



Analysis of data related to ageing of VVER-440 NPP components

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**Shahen Poghosyan, Albert Malkhasyan,
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Abstract

The aim of case study was to demonstrate the applicability of methods for reliability parameters estimation, presented in the guideline (EUR 23954 EN), using the operational data from VVER-440 plants.

Two types of calculations were performed, using Excel functions and WINBUGS scripts, to identify the possible trends of data. The study results are useful in revealing the problematic issues connected with use of data guideline (EUR 23954 EN) and for improvement of decision making process based on calculation results. Practical insights, recommendations and limitations are also discussed.

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1. INTRODUCTION

The case study was performed within Task 4 of Ageing PSA European Network, with the aim to demonstrate the applicability of methods for reliability parameter estimation presented in the guideline (EUR 23954 EN), using the operational data from VVER-440 plants.

The case study includes following steps:

- Selection of representative components for further assessment
- Data gathering from similar NPP
- Data analysis aimed to reveal trend model

Main deliverables from case study are:

- Proving the practical use of EUR 23954 EN data analysis guideline, demonstrating its range of applicability
- Analyzing and choosing the model that fitted best the data (based on calculation results),
- Revealing the problematic issues connected with using of EUR 23954 EN guideline

2. TASK SPECIFICATION

2.1 Aims and objectives of case study

The objective of this case study is to demonstrate the applicability of methods for reliability parameter estimation presented in the guideline (EUR 23954 EN) using the operational data from VVER-440 plants. For this purpose 3 types of components were selected, providing a sufficient diversity of failure modes and data. These components are:

- main feedwater pump
- diesel generator
- 6 kV breakers

Selection of components was done based on following considerations:

- selected components are similar for all VVER plants
- sufficient amount of data available
- diversity in component design, operation and failure modes permits to illustrate applicability of different computation techniques proposed in the guideline

Specific data were gathered from Armenian NPP for 12 years (1996-2007). Generic data on these components were gathered from similar VVER-440 plants (operating countries Czech Republic, Hungary, Slovakia) and they were provided only for the components of approximately the same type (technical specifications, function).

2.2 Selected components

2.2.1 Main feedwater pump

For main feedwater pump the data were gathered from all plants, which were involved in the case study, and 2 failure modes were considered – “fail to start”(FS) and “fail to run”(FR). Though the data were gathered from all the available plants, there was a slight difference in vendors and several parameters (e.g. component boundaries, critical/ non-critical failures). Under these circumstances the grouping (binning) of the operational data should be performed carefully, otherwise the effect of such grouping should be evaluated during results interpretation (detailed data analysis). In preliminary test calculations it was identified and stated that several options could have significant effect on results interpretation.

The pump is centrifugal, horizontal, sectional, single housing and has four stages. It is intended to supply feedwater from deaerators to the steam generators. From design stage it was provided a recirculation line to avoid the pump overheating under low flow rate. Cooling of end gland seals is performed by water from main condensate system or from chemically purified water system. The plain bearing is lubricated by the individual oil system. Other technical features are presented in Table 1.

Table 1 - Pump characteristics

Parameter name	Parameter value
working substance	deaerated water
working substance temperature	159 °C
pump flow rate	850 m ³ /h

pressure by nominal flow	714 m w.c.
on-inlet pressure	not less than 9 m w.c.
return flow line stream rate	200 m ³ /h
oil consumption	1.7 m ³ /h
cooling water discharge rate	5 m ³ /h
asynchronous electric motor	2A3M-2500-6000-Y4
energy consumption	2500 kW
source voltage	6000 V
Current	270 A
revolution per minute	3000

For Armenian NPP pump, the following boundaries were considered:

- Welding and flanges in pipe
- Connection of cable to pump breaker (breaker is within pump's boundaries)
- Lubrication system is not included into the pump's boundaries

The pumps from others plants have similar boundaries as those specified above (for Armenian NPP).

2.2.2 Diesel Generator

For diesel generators were selected 2 failure modes – “fail to start”(FS) and “fail to run”(FR), and the data were gathered from all available plants with some negligible difference in operational parameters. There was identified also a slight difference in diesel generator vendors and boundaries. Diesel generator technical features are presented in Table 2.

Table 2 - Diesel generator parameters

Parameter name	Parameter value
Nominal capacity	1600 kW
Nominal voltage	6.3 kV
Nominal stator current	184 A
Nominal rotor current	320 A
Power factor	0.8

2.2.3 6kV breakers

Since only one Network participant was able to provide sufficient data for “fail to remain in position” failure mode, it was decided to use “fail to change position” failure mode for case study purposes. For the CB analysis it was used only the “fail to operate” failure mode due to the fact that only one Network partner has provided sufficient data separately for “fail to open” and “fail to close”.

The analysis considered only 6kV oil-breakers, as far as for Armenian power plant it was identified a difference in reliability parameters for oil breakers and SF6¹. 6kV breaker technical features are presented in Table 3.

Table 3 - 6kV breaker parameters

Parameter name	Parameter value		
	VMPE-10-630-20UZ	VMPE -10-1000-20UZ	VMPE -10-1600-20UZ
Nominal voltage (kV)	10	10	10
Nominal current (A)	630	1000	1600

¹ During the interpretation of preliminary results it was identified that since 2004 at Armenian NPP on all safety systems took place the replacements of all 6kV oil breakers to SF6. This modernization leads to significant growth of reliability of breakers.

Nominal breaking current (A)	20	20	20
Making current, peak value (kA)	52	52	52
Thermal stability limiting current for 8 s. time interval (kA)	20	20	20
Minimal no-current condition time at automatic reclosure (s.)	0.5	0.5	0.5
Closing time (s.), no more than	0.09	0.09	0.09
Opening time (s.) , no more than	0.3	0.3	0.3
Making electromagnet nominal voltage (V)	220	220	220
Breaking electromagnet nominal voltage (V)	220	220	220
Electromagnet winding consumption current (A), when connected/disconnected, not more than	90/2.5	90/2.5	90/2.5

2.3 Data Description

For this analysis operational data were gathered from 13 units and cover a period of 28 reactor-years. Availability of this kind of representative data enables confidence in interpretation of the results. Data gathering was performed for components specified in chapter 2.2. The list of similar VVER-440 nuclear power plants which provided data is presented in table 4.

Table 4 - List of VVER units that provided data

Country	Type	Commision Date
Medzamor Unit 2	VVER-440/V-270	1980
Mohovce Unit 1 ²	VVER-440/V-213	1998
Mohovce Unit 2	VVER-440/V-213	2000
Bohunice V2 Unit 3	VVER-440/V-213	1985
Bohunice V2 Unit 4	VVER-440/V-213	1985
Paks Unit 1	VVER-440/V-213	1982
Paks Unit 2	VVER-440/V-213	1984
Paks Unit 3	VVER-440/V-213	1986
Paks Unit 4	VVER-440/V-213	1987
Dukovany Unit 1	VVER-440/V-213	1985
Dukovany Unit 2	VVER-440/V-213	1986
Dukovany Unit 3	VVER-440/V-213	1986
Dukovany Unit 4	VVER-440/V-213	1987

Data from mentioned units contain information about following issues:

- Component description
- Commission date
- Component boundaries
- Observation period / covered ages window
- Considered failure modes and operating states
- # of components in the sample for data gathering
- # of observed failures per failure mode (# of observed non-critical failures)
- Dates of failures / failure mode / component ID (Cause of failure)
- Average # of hrs/demands per year per population
- Important modifications (is there any significant measures taken?)
- Performance characteristics
- Environmental conditions
- Period of maintenance

Gathered data were used to assure that use of data from considered plants is acceptable. Particularly data sets were selected and detailed analysis was performed.

2.4 Preliminary data analysis

2.4.1 Preliminary data analysis using WinBUGS

Preliminary analysis was carried out for all 5 failure modes of 3 selected components using WinBUGS scripts and Excel functions. For both programs binned (merged) data were used. Basically 2 models were considered with WinBUGS – Poisson model for failure rate and Binominal model for probability of failures on demands. For each model 3-4 calculation were performed:

- For Poisson model for failure rate:
 - Checking constant failure rate model assumption
 - Checking failure rate loglinear model assumption
 - Checking failure rate power model assumption
- For Binominal model for probability of failures on demand:
 - Checking constant probability of failures on demand model assumption
 - Checking probability of failures on demand complementary log-log model assumption
 - Checking probability of failures on demand logit model assumption
 - Checking probability of failures on demand probit model assumption

Table 5 - List of necessary calculations

Failure mode	All data	All data without first 6 years	All data without A9-A12	A9-A12 data only	Armenian data only
Main feedwater pump FS	4	4	4	4	4
Main feedwater pump FR	3	3	3	3	3
Diesel generator FS	4	4	4	4	4
Diesel generator FR	3	3	3	3	3
6kV breakers FR	3	3	3	3	3

At the beginning of preliminary analysis it was intended to perform calculations for all data set merged together. However after first calculations made for main feedwater pumps, it was identified a large failure rate during the first 6 years (in comparison with middle-age years failure rate) which can also include burn-in failures. Thus it was also decided to calculate all data set without first 6 years. During consideration of this effect of 6 years it was identified also that the first 6 years of whole data set comprised mainly by data of A9, A10, A11 and A12. Based on this fact, it was decided to perform

calculations for all dataset without A9-A12 data as well as for A9-A12 data only. As far as the case study is intended to demonstrate possibility of using methods for reliability parameter estimation for Armenian NPP case using generic data, it was identified as necessary to perform calculation for Armenian NPP data only.

Thus for each failure mode of selected components it was identified the list of calculation needed to be performed during preliminary analysis stage. Totally 70 calculations were performed with WinBUGS. This list is presented in Table 5.

2.4.2 Preliminary data analysis using Excel functions

The same calculations were also performed using parametric test in Excel. However for parametric test in Excel there is a standard set of trend models which needed to be calculated regardless of reliability model type (failure rate, probability). Following trend model calculations are performed for both reliability models:

- Checking constant failure probability or failure rate model assumption
- Checking failure probability or failure rate linear model assumption
- Checking failure probability or failure rate exponential model assumption
- Checking failure probability or failure rate Weibull model assumption

At the preliminary stage it was performed also the identification of confidence level of trend existence with both Excel and WinBUGS. WinBUGS calculations are also checked for convergence.

2.4.3 Comparison of results

After the results for all calculations were obtained, comparison of results was performed for WinBUGS and Excel calculations with the real data, both graphically and parametrically. These comparison sheets were the main tool in qualitative analysis.

2.5 Detailed data analysis

Detailed data analysis aimed to justify the revealed assumption about trend existence. For this purpose were performed additional calculations with partitioned data for different age-intervals as well as for every country and plant independently.

After preliminary data analysis 6 kV breakers were selected because preliminary analysis results revealed trend existence in the most cases.

3. RESULTS

3.1 Main feedwater pump fail to start (FS)

3.1.1 Excel calculations

Results of calculations for “all merged data” and data case “without first 6 years” revealed relatively good fitness of all 4 models (constant, linear, exponential, Weibull). From the qualitative point of view it could mean, that the result of these calculations could be a constant parameter for the probability of failure on demand. This conclusion was confirmed also by other parameters of calculation results. The highest p.value (all data – $p=0.78$, without 6 years – $p=0.88$) was derived for constant trend models.

Results of calculations for “Without A9-A12 data” data case shows very poor fitting for all 4 models with highest p.value $p=0.31$ derived for Weibull model reflecting decreasing trend.

Taking into account that constant model was derived with relatively high p.values and increasing failure trend is not approved, it was concluded that constant trend model is applicable for this case.

3.1.2 WinBUGS calculations

Results of calculations for all merged data are indicating good fitness of all 4 models (constant, complementary log-log, logit, probit). From the qualitative point of view it could mean, that the result of these calculations could be the constant parameter for the probability of failure on demand. This conclusion was confirmed also by other parameters of calculation results. The parameter for goodness of fit for selected trend model p.value showed the best result for the constant model 0.45 vs. 0.38. Graphical representation for parameter b (trend indicating parameter) shows that the parameter “mean value” is very close to the value of “0”, which is indicating the validity of the initial conclusion.

Results of calculations for all merged data without first 6 years are showing better results for fitness of all 4 models than the results for all merged data including 6 years. Again p.value shows the best result for the constant model 0.49 vs. 0.41. The graphical representation for parameter b also shows that the mean value is very close to the value of “0”. Hence the conclusion could be again constant probability for failure on demand.

Performed calculation for all data merged without A9-A12 data indicates very poor fitness of all trend models with very slight prevalence of negative trend. The mean and median values are still close to the “0”. The best p.value was still found for constant probability model, however it is very low – 0.1.

Data analysis for A9-A12 and Armenian data shows trend existence, which is not obvious.

In case of A9-A12 data the derived trend parameters are as follows: p.value = 0.45 for the probit function, 95% of confidence in trend existence. However the trend is highly depend on the peak in the real data (See Figure 3). For the purpose of data analysis for Armenian NPP it is not essential to identify the reason of the data peak in A9-A12 data, because in general all analyses were indicating the absence of trend.

In case of Armenian NPP data the derived trend parameters are as follows: p.value = 0.497 for the logit function, about 75-80% of confidence in trend existence. However it was assumed that 5 failures for 5 components in component set during 12 years is not enough to draw conclusions based on only specific data. Thus the summary conclusion with WinBUGS calculation results is the absence of trend for Armenian NPP.

3.1.3 Calculation comparison

Both calculations done by Excel and WinBUGs show that constant failure trend is applicable for main feedwater pump fail to start case for Armenian NPP. Graphical comparison of calculations is shown in Appendix 2.

3.2 Main feedwater pump fail to run (FR)

3.2.1 Excel calculations

Results of calculations for all merged data revealed poor fitting to all 4 models (constant, linear, exponential, Weibull). The main reason is that all merged data set is quite similar with bath-tub curve, when first years statistics reflects decreasing trend, then constant period is observed and increasing trend is presented in the end.

Calculations performed for “without A9-A12 data” data case shows good fit with constant failure rate model. However increasing trend was observed “without 6 years” data case. This allows concluding that last year failures are dominating. Detailed observation of data shows that increasing trend is caused by Armenian NPP data (3 failures are observed on 22th year of operation see Appendix 1). Investigation of root cause for those 3 years shows that actually they occurred during 3 weeks with the same pump and were connected with a sealing problem. After 2 repairs sealing was changed, so those 3 failures could be taken into account like 1 failure. Recalculation of “without 6 years” data case with improved Armenian NPP data show that increasing trend disappeared and constant failure model is acceptable ($p.value=0.90$ for constant trend model).

Finally constant trend model was considered to be applicable for this case.

3.2.2 WinBUGS calculations

Results of calculations for all merged data are indicating poor fitness of constant and loglinear models ($p.value = 0.1$). For the power model calculation results are indicating an average fitness with $p.value = 0.316$. The trend indicative parameter $a = 0.6$ shows decreasing trend with 97.5 confidence level. However graph presented in Appendix 2 shows data variation similar to a “bath curve”.

Assuming first 6 years data to be burn-in failures, calculation was performed for all the data merged without first 6 years. Results show a $p.value = 0.39$ for the fitness of constant model, and a much better $p.value = 0.47$ for loglinear model. However considering parameter “b” for loglinear trend model the distribution for parameter “b” shows increasing trend - the mean value = 0.027 with 75-90% confidence for increasing trend. The difference in these 2 calculations brings to conflict in conclusions, thus it is necessary to perform additional examination.

Result for the all data merged without A9-A12 data shows poorer result for both constant and loglinear models $p.value(const)=0.26$ and $p.value(log-linear)=0.365$, but with a stronger confidence in increasing trend ($b=0.0553$ with $\approx 94\%$ confidence level). This indicates that A1-A8 and Armenian NPP data together indicate increasing trend and needs further examination.

Separate study results on A9-A12 data shows very poor fitness of all models $p.value(const)=0.0455$, $p.value(log-linear)=0.0265$, $p.value(power)=0.267$. For p.values the constant model has the best p.value, but the both trend models (log-linear and power) shows decreasing trend with 95% confidence level.

Results of Armenian NPP data calculations showed good fitness for all models, however the power trend model calculation did not converge, and the results are not valid for that trend model. Among others the best $p.value = 0.555$ belongs to constant model and the log-linear model has $p.value = 0.415$. The “b” parameter mean value is very close to “0”, and confirms the “no trend” assumption. Looking at graph for Armenian NPP data we can see a pick. Due to examination of operational data, available at ANPP it was found out that it was recurrent failure of the same component, which was not eliminated (not the failures due to ageing). Putting one failure instead of observed 3 failures we will probably get better fit for the constant model.

Separating “all data merged without A9-A12 data” also from Armenian NPP data and plotting it on the graph we could see also decreasing trend of small confidence, as it was observed for A9-A12 data. At the first glance seems that data analysis results are contradictory. However as with the A9-A12 data case, Armenian NPP data is prevailing in the last years of “all data merged without A9-A12 data” dataset. Partially A5-A8 data contributes to the Armenian NPP data. However the average value of failure rate for Armenian NPP data is 2-3 times higher than on A5-A8 NPP (See Figure 26) causing significant increase of failure rate for the latest years of data mixture for “all data merged without A9-A12 data”.

Based on all calculations and considering 10 failures for 5 components for 12 years at Armenian NPP showing no trend, the final conclusion was the absence of trend at Armenian NPP data using generic data. Although some of merged data calculations shows positive trend, however separate analysis for each of the plant reveal no trend presence and in some case there were decreasing trend for failure rate.

Analysis experience with this case shows importance of:

- consideration of difference in average failure rate values while merging data
- performance of different plant data calculations and consideration of those results separately
- taking into account the fact that different plant data prevails in different age windows of the merged data causing wrong interpretation of results for merged data calculations.

3.2.3 Calculation comparison

Both calculations done by Excel and WinBUGs show that constant failure trend is applicable for main feedwater pump fail to run case for Armenian NPP. Graphical comparison of calculations is shown in Appendix 2.

3.3 Diesel generator fail to start (FS)

3.3.1 Excel calculations

Results of calculations for all merged data revealed poor fitting to all 4 models (constant, linear, exponential, Weibull). However decreasing trend is observed for “without 6 years” and “without A9-A12 data” data sets.

Additional calculations performed for Armenian NPP data only show that constant failure rate model is applicable.

Based on the results it was assumed that constant failure model is acceptable for this case.

3.3.2 WinBUGS calculations

Results of calculations for all merged data are indicating very poor fitness for all models. However relatively logit and probit trend models are indicating better fitness rather than constant model (0.027 vs. 0.014) and have 90% confidence level of negative trend.

Further analysis without first 6 years showed following results: constant model is still very poor fitting (0.026), however other models are quite well fitted with p.value range (0.4 – 0.41) and indicating very strong negative trend with confidence level much higher than 97.5%.

Results of calculation for all data without A9-A12 data again shows similar results to the previous calculation with poorer fitting of constant model (p.value = 0.005) and better fitting of trend models (0.43 – 0.443). The best fitted trend model (logit) is still indicating very strong negative trend (the confidence level much higher than 97.5%).

The results of calculation performed for only A9-A12 plants data revealed constant trend rather than negative trend with p.value = 0.3 vs. 0.24

Armenian data analysis was more complicated, as far as all models fitted quite well (p.value: 0.43-0.45, 0.535), however last years of ANPP data indicates significant decreasing number of failures. During discussion of results, it was identified, that there were some modifications on DG during that years and it is reasonable to assume failure rate to be constant, rather than decreasing

trend of failure rate. For subsequent data analysis purposes it is necessary to gather and add data for 2-3 more years of operation to identify, whether the trend is constant within last years of ANPP data, since performed modifications.

Based on that and the fact, that there are significant data from Armenian NPP to justify the results (16 failures during 12 years for 4 components) it was identified that there is no trend observed for Armenian NPP.

3.3.3 Calculation comparison

Both calculations done by Excel and WinBUGs show that constant failure trend is applicable for diesel generator fail to start case for Armenian NPP. Graphical comparison of calculations is shown in Appendix 2.

Detailed observation of further trend of this equipment is necessary to assure calculation results.

3.4 Diesel Generator fail to run (FR)

3.4.1 Excel calculations

Results of calculations for all data cases revealed poor fitting to all 4 models (constant, linear, exponential, Weibull). AFMEA is necessary for this case.

3.4.2 WinBUGS calculations

Results of calculations for all merged data are indicating very poor fitness for all models (0.08 – 0.1). However loglinear and power models indicate decreasing trend with confidence level higher than 90%.

The results of calculations performed for all data merged without first 6 years revealed better fitting of all models (0.17 – 0.2), and the best fitting model is the constant model. For loglinear model there is still a decreasing trend identified, but with 75% of confidence level.

Results for all data merged without A9-A12 data identified very poor fitting for constant (p.value = 0.005) and loglinear (p.value = 0.035) models and less poor fitting for power model (p.value = 0.12). However the power model was not converged and it is not correct to use the results of that model. We can conclude based on the graph presented on Figure 17 and results of loglinear and power trend models, that there is a strong decreasing trend in all data.

The results of calculations for only A9-A12 data shows that the best fitted model is the constant model (p.value = 0.19). The other models are poor fitting models loglinear (p.value = 0.13) and power (p.value = 0.11) both shows decreasing trend with confidence level of 75%. The graph presented in Figure 19 also suggests constant trend model.

The results of calculations for Armenian NPP data shows good fitting of all models constant (p.value = 0.59), loglinear (p.value = 0.415), power (p.value = 0.416). However power trend model was not converged and the loglinear trend model mean and medium values are close to the "0" (there is a slight increasing trend observed).

These results are very similar to the main feedwater pump fail to run mode results. For A9-A12 data we have constant trend. The A1-A8 data analysis suggests decreasing trend. Armenian NPP data analysis suggests constant failure rate with slight increasing trend and it is supposed that the detailed analysis for Armenian NPP using generic data as a prior would have the constant failure rate with a slight decreasing or increasing trend. Thus we can conclude that the results for Armenian NPP would be a constant failure rate.

3.4.3 Calculation comparison

Based on calculations performed by Excel and WinBUGs it was decided to assign constant failure trend model for this case. However necessity of AFMEA analysis and detailed investigation was stressed. Graphical comparison of calculations is shown in Appendix 2.

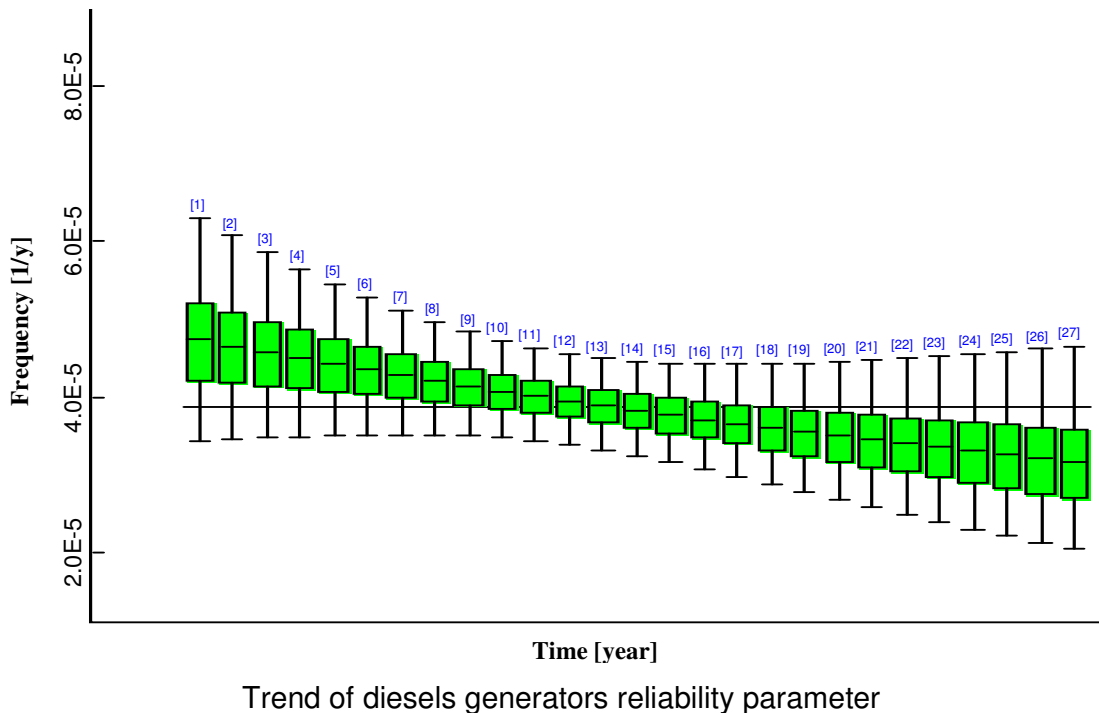
It is necessary to mention that for this case data for Armenian NPP is not sufficient and generic data should be used.

3.4.4 Sensitivity analysis

Investigation of root causes for DG failures recorded at VVERs shows that sometimes it is difficult to clarify the vulnerability to a particular failure mode (fail to start, fail to run). Uncertainties in root cause analysis could lead to inadequate interpretation of ageing-trend analysis for DG reliability parameters.

This issue was discussed with Ageing PSA Network participants. It was proposed to implement sensitivity study in order to check used assumptions. Implementation of sensitivity study was done by combining statistics of both failure modes. The process of reprocessing the combined data revealed that the best fitted model is a loglinear model with p-value equals 0.13.

According to the results of calculation the hypothesis of increasing ageing-trend for diesel-generators was not assured. Hence performed sensitivity study proof results obtained by previous calculations.



3.5 6kV breakers fail to change position (FC)

3.5.1 Excel calculations

Results of calculations for all data cases revealed increasing trend of failure rate. According to the results exponential model is applicable for “all data merged” and “without 6 years” data sets, and Weibull model is applicable for “without A9-A12 data” case.

Additional calculations performed for Armenian NPP data show only that Weibull failure rate model is applicable (increasing trend was assumed).

Based on the results it was assumed that Weibull failure rate model is acceptable for this case.

3.5.2 WinBUGS calculations

Results of calculations for all merged data are indicating quite good fitness for all models constant (p.value = 0.6337), loglinear (p.value = 0.6325), power (p.value = 0.5882). The results for power trend model were not converged, thus only constant and loglinear models remain in consideration. However the trend loglinear model is increasing with 95% of confidence level. On the other hand p.values of loglinear and constant models are equal. Thus data needs further consideration.

Results of calculations for all merged data without first 6 years are indicating the good fitting of all models and no convergence of power model. For constant model p.value = 0.54, loglinear model p.value = 0.53. Still loglinear trend model is decreasing with 90% confidence level.

Results of calculations for all merged data without A9-A12 data shows average fitness of both models: constant (p.value = 0.35) and loglinear (p.value = 0.38). Loglinear trend model shows increasing trend with 90% confidence level.

Results of calculations for only A9-A12 data shows good fitness of constant model (p.value = 0.45), average fitness for loglinear (p.value = 0.355). Loglinear trend model parameter "b" mean value is near "0". The power trend model was not fully converged, thus we would not conclude based on that model and would consider A9-A12 data to be constant.

Result of Armenian NPP data analysis shows average fitness of loglinear model (p.value = 0.29) which is better than constant model (p.value = 0.2) fitness. Confidence level for increasing trend of loglinear trend model is 97.5%.

Based on all those calculations it was preliminary concluded existence of an increasing trend for Armenian NPP data. However for final conclusions more calculations and assessments are necessary.

3.5.3 Calculation comparison

Both calculations done by Excel and WinBUGs show that increasing failure trend is observed for 6kV breakers for Armenian NPP. Graphical comparison of calculations is shown in Appendix 2.

However to be able to assign a specific failure rate trend model (exponential, loglinear or Weibull) to breaker case it is necessary first to draw out main approach for data analysis. It is necessary to select whether generic data should be used by merging method, or generic data should be used as prior information.

4. CONCLUSIONS

Presented case study demonstrated real example of data analysis for selected equipment taking into account data from similar VVER-440 units.

Performed analysis brings to the following conclusions:

- Guideline (EUR 23954 EN) can be used for processing data, however it requires some additional information. The following points of EUR 23954 EN guideline should be detailed:
 - criteria for acceptable p-values,
 - information/ decision making procedure for poor fitting cases,
 - criteria for acceptable ϵ value in Excel calculation.
- Use of Excel sheets is efficient in cases when wide statistics is available;
- Use of WinBUGS code is preferable in cases when amount of data is insufficient;
- Results obtained from Excel calculations are more conservative than the ones obtained with WinBUGS;
- The general approach for data analysis (trend analysis) should be specified in advance. It has to be clearly stated which one from the following approaches will be used for dealing with generic information:
 - generic data merged with plant specific data,
 - generic data used as a prior for plant specific data analysis.
- The issues related to selection of trend model in case when merged data were used and the same behaviour of data was identified (e.g. increasing trend) but different results (trend models) were observed for plant-specific and generic data, should be specified in the guideline (EUR 23954 EN). For example, plant-specific data shows that the best fitted model is Weibull model, whereas generic data (merged with specific data) were described by exponential model.
- For trend analysis detailed information on observed failures is required.

Appendix 1: Integrated data set

1) Main Feedwater Pump (fail to start)

Year	M2 ³	d/ex	A1	d/ex ⁴	A2	d/ex	A3	d/ex	A4	d/ex	A5	d/ex	A6	d/ex	A7	d/ex	A8	d/ex	A9	d/ex	A10	d/ex	A11	d/ex	A12	d/ex
1980	5																									
1981																										
1982																										
1983																										
1984																										
1985																							1	10	0	10
1986																							0	10	0	10
1987																							0	10	0	10
1988																							1	10	0	10
1989											0	5	0	5	0	5	0	5					1	10	0	10
1990											1	5	0	5	0	5	0	5					1	10	0	10
1991											0	5	0	5	1	5	0	5					0	10	0	10
1992											0	5	0	5	0	5	2	5					1	10	1	10
1993											0	5	0	5	0	5	0	5					1	10	0	10
1994											0	5	0	5	0	5	0	5					1	10	1	10
1995			0	5	1	5	1	5	0	5	0	5	0	5	0	5	0	5					0	10	2	10
1996	0	10	0	5	0	5	0	5	1	5	0	5	0	5	0	5	0	5					0	10	0	10
1997	0	10	0	5	0	5	0	5	0	5	0	5	0	5	0	5	0	5					3	10	1	10
1998	0	10	0	5	0	5	0	5	0	5	1	5	0	5	0	5	0	5	0	10			0	10	0	10
1999	1	10	0	5	0	5	0	5	0	5	0	5	0	5	0	5	0	5	0	10			0	10	1	10
2000	0	10	0	5	1	5	0	5	1	5	0	5	0	5	0	5	0	5	0	10	0	10	1	10	1	10
2001	1	10	0	5	0	5	0	5	0	5	0	5	0	5	0	5	0	5	0	10	0	10	2	10	0	10
2002	1	10	0	5	0	5	0	5	0	5	0	5	0	5	0	5	0	5	0	10	1	10	1	10	0	10
2003	0	10	0	5	0	5	0	5	0	5	0	5	0	5	0	5	0	5	1	10	1	10	0	10	0	10
2004	0	10									0	5	0	5	0	5	0	5	0	10	0	10	0	10	1	10
2005	1	10																	0	10	0	10	1	10	0	10
2006	1	10																							1	10
2007	0	10																								

³ M - Armenian (Medzamor) NPP

⁴ d/ex –means demands or exposure time (hours).

⁵ red marked areas indicate commissioning date (it is assumed that commissioning date of equipment is the same with plant)

2) Main Feedwater Pump (fail to run)

Year	M 2	d/ex	A 1	d/ex	A2	d/ex	A3	d/ex	A 4	d/ex	A 5	d/ex	A 6	d/ex	A 7	d/ex	A 8	d/ex	A 9	d/ex	A 10	d/ex	A 11	d/ex	A 12	d/ex	
1978																											
1979																											
1980																											
1981																											
1982																											
1983																											
1984																											
1985																											
1986																											
1987																											
1988																											
1989											0	30358	0	30358	0	30358	0	30358									
1990											0	30358	0	30358	1	30358	0	30358									
1991											0	30358	0	30358	1	30358	0	30358									
1992											0	30358	0	30358	0	30358	1	30358									
1993											0	30358	0	30358	0	30358	0	30358									
1994											0	30358	0	30358	0	30358	0	30358									
1995			1	30437	1	30437	0	30437	1	30437	1	30358	0	30358	1	30358	0	30358									
1996	1	28800	0	30437	0	30437	0	30437	0	30437	0	30358	0	30358	0	30358	1	30358									
1997	1	28800	0	30437	0	30437	0	30437	1	30437	0	30358	0	30358	0	30358	0	30358									
1998	1	28800	1	30437	1	30437	0	30437	0	30437	1	30358	0	30358	0	30358	0	30358	2	33440							
1999	1	28800	0	30437	0	30437	1	30437	0	30437	1	30358	0	30358	0	30358	0	30358	1	33440							
2000	0	28800	0	30437	0	30437	1	30437	0	30437	0	30358	0	30358	0	30358	0	30358	1	33440	0	32825	0	28435	0	29240	
2001	0	28800	0	30437	1	30437	1	30437	0	30437	0	30358	0	30358	0	30358	0	30358	1	33440	2	32825	0	28435	0	29240	
2002	3	28800	0	30437	0	30437	0	30437	0	30437	0	30358	0	30358	0	30358	0	30358	2	33440	2	32825	0	28435	0	29240	
2003	0	28800	0	30437	0	30437	0	30437	1	30437	0	30358	0	30358	0	30358	0	30358	1	33440	1	32825	1	28435	1	29240	
2004	1	28800									0	30358	0	30358	0	30358	0	30358	0	33440	0	32825	0	28435	1	29240	
2005	1	28800																	0	33440	0	32825	0	28435	0	29240	
2006	0	28800																									

3) Diesel Generator (fail to start)

Year	M	d/ex	A	d/ex	A2	d/ex	A3	d/ex	A	d/ex	A	d/ex	A	d/ex	A	d/ex	A	d/ex	A	d/ex	A10	d/ex	A11	d/ex	A12	d/ex		
	2		1						4		5		6		7		8		9									
1978																												
1979																												
1980																												
1981																												
1982																												
1983																												
1984																												
1985																												
1986																												
1987																												
1988																												
1989																												
1990																												
1991																												
1992																												
1993																												
1994																												
1995																												
1996	0	96	2	36	2	36	0	36	0	36	1	22	2	22	1	22	0	22										
1997	1	96	2	36	0	36	0	36	0	36	2	22	1	22	0	22	2	22										
1998	1	96	0	36	0	36	0	36	0	36	1	22	0	22	1	22	1	22	0	36								
1999	2	96	1	36	0	36	0	36	0	36	1	22	1	22	1	22	2	22	0	36								
2000	2	96	0	36	1	36	1	36	1	36	0	22	1	22	1	22	0	22	0	36	0	36	0	36	0	36	0	36
2001	3	96	1	36	0	36	0	36	0	36	2	22	0	22	0	22	0	22	0	36	1	36	0	36	0	36	0	36
2002	2	96	0	36	0	36	0	36	1	36	1	22	1	22	0	22	2	22	0	36	0	36	0	36	0	36	0	36
2003	3	96	0	36	0	36	0	36	0	36	0	22	0	22	1	22	2	22	0	36	0	36	0	36	0	36	0	36
2004	1	96																										
2005	0	96																										
2006	1	96																										

4) Diesel Generator (fail to run)

Year	M2	d/ex	A 1	d/ex	A2	d/ex	A3	d/ex	A 4	d/ex	A 5	d/ex	A 6	d/ex	A 7	d/ex	A 8	d/ex	A 9	d/ex	A10	d/ex	A11	d/ex	A 12	d/ex
1978																										
1979																										
1980																										
1981																										
1982																										
1983																										
1984																										
1985																										
1986																										
1987																										
1988																										
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1996																										
1997																										
1998																										
1999																										
2000																										
2001																										
2002																										
2003																										
2004																										
2005																										
2006																										

5) Breakers (fail to change position)

Year	M2	d/ex.	A1	d/ex.	A2	d/ex.	A3	d/ex.	A4	d/ex.	A11	d/ex.	A12	d/ex.
1978														
1979														
1980														
1981														
1982														
1983														
1984														
1985											0	131400	0	131400
1986											0	131400	0	131400
1987											0	131400	0	131400
1988											1	131400	0	131400
1989											0	131400	0	131400
1990											1	131400	0	131400
1991											0	131400	0	131400
1992											1	131400	0	131400
1993											0	131400	0	131400
1994											1	131400	1	131400
1995											0	131400	0	131400
1996	1	919800									0	131400	0	131400
1997	1	919800									0	131400	1	131400
1998	1	919800									0	131400	1	131400
1999	2	919800	4	941700	3	941700	3	941700	0	941700	0	131400	0	131400
2000	0	919800	1	941700	7	941700	3	941700	0	941700	0	131400	0	131400
2001	6	919800	2	941700	6	941700	3	941700	1	941700	1	131400	0	131400
2002	4	919800	3	941700	5	941700	4	941700	3	941700	0	131400	0	131400
2003	5	919800	3	941700	5	941700	5	941700	1	941700	2	131400	0	131400
2004	1	919800									0	131400	0	131400
2005	3	919800									0	131400	0	131400
2006	4	919800									0	131400	0	131400
2007	4	919800												

Appendix 2: Comparison graphs

Main feedwater pump failures to start (FS)

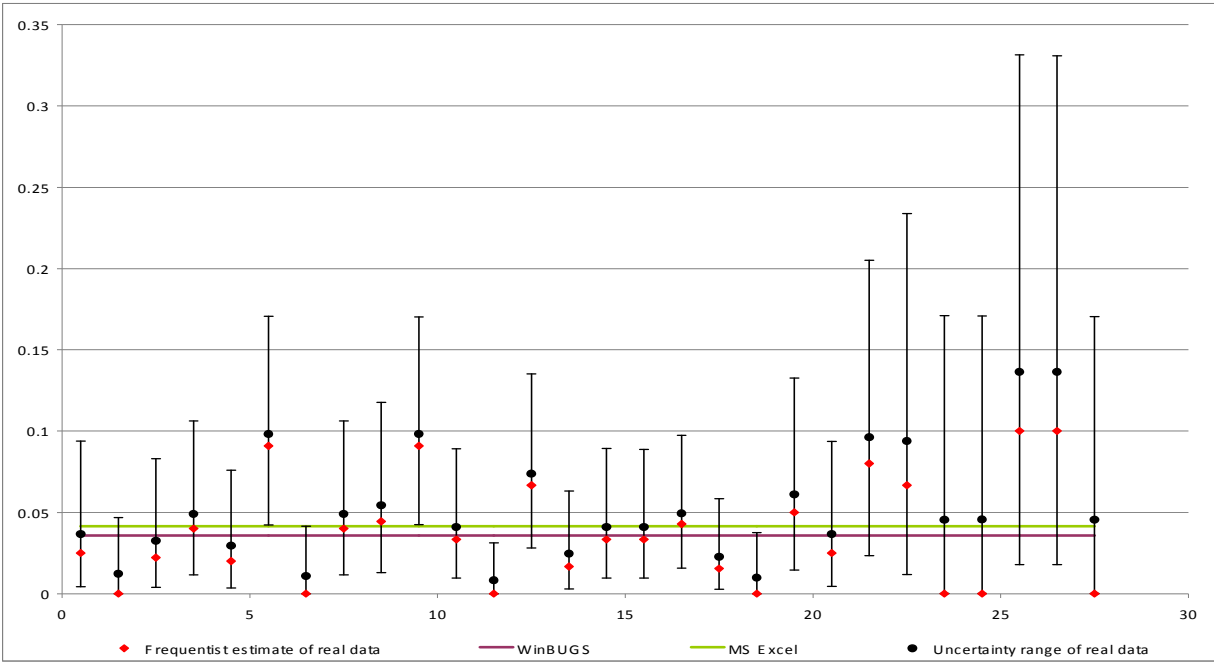


Figure 1 Results for all data merged (MFP FS)

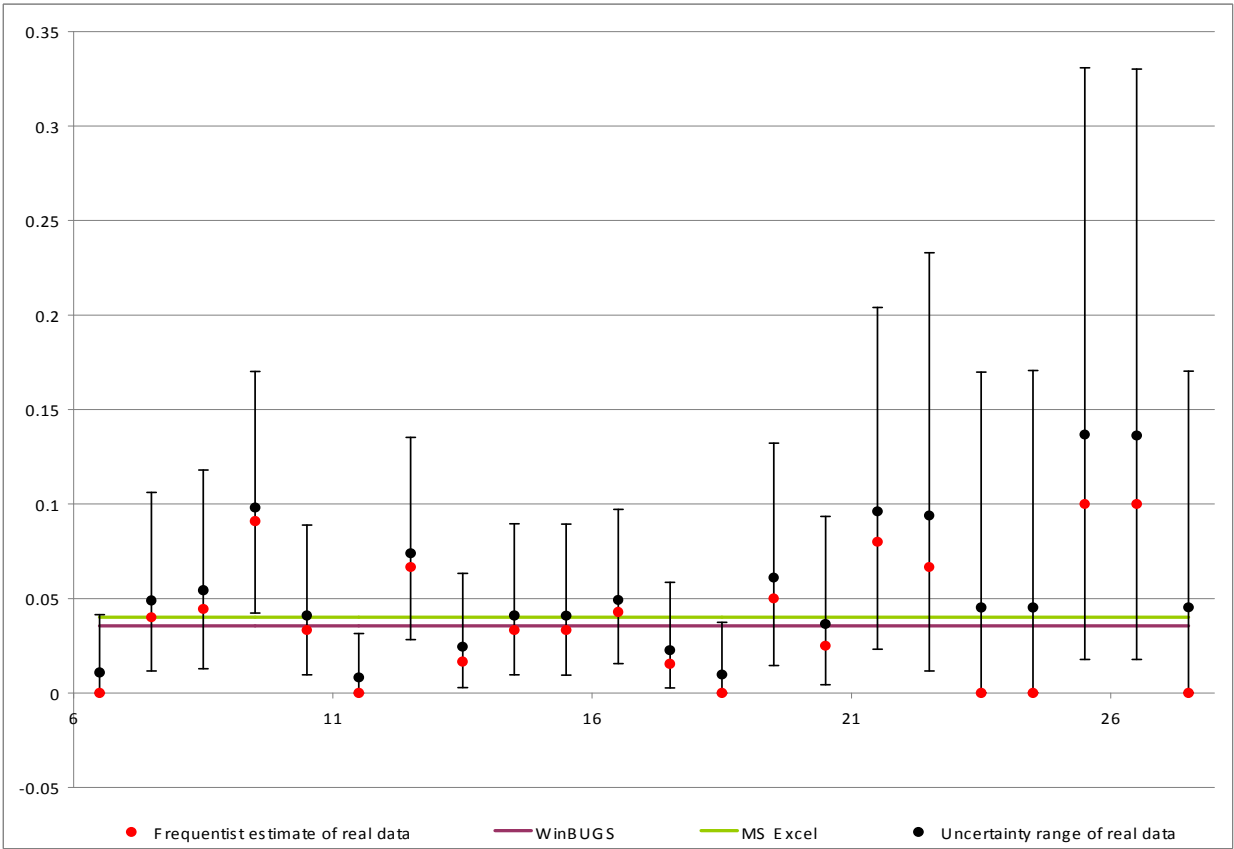


Figure 2 Results for all data merged without first 6 years (MFP FS)

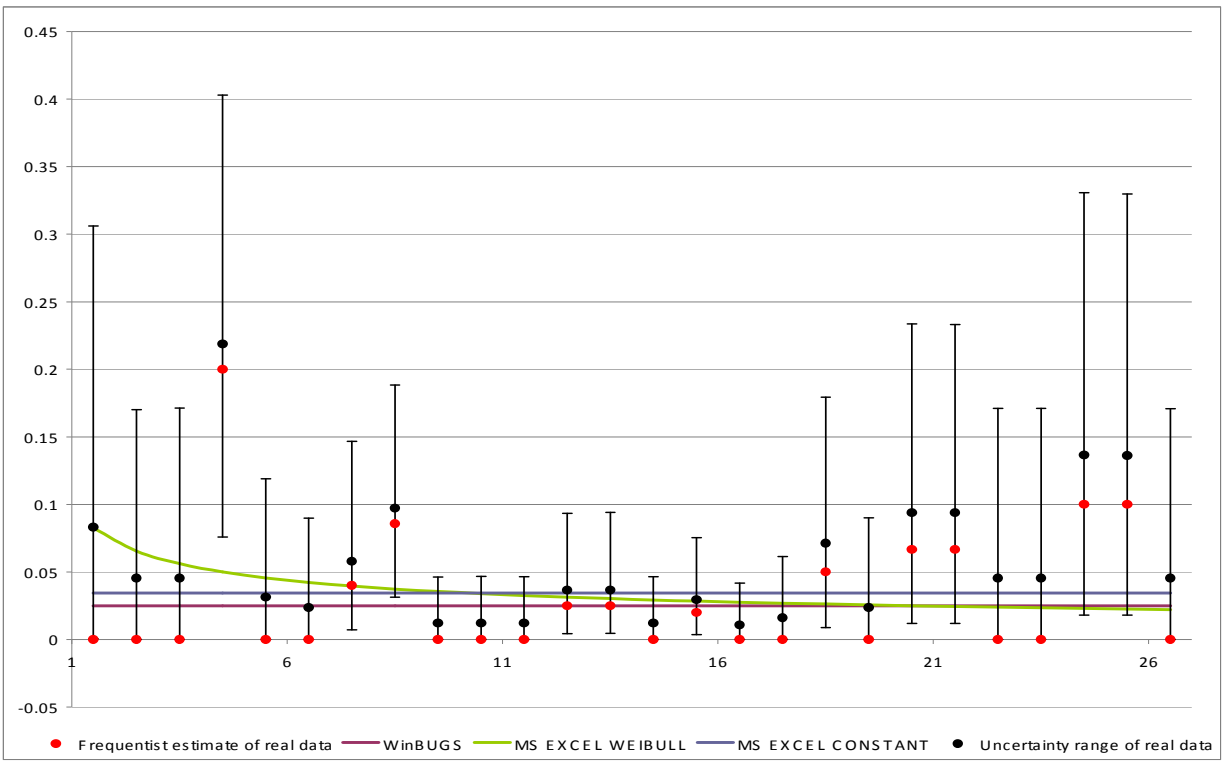


Figure 3 Results for all data merged without A9-A12 data (MFP FS)

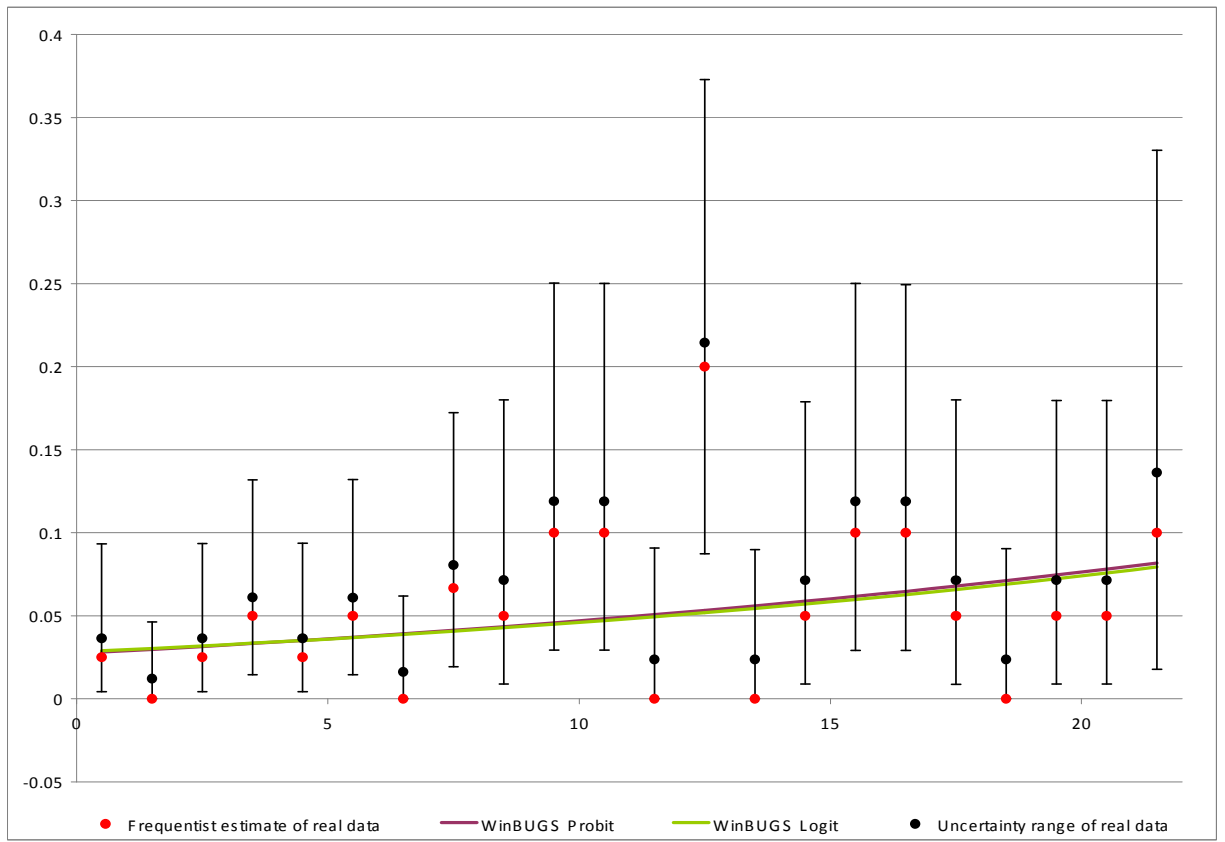


Figure 4 Results for only A9-A12 plant data merged (MFP FS)

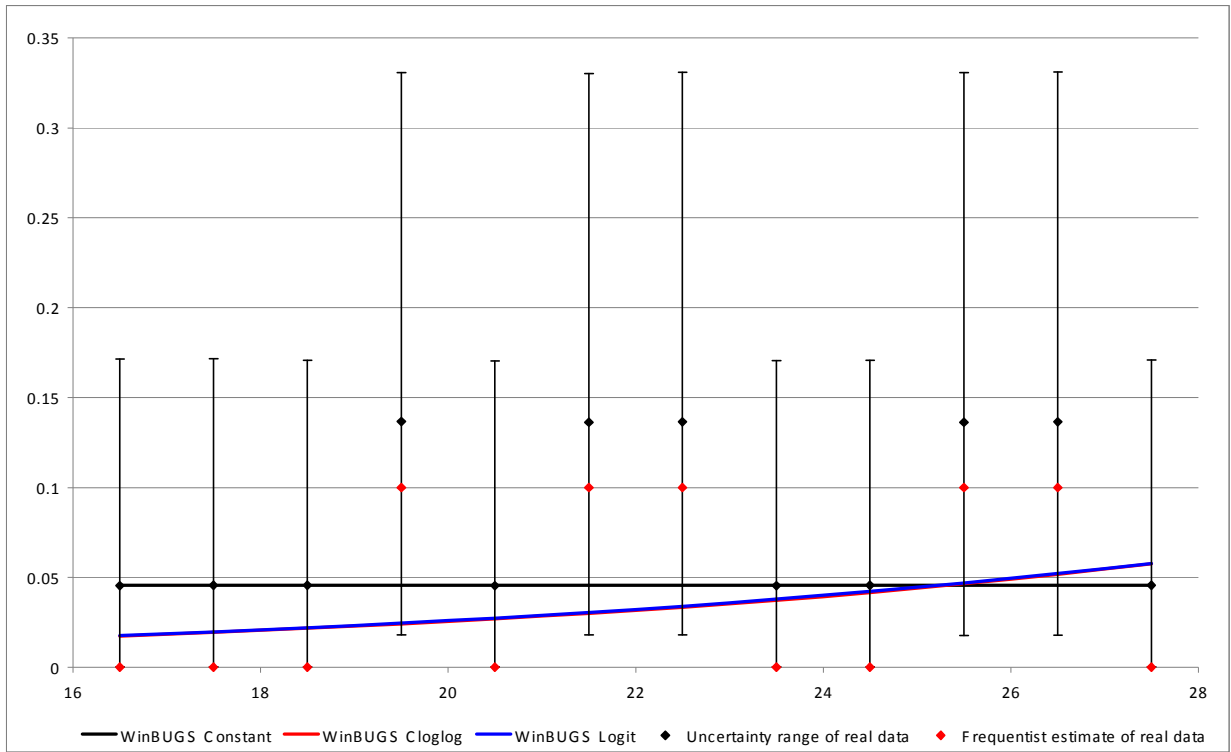


Figure 5 Results for only Armenian NPP data merged (MFP FS)

Main feedwater pump failures to run (FR)

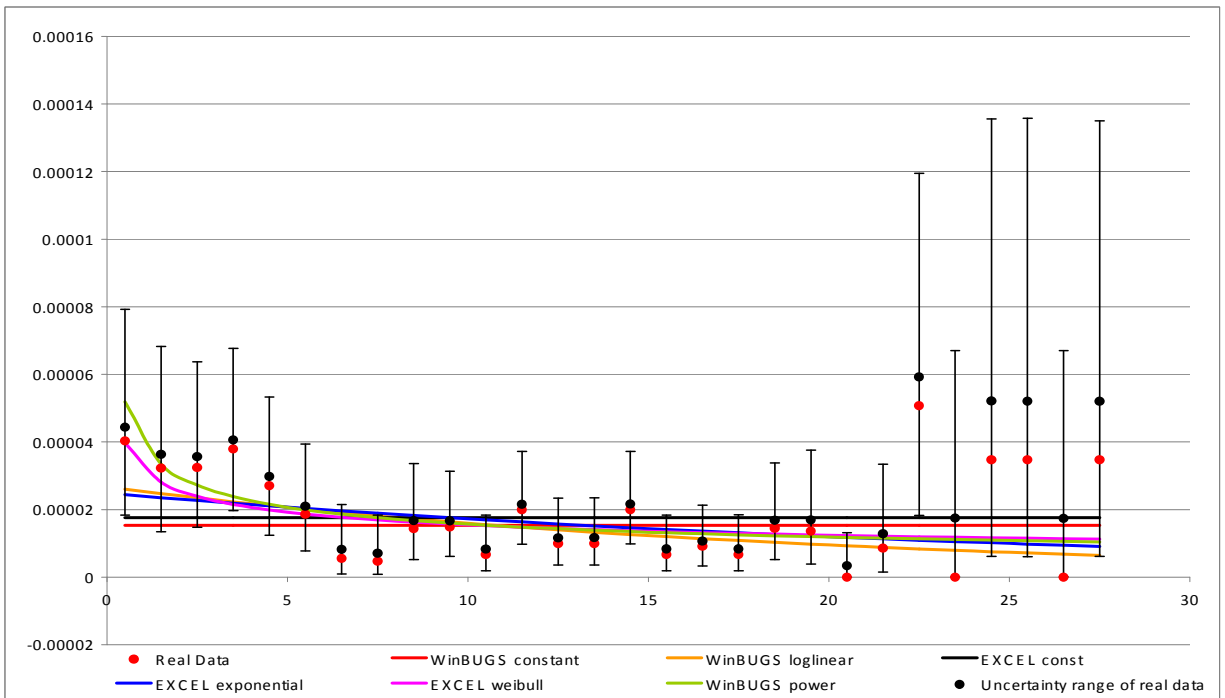


Figure 6 Results for all data merged (MFP FR)

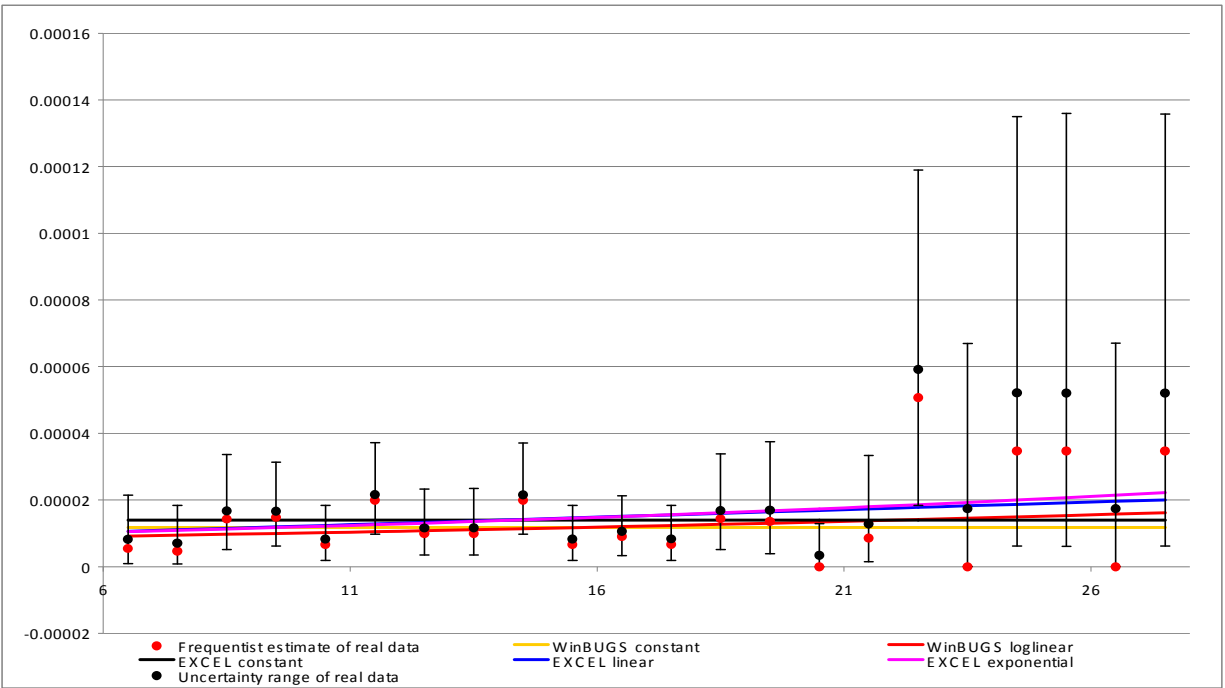


Figure 7 Results for all data merged without first 6 years (MFP FR)

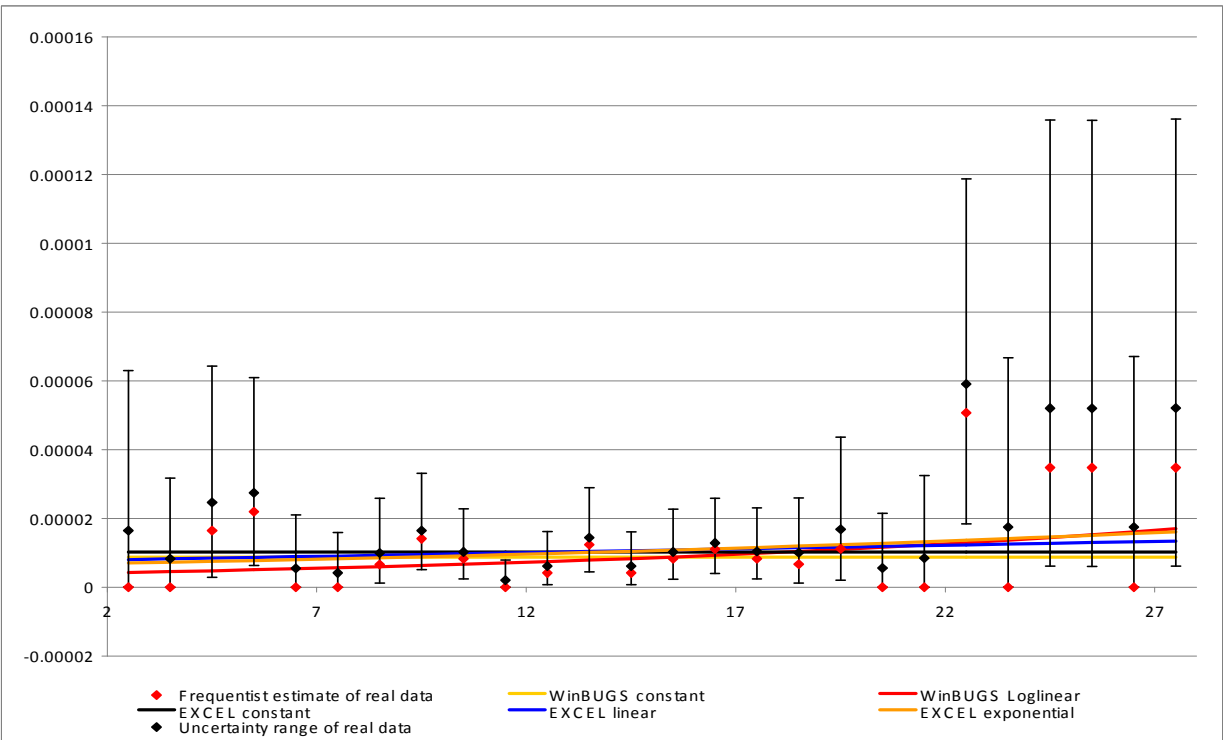


Figure 8 Results for all data merged without A9-A12 data (MFP FR)

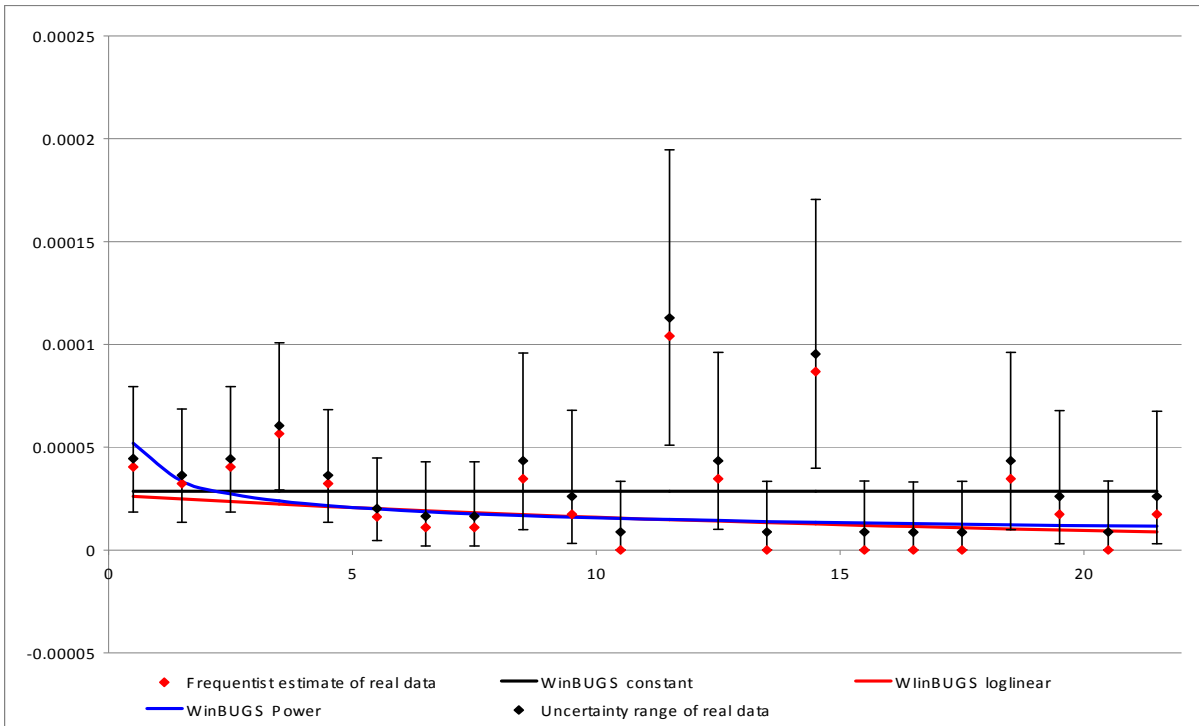


Figure 9 Results for only A9-A12 data merged (MFP FR)

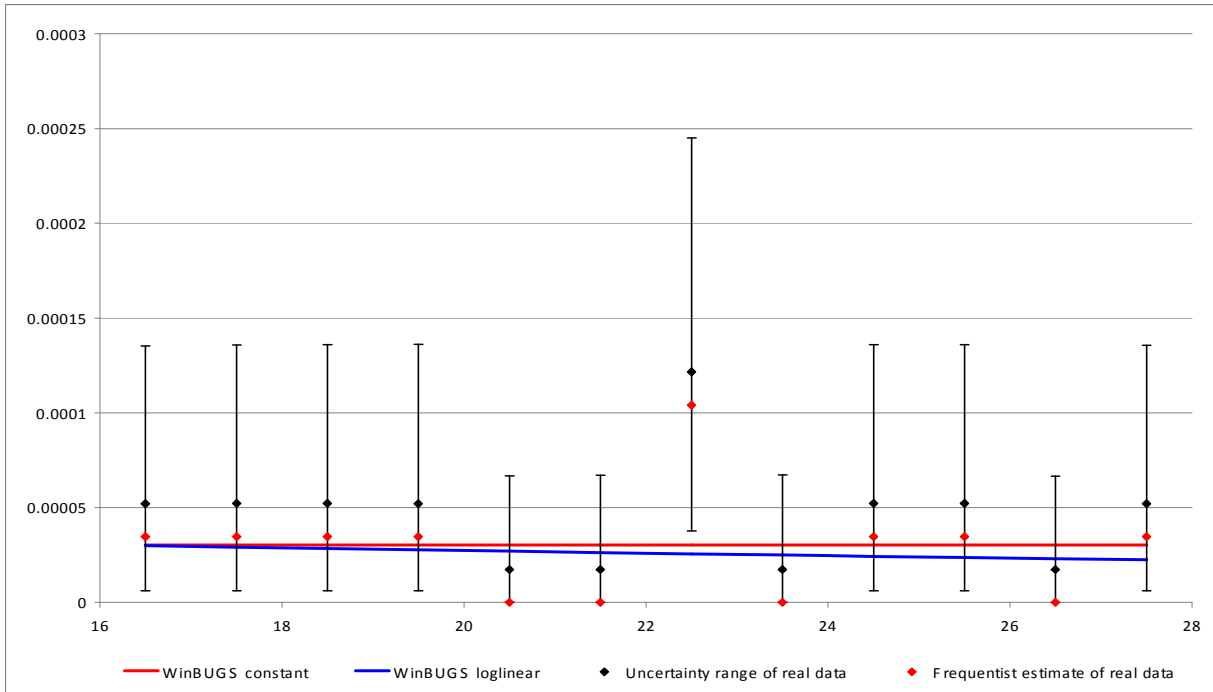


Figure 10 Results for only Armenian NPP data merged (MFP FR)

Diesel generator failures to start (FS)

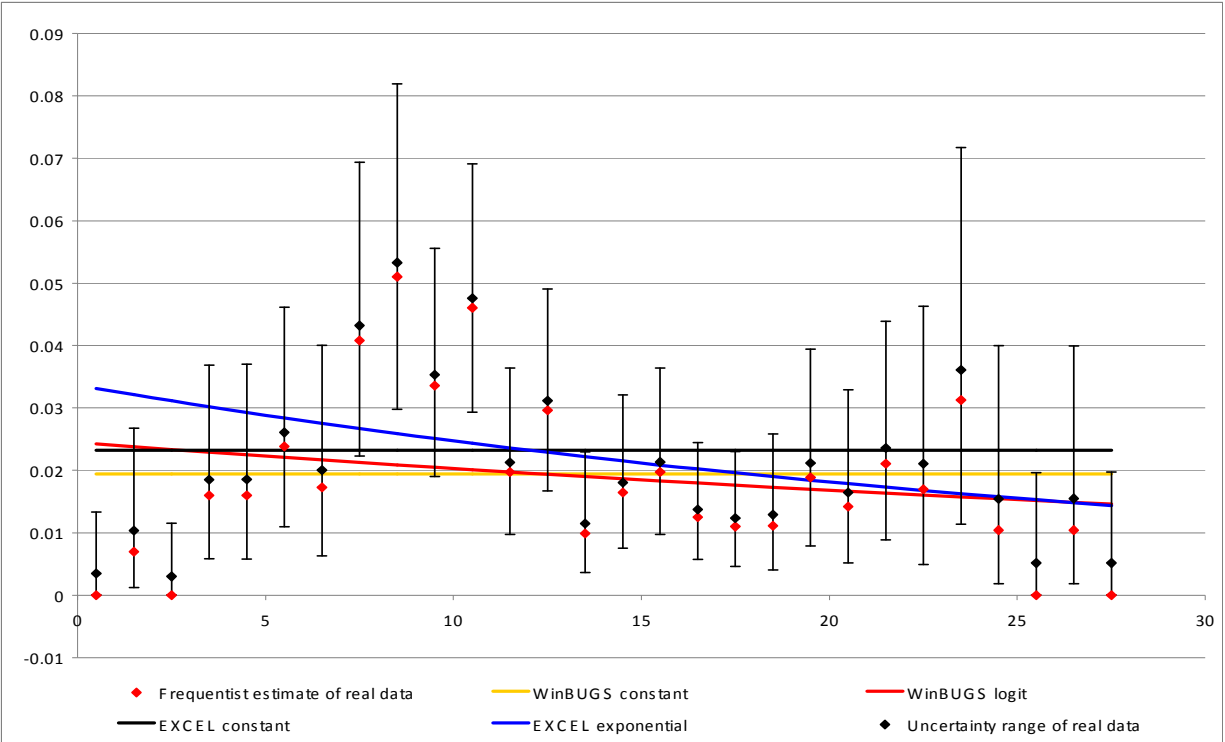


Figure 11 Results for all data merged (DG FS)

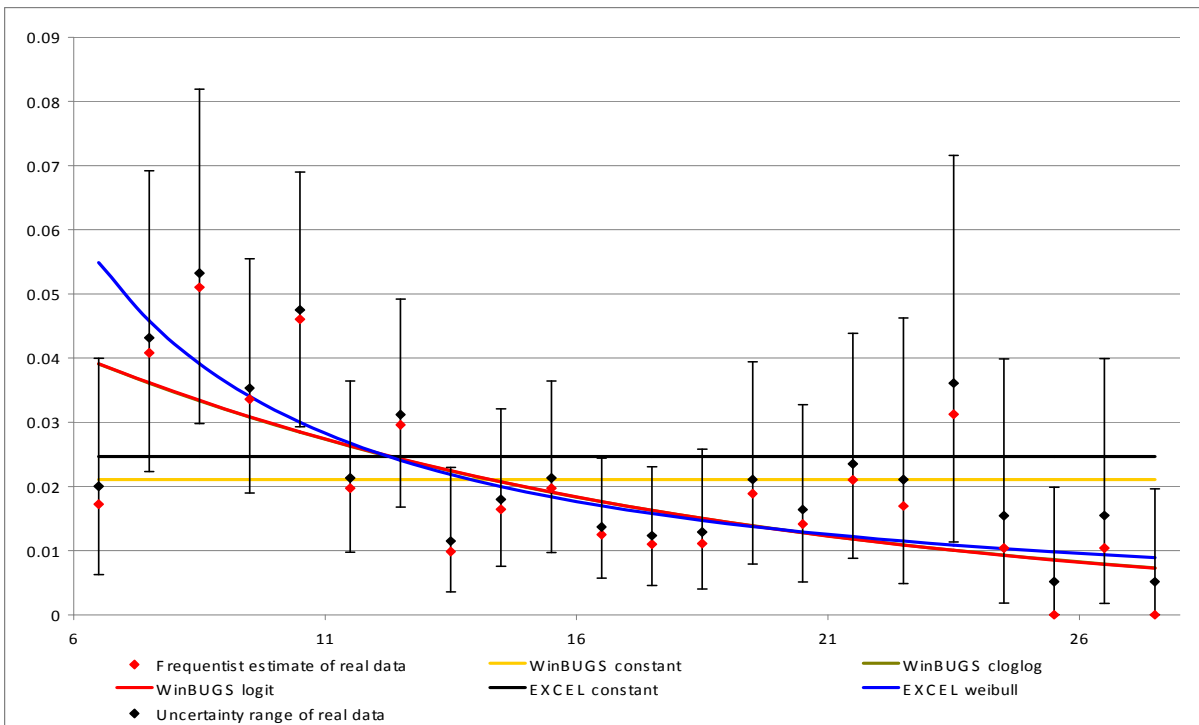


Figure 12 Results for all data merged without first 6 years (DG FS)

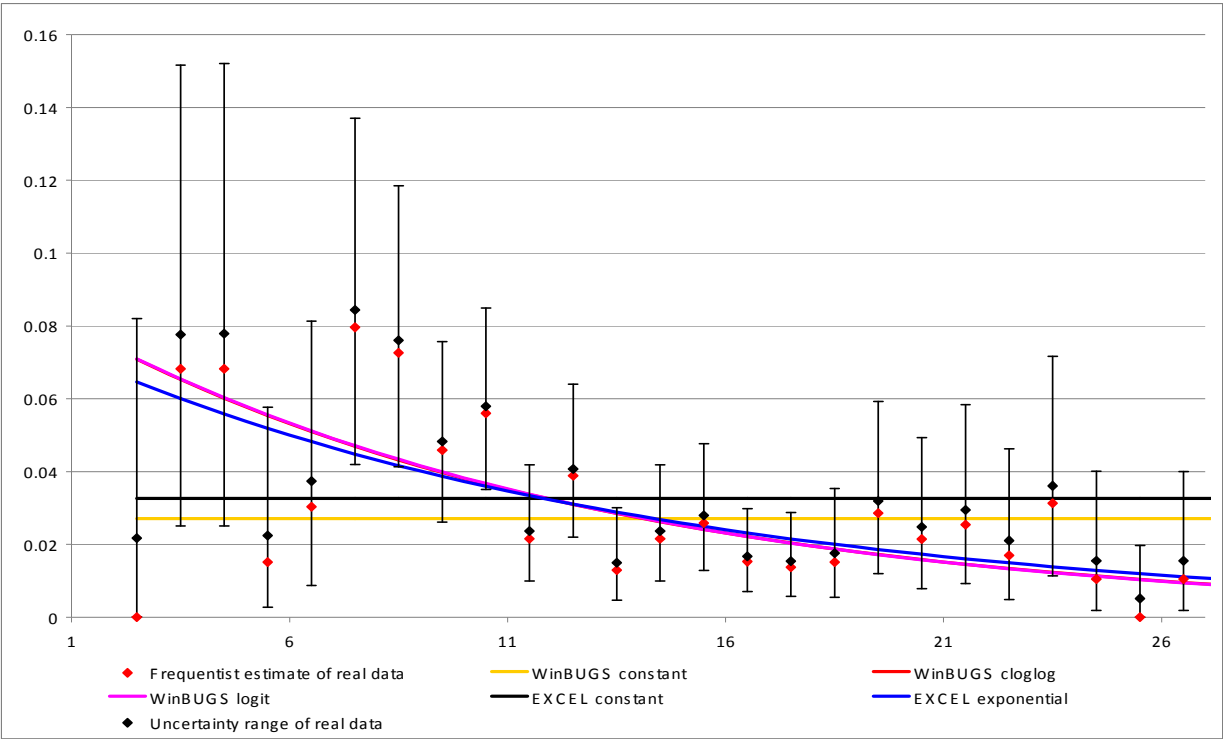


Figure 13 Results for all data merged without A9-A12 data (DG FS)

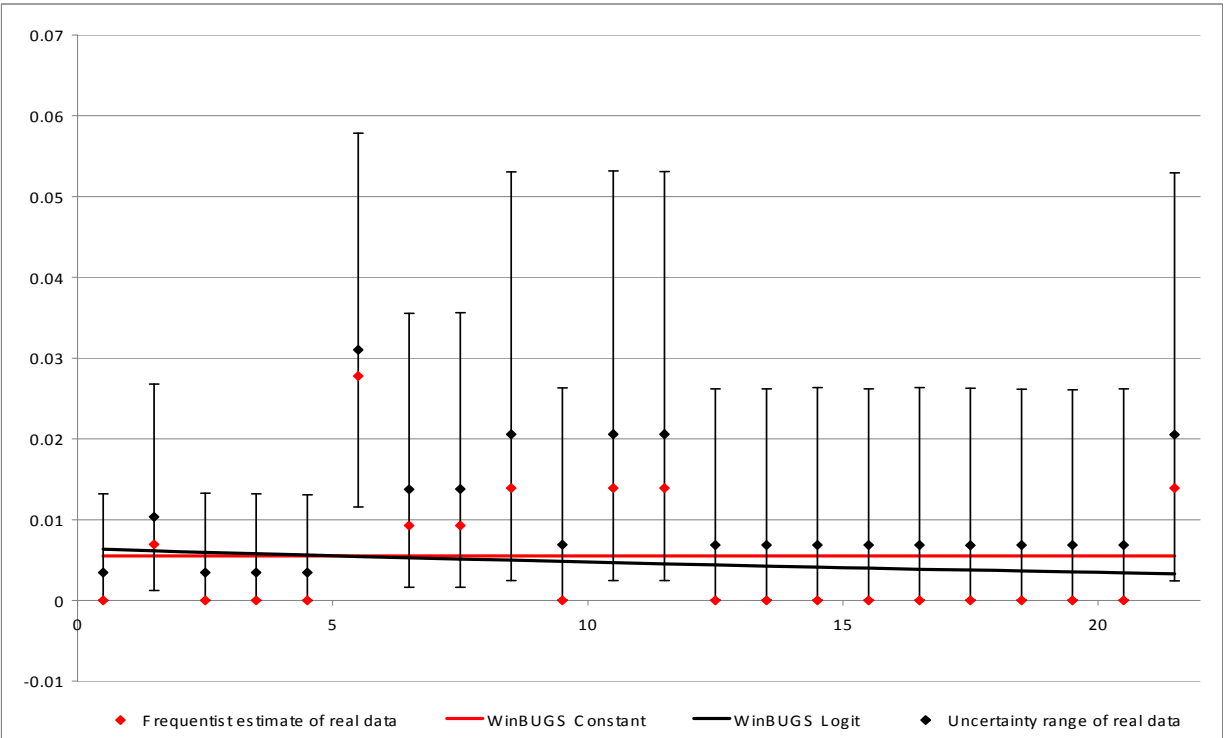


Figure 14 Results for only A9-A12 data merged (DG FS)

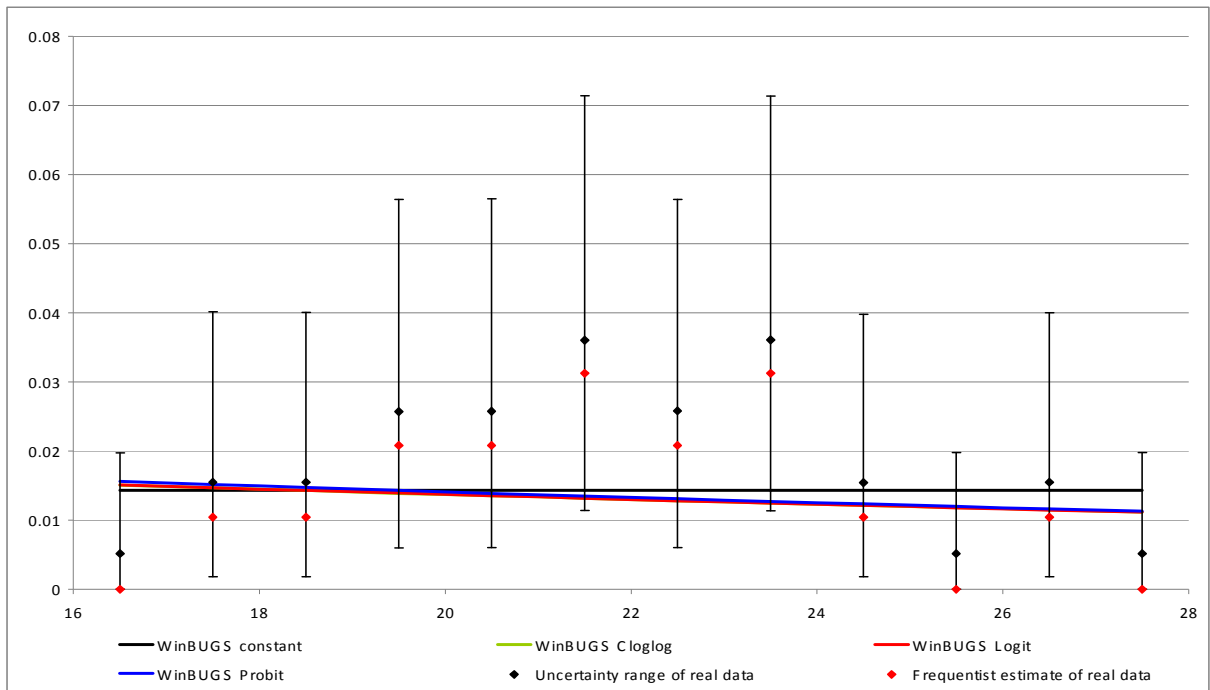


Figure 15 Results for only Armenian NPP data merged (DG FS)

Diesel generator failures to run (FR)

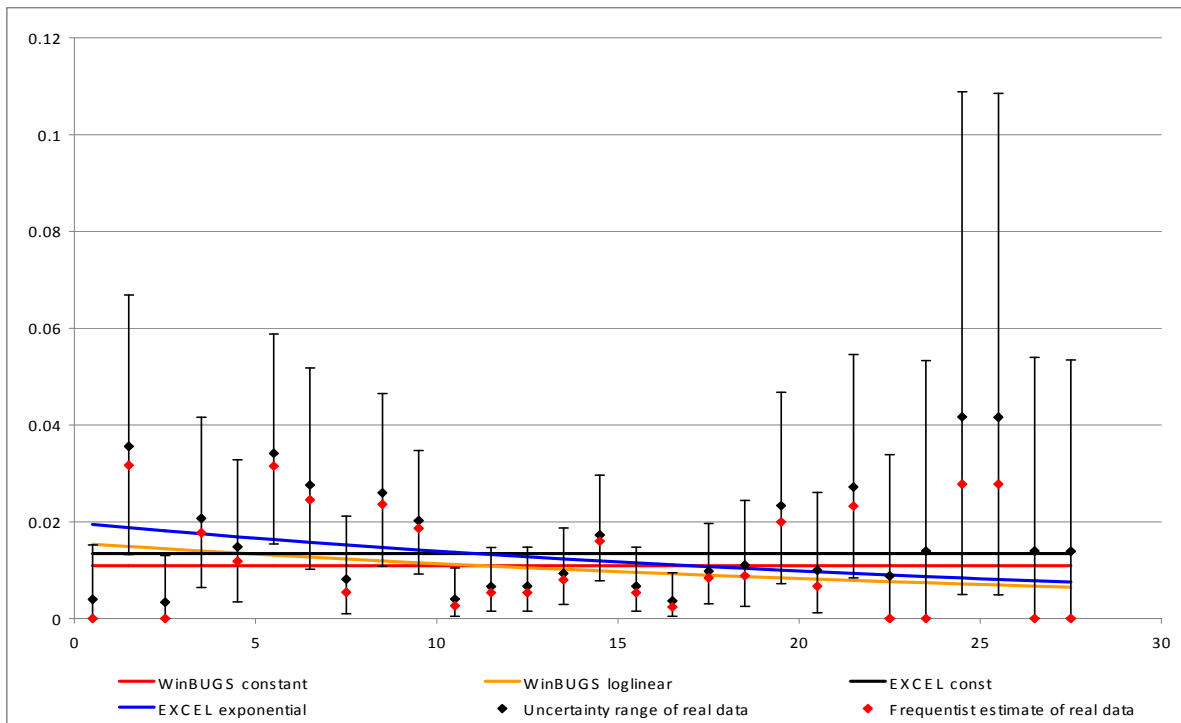


Figure 16 Results for all data merged (DG FR)

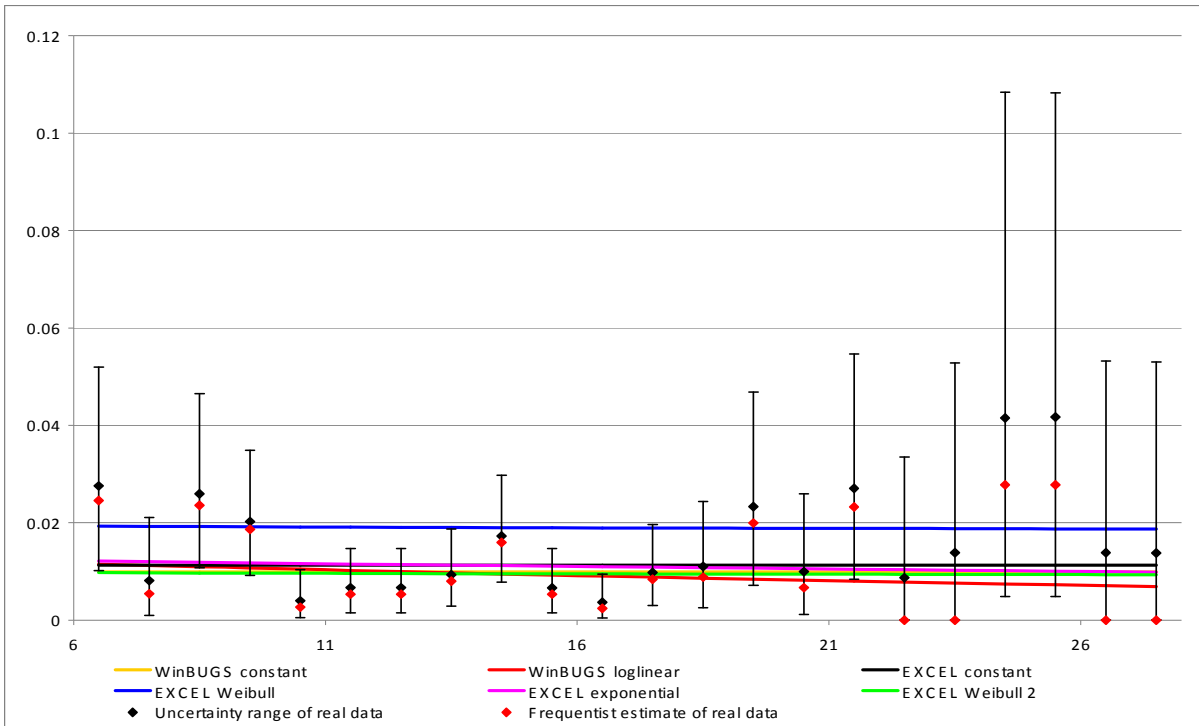


Figure 17 Results for all data merged without first 6 years (DG FR)

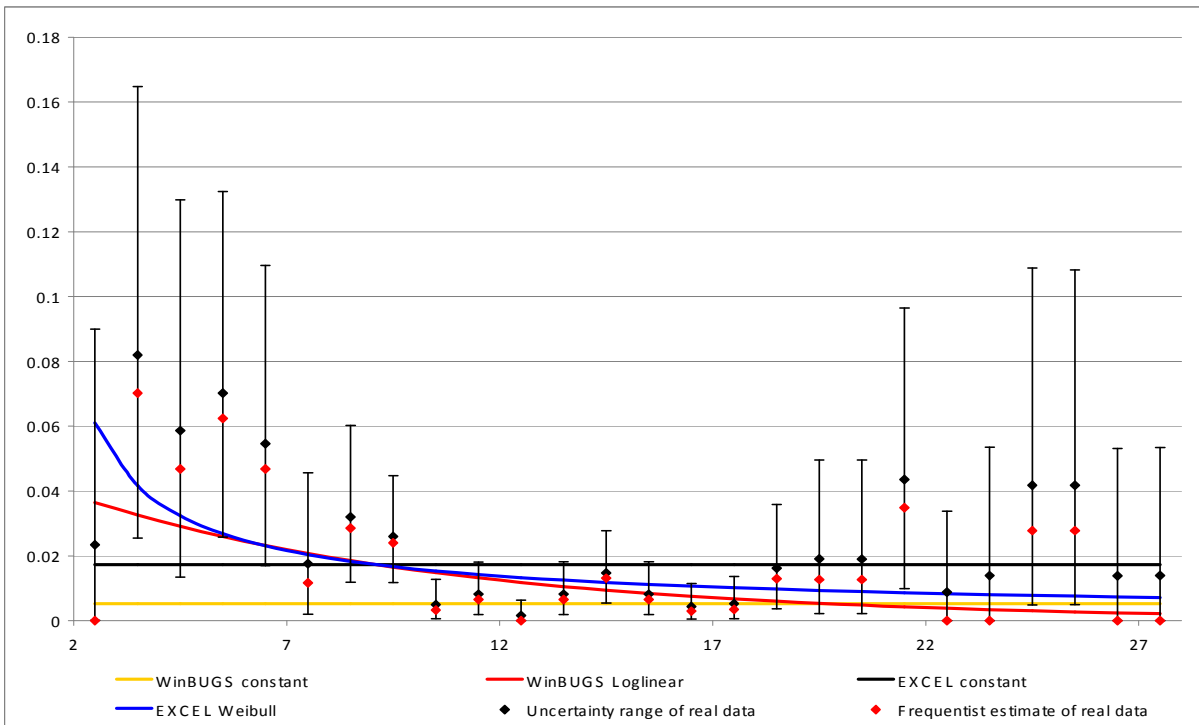


Figure 18 Results for all data merged without A9-A12 data (DG FR)

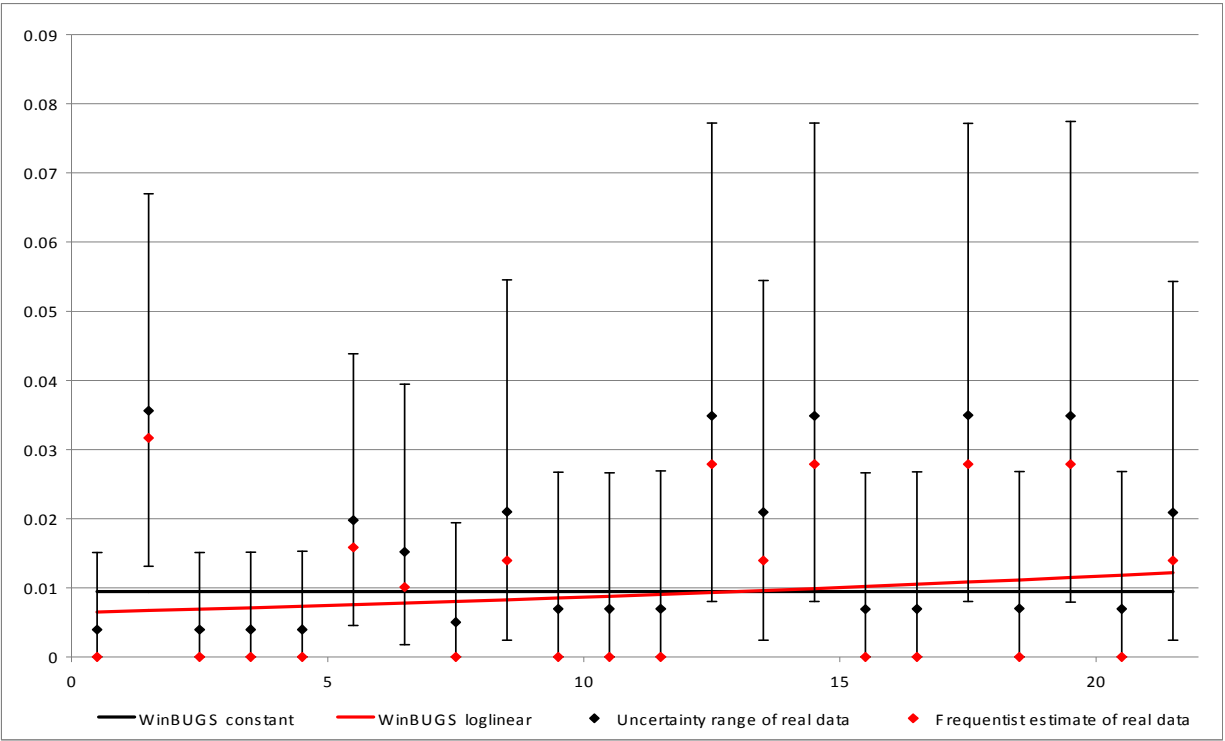


Figure 19 Results for only A9-A12 data merged (DG FR)

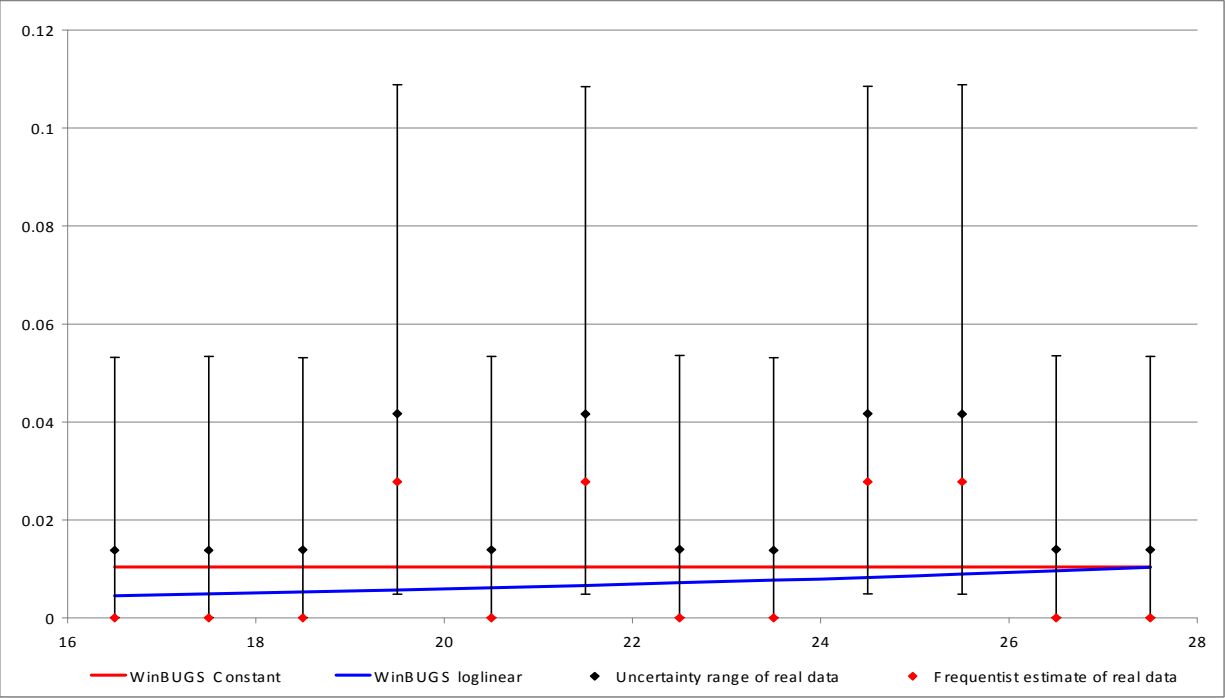


Figure 20 Results for only Armenian NPP data merged (DG FR)

6kV breakers failures to change position (FC)

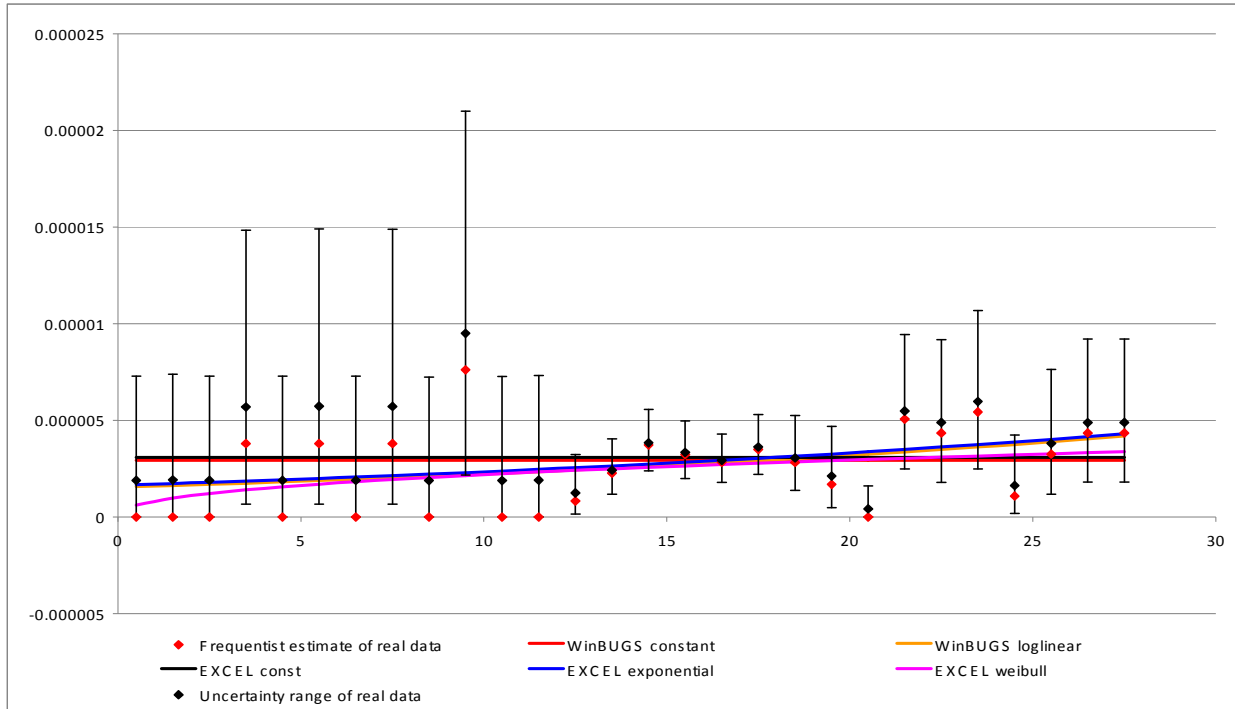


Figure 21 Results for all data merged (6kV FC)

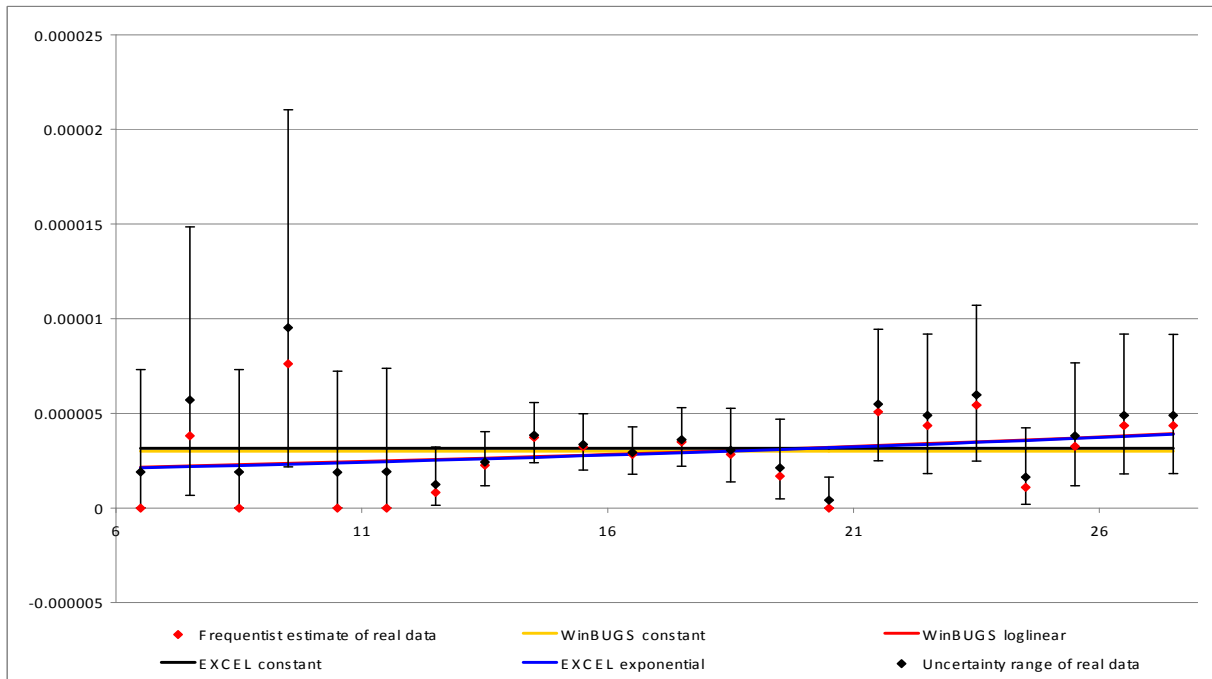


Figure 22 Results for all data merged without first 6 years (6kV FC)

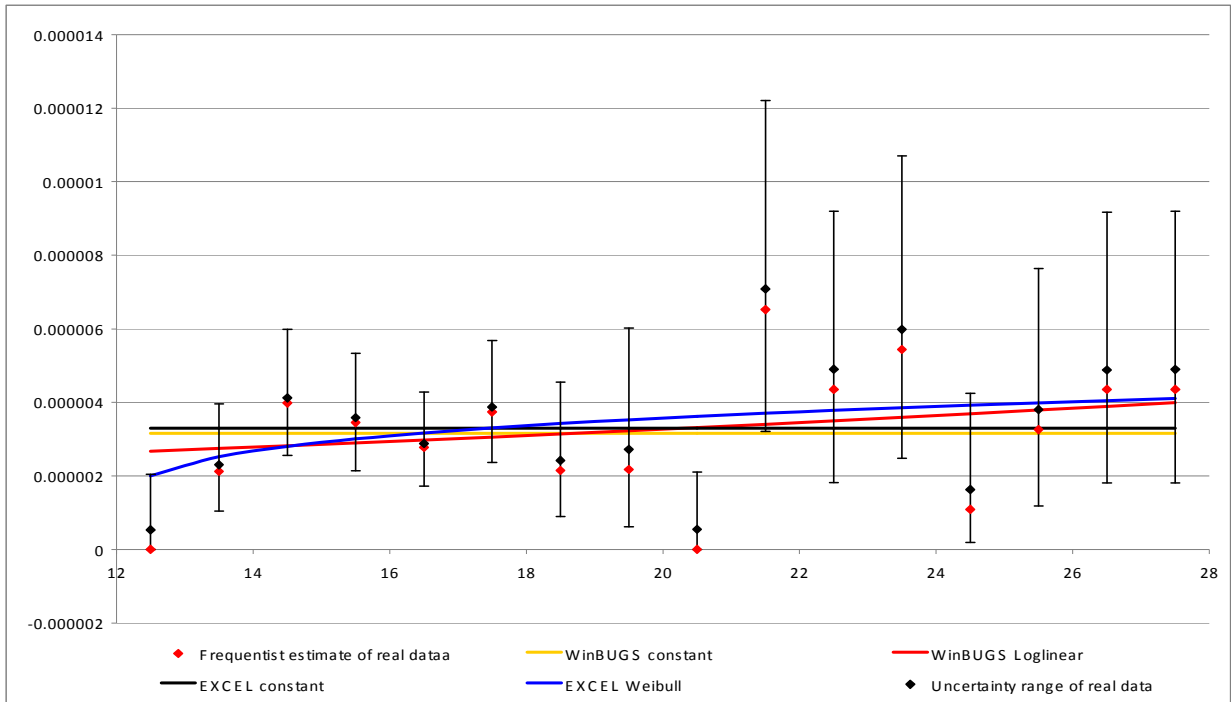


Figure 23 Results for all data merged without A9-A12 data (6kV FC)

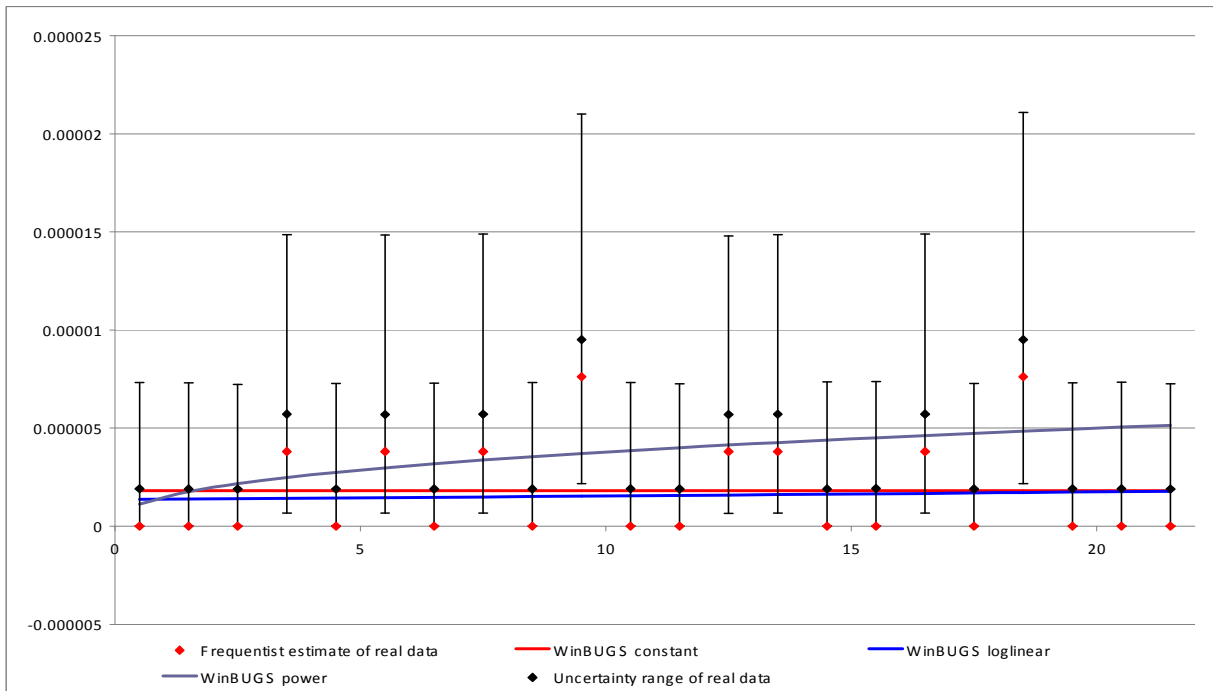


Figure 24 Results for only A9-A12 data merged (6kV FC)

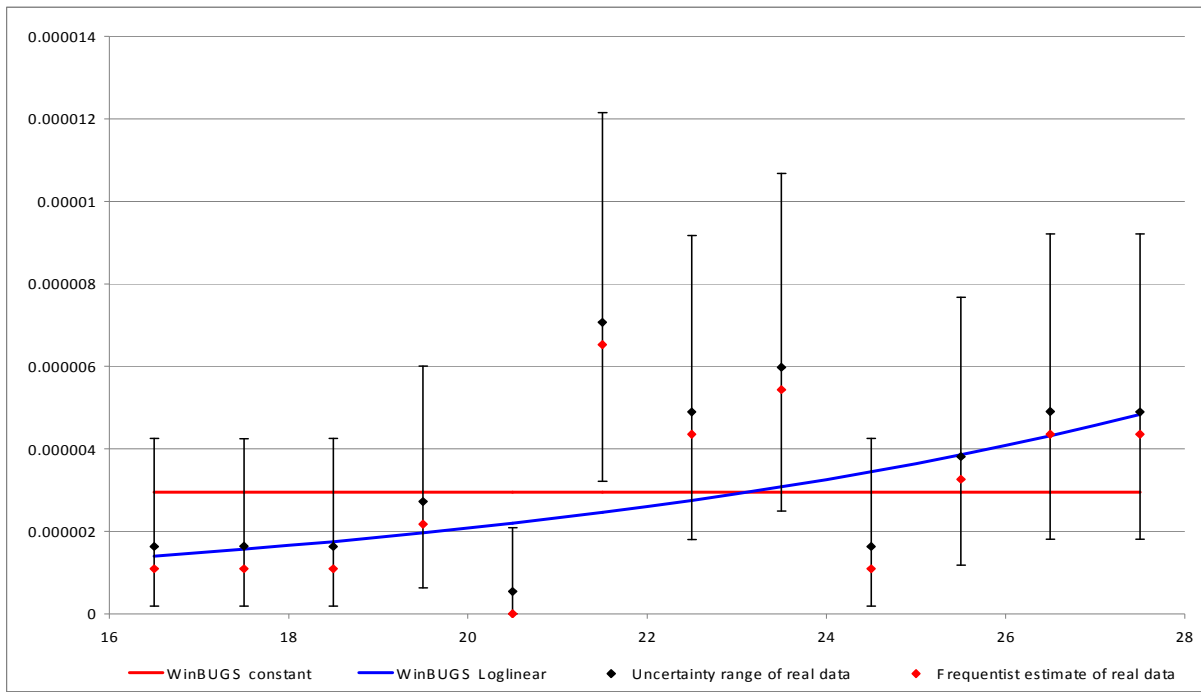


Figure 25 Results for only Armenian NPP data merged (6kV FC)

Appendix 3: Summary results

#	Components /FM	Data set	Software	Model	P (abs)	Δp (%)	θ_1	θ_2	Comments		
1.	MFW / FS	All data	Excell	Constant	0.79	21%	0.041	-	-		
			WINBUGS	Constant	0.44	10.7%	0.0357	-	-		
		First 6 years excluded	Excell	Constant	0,88	12%	0.040	-	-		
			WINBUGS	Constant	0.49	1.9%	0.03565	-	-		
		A9-A12 data excluded	Excell	Weibull	0,31	69%	0,084	-0,406	-		
			WINBUGS	Constant	0.01	80.1%	0.02494	-	-		
2.	MFW / FR	All data	Excell	Linear	0.03	-	-	-	-		
			WINBUGS	Loglinear	0.12	74.9%	-10.53	0.0517	Poor fitting		
		First 6 years excluded	Excell	Exponential	0,56	45%	8,41E-06	0,035	Liner model is fitting with $\epsilon=0.01$, however extremely low θ_2 value (4,50E-07) and p-value lower than for exponential model were observed		
			WINBUGS	Loglinear	0.47	5.6%	-11.77	0.0269	Increasing trend with confidential level between 75% and 90%		
		A9-A12 data excluded	Excell	Constant	0.80	20%	1,01E-05	-	-		
			WINBUGS	Loglinear	0.36	27.1%	-12.5	0.0553	Increasing trend with confidential level between 90% and 95%		
		3.	DG / FS	All data	Excell	Exponential	0.10	-	-	-	-
					WINBUGS	Probit	0.03	94.6%	-1.961	-0.008	Decreasing trend with confidential level of 90%
First 6 years excluded	Excell			Weibull	0.92	8%	0,579	-1,259	-		
	WINBUGS			Comp.log-log	0.41	18.0%	-3.142	0.0081	Decreasing trend with confidential level of 97.5%		
A9-A12 data excluded	Excell			Exponential	0.60	40%	0,077	-0,073	-		
	WINBUGS			Logit	0.44	11.3%	-2.486	-0.0868	Decreasing trend with confidential level of 97.5%		

4.	DG / FR	All data	Excell	Exponential	0.27	-	-	-	Decreasing trend with confidential level between 90% and 95%
			WINBUGS	Loglinear	0.10	79.2%	-4.161	0.0318	
		First 6 years excluded	Excell	Constant	0.29	-	-	-	The p-value for all models are in the range from 0,0015 to 0.29. Poor fitting is assumed
			WINBUGS	Constant	0.21	57.9%	0.009895	-	
		A9-A12 data excluded	Excell	Weibull	0.13	-	-	-	
			WINBUGS	Loglinear	0.03	93.1%	-3.029	0.1128	Decreasing trend with confidential level of 97.5%
5.	Breakers 6kV	All data	Excell	Exponential	0.91	9%	1,64E-06	0,035	-
			WINBUGS	Loglinear	0.63	26.5%	-13.38	0.0362	Increasing trend with confidential level between 95% and 97.5%
		First 6 years excluded	Excell	Exponential	0.84	16%	1,76E-06	0,029	-
			WINBUGS	Loglinear	0.53	5.9%	-13.23	0.0284	Increasing trend with confidential level less than and about 90%
		A9-A12 data excluded	Excell	Weibull	0.85	15%	2,31E-06	0,209	Poor fitting in case of $\epsilon=0.01$. Poor fitting for all models (excluding Weibull) for $\epsilon=0.01 - 0.1$
			WINBUGS	Loglinear	0.37	24.5%	-13.17	0.0269	Increasing trend with confidential level about 85%

European Commission

EUR 24643 EN – Joint Research Centre – Institute for Energy

Title: Analysis of data related to ageing of VVER-440 NPP components

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Abstract

The aim of case study was to demonstrate the applicability of methods for reliability parameters estimation, presented in the guideline (EUR 23954 EN), using the operational data from VVER-440 plants.

Two types of calculations were performed, using Excel functions and WINBUGS scripts, to identify the possible trends of data. The study results are useful in revealing the problematic issues connected with use of data guideline (EUR 23954 EN) and for improvement of decision making process based on calculation results. Practical insights, recommendations and limitations are also discussed.

The report was prepared by the Nuclear & Radiation Safety Center (NRSC), Yerevan, Armenia, in cooperation with the Institute for Energy, EC Joint Research Centre, Petten, Netherlands, in the framework of the EC JRC Ageing PSA Network Task 4 activities.

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