Krypton User Guide

Document Revision 2.0

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1 Initial Setup

It is important to ensure that the web version of Krypton is accessed through the Google Chrome web browser as the compatibility of the program has been tested only with that specific web browser.

2 Safety Criteria Derivation Process

The following section outlines the steps required to carry out the safety criteria derivation process.

2.1 Part A – Determine Probability of Coincidence

2.1.1 Analysis Type

The user must first identify the type of analysis he/she will be preforming a calculation on as the outcome will be very different depending on his/her requirements.

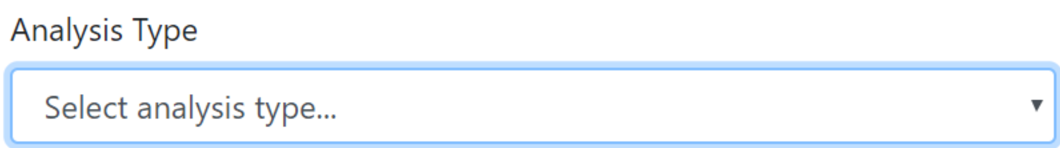

Figure 1 - Probability of Coincidence (Analysis Type)

The user can choose between an individual case or a societal case. Once selected, the user will notice the input parameters change depended on the type of analysis they want to preform.

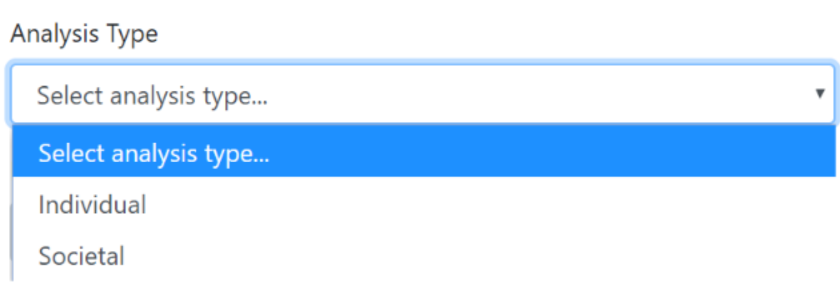

Figure 2 - Probability of Coincidence (Analysis Options)

2.1.2 Individual Case

Assuming the user has selected to preform a calculation for an individual case he/she will see the following input parameters below. Otherwise, the user should skip ahead to **Part 2.1.3 Societal Case**.

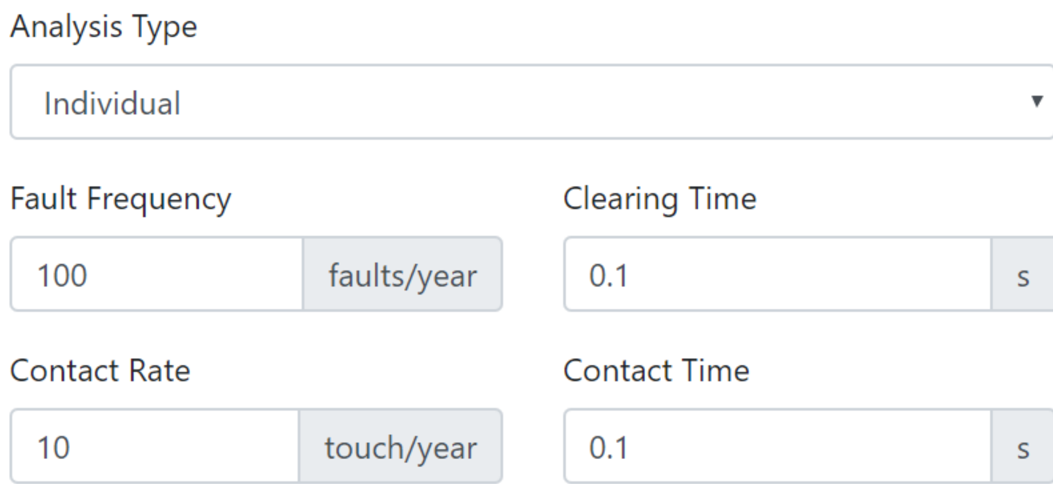

Figure 3 - Probability of Coincidence (Individual Case Input Parameters)

Fault Frequency

The user can dial-up the fault frequency from 0 faults/year by increments of 10 faults/year. It is also possible for the user to manually enter the exact fault frequency they desire.

Contact Rate

The user can dial-up the contact rate from 0 touch/year by increments of 10 touch/year. It is also possible for the user to manually enter the exact contact rate they desire.

Clearing Time

The user can dial-up the clearing time from 0 sec by increments of 0.1 to 1.0 sec. It is also possible for the user to manually enter the exact clearing time they desire. The default clearing time is set to 0.1 sec and the maximum value of the clearing time is 1.0 sec. This value is used both for determining the probability of coincidence and for the probability of fibrillation in **Step B**.

2.1.3 Societal Case

Assuming the user has selected to perform a calculation for a societal case he/she will see the following input parameters below.

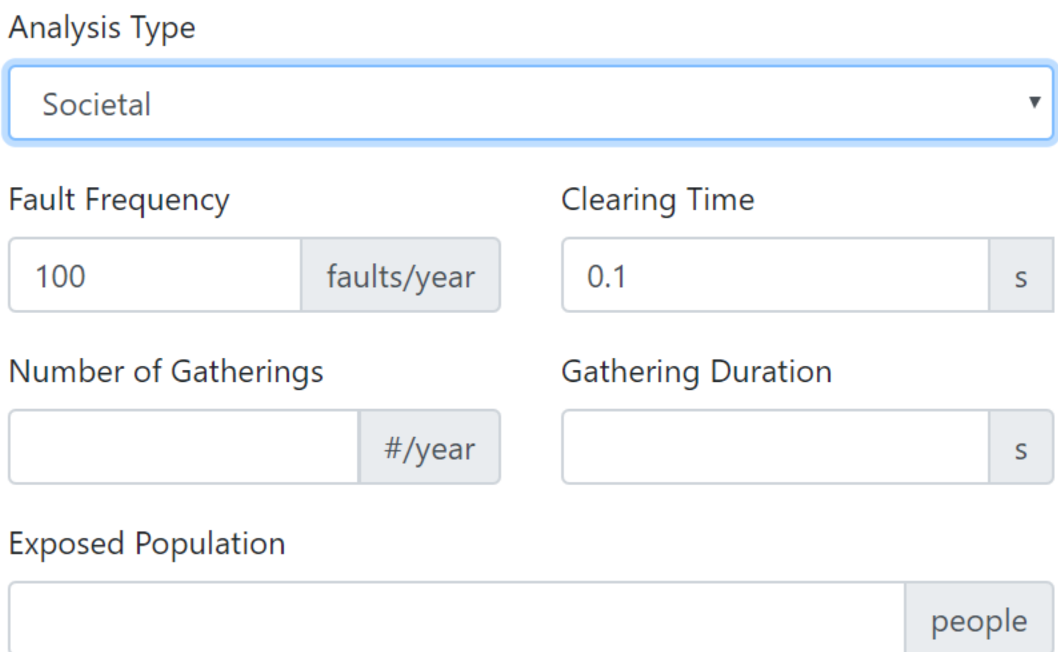

Figure 4 - Probability of Coincidence (Societal Case Input Parameters)

Fault Frequency

The user can dial-up the fault frequency from 0 faults/year by increments of 10 faults/year. It is also possible for the user to manually enter the exact fault frequency they desire.

Clearing Time

The user can dial-up the clearing time from 0 sec by increments of 0.1 to 1.0 sec. It is also possible for the user to manually enter the exact clearing time they desire. The default clearing time is set to 0.1 sec and the maximum value of the clearing time is 1.0 sec. This value is used both for determining the probability of coincidence and for the probability of fibrillation in **Step B**.

Number of Gatherings

The user can dial-up the number of gatherings from 0 #/year by increments of 10 #/year. It is also possible for the user to manually enter the exact number of gatherings they desire.

Gathering Duration

The user can dial-up the gathering duration from 0 sec by increments of 1 sec. It is also possible for the user to manually enter the exact gathering duration they desire.

Exposed Population

The user can dial-up the exposed population from 0 people by increments of 10 people. It is also possible for the user to manually enter the exact exposed population they desire.

2.2 Part B – Determine Probability of Fibrillation

2.2.1 Shock Type

The user must first identify the type of shock path he/she will be looking at for their analysis before preforming a calculation as the outcome will be very different depending on his/her requirements.

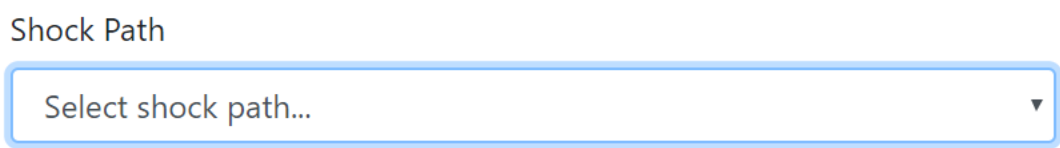

Figure 5 - Probability of Fibrillation (Analysis Type)

The user can choose between a touch potential or a step potential. The input parameters for the probability of fibrillation will change very slightly depending on which shock path the user selects.

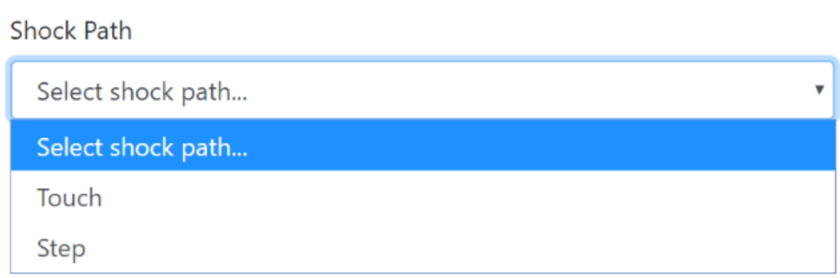

Figure 6 - Probability of Fibrillation (Analysis Options)

Applied Voltage

The user can dial-up the applied voltage from 0 Volts by increments of 10 Volts. It is also possible for the user to manually enter the exact applied voltage they desire.

Soil Resistivity

The user can dial-up the soil resistivity from 0 Ω×m by increments of 10 Ω×m. It is also possible for the user to manually enter the exact soil resistivity they desire.

Surface Depth

The user can dial-up the surface depth from 0 meters by increments 1 meter. It is also possible for the user to manually enter the exact surface depth they desire. If the surface depth is left at 0 meters the surface resistivity is voided as seen below.

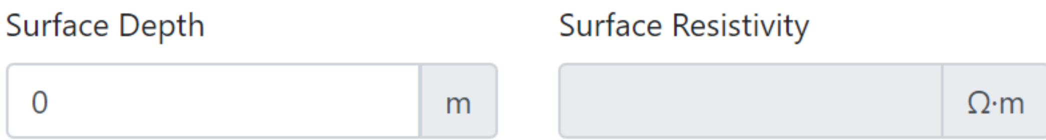

Figure 7 - Probability of Fibrillation (Surface Depth Input)

Surface Resistivity

As mentioned above, the surface resistivity can only be entered if a number larger than 0 is entered for the surface depth (as seen below). Once that number is entered, the user can dial-up the surface resistivity from 0 Ω×m by increments of 1 Ω×m. It is also possible for the user to manually enter the exact surface resistivity they desire.

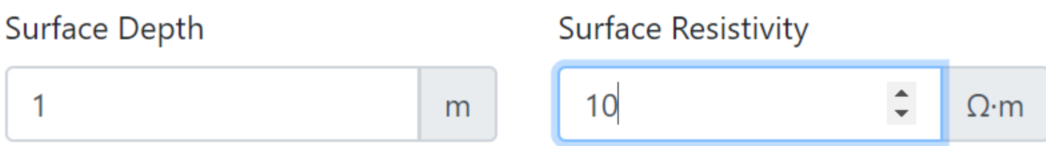

Figure 8 - Probability of Fibrillation (Surface Resistivity Input)

Contact Surface Conditions

This input is strictly for a touch case and is automatically set to “Dry (Normal)” whenever entering Krypton or when resetting the program. The user can choose between the three options shown below. Each surface condition will change the body resistance of the person present during the fault, which will ultimately affect the outcome of what the probability of fibrillation calculates to.

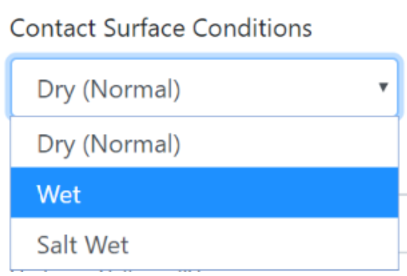

Figure 9 - Probability of Fibrillation (Contact Surface Types)

Additional Contact Resistance

This resistance is strictly for a touch case and is automatically set to 0 Ω and can be dialed up by increments of 10 Ω. It is also possible for the user to manually enter the exact contact resistance they desire. This resistance accounts for the resistance a person’s hand creates when coming into contact with the faulted object.

Shoe Type

This input is automatically set to “Bare Feet” whenever entering Krypton or when resetting the program. The user can choose between the three options shown below. Each shoe type will change the total body resistance of the person present during the fault, which will ultimately affect the outcome of what the probability of fibrillation calculates to.

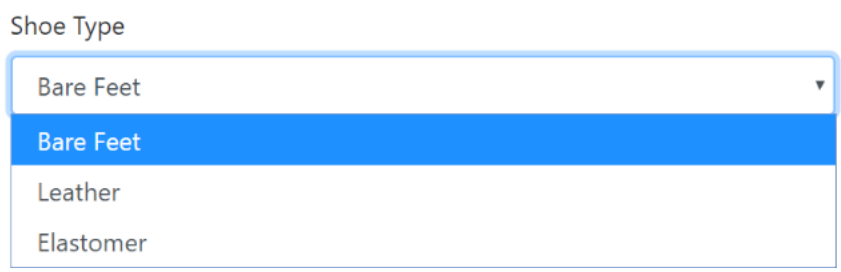

Figure 10 - Probability of Fibrillation (Shoe Type Options)

2.3 Results

Once the user is completely satisfied with the input parameters that they entered, they can either press the “enter” key or they can press the “Calculate” button at the bottom right of the page. Once the user has done that, a variety of results will appear on the user’s screen. If the user has decided to perform a risk assessment regarding a societal case, please read Sections **2.3.4** and **2.3.5** as well.

2.3.1 Probability of Fatality

The probability of fatality will be highlighted under the heading “Results”.

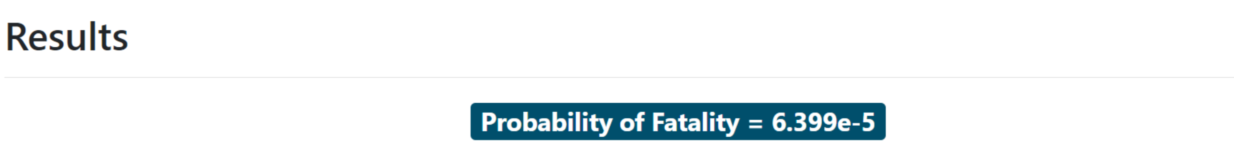

Figure 11 - Probability of Fatality Result

Above the probability of fatality, the user will be able to see the respect values of the probability of coincidence (denoted as P_C) and the probability of fibrillation (denoted as P_F) as shown below.

Figure 12 - Probability of Coincidence and Fibrillation Results

2.3.2 Decision Level Indicator

The user will also be able to see the risk associated with the probability of fatality calculated by Krypton and gives the user the suggestion on which level of management should be consulted based on the results (this risk assessment follows BC Hydro's risk assessment matrix).

Figure 13 - Probability of Fatality (Decision Indicator)

2.3.3 Fibrillation Curve

As the user scrolls through the results, they will notice a fibrillation curve (see below). This fibrillation curve will show the body current as a function of the probability of fibrillation. It helps the user understand exactly what the probability of fibrillation would be based on the body current of the person experiencing the fault.

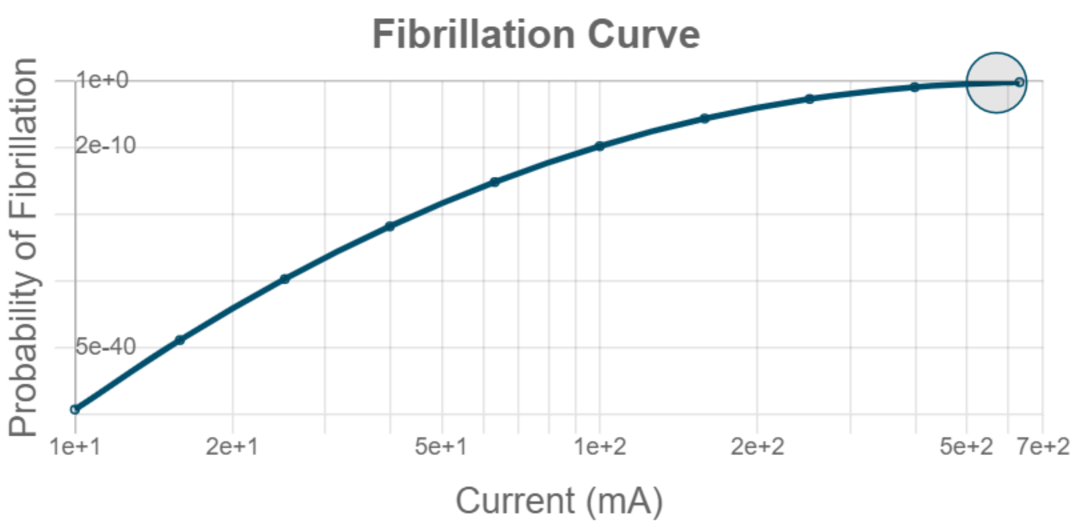

Figure 14 - Fibrillation Curve (Results)

2.3.4 Societal Curve

In the case that the user has chosen to perform a risk assessment on a societal case, they will see a societal curve within the results of their calculation (see below). This societal curve will show the expected number of people affected (N) as a function of the probability of coincidence. This helps the user to get a better understanding of how many people will have either a lower or higher chance of being affected by the fault.

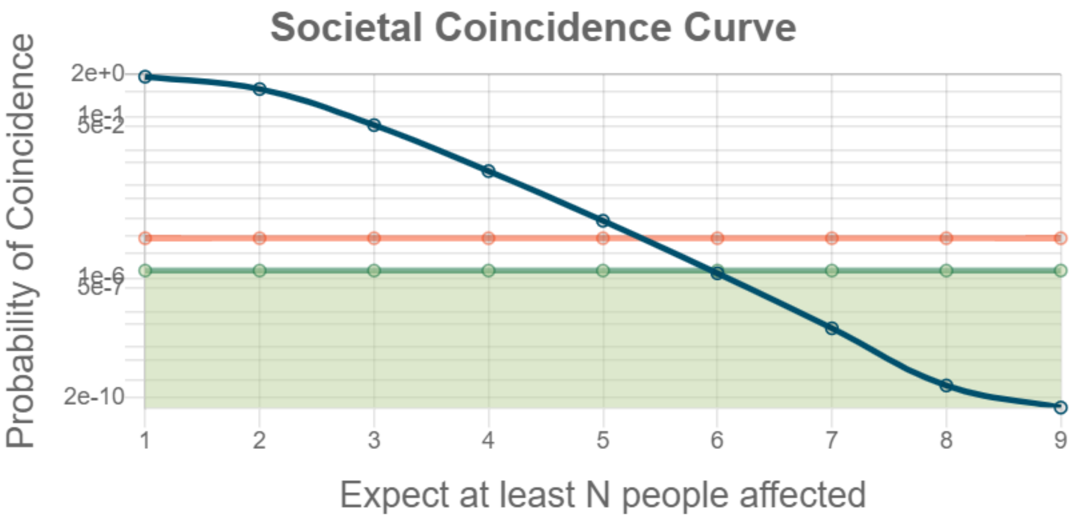

Figure 15 - Probability of Societal Coincidence (Results)

2.3.5 Societal Fatality Curve

In the case that the user has chosen to perform a risk assessment on a societal case they will see a societal fatality curve within the results of their calculation. This societal fatality curve will show the number of fatalities (N) as a function of the probability of fatality. This helps the user to get a better understanding of how many people will have either a lower or higher chance of being fatally injured by the fault.

3 Settings

The user can change the settings of the program by selecting the gear located at the top right of the page. Once the settings pop up (see below), the user will have the option of manipulating aspects like the risk threshold, population percentile rank, body resistance and the breaker failure to their choosing. Please see **Sections 3.1**, **3.2**, **3.3** and **3.4** for full details.

3.1 Risk Threshold

The user will be able to manipulate how low and how high the risk threshold is based on the BC Hydro risk assessment matrix. The user can change the thresholds by dialing up or dialing down. It is also possible for the user to enter the exact thresholds they desire.

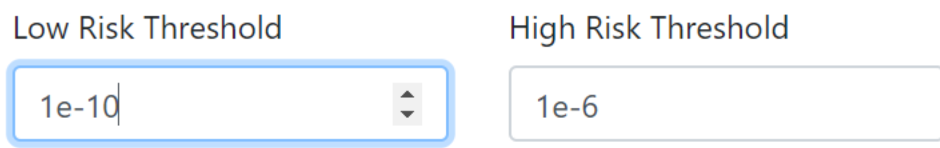

Figure 16 - Risk Threshold Input (Settings)

3.2 Population Percentile Rank

The percentile rank is automatically set to 50% whenever entering Krypton or when resetting the program. The user can choose between the three options shown below depending on how sensitive their study will be. Each percentage is directly related to a certain body resistance, which also depends on the type of moisture surface condition the user selected in **Section 2.2** under **"Contact Surface Conditions"**.

Figure 17 - Population Percentile Selection (Settings)

3.3 Body Resistance and Override

The body resistance override checkbox is automatically selected, and the default body resistance is set to 1000 Ω when starting up Krypton or when resetting the program. If the user chooses to override the body resistance, they may change it to any value. The user can change the body resistance by dialing up or dialing down. It is also possible for the user to enter the exact body resistance they desire. The user may also choose to de-select the override checkbox, in which case, Krypton will automatically set the body resistance to 1000 Ω.

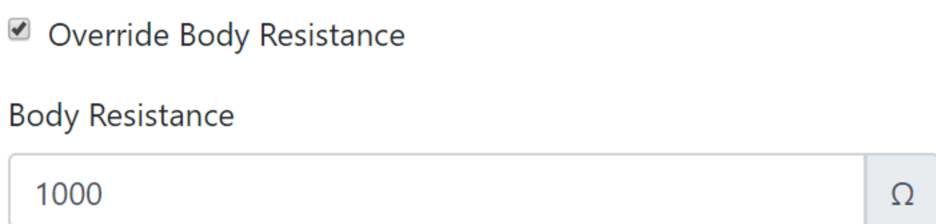

Figure 18 - Body Resistance Override (Settings)

3.4 Breaker Failure Probability

The user can incorporate breaker failure probability into their analysis by selecting the checkbox labelled “Include breaker failure probability”.

3.4.1 Breaker Type

The breaker type is automatically set to “Custom” when starting up Krypton or when resetting the program. The user can choose between four different types of breakers as well as a custom breaker by selecting the drop-down menu. The type of breaker selected in their analysis will depend on the design of the system.

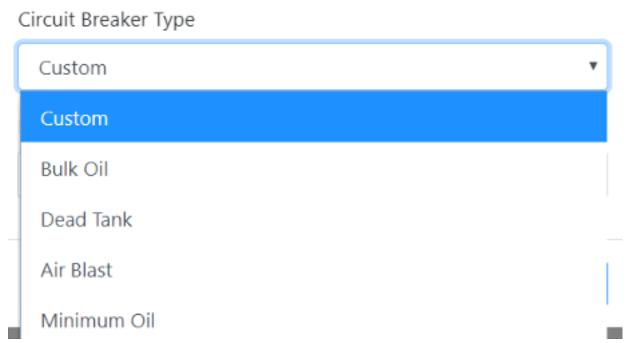

Figure 19 - Breaker Type Selection (Settings)

3.4.2 Number of Breakers

The number of breakers is automatically set to 1 when starting up Krypton or when resetting the program. The user can choose between using 1, 2, 4 or 6 breakers by selecting the drop-down menu. The number of breakers selected in their analysis will depend on the design of the system.

3.4.3 Breaker Size

The breaker size is automatically set to 69 kV when starting up Krypton or when resetting the program. The user can choose between using 69, 138, 230, 287, 360 and 500 kV breakers (standard sizes) by selecting the drop-down menu.

3.4.4 Custom Breaker

The custom breaker option allows the user to input a custom breaker failure rate and clearing time delay (the other breakers already have a set breaker failure rate and clearing time delay, which can change based on the number of breakers and the breaker size. The user can dial-up the breaker failure rate from 0% by increments of 0.01% to 100%. It is also possible for the user to manually enter the exact breaker failure rate they desire. The user can also dial-up the clearing time delay from 0 cycles by increments of 1 cycle. It is also possible for the user to manually enter the exact clearing time delay they desire.

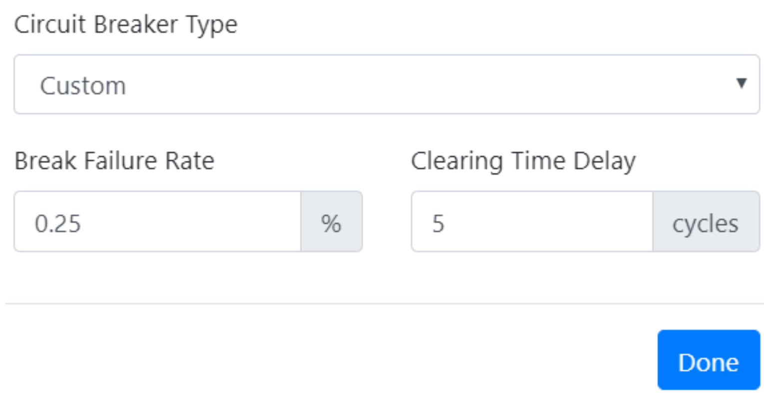

Figure 20 - Custom Breaker Type Input (Settings)

4 Reset

The user can reset Krypton at anytime by clicking the rotating arrow located at the top right of the page or alternatively, by simply refreshing the web browser.

5 Help/Support

The user can get support with understanding the technical side of Krypton at anytime by clicking the question mark at the top right of the page. Once selected, the user will receive information regarding Krypton and the standards used to create it, the probability of coincidence, the probability of fibrillation, and an explanation regarding the results.

6 Custom Template

The user can create their own custom template for a certain calculation or project by selecting the custom template tab in the top left. Please follow the steps listed below to create a custom template.

1) Select the “Custom Template” tab in the top left of the page, toggle the save selection, enter the name you would like to call the template and then select the “generate template” button.

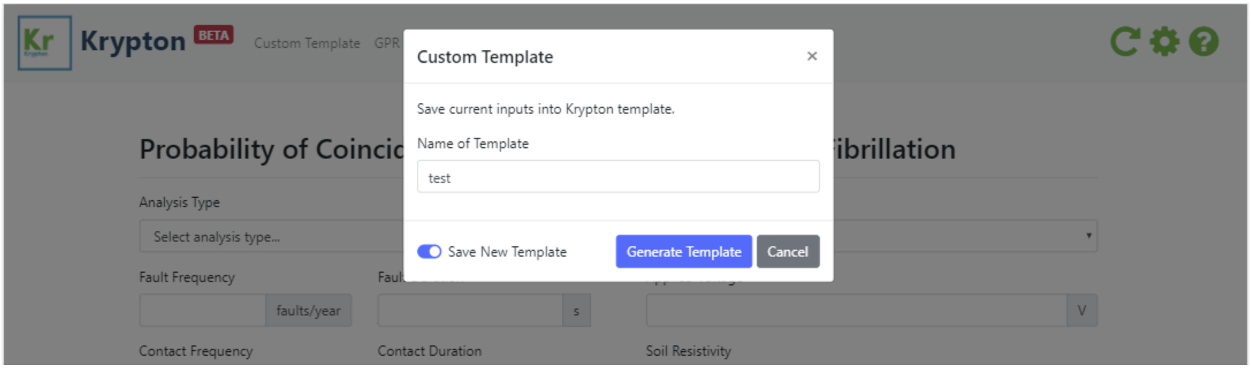

Figure 21 - Custom Template Naming

2) The user will notice a JSON file has been downloaded.
3) Once downloaded, click on the JSON file and open it in a text file.

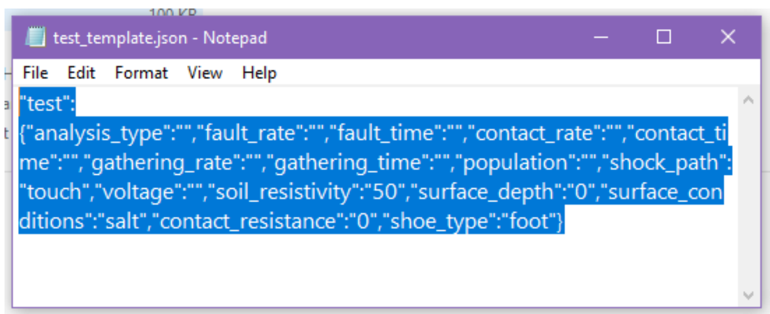

Figure 22 - Custom Template Input Selection

4) Copy everything inside the text file and then open the templates.js file (located in the Krypton folder).
5) Once on the default file, before the last bracket, add comma and then copy and paste the information from the text file.

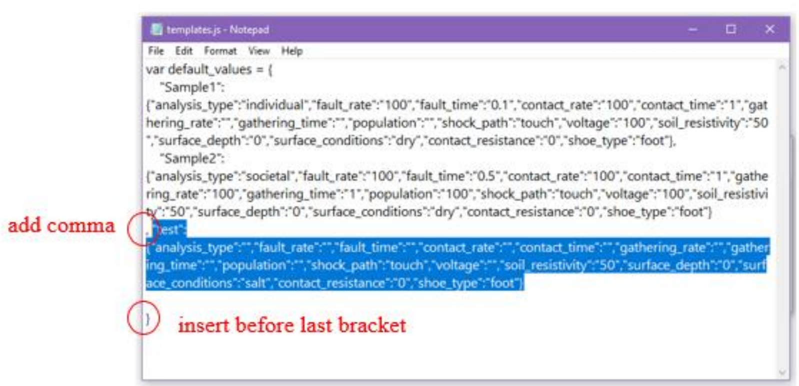

Figure 23 - Custom Template (Pasting Inputs)

6) Save the default.js file and then re-open Krypton
7) Select the "Load Defaults" tab at the top left of the page and below that the user will see the name of their default file.

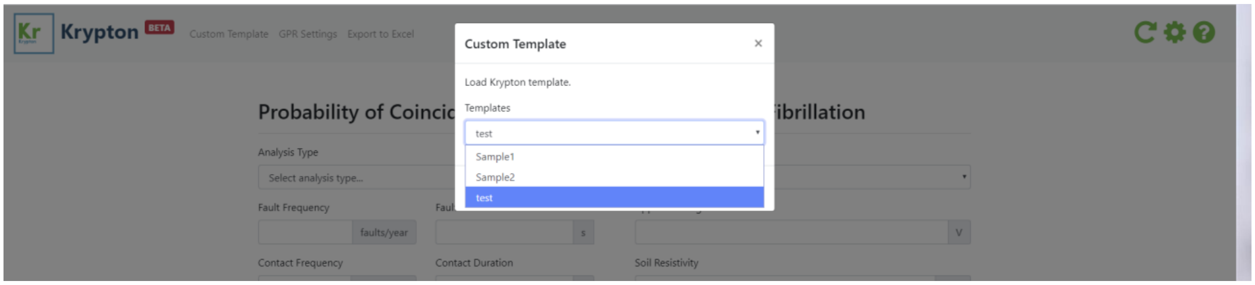

Figure 24 - Custom Template (Final Step)

8) Once selected, Krypton will fill in all the information based on the content in the templates.js file that was entered by the user in Step 5.
9) Repeat steps 1-8 to create a new template. The user may add as many templates as they wish.

7 Export to Excel

Once the user has completed an analysis, they have the option of exporting all the data within the design curves that are located under the results. The user can select the "Export to Excel" tab at the top of the page, which will begin to download a CSV file onto the computer. Once selected, the file will open an excel sheet that shows all the relevant data that is used to create all the design curves (which include the fibrillation curve, the fatality curve, etc.).

8 Ground Potential Rise (GPR)

The user can include GPR in their analysis. To do so, the GPR profile needs to be converted to a two-column table in Excel.

8.1 Setup

Format the GPR profile into a table as shown below. Applied voltage must be in the first column, and the associated radial distance must be in the second column. The headings can be any name preferred by the user. The user may include as many rows as they wish.

Applied Voltage (V)	Radial Distance (m)
1000	10
700	20
500	30

400	40
350	50

8.2 Input GPR Data

To input the GPR profile, select the “GPR Settings” tab on the top bar of Krypton. This will open a modal. Copy the entire table (with or without the headings) into the textbox labelled “Paste GPR data here”. No additional formatting is required.

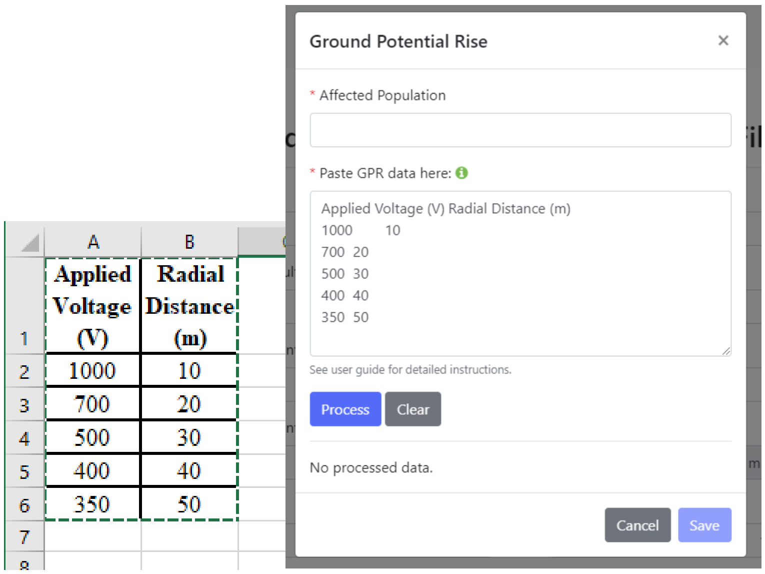

Figure 25 - GPR Selecting Data

Click “Process” to process this GPR profile. This will produce a table below the textbox if the input followed the correct format.

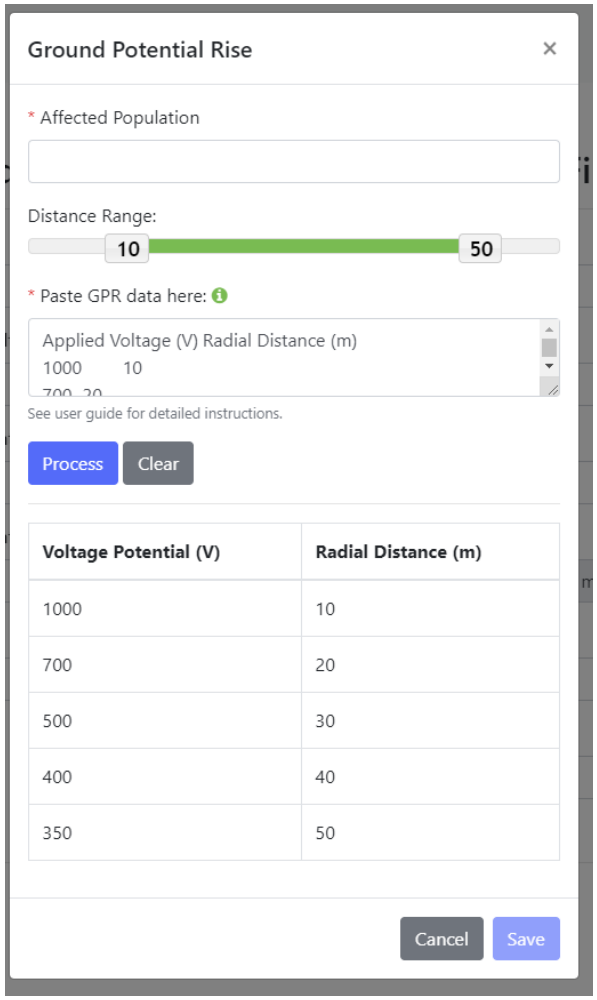

Figure 26 - GPR Input Parameters

Otherwise, an error message will appear.

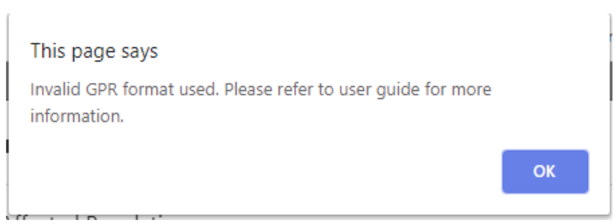

Figure 27 - GPR Invalid Data Message

The user should check the table to ensure that the data provided was translated correctly.

8.3 Other GPR Inputs

In order to perform a GPR analysis, the user must also provide the number of "Affected Population" and the range of radial distances to consider. The "Distance Range" is available as a slider bar and has a default value of the closest distance entered to the farthest distance entered. The user can adjust this slider to change the range of distances considered.

Once all the necessary data is complete, the “Save” button will be activated and the user can save their GPR profile.

8.4 Run a GPR Analysis

To complete the GPR analysis, all regular field must be filled. The GPR profile is only applied in societal cases.

Click “Calculate” to perform the analysis.

8.5 GPR Results

The GPR specific results are located at the bottom of the page, under the “GPR Results” heading. Three cases will be reported: the average case, the best case, and the worst case. Please see the Design Document for more information regarding these calculations.

The GPR-related plots are similar to the societal fatality plot. As such, the numbers reported are the probability of fatality for at least N number of people. The high risk and low risk threshold are mapped onto the plot. The user can also hover over specific points to see their exact value.

Figure 28 - GPR Results

9 Equations & Calculations

Below, the user can see all the relevant equations that were used to calculate the probability of coincidence (both for individual and societal), probability of fibrillation, the probability of fatality and all the body and ground resistances as well. This can also be found in more detail in our Design Document.

9.1 Calculating Body Resistance

The body resistance varies probabilistically for each individual based on external conditions such as surface area, degree of moisture, temperature, skin type, etc. For Krypton, the only conditions that are taken into consideration are the contact surface area, degree of moisture (dry, wet, saltwater wet) and the population percentile rank (5%, 50%, and 95%). The default settings in Krypton will be set to dry conditions for the 50-percentile rank as it is representative of the average population in the most common condition and can be modified by the user to the 5-percentile rank or the 95-percentile rank for full analysis. The user will also be able to use a fixed value for the body resistance (e.g. 1000 **Ω**).

The portion of the body resistance considered varies between different current paths. In the case of touch voltage, the current will flow from a hand to both feet, and only the resistances corresponding to these body parts are considered. From the data presented in IEC-479 [4], we use a body factor of 0.75 to adjust the full body resistance to only the portion relevant to our calculations. Similarly, in the case of step voltage, the current will flow through the two legs. We adjust for this scenario using a body factor of 0.275 [5] on the full body resistance for the 'left foot to right foot' current path. **For more information on calculating body resistance please see the design document.**

9.2 Calculating Ground Resistance

The resistance of one foot (R_f) is determined by the soil resistivity. The resistance is a result of the soil that is directly connected in the circuit between the body and the true zero potential ground through the two feet. In order to simplify the resistance, we consider the two feet conducting to the soil each to be a conducting metallic disc. The ground resistance is then calculated using the following equation where ρ is the ground resistivity and r_{foot} is the radius of the conducting metallic disk used to model the foot.

$$R_f = \frac{\rho}{4r_{foot}} \tag{1}$$

In this assumption, we neglect the resistance of less significant contributors such as shoes or socks. In the case where this resistance is not negligible, such as highly resistive work boots, the resistance can be added to the calculations as a user input. Krypton has a drop-down input where a user can select the type of shoes, and the corresponding resistance is factored into the calculation.

$$R_f = \frac{\rho}{4r_{foot}} + R_{boots} \tag{2}$$

Since there is generally a top layer made of a different material, such as concrete, sand, or topsoil, the resistance calculations are modified slightly to account for this when necessary. According to the IEEE-80 standards, the surface layer can be considered as a derating factor using the equation [1] below,

$$C_s = 1 - \frac{0.09\left(1-\frac{\rho}{\rho_s}\right)}{2h_s+0.09} \quad (3)$$

where h_s is the thickness of the surface layer, ρ_s is the resistivity of the surface layer, and ρ is the resistivity of the soil below.

The ground resistance is multiplied by the derating factor during calculations to add the effect of the surface layer. It is important to account for the reduction of resistance as well as the surface layer resistivity since both factors increase the effective current through the body. **For more information on calculating ground resistance please see the design document.**

9.3 Calculating Thevenin Resistance

When a circuit is established during a fault occurrence, the current flows through both the body as well as the ground. The total resistance of the circuit is determined using an equivalent circuit. The total Thevenin resistance can be calculated as the following:

	Step	Touch
Thevenin resistance	$R_{total} = 2R_F + R_B$ (4)	$R_{total} = R_B + \frac{R_F}{2}$ (5)

9.4 Calculating Probability of Coincidence (Individual Case)

The probability of coincidence values for both individual and societal cases are determined entirely upon user inputs including:

- Average rate of fault occurrence (Fault Frequency, n_f)
- Average duration of fault occurrence in seconds (Fault Duration, t_f)
- Average rate of gatherings at the target location (Number of Gatherings, n_g)
- Average duration of each gathering (Gathering Duration, t_g)
- Average rate of contact between an individual and the energized element (Number of Contacts, n_c)
- Average duration of each contact (Contact Duration, t_c)

In each case of individual and societal, we calculate the probability of coincidence separately for the case of step voltage versus touch voltage. In a step voltage scenario, we assume the individual is present at the target location for a "gathering" and consider only the fault parameters and the gathering parameters. In a touch voltage scenario, we assume the individual is in contact with the faulted element and consider on the fault parameters and the contact parameters.

Using characteristics of the Poisson distribution as described in the Appendix A.1.1.in EG0 Power System Earthing Guide [2], we arrive at the probability of coincidence for individual risk of the following.

$$P_{coincidence} = \frac{n_c \cdot n_f \cdot (t_c + t_f)}{365 \times 24 \times 60 \times 60} \qquad (6)$$

where n_c is the number of contacts per year, n_f is the number of faults per year, t_c is the average contact time, and t_f is the average fault duration. **For more information on calculating probability of coincidence for an individual case please see the Design Document.**

9.5 Calculating probability of Coincidence (Societal Case)

The probability of coincidence for a societal case refers to multiple events, multiple contact and multiple people coincidence. Krypton follows the computational methods for the probability of societal coincidence as defined in the Appendix A.1.2.(B) in EG0 Power Systems Earthing Guide [2].

$$P_{coincididence} = \frac{1}{K} \times \left[\frac{f_d + p_d}{T} - \frac{{f_d}^2 + {p_d}^2}{2KT}\right] \qquad (7)$$

In the equation above, f_d is the fault duration in seconds, p_d is the presence duration in seconds, T is the time period for calculations in years, and K is the constant to convert seconds into year time base, which is 356 x 24 x 60 x 60. T will be 1 for Krypton's coincidence probability computation.

When the individual has a pattern of behaviour which equates to multiple contacts with items associated with a fault in time T, the probability of non-coincidence with a single fault is written in the Appendix A.1.2.(B) in EG0 Power System Earthing Guide [2] as follows:

$$P_{NCmulti-presences} = (1 - P_C)^{P_n T} \qquad (8)$$

Where P_c is the equation 8 above, $p_n T$ is the number of contacts over time T.

For the societal case, Argon presents its risk assessment result in the F-N curves, which has the number of fatalities on the x-axis, and the frequency of N or more fatalities on the y-axis.

The expected number of times (EV) that from a population size N, at least i people are coincident with any fault in time T is defined in the Appendix A.1.2(B) in EG0 Power System Earthing Guide [2] as follows:

$$EV = \sum_{i=j}^{N} 1 - \left[1 - \binom{N}{i} P_{C\ multi-presences}{}^{i} \times \left(1 - P_{C\ multi-presences}\right)^{N-i}\right]^{f_n T} \tag{9}$$

Where $f_n T$ is the average number of faults over time T. **For more information on calculating probability of coincidence for an societal case please see the design document.**

9.6 Probability of Fibrillation Calculation

Ventricular fibrillation occurs probabilistically relative to the body current (also referred to as the fibrillation current). To compute the density function of the probability of fibrillation curve we used the Log – Normal distribution method. Using Figure 20 from IEC-479, we collect three data points of body current at 5%, 50% and 95% of the probability of fibrillation for each shock duration. This gives is the necessary information in order to determine the parameters for the cumulative distribution for the probability of ventricular fibrillation as a function of body current.

Based on the data points for each shock duration, we determine the parameters for the Logarithmic Normal Distribution using MATLAB. More specifically, since the Logarithmic Normal Distribution has only 2 parameters (mean and sigma), we can find the best value for these parameters based on the minimum squared error. Then we plot the cumulative distributions in MATLAB and determine the mean and sigma based on shock duration.

From the means and variances determined in MATLAB, we find a relationship to shock duration. Since the mean stops decreasing after a certain point (t = 1s), this linear downward sloping relationship is only valid until t = 1s. We choose 1s as the upper limit as it is more than enough to cover all fault scenarios. This provides all the necessary data to generate a probability surface as a three-dimensional function giving the probability of ventricular fibrillation for each body current and shock duration pair.

The probability of ventricular fibrillation relies of two inputs: current and time. The probability surface is created for a touch voltage scenario where the current flows directly through the heart. For the step voltage scenario where the current is assumed to only flow through the two legs, the chance of ventricular fibrillation is greatly reduced. We use a heart factor of 0.04 taken from Table 12 in IEC-479 [4] and apply it to the calculated current before computing the probability of ventricular fibrillation to compensate for this difference.

We select the Logarithmic Normal Distribution (lognormal) to model the probability of fibrillation in Krypton. This distribution shows the least amount of accumulated squared error for the range of time we examine. This distribution is also cited in multiple papers [5][6] to be a favourable representation of the probability of fibrillation for research purposes. Thus, we arrive at the following equation to determine the probability of fibrillation in Krypton.

$$\mu = -2.84(t_{shock}) + 6.86 \tag{10}$$

$$\sigma = -0.0009(t_{shock}) + 0.3242 \tag{11}$$

$$P_{fibrillation} = lognormal\left(\frac{V_{applied}}{R_{total}}, \mu, \sigma^2\right) \tag{12}$$

9.7 Probability of Fatality

In Argon [3], the probability of fatality is defined to be follows:

$$P_{Fatality} = P_{Coincidence} \times P_{Ventricular\ Fibrillation} \tag{13}$$

The probability of fatality captures the likelihood of an individual failing to survive in the case of a fault occurring and the individual being present at the time of the fault. The probability of ventricular fibrillation captures the likelihood of survival given a step or touch voltage while the probability of coincidence captures the likelihood of a fault occurring and the individual begin present at the time of the fault.

10 References

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[3] Ground potential rise at overhead AC transmission line structures during power frequency faults: Working group B2.56. Paris: CIGRÉ, 2017.

[4] Effects of Current on Human Beings and Livestock. General Aspects, DD IEC/TS 60479-1:2005, 2005.

[5] A. Dimopoulos, H. Griffiths, N. Harid, A. Haddad, A. Ainsley and G. Mpofu, "Probability Surface Distributions for Application in Grounding Safety Assessment," IEEE Transactions on Power Delivery, vol. 27, no. 4, pp. 1928-1936, 2012.

[6] G. Biegelmeier and W. R. Lee, “New considerations on the threshold of ventricular fibrillation for a.c. shocks at 50–60 Hz,” Proc. Inst. Elect. Eng., vol. 127, no. 2, pt. A, pp. 103–110, Mar. 1980.