

Lightning Risk Assessment Tool, Implementation of the IEC 62305-2 Standard on Lightning Protection

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Abstract— A comprehensive implementation of the risk management methodology detailed in the IEC 62305-2:2010 (*Protection against lightning, Part 2: Risk management*), called the Lightning Risk Assessment (LIRA) tool, is presented. LIRA was developed to facilitate the risk assessment calculations presented in IEC 62305-2 by means of a Graphical User Interface (GUI) that allows specifying all input parameters, in accordance with the definitions and values presented in the standard. The user has access to all the parameter values and calculation methods as detailed in the standard. This tool provides the capability to evaluate unlimited individual services in an unlimited number of zones in addition to a report generation capability that lists all input parameters and calculation results in several report formats. Furthermore, LIRA provides a direct interface to a Monte Carlo statistical tool, previously developed at the Kennedy Space Center (KSC), as an additional method of evaluating the annual number of dangerous events. The Hospital case study detailed in Annex E.4 of the standard is presented and final results from LIRA are compared to those in the standard. A case study of a typical Florida household is also presented using the Monte Carlo statistical tool as the input source of the annual number of dangerous events.

Keywords—Lightning Protection; Risk Assessment; Risk Analysis

I. INTRODUCTION

The IEC 62305-2:2010 [1] presents a comprehensive methodology to assess the risk related to loss due to lightning flashes. Hazards are defined depending on the lightning strike attachment point, the type of damage or injury caused by the flash, and the amount and type of loss. The risk assessment procedure presented in [1] helps in determining the necessity of new protection measures and evaluates the performance of existing protection measures in reducing the loss due to lightning flashes. The Lightning Risk Assessment (LIRA) tool assists in performing the risk assessment by allowing the user to enter, via graphical user interfaces (GUIs), the environment, structure, service lines and zones characteristics and factors and then uses these inputs to perform the risk calculations as outlined in the standard.

The current version of the standard has no software tool reference as its previous edition did. The Simplified IEC Risk Assessment Calculator (SIRAC) is a software tool presented in Annex J of the first edition of the IEC 62305-2:2006 that

provided a simple risk calculator tool based on the standard calculations but with a limited subset of parameters available and tailored to relatively simple structures. In addition to giving the user the capability of changing all parameters as presented in the standard, LIRA incorporates all the technical changes of the latest edition of the standard, including the latest equations and tables. LIRA was developed to allow the user to comprehensively implement the risk assessment procedure detailed in [1]. Note that LIRA should be used in conjunction with the standard throughout the risk analysis and risk calculation process.

LIRA's features are described in Section II. Two risk assessment case studies; a hospital, as detailed in [1], Annex E.4, and a Florida household, are presented in Section III. The results are discussed in Section IV and the conclusions are presented in Section V.

II. LIRA FEATURES AND CAPABILITIES

A. LIRA Capabilities

LIRA was created and programmed using the MATLAB GUIDE environment. It consists of a main GUI (see Fig. 1) that lays out four risks panels, one for each type of loss. Risk components (R_A , R_B , R_U , R_V , R_C , R_M , R_W , and R_Z) may be added by selecting a component from the drop-down menu and clicking the "Add" button. The action will pop up a window that contains the applicable parameters for the selected risk component (see Fig. 2). Parameters that are not applicable remain disabled until pertinent selections are made by the user (e.g. calculating N_L as per the IEC equation results in the required input parameters being enabled, see Fig. 3). After specifying all the required parameters, calculations are made and the user can proceed to save the risk component to the main GUI by assigning a description (see Fig. 3, Fig. 4, and Fig. 5). There are no limits to the number of zones that can be added to the project or the number of services that can be specified for each zone. As shown in Fig. 5 LIRA places the resulting R_U component (zone 2, power service line) related to loss of human life in the Type 1 – Risk of Loss of Human Life panel and the resulting risk component for the same zone/service related to loss of economic value in the corresponding Type 4- Risk of Loss of Economic Value panel. As more components are added, the total risk of loss (e.g. Total

R_{U1}), is updated to reflect the total risk component for the corresponding loss. When all components are finally added, the risk calculations are made and final results are displayed in the main GUI window, highlighting those risks (R_1 , R_2 , R_3 , and R_4) that exceed the tolerable risks as specified in the IEC standard (see Fig. 6, which shows the results for the hospital case study).

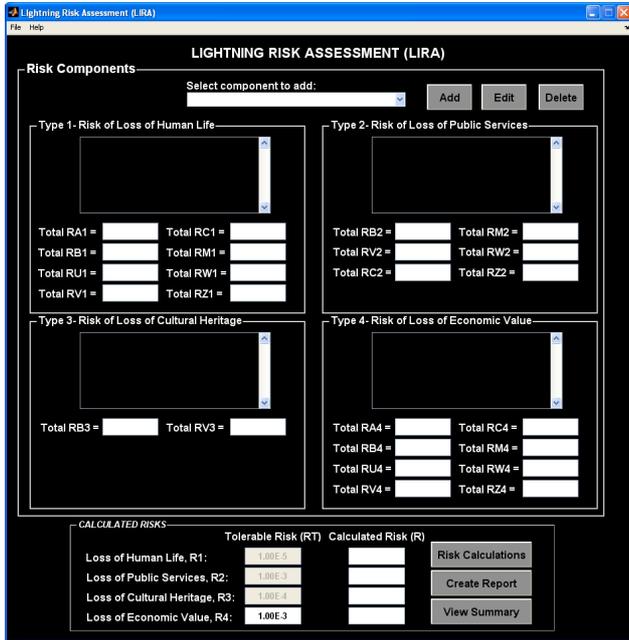


Figure 1. LIRA Main GUI.

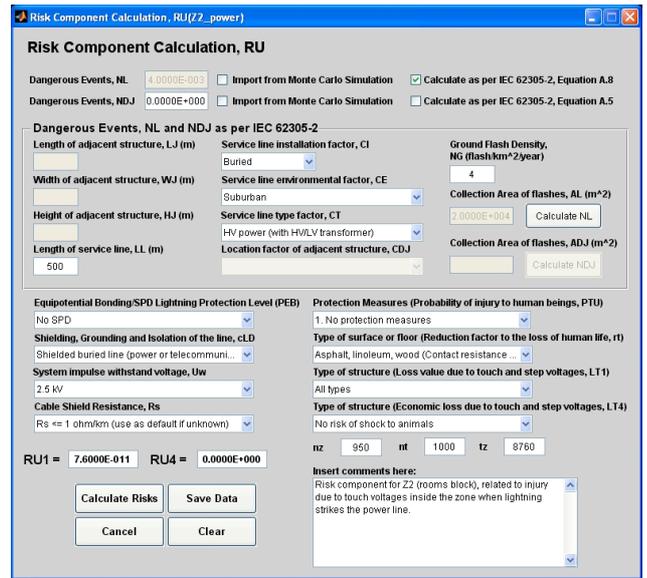


Figure 3. R_U risk component for the rooms block zone.



Figure 4. Risk component name.

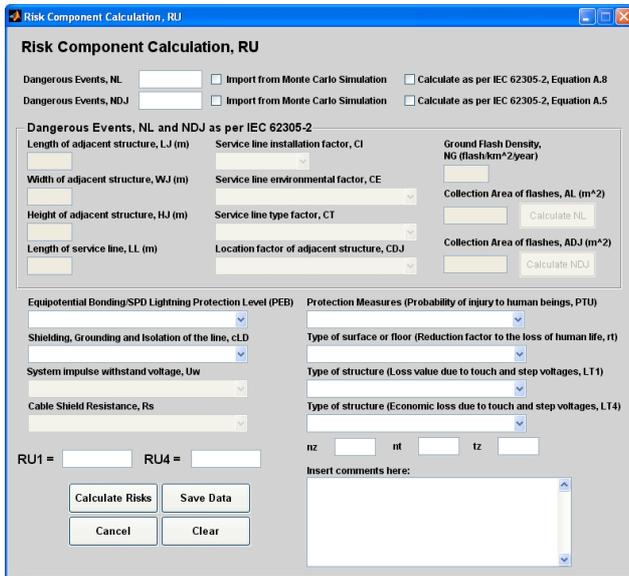


Figure 2. R_U component GUI.

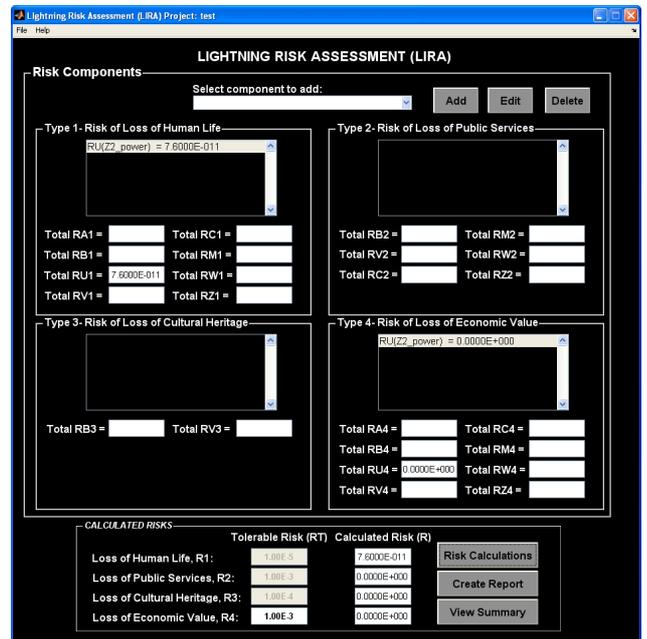


Figure 5. LIRA Main GUI with added risk component.



Figure 6. LIRA Main GUI displaying final results after all components have been added.

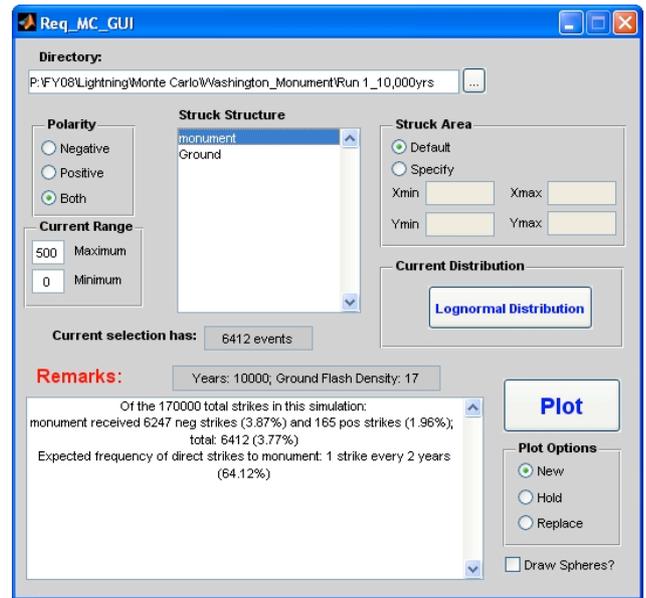


Figure 7. Monte Carlo statistical tool GUI with results for the Washington monument.

- A printable summary of the total risk components and risk results is available to the user (see Fig. 8, which shows the results of the hospital case study, Section III.A).

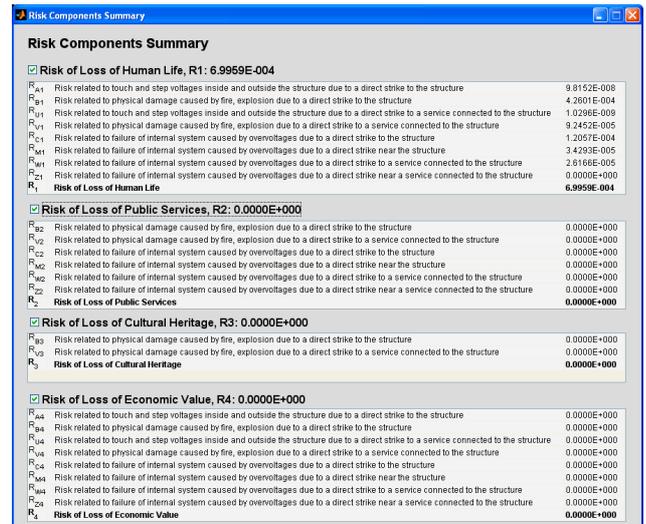


Figure 8. Risk components summary for the hospital case study, Section III.A.

- LIRA creates a report including all the input parameters used to calculate each risk component along with the results. The report file is a LaTeX source file that can be compiled as a PDF file using LaTeX or pdfLaTeX. Fig. 9 shows the first two pages of the risk report generated for the hospital case study (shown for solution “b” of the hospital case study). At the end of the report, all risk components are tabulated as shown in Fig. 10 and Fig. 11 (shown for solution “b” of the hospital case study).

1 Risks

The risk, as defined in the IEC 62305-2:2010, is the relative value of a probable average annual loss in a structure due to lightning flashes.

1.1 Risk of loss of human life, R_1

IEC 62305-2:2010 defines the risk of loss of human life (R_1) as follows:

$$R_1 = R_{A1} + R_{B1} + R_{C1} + R_{M1} + R_{V1} + R_{W1} + R_{Z1}$$

NOTE 1: Only for structures with risk of explosion and for hospitals with life-saving electrical equipment or other structures when failure of internal systems immediately endangers human life.

The tolerable level of risk for loss of human life, R_T , as specified in IEC 62305-2:2010 is:

$$R_T = 1.0000 \times 10^{-5}$$

The calculated risk of loss of human life, R_1 , for the Hospital, solution b resulted in:

$$R_1 = 2.2241 \times 10^{-6}$$

2 Parameters for Risk Component R_A

R_A is the risk component due to direct strikes to the structure related to injury to living beings caused by electric shock due to touch and step voltages inside and outside the structure.

$$R_A = N_D \times P_A \times L_A$$

2.1 Risk Component $R_{A(Z1)}$

• Comments:

Risk component for Z1 (outside building) related to injury caused by touch and step voltages outside the hospital.

2.1 Risk Component $R_{A(Z1)}$ 2 PARAMETERS FOR RISK COMPONENT R_A

- L - length of the structure (m).
 $L = 50.0000$
- W - width of the structure (m).
 $W = 150.0000$
- H - height of the structure (m).
 $H = 10.0000$
- N_G - lightning ground flash density (flash/km²/year):
 $N_G = 4.0000$
- c_D - location factor of the structure:
Isolated object: no other objects in the vicinity, $c_D = 1.0000$
- A_D - collection area of flashes striking the isolated structure (m²):
 $A_D = 2.2327 \times 10^4$
- N_D - average annual number of dangerous events to the structure. Dangerous events were calculated as specified in IEC 62305-2, Equation A.4.
 $N_D = 8.9310 \times 10^{-2}$
- P_{TA} - probability reducing P_A as a function of typical protection measures against touch and step voltages:
1. No protection measures, $P_{TA} = 1.0000$
- P_B - probability that a flash to the structure will cause physical damage as a function of the Lightning Protection Levels of the Lightning Protection System (LPS):
Structure protected by LPS Class I, $P_B = 2.0000 \times 10^{-2}$
- P_A - probability of injury to living beings due to touch and step voltages caused by a lightning flash to the structure, depending on the adopted LPS and additional protection measures provided:
 $P_A = 2.0000 \times 10^{-2}$
- r_t - factor reducing the loss of human life depending on the type of soil or floor:
Agricultural, concrete (Contact resistance less than 1 kilo-ohm), $r_t = 1.0000 \times 10^{-2}$
- L_{T1} - loss of life related to injury to living beings caused by electric shock due to one dangerous event:
Type of Structure: All types, $L_{T1} = 1.0000 \times 10^{-2}$
- n_z - number of possible endangered persons in the zone:
 $n_z = 1.0000 \times 10^1$
- n_t - expected total number of people in the structure:
 $n_t = 1.0000 \times 10^3$
- t_z - time, in hours per year, for when people are present in the zone:
 $t_z = 8.7600 \times 10^3$
- L_{A1} - loss of life related to injury to living beings caused by electric shock due to lightning flashes to the structure:
 $L_{A1} = 1.0000 \times 10^{-6}$
- Risk Component $R_{A1(Z1)}$ - risk component due to direct strikes to the structure and related to loss of human life due to injury to living beings caused by electric shock:
 $R_{A1(Z1)} = 1.7862 \times 10^{-9}$

Figure 9. Risk report example.

C. LIRA Future Enhancements

The current version of the LIRA does not implement the cost-benefit analysis as outlined in [1], Annex D. The risk of economic loss, R_4 , is calculated by LIRA under the assumption that the value ratios (using c_a , c_b , c_c , c_s , and c_t) are equal to 1. The representative value of tolerable risk, R_T , for economic loss (10^{-3}) is used, as suggested by the standard. The cost-

benefit analysis will be implemented in a future version of LIRA.

III. CASE STUDIES

To demonstrate the capability of LIRA, two case studies are presented. The first case study is the hospital facility (Section III.A) considered in [1], Annex E.4, where we compare the results given in the standard with those obtained using LIRA. The second case (Section III.B) is a typical Florida household with lightning protection system (LPS) for which we use the Monte Carlo statistical tool to simulate lightning activity and incidence and import the number of dangerous events per year. The risk results obtained with LIRA are presented.

A. Hospital facility

The hospital facility case study presented in [1] is evaluated using LIRA and the results are presented in this section. Since LIRA does not incorporate the cost analysis procedure outlined in the standard, only the results for the risk of loss of human life, R_1 , are tabulated. The parameters for the structure, service lines, and zones characteristics used by LIRA in its calculations are those specified in [1], Annex E.4 (Tables E.22, E.23, E.24, E.25, E.26, E.27, E.28, and E.29). Table I shows the comparison of the resulting risks related to loss of human life. Note that the difference in the results in Table I is due to risk component numerical rounding made in [1]. A summary of the risks results generated by LIRA for the hospital case study is also shown in Fig. 8.

TABLE I. RISK OF LOSS OF HUMAN LIFE, R_1 : HOSPITAL

	IEC 62305-2:2010	LIRA
Total R_{A1}	10×10^{-8}	9.8152×10^{-8}
Total R_{B1}	4.26×10^{-4}	4.2601×10^{-4}
Total R_{C1}	≈ 0	1.0296×10^{-9}
Total R_{V1}	9.245×10^{-5}	9.2452×10^{-5}
Total R_{M1}	1.2057×10^{-4}	1.2057×10^{-4}
Total R_{W1}	3.429×10^{-5}	3.4293×10^{-5}
Total R_{Z1}	2.616×10^{-5}	2.6166×10^{-5}
R_1	6.996×10^{-4}	6.9959×10^{-4}

Table II shows the comparison of the risk results if solution “b”, as specified in [1], is implemented. Note that the difference in the results in Table II is due to risk component numerical rounding made in [1]. See Fig. 10 and Fig. 11 for the tabulated report of the risk components calculated by LIRA for solution “b” of the hospital facility.

TABLE II. RISK OF LOSS OF HUMAN LIFE, R_1 : HOSPITAL, SOLUTION “B”

	IEC 62305-2:2010	LIRA
Total R_{A1}	≈ 0	1.9630×10^{-9}
Total R_{B1}	1.74×10^{-6}	1.7326×10^{-6}
Total R_{C1}	≈ 0	1.0296×10^{-11}
Total R_{V1}	1.8×10^{-7}	1.8801×10^{-7}
Total R_{M1}	2.4×10^{-7}	2.4101×10^{-7}
Total R_{W1}	3×10^{-8}	3.4294×10^{-8}
Total R_{Z1}	3×10^{-8}	2.6166×10^{-8}
R_1	2.22×10^{-6}	2.2241×10^{-6}

Risk Component	Hospital, solution b	Comments
$R_{A1(Z1)}$ Section 2.1	1.7862×10^{-9}	Risk component for Z1(outside building) related to injury caused by touch and step voltages outside the hospital.
$R_{A1(Z2)}$ Section 2.2	1.6969×10^{-10}	Risk component for Z2 (rooms block) related to injury caused by touch and step voltages inside the hospital.
$R_{A1(Z3)}$ Section 2.3	6.2517×10^{-12}	Risk component for Z3 (operating block) related to injury caused by touch and step voltages inside the hospital.
$R_{A1(Z4)}$ Section 2.4	8.9310×10^{-13}	Risk component for Z4 (intensive care unit) related to injury caused by touch and step voltages inside the hospital.
$R_{B1(Z2)}$ Section 3.1	1.6969×10^{-6}	Risk component for Z2 (rooms block), related to physical damage due to fire in the zone.
$R_{B1(Z3)}$ Section 3.2	3.1258×10^{-8}	Risk component for Z3 operating block), related to physical damage due to fire in the zone.
$R_{B1(Z4)}$ Section 3.3	4.4655×10^{-9}	Risk component for Z4 (intensive care unit), related to physical damage due to fire in the zone.
$R_{U1(Z2, power)}$ Section 4.1	7.6000×10^{-13}	Risk component for Z2 (rooms block), related to injury due to touch voltages inside the zone when lightning strikes the power line.
$R_{U1(Z2, telecom)}$ Section 4.2	9.1200×10^{-12}	Risk component for Z2 (rooms block), related to injury due to touch voltages inside the zone when lightning strikes the telecom line.

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Risk Component	Hospital, solution b	Comments
$R_{U1(Z3, power)}$ Section 4.3	2.8000×10^{-14}	Risk component for Z3 (operating block), related to injury due to touch voltages inside the zone when lightning strikes the power line.
$R_{U1(Z3, telecom)}$ Section 4.4	3.3600×10^{-13}	Risk component for Z3 (operating block), related to injury due to touch voltages inside the zone when lightning strikes the telecom line.
$R_{U1(Z4, power)}$ Section 4.5	4.0000×10^{-15}	Risk component for Z4 (intensive care unit), related to injury due to touch voltages inside the zone when lightning strikes the power line.
$R_{U1(Z4, telecom)}$ Section 4.6	4.8000×10^{-14}	Risk component for Z4 (intensive care unit), related to injury due to touch voltages inside the zone when lightning strikes the telecom line.
$R_{V1(Z2, power)}$ Section 5.1	7.6000×10^{-9}	Risk component for Z2 (rooms block), related to physical damage in the zone when lightning strikes the power line.
$R_{V1(Z2, telecom)}$ Section 5.2	1.7653×10^{-7}	Risk component for Z2 (rooms block), related to physical damage in the zone when lightning strikes the telecom line.
$R_{V1(Z3, power)}$ Section 5.3	1.4000×10^{-10}	Risk component for Z3 (operating block), related to physical damage in the zone when lightning strikes the power line.
$R_{V1(Z3, telecom)}$ Section 5.4	3.2518×10^{-9}	Risk component for Z3 (operating block), related to physical damage in the zone when lightning strikes the telecom line.
$R_{V1(Z4, power)}$ Section 5.5	2.0000×10^{-11}	Risk component for Z4 (intensive care unit), related to physical damage in the zone when lightning strikes the power line.

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Figure 10. LIRA risk component summary for Hospital case study, solution “b”.

Risk Component	Hospital, solution b	Comments
$R_{U1(Z4, telecom)}$ Section 5.6	4.6455×10^{-10}	Risk component for Z4 (intensive care unit), related to physical damage in the zone when lightning strikes the telecom line.
$R_{C1(Z2)}$ Section 6.1	1.6960×10^{-7}	Risk component for Z2 (rooms block), related to failure of internal systems connected to the power and telecom lines due to overvoltages.
$R_{C1(Z3)}$ Section 6.2	6.2486×10^{-8}	Risk component for Z3 (operating block), related to failure of internal systems connected to the power and telecom lines due to overvoltages.
$R_{C1(Z4)}$ Section 6.3	8.9265×10^{-9}	Risk component for Z4 (intensive care unit), related to failure of internal systems connected to the power and telecom lines due to overvoltages.
$R_{M1(Z2)}$ Section 7.1	2.4133×10^{-8}	Risk component for Z2 (rooms block), related to failure of internal systems connected to the power and telecom lines due to overvoltages.
$R_{M1(Z3)}$ Section 7.2	8.8911×10^{-9}	Risk component for Z3 (operating block), related to failure of internal systems connected to the power and telecom lines due to overvoltages.
$R_{M1(Z4)}$ Section 7.3	1.2702×10^{-9}	Risk component for Z4 (intensive care unit), related to failure of internal systems connected to the power and telecom lines due to overvoltages.
$R_{W1(Z2, power)}$ Section 8.1	7.6000×10^{-10}	Risk component for Z2 (rooms block), related to failure of internal systems connected to the power line due to overvoltages.

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Risk Component	Hospital, solution b	Comments
$R_{W1(Z2, telecom)}$ Section 8.2	1.7653×10^{-8}	Risk component for Z2 (rooms block), related to failure of internal systems connected to the telecom line due to overvoltages.
$R_{W1(Z3, power)}$ Section 8.3	2.8000×10^{-10}	Risk component for Z3 (operating block), related to failure of internal systems connected to the power line due to overvoltages.
$R_{W1(Z3, telecom)}$ Section 8.4	6.5037×10^{-9}	Risk component for Z3 (operating block), related to failure of internal systems connected to the telecom line due to overvoltages.
$R_{W1(Z4, power)}$ Section 8.5	4.0000×10^{-11}	Risk component for Z4 (intensive care unit), related to failure of internal systems connected to the power line due to overvoltages.
$R_{W1(Z4, telecom)}$ Section 8.6	9.2910×10^{-10}	Risk component for Z4 (intensive care unit), related to failure of internal systems connected to the telecom line due to overvoltages.
R₁ Section 1.1	2.2241 × 10⁻⁶	Risk of Loss of Human Life

Figure 11. LIRA risk component summary for Hospital case study, solution “b” (cont’d).

B. Florida household

The Florida household case is modeled using the Monte Carlo statistical tool [2] and the risk is evaluated using LIRA. The results are presented in this section. The parameters for the structure, service lines, and zones characteristics used by LIRA are presented in Tables III through VII.

TABLE III. FLORIDA HOUSEHOLD CHARACTERISTICS

Parameter	Comment	Value
Dimensions (m)	Length, width, height	18.3, 18.3, 6.1
Ground Flash Density	l/km ² /year	17
LPS	Class IV	0.2

The following zones are defined: a) Z₁, outside the house, and b) Z₂, inside the house. For zone Z₁, it is assumed that people are not outside the house during a thunderstorm. Therefore, risk components applicable to zone Z₁ (R_A only) are disregarded. The parameters applicable to zone Z₂ are given in Table IV.

TABLE IV. PARAMETERS FOR ZONE Z2, INSIDE THE HOUSE

Parameter	Comment	Value
Protection measures	None	1
Type of floor	Concrete	10 ⁻²
Endangered persons	-	5
Total number of persons	-	5
Time present in zone	Hours/year	8760
Fire protection	Manual	0.5
Risk of fire	Ordinary	10 ⁻²
Special Hazard	None	1
L ₁ : Loss of human life	D1: due to touch and step voltage, L _T	10 ⁻²
	D2: due to physical damage, L _F	10 ⁻²

The parameters applicable to the power service line are given in Table V, to the cable service line in Table VI, and to the phone service line in Table VII.

TABLE V. PARAMETERS FOR THE POWER SERVICE LINE

Parameter	Comment	Value
Length (m)	-	500
Installation factor	Buried	0.5
Environmental factor	Suburban	0.5
Line type factor	HV power	0.2
Adjacent structure	None	-
Shield of line	Unshielded	-
SPD LPL	Class IV	0.05
Shielding/Ground/Isolation	Unshielded	1

TABLE VI. PARAMETERS FOR THE CABLE SERVICE LINE

Parameter	Comment	Value
Length (m)	-	200
Installation factor	Buried	0.5
Environmental factor	Suburban	0.5
Line type factor	Telecom line	1
Adjacent structure	None	-
Shield of line	Unshielded	-
SPD LPL	None	1
Shielding/Ground/Isolation	Unshielded	1

TABLE VII. PARAMETERS FOR THE PHONE SERVICE LINE

Parameter	Comment	Value
Length (m)	-	200
Installation factor	Buried	0.5
Environmental factor	Suburban	0.5
Line type factor	Telecom line	1
Adjacent structure	None	-
Shield of line	Unshielded	-
SPD LPL	None	1
Shielding/Ground/Isolation	Unshielded	1

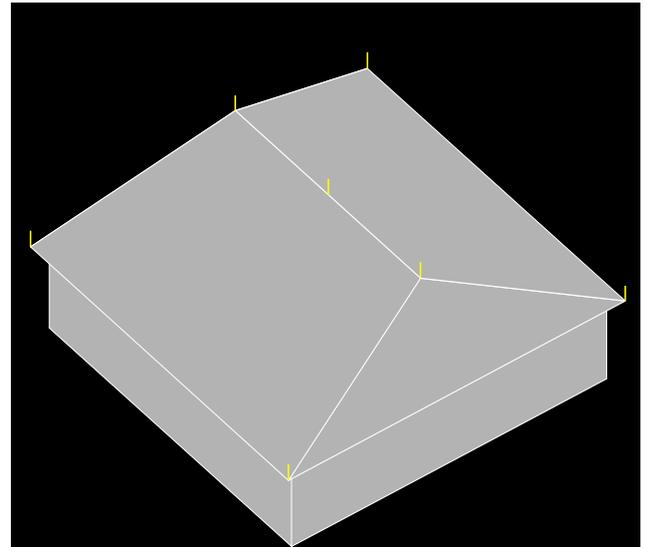


Figure 12. Monte Carlo model for a Florida house.

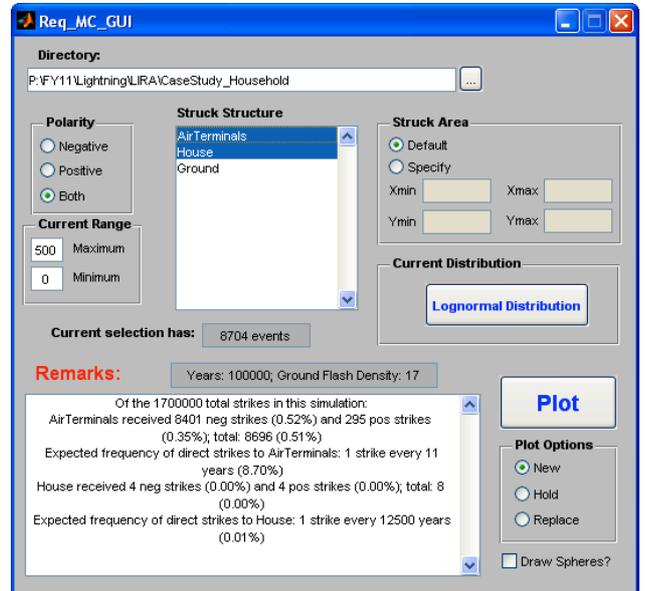


Figure 13. Monte Carlo statistical tool GUI results.

Fig. 12 illustrates the Monte Carlo statistical tool model for the house with the dimensions and LPS as described in Table III. The Monte Carlo statistical tool uses this model to determine the probability of direct attachments to the house in a period of 100,000 years. Fig. 13 shows the Monte Carlo statistical tool GUI with the resultant number of events for the Florida house, including its LPS, in a 100,000-year period. The 8,704 events are equivalent to 0.08704 events per year. LIRA uses this number as the annual number of dangerous events due to direct strikes to the house and its LPS. Note that if using equation A.2 in [1], the number of dangerous events would be 0.0448 per year. This shows that the Monte Carlo statistical tool is slightly more conservative than the IEC standard in estimating the number of dangerous events for these low heights.

Fig. 14 shows the GUI for component R_A using the imported dangerous events from the Monte Carlo simulation. Table VIII shows the resulting risks related to loss of human life as calculated by LIRA for the Florida household. Fig. 15 illustrates the LIRA GUI showing the calculated results.

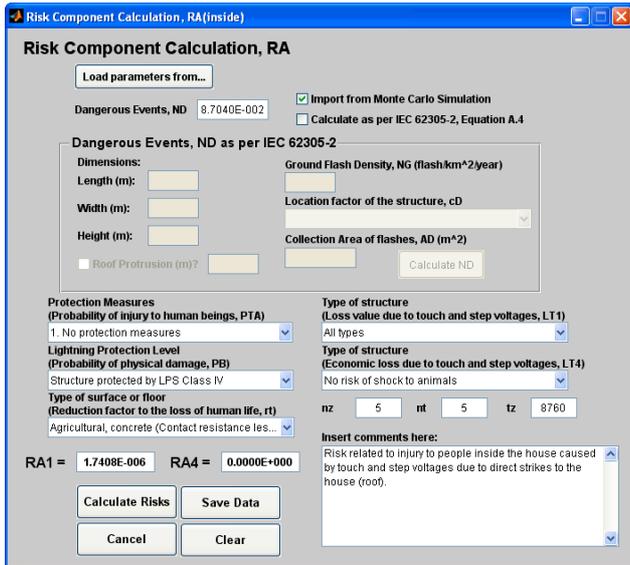


Figure 14. Risk component R_A using imported events from the Monte Carlo statistical tool.

TABLE VIII. RISK OF LOSS OF HUMAN LIFE, R_1 : FLORIDA HOUSEHOLD.

	LIRA
Total R_{A1}	1.7408×10^{-6}
Total R_{B1}	8.7040×10^{-7}
Total R_{U1}	6.8850×10^{-6}
Total R_{V1}	3.4425×10^{-6}
R_1	1.2939×10^{-5}

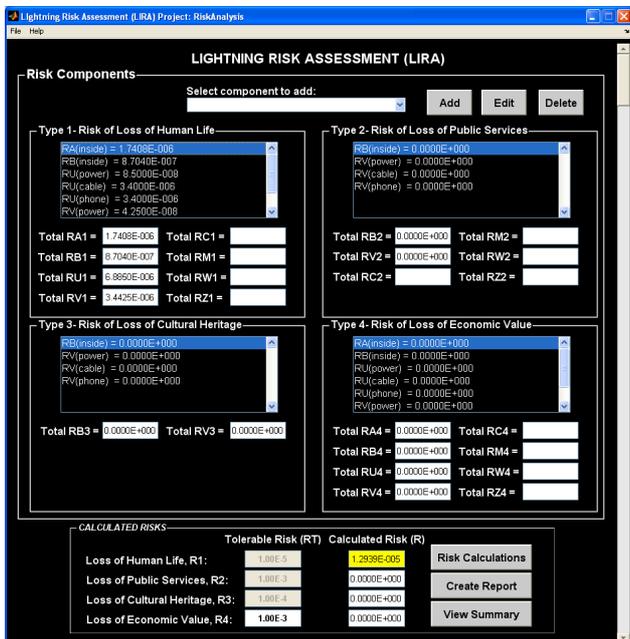


Figure 15. LIRA GUI showing risk results for the Florida household case study.

Since $R_1 = 1.2939 \times 10^{-5}$ is greater than the IEC proposed tolerable value, $R_T = 10^{-5}$, we need to reduce the loss by providing additional protection measures such as installing surge protective devices (SPDs) of lightning protection level (LPL) IV at the cable and phone service lines entrance. Modifying this parameter in LIRA results in new values for the risk components R_U and R_V as shown in Table IX and Fig. 16 (solution “a”).

TABLE IX. RISK OF LOSS OF HUMAN LIFE, R_1 : FLORIDA HOUSEHOLD, SOLUTION “A”.

	LIRA
Total R_{A1}	1.7408×10^{-6}
Total R_{B1}	8.7040×10^{-7}
Total R_{U1}	4.2500×10^{-7}
Total R_{V1}	2.1250×10^{-7}
R_1	3.2487×10^{-6}



Figure 16. LIRA GUI showing risk results for the Florida household case study, solution “a”.

IV. RESULTS

The risks results comparison shown in Table I and Table II validates that the results provided by LIRA agree with the ones presented in [1]. These results demonstrate that LIRA incorporates the equations and procedures as outlined in the standard yielding the same results. The differences observed between the results are due to numerical rounding made in the IEC standard. The Florida household case study presented in this paper demonstrates the capability of LIRA to import the simulation results provided by the Monte Carlo statistical tool when determining the annual number of dangerous events to be used in the risk analysis calculations.

V. CONCLUSIONS

The risk assessment procedure presented in [1] requires many calculations to obtain the final risk results. LIRA simplifies these calculations by providing a comprehensive user interface that takes the known input parameters and performs the calculation algorithms as specified by the IEC standard. Furthermore, LIRA provides the user with a complete risk assessment report with the individual parameter values used in the calculation of each risk component. More importantly, LIRA provides an interface to a Monte Carlo statistical tool to import the number of dangerous events for complex structures.

REFERENCES

- [1] IEC 62305-2, Ed. 2: Protection against lightning – Part 2: Risk management, 2010.
- [2] C. T. Mata, V. A. Rakov, "Evaluation of lightning incidence to elements of a complex structure: a Monte Carlo approach", International Conference on Grounding and Earthing & 3rd International Conference on Lightning Physics and Effects (Ground 2008; 3rd LPE), Florianopolis, Brazil, November 2008.