consequence types are defined per study, so each study carries the criteria it was assessed against.

7.2 Defining Types and Severity Levels

The Consequence Types tab holds two tables. The upper one lists the types; selecting a type loads its severity levels into the lower one. Each table has its own Add button, filter box, and reorder arrows.

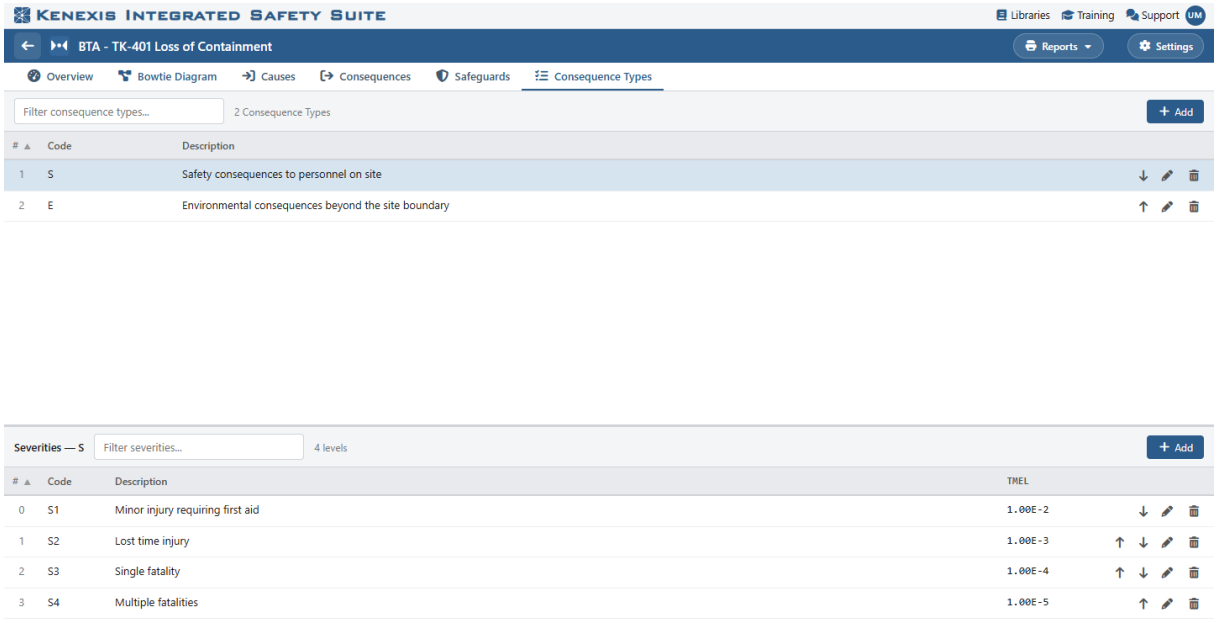


Figure 7-1. The Consequence Types tab. Selecting a type in the upper table loads its severity levels, with their tolerable frequencies, into the lower table.

A consequence type needs only a Code and a Description. The code is what identifies the type throughout the study: it heads the type’s column in the Consequences table, labels its list in the Consequence dialog, and labels its row in the diagram’s detail panel. Short codes such as S for safety and E for environmental keep those displays readable.

7.3 Severity Levels and the TMEL

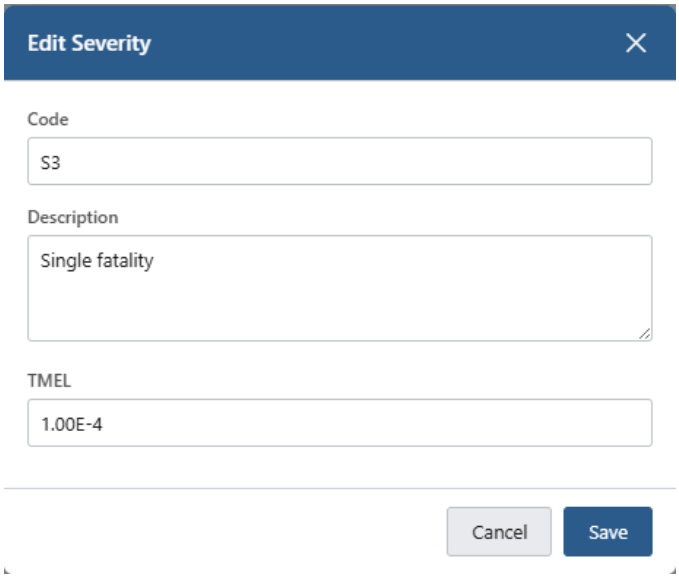


Figure 7-2. The Severity dialog.

Table 7-1. Fields in the Severity dialog.

Field	Purpose
Code	The severity's short label, up to 5 characters, shown in the tables and on the diagram.
Description	What this level of severity means — the wording your organization uses, such as a single fatality or a reportable release.
TMEL	The Tolerable Maximum Event Likelihood: the highest frequency at which an outcome of this severity is tolerable. Entered as a decimal or in scientific notation, in the same units as the study's frequencies.

Order the levels from least to most severe with the Move Up and Move Down arrows; that order is the order they appear in when an analyst chooses one. As severity increases the tolerable frequency falls, so a study's TMEL values normally descend by an order of magnitude at each level.

7.4 Assigning a Severity to a Consequence

Open a consequence and choose, for each consequence type, the severity level that outcome represents. A single outcome can be assessed in several categories at once — a fire may be a serious safety outcome and a moderate environmental one — and Kenexis Bowtie keeps one selection per type per consequence, so each category is judged against its own criteria.

7.5 Reading the Tolerability Indicator

Once a severity is selected, the consequence's detail panel on the diagram shows one row per consequence type, giving the type's code, the selected severity's code, and a colored dot: green where the calculated frequency is at or below that severity's TMEL, red where it is above.

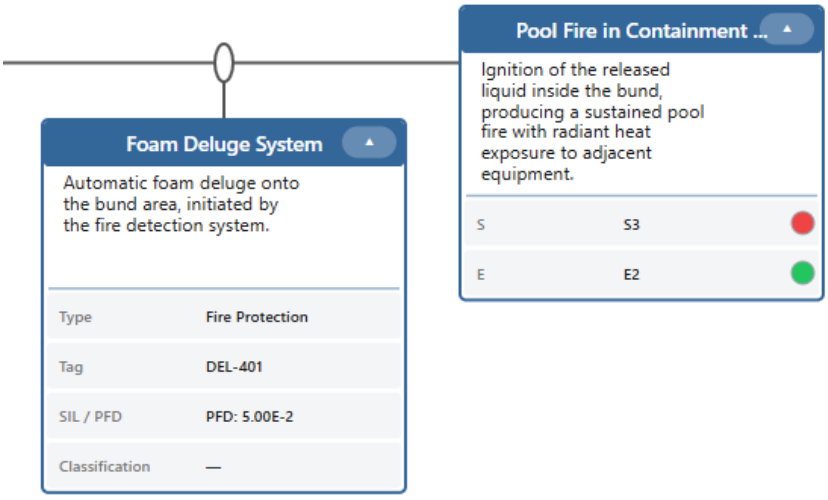


Figure 7-3. A consequence assessed in two categories. The upper row is above its tolerable frequency and shows red; the lower row is within its tolerable frequency and shows green.

This is the study's conclusion in a single glance, and it is the reason to define consequence types early. A red dot is the prompt to act: add or improve a barrier on that branch, and record the action as a recommendation (section 8.4). A gray dot indicates that the comparison is not yet possible — either the frequency has not been calculated, or the selected severity has no tolerable frequency defined.

8 Study Overview, Revisions, and Recommendations

8.1 The Overview Tab

The Overview tab is the study's front page. Four tiles across the top count the bowties, causes, consequences, and distinct barriers in the study, and beneath them sit the study's properties, its revision history, and its recommendations.

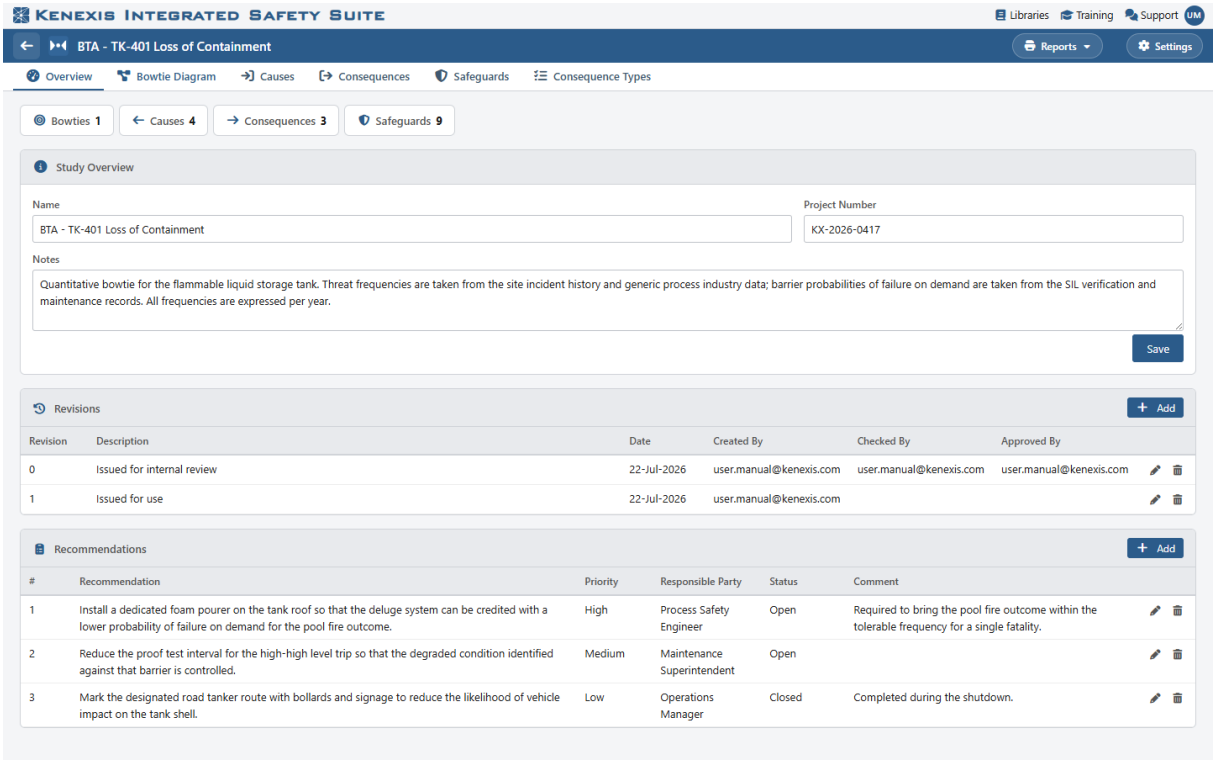


Figure 8-1. The Overview tab: counts, study properties, revision history, and recommendations.

8.2 Study Properties

The Study Overview card holds the study Name, a Project Number, and free-text Notes, and Save commits changes to all three. Renaming the study here renames it in the KISS Project Manager as well. The Notes field is the natural place to record the basis of the study: where the cause frequencies came from, how the barrier probabilities were established, and the time units the study is expressed in.

8.3 Revisions

The Revisions card records the study's issue history. Add creates a revision with a Revision label, a Description, and Remarks; Kenexis Bowtie stamps the date and the author automatically.

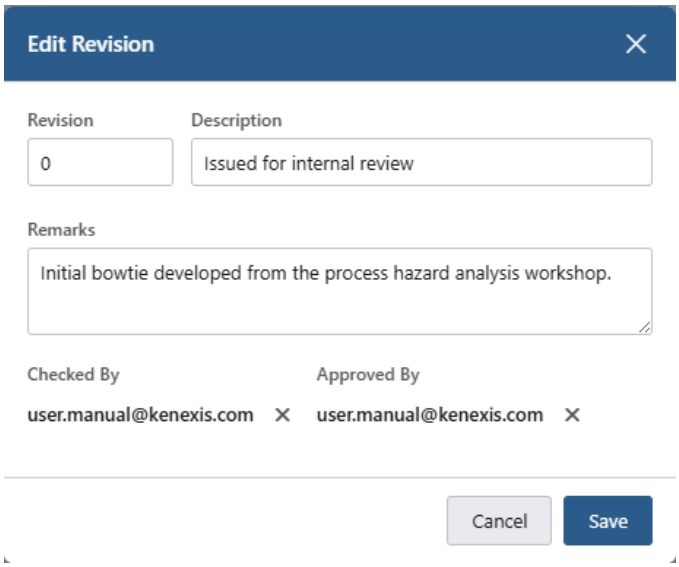


Figure 8-2. The Revision dialog. Mark as Checked and Mark as Approved stamp the current user against the revision.

Opening an existing revision adds Mark as Checked and Mark as Approved buttons, which stamp your name into the Checked By and Approved By columns; the clear button beside a stamped name removes it if the review has to be repeated. The result is a simple, visible sign-off trail on the study's front page.

8.4 Recommendations

The Recommendations card records the actions arising from the study — most often the response to an outcome that came out above its tolerable frequency.

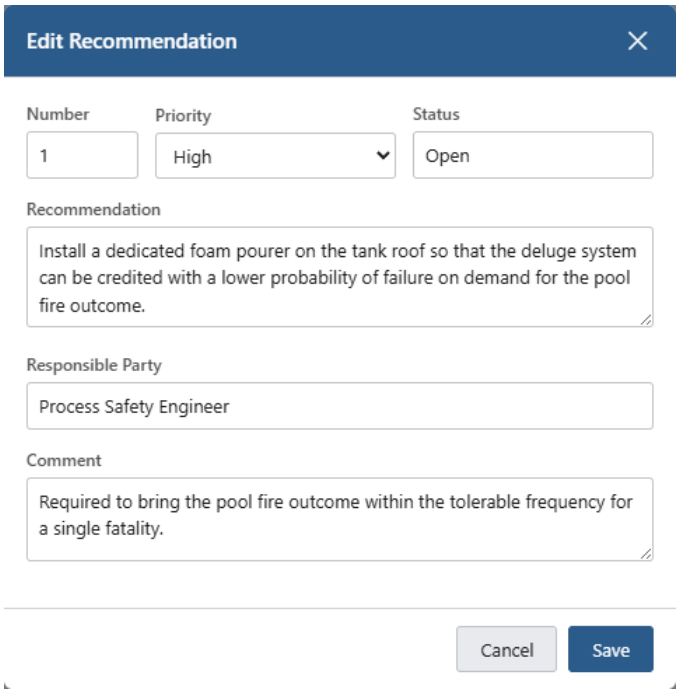


Figure 8-3. The Recommendation dialog.

Table 8-1. Fields in the Recommendation dialog.

Field	Purpose
Number	The recommendation's number. Kenexis Bowtie suggests the next unused number.
Priority	High, Medium, or Low.
Status	Free text recording where the action stands, such as open or closed.
Recommendation	The action itself.
Responsible Party	The person or role accountable for the action.
Comment	Progress notes, or the evidence that closed the action.

Recommendations are listed in number order and export to their own report, which makes the card a practical action register for the study.

9 Reports

9.1 The Reports Menu

The Reports menu in the study header produces the study's deliverables. Each report is generated on demand and downloaded to your computer.

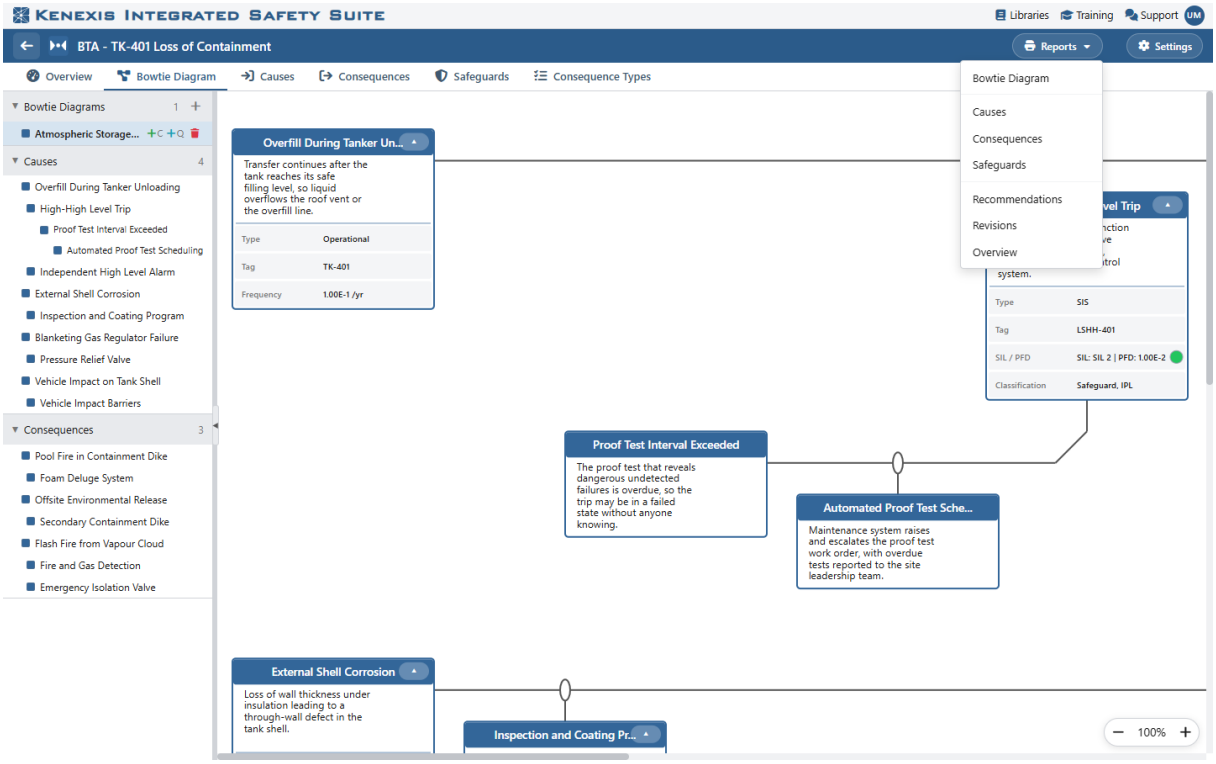


Figure 9-1. The Reports menu.

9.2 The Bowtie Diagram Report

The Bowtie Diagram report is the study's main deliverable: a Word document containing every bowtie in the study, each rendered as a full diagram with its top event title and description as a heading, one bowtie per page. It is the only report with options, which are set in a dialog before it is generated.

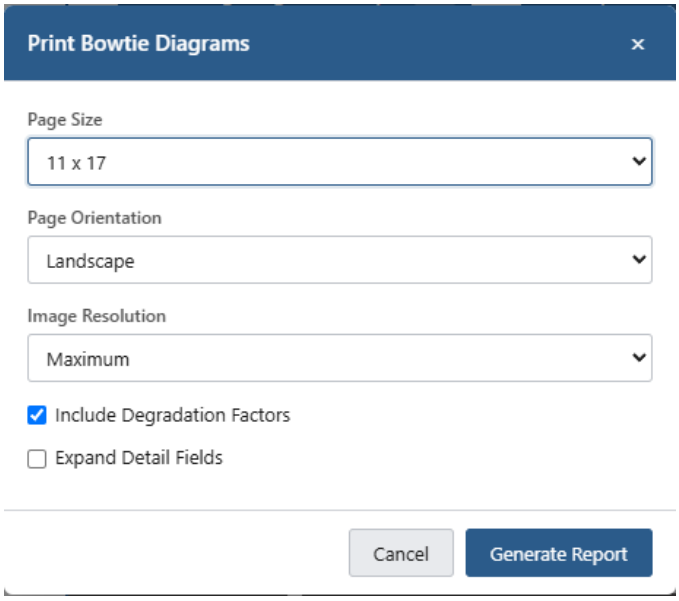


Figure 9-2. The Print Bowtie Diagrams dialog.

Table 9-1. Options in the Print Bowtie Diagrams dialog.

Option	Effect
Page Size	8.5 × 11 or 11 × 17. The larger page suits studies with many causes or long barrier chains.
Page Orientation	Portrait or Landscape. A bowtie is a wide diagram, so landscape is the usual choice.
Image Resolution	Maximum, the default, renders each diagram at full size, giving the greatest detail on a large page; Dynamic scales it to fit the page.
Include Degradation Factors	Draws escalation factors and their controls alongside the barriers they relate to.
Expand Detail Fields	Includes the detail rows — tags, frequencies, SIL and PFD — beneath each element, exactly as the Expand All Details view shows them on screen.

9.3 The Spreadsheet Reports

The remaining reports are Excel workbooks, generated immediately with no options. Each covers one part of the study and is intended for review, circulation, and tracking rather than for re-import.

Table 9-2. The spreadsheet reports and their contents.

Report	Contents
Causes	Every cause with its top event, tag, type, entered frequency, mitigated frequency, description, and notes.
Consequences	Every consequence with its top event, calculated frequency, selected severity in each consequence type, description, and notes.
Safeguards	Every barrier with its tag, type, classification flags, claimed SIL, probability of failure on demand, required response time, description, notes, and the number of places it is used.

Report	Contents
Recommendations	The action register: number, recommendation, priority, responsible party, status, and comment.
Revisions	The issue history, including the checked-by and approved-by stamps.
Overview	The study's properties and its element counts as a summary sheet.

Numeric cells carry scientific number formatting, so frequencies and probabilities read the same way in Excel as they do on screen.

10 Diagram Settings

The Settings button in the study header opens the Diagram Settings dialog, which controls how the study's diagrams are drawn. The settings belong to the study, so every analyst opening it sees the same diagram.

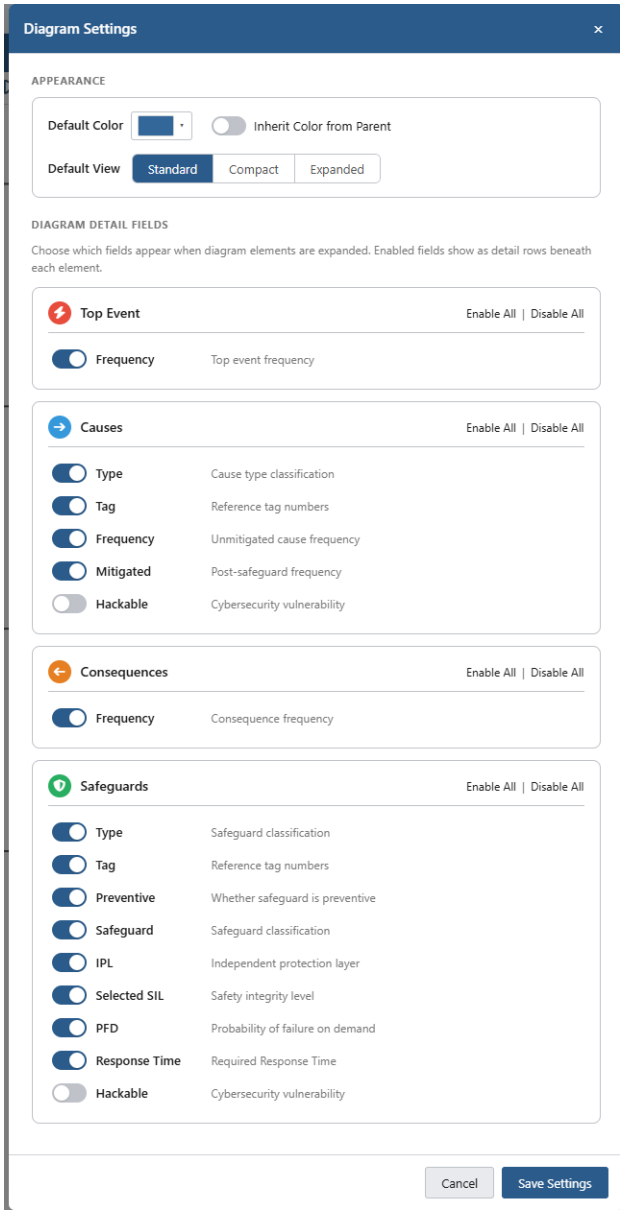


Figure 10-1. The Diagram Settings dialog.

10.1 Appearance

Table 10-1. Diagram appearance settings.

Setting	Effect
Default Color	The color given to new elements. The picker offers the same swatch palette as the element dialogs, including the colors already used in the study.
Inherit Color from Parent	When on, a new element takes the color of the element it is added to, so a cause and its barriers form a color family.
Default View	How the diagram is drawn when the study is opened: Standard, Compact, or Expanded — the last of these opening every detail panel.

10.2 Diagram Detail Fields

The remainder of the dialog chooses which detail rows appear when a diagram element is expanded, with a card for each element type and an independent toggle for each row. Enable All and Disable All at the head of a card set the whole group at once.

Table 10-2. Detail rows available for each element type.

Element	Rows available
Top Event	Frequency.
Causes	Type, Tag, Frequency, Mitigated, Hackable.
Consequences	Frequency.
Safeguards	Type, Tag, Preventive, Safeguard, IPL, Selected SIL, PFD, Response Time, Hackable.

Use these toggles to match the diagram to its audience. A workshop reviewing barrier coverage may want only tags and titles; a report supporting a SIL decision will want the SIL and PFD rows on. The Hackable rows are off by default and are turned on for security-informed studies.

11 Calculations

11.1 What Kenexis Bowtie Calculates

Kenexis Bowtie calculates three quantities and evaluates two comparisons. The quantities are the mitigated frequency of each cause, the frequency of the top event, and the frequency of each consequence. The comparisons are the tolerability of each consequence against its severity's tolerable frequency, and the achievement of each barrier's claimed safety integrity level. Everything else in a study — the frequencies of the causes, the probabilities of failure on demand of the barriers, the severity selections, and the tolerable frequencies — is entered by the analyst.

The calculation runs automatically. Opening a study calculates it, and every edit recalculates it, so the values on the diagram and in the tables are always current with the data behind them.

11.2 Notation

Table 11-1. Notation used in this chapter.

Symbol	Meaning	Units
f	The frequency entered against a cause	events per unit time
PFD	A barrier's probability of failure on demand	dimensionless
f-mitigated	A cause's frequency after its preventive barriers	events per unit time
f-top	The top event frequency	events per unit time
f-consequence	A consequence's frequency	events per unit time
TMEL	A severity level's tolerable maximum event likelihood	events per unit time

11.3 Mitigated Cause Frequency

Each preventive barrier on a cause lets through only the fraction of demands it fails to catch. Barriers on the same cause act in series, so their probabilities of failure on demand multiply together and the cause's frequency is reduced by the product.

$$f_{\text{mitigated}} = f \cdot \prod_{\text{barriers}} \text{PFD}$$

A cause with no preventive barriers passes its frequency through unchanged, which is the correct result: with nothing in the way, every occurrence of the cause produces the top event.

11.4 Top Event Frequency

The top event occurs whenever any cause defeats its barriers, so the mitigated frequencies of all the causes add together.

$$f_{\text{top}} = \sum_{\text{causes}} f_{\text{mitigated}}$$

Because the contributions add, the top event frequency is dominated by whichever cause has the largest mitigated frequency. That makes the Mitigated Freq column of the Causes table the fastest way to see where additional prevention would pay, and it is often a cause with modest frequency and weak barriers rather than the most frequent cause.

11.5 Consequence Frequency

Each consequence is reached from the top event through its own chain of mitigative barriers, which reduce it the same way preventive barriers reduce a cause.

$$f_{\text{consequence}} = f_{\text{top}} \cdot \prod_{\text{barriers}} \text{PFD}$$

A consequence with no mitigative barriers occurs as often as the top event itself. Every consequence starts from the same top event frequency, so the consequences of one bowtie differ from one another only by their own barriers.

11.6 A Worked Example

Consider a top event with two causes. The first occurs three times in ten years and is protected by two independent barriers; the second occurs four times in a hundred years and is protected by one. All frequencies are per year.

Table 11-2. Inputs to the worked example.

Cause	Frequency	Barrier probabilities of failure on demand
First cause	3.00E-1	1.00E-1 and 1.00E-2
Second cause	4.00E-2	5.00E-2

Applying section 11.3 to each cause in turn:

$$f_{\text{mitigated},1} = 3.00 \times 10^{-1} \cdot 1.00 \times 10^{-1} \cdot 1.00 \times 10^{-2} = 3.00 \times 10^{-4}$$

$$f_{\text{mitigated},2} = 4.00 \times 10^{-2} \cdot 5.00 \times 10^{-2} = 2.00 \times 10^{-3}$$

The two barriers on the first cause reduce it by three orders of magnitude between them, which leaves the less frequent but more weakly protected second cause dominating the study. Adding the contributions gives the top event frequency:

$$f_{\text{top}} = 3.00 \times 10^{-4} + 2.00 \times 10^{-3} = 2.30 \times 10^{-3}$$

Suppose a single consequence follows, protected by one mitigative barrier with a probability of failure on demand of one in a hundred:

$$f_{\text{consequence}} = 2.30 \times 10^{-3} \cdot 1.00 \times 10^{-2} = 2.30 \times 10^{-5}$$

If that outcome is assessed at a severity level whose tolerable frequency is 1.00E-4 per year, the calculated frequency is below it, the comparison in section 11.7 passes, and the diagram shows a green indicator against that consequence type.

11.7 The Tolerability Comparison

For each consequence type in which a consequence has been assessed, Kenexis Bowtie compares the calculated frequency against the tolerable frequency of the selected severity level.

$$f_{\text{consequence}} \leq \text{TMEL}$$

The comparison is inclusive: a frequency exactly equal to the tolerable frequency is tolerable and shows green. The result is reported as the colored dot described in section 7.5, and is evaluated separately for each consequence type, so one outcome can be tolerable environmentally and intolerable for safety at the same time.

11.8 The SIL Achievement Indicator

Where a barrier carries both a claimed safety integrity level and a probability of failure on demand, Kenexis Bowtie checks the one against the other. The target for each level is the upper bound of its band in IEC 61511:

$$\text{PFD} \leq 10^{-n} \; for \; \text{SIL}n$$

So SIL 1 requires a probability of failure on demand of 0.1 or lower, SIL 2 requires 0.01 or lower, SIL 3 requires 0.001 or lower, and SIL 4 requires 0.0001 or lower. A barrier meeting its claim shows a green dot on its SIL and PFD detail row, and one whose entered probability is weaker than the level claimed for it shows red — a prompt to revisit either the claim or the data behind it. The indicator appears once both values are present.

Verification remains a Kenexis SIS activity

The indicator is a consistency check on what has been entered, not a verification calculation. Establish a barrier's probability of failure on demand in a Kenexis SIS SIL verification, or from your maintenance and proof test records, and enter the resulting figure here. When that figure is revised, update the barrier so the bowtie continues to reflect it.

11.9 Complete Data and Missing Results

Kenexis Bowtie reports a result once every value that result depends on is present, which keeps a partly-built study from presenting a number that understates the risk. The dependencies follow the shape of the diagram:

- A cause's mitigated frequency needs the cause's own frequency and a probability of failure on demand on each of its preventive barriers.
- The top event frequency needs a mitigated frequency from every cause on the diagram.

- A consequence's frequency needs the top event frequency and a probability of failure on demand on each of its mitigative barriers.

Because the top event draws on every cause, a single missing value leaves the frequency badges downstream of it reading NaN, on screen and in the printed diagram, and the tolerability dots gray. When results do not appear, look for the element that is still incomplete — most often a barrier added a moment ago whose probability of failure on demand has not been filled in yet. Supplying it restores the whole chain immediately.

11.10 Units and Number Format

Kenexis Bowtie carries frequencies in whatever unit you enter them in and applies no conversion, so the study is consistent as long as you are: enter every cause frequency and every tolerable frequency in the same unit. Events per year is the usual convention, and is the unit the diagram's cause detail row assumes when it labels a frequency. Probabilities of failure on demand are dimensionless and are unaffected.

Frequencies, probabilities, and tolerable frequencies are all displayed in scientific notation to three significant figures — 2.30E-3 means 2.30×10^{-3}. Entry is more forgiving than display: the same value may be typed as 0.0023 or as 2.3E-3, and Kenexis Bowtie reformats it. The full precision of every entered and calculated value is retained behind the displayed figure.

Appendix A The Study Workbook

Export writes the whole study to a single Excel workbook, and Import reads that workbook back as a new study. The sheets below are what the workbook contains. Knowing its structure is useful when a study has to be reviewed offline, assembled from existing data, or moved between servers.

Table A-1. Sheets in the exported study workbook.

Sheet	One row per	Key columns
Study	The study	Name, project number, notes
TopEvents	Bowtie diagram	Title, bowtie name, frequency, description
Causes	Cause	Top event, title, tag, type, frequency, mitigated frequency, linked safeguards
Consequences	Consequence	Top event, title, frequency, one column per consequence type, linked safeguards
Safeguards	Barrier	Title, tag, type, preventive, safeguard, IPL, selected SIL, PFD, response time
ConsequenceTypes	Consequence type	Code, description, and its severity levels with their tolerable frequencies
DegradationFactors	Escalation factor	The barrier's tag, title, description
DegradationControls	Escalation factor control	The barrier's tag, the factor, title, description
Recommendations	Recommendation	Number, description, priority, responsible party, status, comment
Revisions	Revision	Revision, description, remarks, created by, date, checked by, approved by
Settings	Setting	The diagram settings from Chapter 10, as key and value

Barriers travel by tag

The Causes and Consequences sheets attach barriers by listing their tags, and the escalation factor sheets refer to their barrier the same way. Give every barrier a distinct Tag and the workbook round-trips completely, including every attachment.