ABSTRACT

The main goal of that project was to carry out a feasibility study of a methodology devoted to evaluate the statistical evidence of plant-specific failure data. Hence it will effect on the capital economical cost for both safety and maintenance processes in an indirectly way. It can modify the PSA model and its results, which are effect on safety and maintenance. Due to this project studies, the NPP components keep running for longer time without stopping, which it can predict the failure rate for different components in nuclear plant and then eliminate it as possible as it can. Hence, that will improve its productivity and will low maintenance costs for each components in NPP as well.

The main problem in our studies is that most of nuclear power plants are completely sure about their own data and utilize it when estimating failure rates of various components, because it is the most representative data. However, there is no specific confirmed methodology to evaluate the operative experience failure data statistical evidence of the plant.

Throughout this project, a simulation programs such as Risk Spectrum, which was used for recalculating the CDF(core Damage Frequencies). The other Program was Minitab 17, which was used for comparing between Bayesian and MLI Techniques by hypothesis test method and gave the mean standard deviation ratio for each basic event at various time periods. The standard deviation ratio is the tool, which indicates to the comparison between MLI and Bayesian by using data. In order to decide either our hypothesis was true or not and then realize which technique could be used to estimate failure rate in nuclear power planet.

Finally, the statistical distribution graphs will be used to determine which technique is more appropriate for selected events.

These data analyses during the study gave four valuable results, which their Bayesian values were not appropriate within operation. Hence, it must be modified and addressed by means of Maximum Likelihood (MLI) to be more accurate and efficiently. Therefore, it led to recalculate the core damage frequency (CDF) for the whole NPP.

Finally, If the operative experience data is statistically significant it can be used alone when estimating failure rates.

ETSEIB

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1- GLOSSARY

PSA : Probabilistic Safety Assessment

NPP : Nuclear Power Plant

LOCA: Loss of Coolant Accidents

TS : Technical Specifications

LCO : Limiting Conditions for Operation.

SRs: Surveillance Requirements

AOTs: Allowed Outage Times

STI : Surveillance Test Intervals

EOPs: Emergency Operating Procedures

RR : Risk Reduction

FV : Fussell- Vessely

RRW : Risk Reduction Worth

CR: Criticality Importance

RA : Risk Achievement

RAW : Risk Achievement Worth

PD: Partial Derivative

BI: Birnbaum Importance

P_R : Probability of Reference Equation

P_0: Probability of the Equation given that P(BE)=0=> never fails

P_1 : Probability of the Equation given that P(BE)=1≈> has failed

FMEA: Failure Mode & Effect Analysis

FTA : Fault Tree Analysis

MCS: Minimal Cut Set

RS : Risk Spectrum

CDF: Core Damage Frequency

FR: Failure Rate

Bay : Bayesian

MLI : Maximum Likelihood

Gen: Generic

DE: Direct Estimation

OE: Operating Experience

MLI0: Origin MLI

Bay0 : Origin Bay

St.Dev : Standard Deviation Ratio

2- PREFACE

This project is a cooperated project between Nuclear Engineering Research Group (NERG) and Spanish nuclear power plants a whole continuing project between the two sides in order to do various calculations which are related to operation and safety issues in that nuclear power plant. This particular research is considered a certain integral part, which is doing continuously to examine the behavior of different components during operating times and within the maintenance periods as well.

The main purpose of this project is building a specific methodology to evaluate statistical evidences of failure data for safety assessment. This methodology is very important for many reasons. Firstly, in order to evaluate a way to assess the statistical evidence of operative experience data. If the operative experience (OE)data is statistically significant it can be used alone when estimating failure rates.

It is a great chance to do my master thesis in this area to develop the safety systems in the nuclear industry and to prove that this field has the highest level of safety and productivity to produce the energy in safer and simpler way.

3- INTRODUCTION

This project introduces different techniques of data analysis as Bayesian Techniques and Direct Estimation (DE),which is known as Operating Experience (OE) as well or MLI Technique. Generic Technique is used as well, but in a small scale because of its low accuracy in this area to investigate the methodology of failure data in NPP.

First of all, must have a look on the document, which has all the information and references for each failure event, which occurred during reactor operating lifetime and its maintenance periods. From this document which is called here (APS-IT-403), all the necessary items will be completely available.

Then, we have to use two soft programs to extract the basic events with the highest importance figures values in a certain NPP to have the priority to select it in recalculating the core damage frequency and do the maintenance activities to their firstly when the budget is not enough.

Minitab program is used as well to compare between Bayesian and MLI Techniques by hypothesis test method and gave the mean ratio between MLI std and Bayesian std for each failure event at various time periods. The other task for Minitab 17 program was extract distribution graphs for various MLI values and BAY values in one graph. In order to compare the distribution width between two shapes for Data analysis and help to know, which technique is more appropriate for each failure event.

3.1. Objectives

It also concern on developing a methodology to assess the statistical evidence of operative experience data. If the operative experience data is statistically significant it can be used alone when estimating failure rates.
The main target of this project is to study the feasibility of standard deviation as figure to asses statistical the evidence for failure data.

3.2. Scope

The scope of the text includes from a brief explanation of feasibility study to evaluate statistical evidences of failure data throughout using Risk Spectrum program to extract the basic events occur. Then Minitab 17 program is used to show the standard deviation for each basic events and comparing between Bayesian and MLI Techniques by hypothesis test method and gave the mean standard deviation ratio for each basic events at various time periods. The other task for Minitab 17 program was extract distribution graphs for various MLI values and BAY values in one graph to see the width distribution between two shapes and see the appropriate technique for that event.

4.Probablistic Safety Assessment

4.1. PSA Introduction

Many nuclear power plant(NPP)organizations have performed probabilistic safety assessments(PSAs)to identify and understand key plant vulnerabilities[1].As a result of the availability of these PSA studies, there is a desire to use them to enhance plant safety and to operate the plants in the most efficient manner practicable. PSA is an effective tool for this purpose as it assists plant management to target resources where the largest benefit for plant safety can be obtained[2]. However, any PSA which is to be used to support decision making at NPPs must have a credible and defensible basis. Therefore, it is very important that a ‘Living PSA’ be accepted by the regulator. Also, the establishment of an adequate and effective quality assurance framework is fundamental to any PSA project[1].

PSA can be used to explore the risk significance of the various aspects of plant design or operation, to explore the risk impact of changes in plant design or operation, and for the evaluation of abnormal events that occur at the plant[3]. In the following paragraphs the term issue is used to denote any plant design or operational feature, any proposed change of plant design or operational feature, and any plant events for which a PSA based evaluation is requested. The necessity for these evaluations is the rational for establishing a PSA applications program.

Any issue that is going to be evaluated needs to be explicitly defined together with the type of results required as input to the decision making. As already stated, as part of the evaluation, the PSA should be used in combination with other methods and sources of information. The PSA can be used to evaluate the risk significance of each issue, or to define a risk measure as the basis of prioritizing the various issues under review.
To use a PSA as part of the evaluation process, it is necessary to relate the issue to one or more specific elements of the PSA model. If such a relationship cannot be found or the issue cannot be fully addressed by the existing PSA model, then it may be possible, in some cases, to modify the PSA or supplement it with new models or tasks. This, for instance, would be the case when the PSA model needs to be expanded by including a new mode of operation, a new hazard event, etc. In all these cases, the relevant specific task procedures should be used in order to implement the necessary modifications, or, if necessary, new task procedures should be developed[4].

4.2. PSA Application

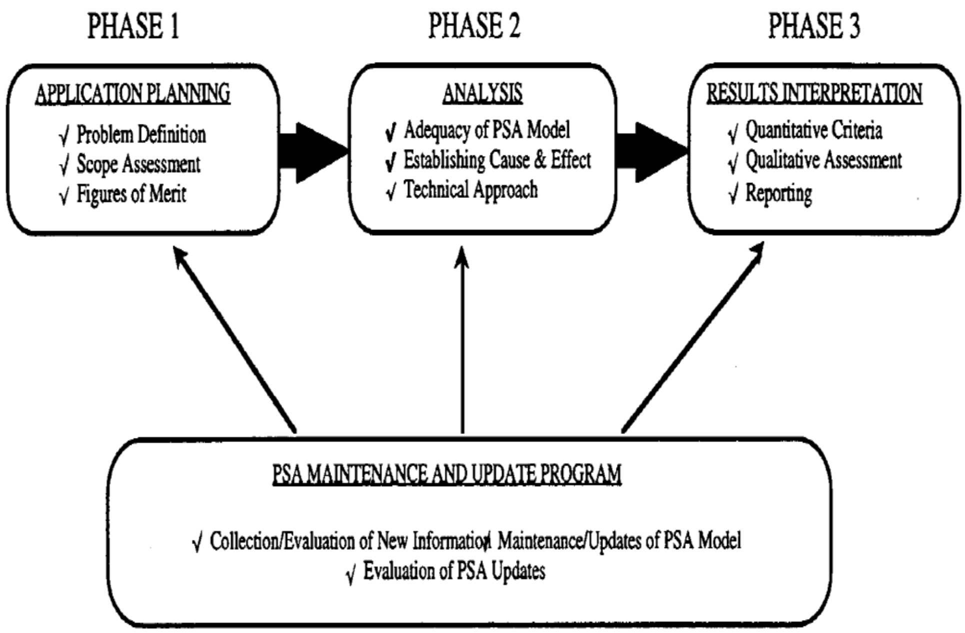

Figure 1: PSA Application Process [Ref 1] P.12

4.2.1. Use of PSA to support NPP design

PSA has become an important tool in the nuclear power plant design process. A PSA provides a fully integrated model of the entire plant that can be used to examine the risk from a variety of possible initiating events (e.g. transients, LOCAs, support system failures, etc.)[5].

The PSA consistently accounts for both the event frequency and the potential consequences from equipment failures or human errors. The model combines front-line safety systems and support systems in a manner that allows designers to identify the risk significance of important inter system dependencies.

The PSA allows designers to quantify the likelihood of “passive” and “active” failure modes, to examine the significance of single failures and multiple failures, and to determine the risk importance of “safety”, “safety related” and “non-safety “systems. Consideration of only a limited set of design basis accidents and application of traditional deterministic design criteria for individual safety functions, systems, and component does not provide the same benefits as the combination of traditional approaches and PSA[6].

PSAs to support new designs are often performed by the reactor vendor and are based on a prototype of the plant design. Preliminary PSA models are used early in the design process as an internal analysis tool.
The PSA models and analyses are refined and become more complete as the design matures. The final PSA may be submitted to the regulatory body as part of the supporting documentation for the plant design and licensing criteria[7].

4.2.2. Use of PSA in NPP maintenance

PSA can be used to identify systems for which detailed study of maintenance activities is appropriate. This detailed study can then be carried out using other techniques.
PSA can subsequently be used to monitor the risk impact of changes in maintenance and testing strategies, provided adequate data on the change in system or component reliability is available[8].

If there is a risk monitor model, the PSA can also be used to examine the risk impacts over the set of activities from the proposed maintenance schedule. This will include the specific combinations of equipment that are removed from service, the frequency and duration of planned maintenance, and the plant operating mode for each activity. This will provide a risk profile for the duration of the schedule, the mean risk over the duration, and the integrated core damage probability for the complete set of activities[9].

The use of PSA should help maintenance staff to optimize the maintenance program, i.e. (a) to identify equipment requiring somewhat upgraded preventive maintenance, (as an increase in its reliability results in a substantial gain in safety), (b) to identify equipment requiring sustained or slightly reduced preventive maintenance (as a decrease in its reliability does not affect the level of safety) and (c) to identify equipment requiring only corrective maintenance (as its unavailability does not result in a major increase in risk)[10].

4.2.3. Use of PSA in connection with NPP technical specifications (TS)

Technical specifications (TS) are safety rules for NPPs that are approved by the regulatory authority. The technical specifications define limits and conditions for operations, testing, and maintenance activities as a way to assure that the plant is operated safely in a manner that is consistent with the assumptions made in the plant safety analyses. The TS define limiting conditions for operation (LCOs) and surveillance requirements (SRs)[11].

LCOs define equipment operability requirements and allowed outage times (AOTs). The AOT for a particular system or component specifies the time period during power operation within which any repair or maintenance should be completed. AOTs are increasingly being defined for shutdown. If the AOT when at power is exceeded, the plant operating mode must change, or the plant must be shut down. The frequency and type of maintenance are not controlled by the LCOs, but the duration of maintenance and the combinations of components that may be simultaneously unavailable are controlled.

Surveillance requirements define the safety system (and safety related/supporting) testing requirements and the surveillance test intervals (STIs). The STIs control the frequency of testing. In some cases, the surveillance requirements also define the scheduling of tests and specific testing strategies. If the STI is exceeded, the affected equipment must be considered inoperable and, according to the AOTs, the plant operating mode must change, or the plant must be shutdown[12].

PSAs are used in several Member States to develop quantitative bases for optimized limits on equipment AOTs, STIs, and testing strategies.

PSAs can be used to modify AOTs and STIs based on a quantitative analysis of specific contributors to overall plant risk. The benefits from these risk based analyses include:
- Consistent basis for AOTs that account for the installed level of redundancy, operating configuration, equipment reliability, and risk importance of each system.
- Justification for planned preventive maintenance schedules during power operation and during shutdown conditions.
- Specification of STIs that minimize total unavailability from undetected incipient failures and from test induced failures.
- More effective surveillance requirements and functional testing strategies to identify incipient failures and to minimize CCF mechanisms.
- Improved communication between plant operators and regulatory authorities through a common basis for understanding and quantitative measurement of the risk impact from new or revised technical specifications.
- Reduction of requests for regulatory relief from excessively restrictive LCOs.

As a comprehensive tool describing the risk associated with a particular plant configuration, the PSA can provide useful support to TS exemption justifications and/or to proposals for mitigation or compensatory measures, or to justify the relevance of these measures[13].

4.2.4 PSA based evaluation and rating of operational events

The main purpose of the operational events analysis is to evaluate the safety significance of the events and to establish an event importance ranking.

The use of PSA for the analysis of operational events increases the understanding of the plant vulnerabilities given the event occurrence, and provides the basis for effective experience feedback. The purpose of PSA based operational event evaluation is to characterize the relative risk importance of operational events for optimizing feedback of operating experience, to derive insights and to support the evaluation of plant specific design and operational problems as the events occur[14].

PSA can be used to analyze plant events which may initiate a plant trip, degrade or disable safety systems, or both simultaneously. The application can then provide an estimate, in terms of a conditional probability, of the margin for an accident with unacceptable consequences[15].

Thus, the basic purpose of PSA based operational event analysis is to determine how an operational event could have degenerated into an accident with more serious consequences and to derive the conditional probability of core damage due to such event[16],[17].

4.2.5. Use of PSA to improve emergency operating procedures (EOPs)

EOPs are predefined and documented procedures that operators follow when activating plant protective features. These documents are used to verify the automatic action of safety systems, to diagnose the situation by following a predefined logical process for selecting the appropriate procedure, and to take action as prescribed by this specific procedure. EOPs in some form are required and are in use as far as is known in almost any nuclear power plant in the world[18].

The improved understanding of nuclear accidents is a result of the gains from research and development activities in severe accident phenomenology and in the application to the analysis of realistic accident progressions. For its part, the increased characterization of nuclear accidents as to modeling and probability stems from the plant specific nature of modern PSAs, the inclusion of all internal and external events for various operating and shutdown modes, and the comprehensive analyses of these accidents scenarios through PSA[19].
Deterministic calculations of the effects of system operations in accidents are enhanced by the augmented description of boundary conditions and integral plant responses that can be derived from PSA analyses.

4.2.6. Use of PSA to improve operator training programs

PSA can support EOP training because it provides information on the accident processes, the relative likelihood of the dominant accident sequences and the associated operator actions required to prevent core damage. Thus, PSA can be used to help in the selection of accident scenarios for training. Absolute sequence frequency and risk significance in terms of relative contribution to the core damage frequency can be used as selection guides.
Similarly, the relative consequences of various operator errors and the PSA predicted chance of failure can be used to select those actions that would benefit from emphasized training.

PSA results highlight the significant contributors to core damage. It is not usual to find that many of these contributors are human errors. Sometimes, the high probabilities for these human type events arise from deficiencies in training. The impact of training in the human failure probability can be analyzed if "operator training" is one of the performance shaping factors considered in the analysis of the human failure events. By performing sensitivity analyses, PSA analysts can determine how enhanced training can contribute towards reducing risk.

PSA can be used to improve operator training for emergency conditions because it can help to select and rank the accident scenarios based on established criteria: accident sequence contribution to core damage, fractional contribution of human errors in the sequence, sequence consequence, etc[20].

5. Quantification PSA

-In the PSA Quantification Task, all the models and products of previous PSA tasks (Accident Sequence Analysis, System Analysis, Data Analysis, …) are used and linked together. The Boolean models are transformed into a logical equivalent form (containing minimal cut sets) that allows to estimate probabilities or frequencies for parts of the models or the whole PSA.

The size and complexity of the models for a NPP PSA is such that simplifications or approximations must be done to be able to quantify the models with an acceptable effort. Such approximations are well known and reasonable, and don't question the validity of the PSA results.

Once the PSA results and the Boolean equations in terms of Minimal Cut Sets are known, several techniques are used to analyze the PSA results. Especially useful for that purpose are the Importance Measures of the Basic Events, since they reveal the basic events that mostly contribute to the plant risk and how sensible are the PSA results to changes in their probabilities.

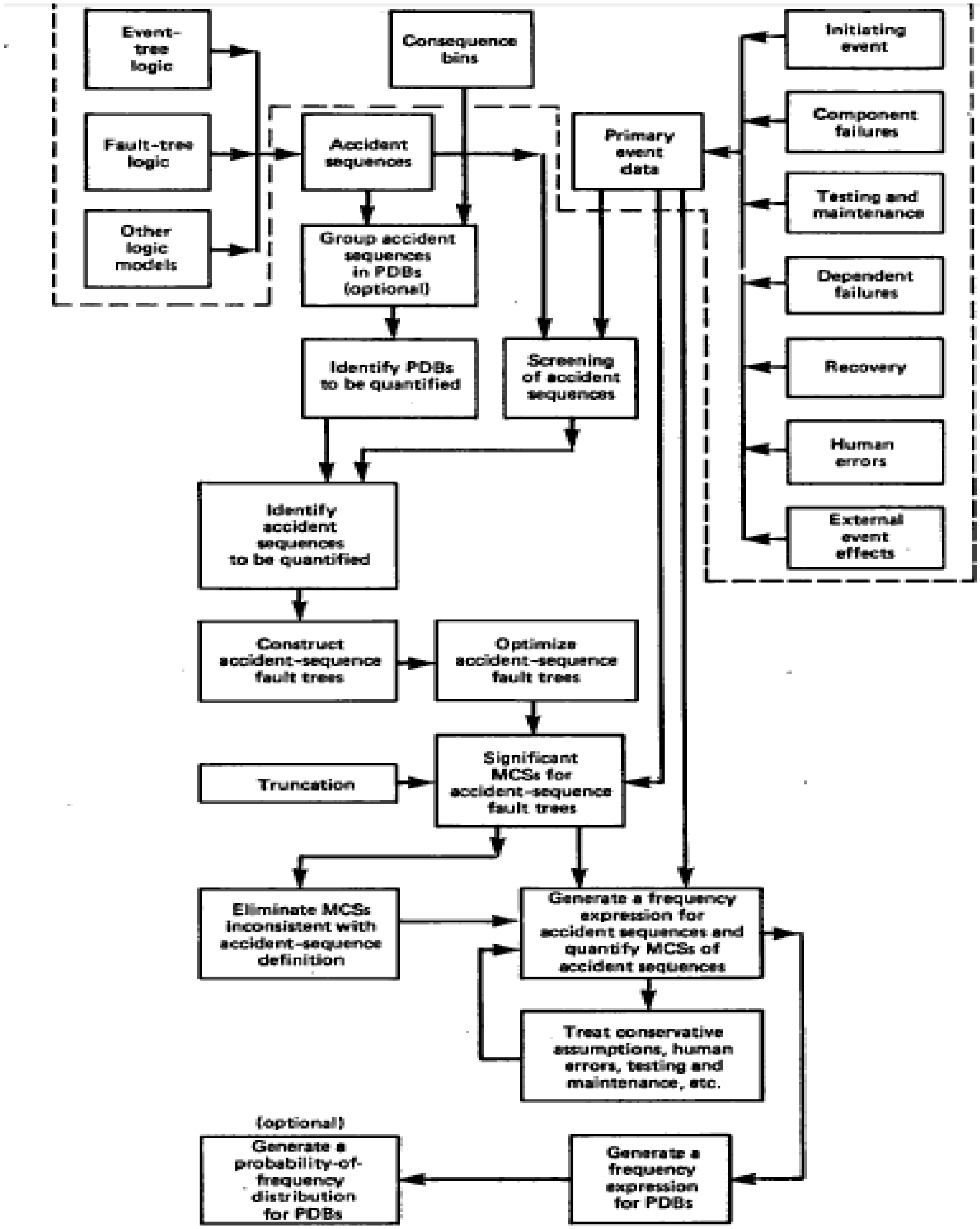

Figure 2: Quantification PSA Process [Ref 1] p.25

5.1. Sensitivity Analysis

The sensitivity analyses of potential component dependences consist of identifying minimal cut sets, some or all of whose components are potentially susceptible to dependences because of defined identified characteristics. Are natively high dependent failure probability is then assumed. If the use of this high dependent failure probability results in a significant change in the core damage frequency, then precautions, actions, or conditions are to be described, which serve to reduce the potential dependence. The sensitivity analysis of potential human error dependences entails identification of minimal cut sets containing multiple human errors and then a description of defenses, management controls, or conditions which serve to reduce the potential dependence.

The sensitivity analyses consist of three parts: sensitivity analyses of potential component failure dependences, of potential human error dependences, and of major assumptions recognized by the analyst to be overly conservative.

In some cases the Sensitivity Analysis just affects the data or parameter involved in the basic event probability calculations and a reassessment of the already obtained core damage equation would be enough. When the changes introduce significant distortion of the data or the models, such as changes of success criteria or modeling assumptions, it would be necessary to modify the models and re-quantify again the whole PSA.

The purpose of the sensitivity analyses is twofold: **(1)** to determine how sensitive the core damage frequency is to possible dependences among component failures and among human errors; (2) to address those assumptions suspected of having a potentially significant impact on the results.

5.2. Uncertainty Analysis

The component reliability data and other probabilities of basic events used in the calculations are not exactly known. There is a certain degree of uncertainty in their estimations. These uncertainties can be characterized by a distribution function (normal, lognormal, gamma...) of the parameters used in the model instead of the mean fixed value used.

Calculations formerly done with the mean values of the distributions provide a result known as a **"**Point Estimate Value**".**

The uncertainty of the input parameters can be propagated through the model to obtain a distribution of the core damage frequency. The mean value of the core damage frequency distribution is not the same than its Point Estimate Value**.**

The propagation of the uncertainty of basic event reliability estimates to the PSA results can very hardly be done analytically in some simple cases. Therefore, Monte Carlo simulation with several sampling techniques are used to obtain an uncertainty distribution of the core damage frequency. After a sufficient amount of simulation trials a table distribution or histogram of the PSA results can be obtained. From it, the mean and median values and percentiles can be derived.

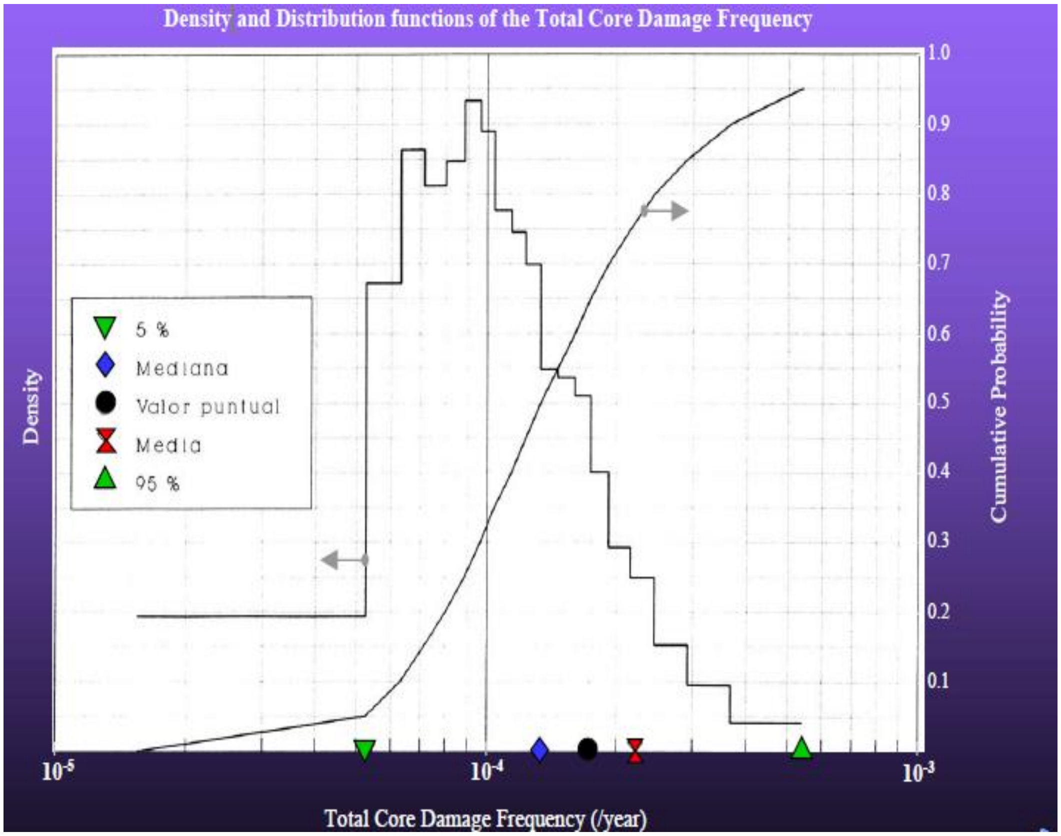

Figure 3: Density and Distribution functions of the Total Core Damage Frequency

5.3. Importance Analysis

The purpose of the importance evaluations is to identify the important accident sequences, system failures, and component failures and human errors with regard to core damage frequency. The importance evaluations are presented in a hierarchical fashion to allow tracing from the important accident sequence to the important system failure (or failures) in the accident sequence to the important component failures or human errors contributing to the system failure.

5.3.1. Most common Risk Importance measures

The importance evaluations consist of the calculation of three importance measures. The first measure is the usual fractional contribution to the core damage frequency or to the system unavailability and is sometimes called the Fussell-Vesely(FV) importance measure. The FV importance measure is often used as a measure of risk importance. The second measure is called the Risk Achievement Worth (RAW) and it is used as a measure of safety importance. RAW is preferred for daily configuration control. The Risk Reduction Worth (RRW) represents the maximum decrease in risk for an improvement to the element associated with the basic event. [21]

Table 1. Risk Importance measures[Ref.2] P.3

Measure	Abbreviation	Principle
Risk reduction	RR	$R(\text{base}) - R(x_i = 0)$
Fussell–Vesely	FV	$\frac{R(\text{base}) - R(x_i = 0)}{R(\text{base})}$
Risk reduction worth	RRW	$\frac{R(\text{base})}{R(x_i = 0)}$
Criticality importance	CR	$\frac{R(x_i = 1) - R(x_i = 0)}{R(\text{base})} \times x_i(\text{base})$
Risk achievement	RA	$R(x_i = 1) - R(\text{base})$
Risk achievement worth	RAW	$\frac{R(x_i = 1)}{R(\text{base})}$
Partial derivative	PD	$\frac{R(x_i + \partial x_i) - R(x_i)}{\partial x_i}$
Birnbaum importance	BI	$R(x_i = 1) - R(x_i = 0)$

Where, R(xi =1), the increased risk level without basic event (xi)
R(xi =0), the decreased risk level with the basic event optimized
R(base), the present risk level
RR, risk reduction
RA. Risk Achievement.

- Fussell-Vesely, FV

$$FV(BE) = \frac{\boldsymbol{P}\mathrm{R}-\mathrm{P0}}{PR} = \frac{RR}{R(base)} \qquad \text{(Eq. 5.3.1)}$$

$0 \leq FV \leq 1$ $\qquad$ $0\% \leq FV \leq 100\%$

Basic event contribution to the equation probability; It is the relative reduction of the equation probability in case that the basic event would never happen.

- Risk Reduction Worth, RRW

RRW(BE) = $\frac{PR}{P0}$ = $\frac{1}{1-FV}$ (Eq. 5.3.2)

$1 \leq RRW \leq \infty$

It is the reduction factor in the equation probability that would be achieved if the event would never occur (the component would never fail).

- Risk Achievement Worth, RAW

RAW(BE) = $\frac{P1}{PR} = \frac{\mathrm{RA}}{\mathrm{R(base)}} + 1$ (Eq. 5.3)

$1 \leq RAW$

It is the incremental factor in the equation probability that would be obtained if the event happens for sure .

Where,
P_R: is Probability of **R**eference Equation
P_0: is Probability of the Equation given that P(BE)=**0**=>never fails
P_1 : is Probability of the Equation given that P(BE)=**1**≈> has failed

5.3.2. Application of Importance measures

5.3.2.1 Test and maintenance activities

Nowadays, the most important area where importance measures are applied is in test and maintenance programs. The influence of T and M is completely connected to the change of the unavailability and not to a change in the defense in depth against a failure of the component.

Special attention needs to be given to basic events that normally have a low failure rate (because of good maintenance), and for that reason do not appear in the risk equation. In that events with high RAW may be deleted. Such basic events could theoretically be safety significant, although they are missed in all categories of importance measures, because they are not in the risk equation. For most applications this is a minor problem, because decreasing and maintenance activities for these basic events , will not increase the failure rate to one. In reality, changing test and maintenance activities will at the most change the failure rate by a factor 10- 100.

FV alone could be used to identify potential components for safety improvements. To identify the component for T and M-relaxation both BI and FV are needed. Since combination of FV = high and BI = low are very unlikely. BI alone could be used for that purpose.

This last remark is especially useful when ranking is performed. Because two parameter ranking is complex. FV-ranking is preferable for safety improvements applications and BI-Ranking for T&M relaxation usage[22].

5.3.2.2 Daily Configuration Control

Another use of importance measures is daily configuration control. Central in this application is the question what will be the result when a certain component is taken out of service. The most suited importance measures for this usage is RAW. Two warnings must be made to use RAW for this application.

1- Truncation problem: the final Custer equation is only applicable for changes around the average unavailability. When the unavailability of a component is changed from average to 1, as is done in the definition of RAW, the truncation rules are not applicable anymore. Because of the truncation problem the final Custer-equation is incomplete and produces an incorrect Raw list.

2- More components unavailable: when two or more components are unavailable, RAW cannot be used to calculated the new frequency.

In order to overcome on these two problems, so called risk monitors are developed. A risk monitor is a fast running PSA-model, that can easily calculate the new result when one or more components are shut-off.
A risk monitor can also produce a real RAW-list. This is a RAW-list that takes care of the truncation problem, by recalculation of the model for every component.

5.3.2.3 Design of nuclear power plants

A traditional application of importance measures is in the design or redesign of nuclear power plants. When a first conceptual plant design exists, this design could be optimised by risk importance ranking of the components. When risk significant components are selected this way, the risk frequency can be improved by decreasing the unavailability of the selected component, by improving the defence in depth against failure of the component or by decreasing the contribution initiating event frequencies. So, potential remedies are not only to be found in the component itself. Therefoe, the complementary use of two importance measures is typical for this application. The combination of FV and BI is advised. This also applies to the process of backfitting nuclear plants.

FV importance could be used for the selection of candidate components for improvement. In the engineering process complementary BI information is very useful. When BI is high and the basic components unavailability already fairly low, one could think of introducing extra redundancy[23].

6. Data Analysis

6.1. Bayesian Technique

6.1.1. Bayesian Techniques definitions

The general set of statistical techniques can be divided into a number of activities, many of which have special Bayesian version

Statistical inference

Bayesian inference is an approach to statistical inference, that is distinct from frequentist inference. It is specifically based on the use of Bayesian probabilities to summarize evidence[25].

Statistical modeling

The formulation of statistical models using Bayesian statistics has the unique feature of requiring the specification of prior distributions for any unknown parameters. These prior distributions are as integral to a Bayesian approach to statistical modeling as the expression of probability distributions. Prior distributions can be either hyper parameters or hyper prior distributions.

Design of experiments

The Bayesian design of experiments includes a concept called 'influence of prior beliefs'. This approach uses sequential analysis techniques to include the outcome of earlier experiments in the design of the next experiment. This is achieved by updating 'beliefs' through the use of prior and posterior distribution. This allows the design of experiments to make good use of resources of all types. An example of this is the multi-armed bandit problem.

Statistical graphics

Statistical graphics includes methods for data exploration, for model validation, etc. The use of certain modern computational techniques for Bayesian inference, specifically the various types of Markov chain Monte Carlo techniques, have led to the need for checks, often made in graphical form, on the validity of such computations in expressing the required posterior distributions.

Bayesian statistics is a subset of the field of statistics in which the evidence about the true state of the world is expressed in terms of degrees of belief or, more specifically, Bayesian probabilities. Such an interpretation is only one of a number of interpretations of probability and there are other statistical techniques that are not based on "degrees of belief". One formulation of the "key ideas of Bayesian statistics" is "that probability is orderly opinion, and that inference from data is nothing other than the revision of such opinion in the light of relevant new information.

Bayesian probability is one interpretation of the concept of probability. In contrast to interpreting probability as frequency or propensity of some phenomenon, Bayesian probability is a quantity that we assign for the purpose of representing a state of knowledge, or a state of belief. In the Bayesian view, a probability is assigned to a hypothesis, whereas under frequentist inference, a hypothesis is typically tested without being assigned a probability.

The Bayesian interpretation of probability can be seen as an extension of propositional logic that enables reasoning with hypotheses, i.e., the propositions whose truth or falsity is uncertain.

Bayesian probability belongs to the category of evidential probabilities; to evaluate the probability of a hypothesis, the Bayesian probabilistic specifies some prior probability, which is then updated in the light of new, relevant data (evidence). The Bayesian interpretation provides a standard set of procedures and formulae to perform this calculation.

6.1.2. Bayesian methodology

Bayesian methods are characterized by the following concepts and procedures:

- The use of random variables, or, more generally, unknown quantities, to model all sources of uncertainty in statistical models. This also includes uncertainty resulting from lack of information.
- The need to determine the prior probability distribution taking into account the available (prior) information.
- The *sequential use of the* Bays' formula: when more data becomes available, calculate the *posterior distribution* using the Bayes' formula; subsequently, the posterior distribution becomes the next prior.
- For the frequentist a hypothesis is a proposition (which must be either true or false), so that the frequentist probability of a hypothesis is either one or zero. In Bayesian statistics, a probability can be assigned to a hypothesis that can differ from 0 or 1 if the truth value is uncertain.

6.2. MLI Technique

Maximum likelihood estimation is a technique used to estimate the failure rate for various components in the nuclear power plant, instead of using Bayesian or generic technique. MLI must use under certain circumstances, if these requirements does applied, so it could not use MLI for these failure rates. These requirements such as MLI standard deviation and its distribution width must be almost the same Bayesian standard deviation.

MLI is calculated from equations below, which got $MLI0)_{alpha}$, $MLI0)_{beta}$ and $MLI0)_{mean}$ essentially from the document (APS-IT-403) and assume the time.

- For alpha MLI values: $MLI)_{alpha} = MLI0)_{alpha} + MLI0)_{mean} \times Time$ (Eq. 6.2.1)
- For beta MLI values: $MLI)_{beta} = MLI0)_{beta} + Time$ (Eq. 6.2.2)

Maximum likelihood estimation is a totally analytic maximization procedure. It applies to every form of censored or multi censored data, and it is even possible to use the technique across several stress cells and estimate acceleration model parameters at the same time as life distribution parameters. Moreover, MLE's and Likelihood Functions generally have very desirable large sample properties:

- they become unbiased minimum variance estimators as the sample size increases
- they have approximate normal distributions and approximate sample variances that can be calculated and used to generate confidence bounds
- likelihood functions can be used to test hypotheses about models and parameters

The advantages of this method are:

- Maximum likelihood provides a consistent approach to parameter estimation problems. This means that maximum likelihood estimates can be developed for a large variety of estimation situations. For example, they can be applied in reliability analysis to censored data under various censoring models.
- Maximum likelihood methods have desirable mathematical and optimality properties. Specifically,
  1. They become minimum variance unbiased estimators as the sample size increases. By unbiased, we mean that if we take (a very large number of) random samples with replacement from a population, the average value of the parameter estimates will be theoretically exactly equal to the population value. By minimum variance, we mean that the estimator has the smallest variance, and thus the narrowest confidence interval, of all estimators of that type.
  2. They have approximate normal distributions and approximate sample variances that can be used to generate confidence bounds and hypothesis tests for the parameters.

The disadvantages of this method are:

- The likelihood equations need to be specifically worked out for a given distribution and estimation problem. The mathematics is often non-trivial, particularly if confidence intervals for the parameters are desired.
- The numerical estimation is usually non-trivial. Except for a few cases where the maximum likelihood formulas are in fact simple, it is generally best to rely on high quality statistical software to obtain maximum likelihood estimates. Fortunately, high quality maximum likelihood software is becoming increasingly common.
- Maximum likelihood estimates can be heavily biased for small samples. The optimality properties may not apply for small samples.
- Maximum likelihood can be sensitive to the choice of starting values.

Most general purpose statistical software programs support maximum likelihood estimation (MLE) in some form. MLE estimation can be supported in two ways.

1. A software program may provide a generic function minimization (or equivalently, maximization) capability. This is also referred to as function optimization. Maximum likelihood estimation is essentially a function optimization problem.

   This type of capability is particularly common in mathematical software programs.

2. A software program may provide MLE computations for a specific problem. For example, it may generate ML estimates for the parameters of a Weibull distribution.

   Statistical software programs will often provide ML estimates for many specific problems even when they do not support general function optimization.

The advantage of function minimization software is that it can be applied to many different MLE problems. The drawback is that you have to specify the maximum likelihood equations to the software. As the functions can be non-trivial, there is potential for error in entering the equations.

The advantage of the specific MLE procedures is that greater efficiency and better numerical stability can often be obtained by taking advantage of the properties of the specific estimation problem. The specific methods often return explicit confidence intervals. In addition, you do not have to know or specify the likelihood equations to the software. The disadvantage is that each MLE problem must be specifically coded.

6.3. Application of data analysis in this project (failure rate calculations)

Throughout this study, different techniques of data analysis are using such as Bayesian Technique and Direct Estimation (DE), which is known as Operating Experience (OE) or MLI Technique. Generic Technique is used as well, but in a small scale because of its low accuracy in this area.

First of all, must have a look on the document which related to the required Nuclear Power Plant. This document have all the information and references for each previous failure rate, which happened during reactor operating lifetime and its maintenance periods. From this document which is called here (APS-IT-403), all the necessary items will be completely available.

By using Risk Spectrum Program, which extract and get all the basic events for our Nuclear power plant. This was done by RS PSA program and ran it as shown in Figure 4.

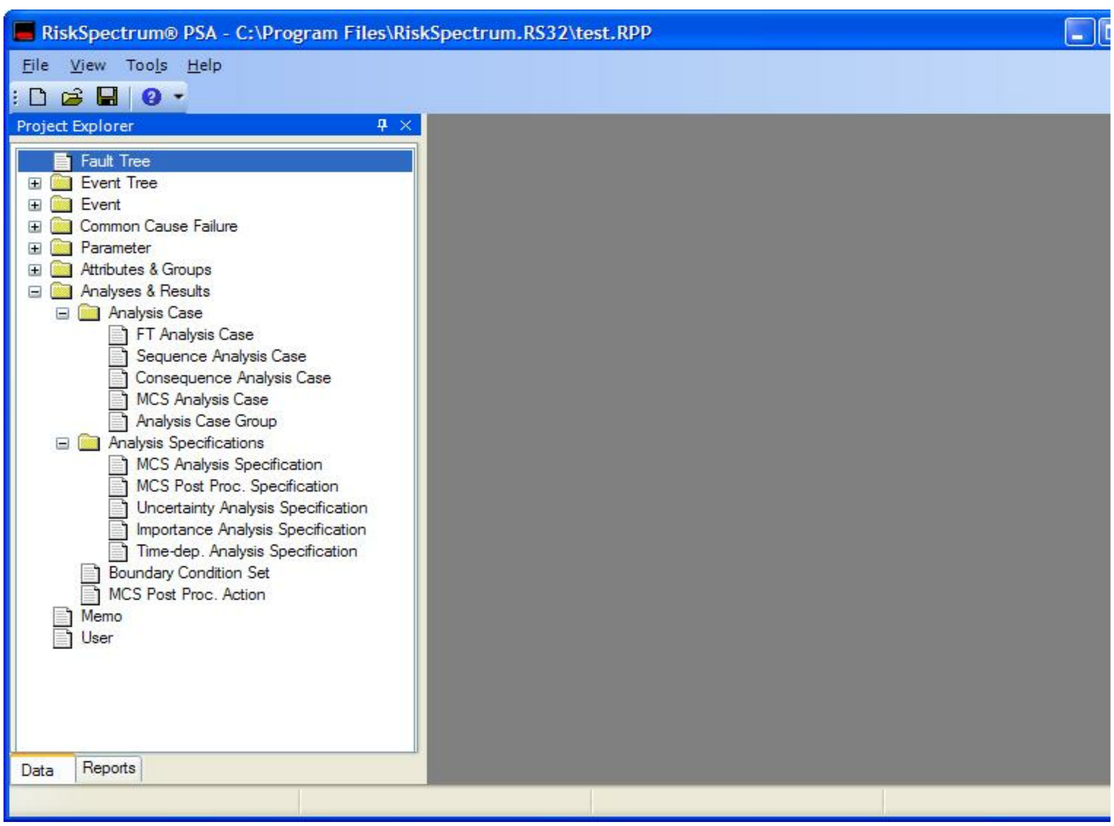

Figure 4: Analyses and results in Project Explorer.

It has shown about 700 basic events, which may occurred in NPP and then it has to be classified and reduced in according to their importance. For example, all values which have RIF (RAW) equal to (9.99 E+09) or which less than (2.00 E+00) must be removed from the table as shown in the excel file (full 1).

ID	Normal value	FC	FV	RDF	RIF
1FOIHRECAH	4.83E-03	2.83E-01	2.83E-01	1.39E+00	5.92E+01
1IE0000T2F	9.51E-01	2.04E-01	2.04E-01	1.26E+00	9.99E+99
1IE0000S2F	2.99E-04	2.03E-01	2.03E-01	1.26E+00	9.99E+99
1FOAACONTH	6.71E-05	1.52E-01	1.52E-01	1.18E+00	2.24E+03
1VK360002O	2.83E-02	1.47E-01	1.44E-01	1.17E+00	5.94E+00
1IE0000T4F	2.66E-01	1.29E-01	1.29E-01	1.15E+00	9.99E+99
1VK360002F	2.11E-02	1.10E-01	1.06E-01	1.12E+00	5.94E+00
1F1FEDYBLH	4.41E-03	1.03E-01	1.03E-01	1.12E+00	2.43E+01
1FOFEDYBLH	2.17E-02	9.73E-02	9.73E-02	1.11E+00	5.39E+00
1IE0000T1F	3.38E-02	9.63E-02	9.63E-02	1.11E+00	9.99E+99

Table 2-Some basic events from Excel file (Full 1)

ID	FR or P	Bay or OE	distrib	mean	param1	param2
1BLBC0G1BF	FR	Bay	Gamma	1.81E-07	0.5	2758432.59
1BLBC0G1AF	FR	Bay	Gamma	1.81E-07	0.5	2758432.59
1M5RS000AM						
1BHCA007AF	FR	Bay	Gamma	2.41E-07	0.5	2074406.25
1M4CA007AM						
1M3RRPORVM						
1CACAB21AF						

Table 3-Some basic events from Excel File (Full 4)

After that, the failure events should be classified by using the document (APS-IT-403) and calculate the failure rate (FR) for each failure event .it must understand some

Spanish words which indicates to our calculation such as *Tasa horaria* which means FR, *Media* which means mean, Alfa indicates to Parameter 1, Beta indicates to Parameter 2 and *Esta Directa* which means OE.

RAW value is one of the most important values in the table, since it used as a measure of risk importance for components and is preferred for daily configuration control.

Then, the highest importance figure values will keep remaining and skip the other values, as shown in details in Table B-1 in Appendix book and shown in a brief in excel file (Full 5).

At that limit, we already extract many values for various components and for many failure events by using document data such as number of failures, hours/demands ratio, the mean value and distribution types.

In order to determine the technique for each failure event, still need the following rules and equations to achieve that purpose. These equations are used to find many values for distribution parameters as well.

-Therefore, in case of Failure = 0

IF hours/demands ≥ 3* $\frac{1}{mean\ \ G}$

We will use, the relation MLI = $\frac{1}{2*\frac{\text{hours}}{demands}}$ (Eq. 6.3.1)

IF it is not greater than , we will use Bayesian.

-**In case of failures = 1**

IF hours/demands ≥ $\frac{1}{mean\ \ Generic}$

We will use MLI for ϒ, β

IF not, we will use Bay

-In case of Failures > 1

We will use MLI unless you demonstrate that the statistical evidence of your data is not enough to use it .

The statistical distribution for FR is GAMMA

-**In case of OE or MLI** :-

Which, mean = $\frac{\alpha}{\beta}$, (Eq.6.3.2)

where, α indicates to number of Failures

β indicates to number of hours.

-**In case of Bayesian for Gamma**

Mean)$_B$ = $\frac{\alpha B}{\beta B}$ (Eq. 6.3.3)

Which, $\alpha_B = \alpha_{OE} + \alpha_G$

$\beta_B = \beta_{OE} + \beta_G$

The statistical distribution for P is BETA .

-**In case of MLI**

Which, mean = $\frac{\alpha}{\alpha+\beta}$ (Eq.6.3.4)

Where, α indicates to number of Failures

β indicates to number of hours.

-In case of Bayesian for Beta

Which, , $\alpha_B = \alpha_{OE} + \alpha_G$

$\beta_B = \beta_{OE} + \beta_G$

$\text{Mean})_B = \alpha_B / (\alpha_B + \beta_B)$ (Eq.6.3.5)

All the previous calculations were applied in the table B-2 in Appendix book in details for all components for basic events with the highest importance value, in order to calculate the failure rate for various cases.

7- The project methodology

The methodology that used during this project, divided into two main parts.

First, the failure rates information will be checked by the document (APS-IT-403) as the main reference for getting the distribution parameter values.

Second, Risk Spectrum Program will be used to extract and get all the failure events for our Nuclear power plant as shown in Figure 4

After that, the failure events should be classified by using the document (APS-IT-403) and calculate extract many information, such as number of failures, hours/demands ratio, the mean value and distribution types.

Therefore, Minitab 17 program, will be used for comparing between Bayesian and MLI Techniques by hypothesis test method and gave the mean standard deviation ratio for MLI and Bay for each failure event at various time periods. It also used to extract statistical distribution graphs for various MLI values and BAY values in one graph to see the width distribution between two shapes as it will shown in next pages for Data analysis.

Finally, the hypothesis on this study will depend on using MLI Technique to estimate the failure rate, if MLI standard deviation was almost the same Bayesian standard deviation. Otherwise, more details must be required to make MLI standard deviation much closer to Bayesian standard deviation. If MLI and Bay could not be almost the same, so Bayesian technique still using to estimate failure rates.

8. Software Program Used in this project

8.1. Risk Spectrum PSA

8.1.1. Risk Spectrum as general

Risk Spectrum® is the product family name of one of the most advanced Risk and Reliability Analysis software in the world. The family includes advanced tools for:

- Failure Mode & Effect Analysis (Risk Spectrum FMEA)
- Fault Tree Analysis (Risk Spectrum FTA)
- Fault Tree and Event Tree Analysis (Risk Spectrum PSA)
- Documentation (Risk Spectrum Doc)
- Risk Monitoring (Risk Spectrum Risk Watcher)

Risk Spectrum PSA, Scand power's top-of-the-line product, is licensed for use at half of the world's nuclear power plants. The user group consists of companies and organizations in different industries:

- Nuclear industry
- Oil & Gas industry
- Defense industry
- Aviation and space industry
- Chemical and process industries
- Transportation industry (cars and trains)

8.1.2. Risk Spectrum PSA software

Risk Spectrum® PSA is an advanced fault tree and event tree software tool licensed for use at half of the world's nuclear power plants.

Risk Spectrum PSA offers an intuitive user interface for modeling everything from the basic fault tree with AND and OR-gates to advanced fault tree and event tree integration of sequences in linked event trees with boundary conditions and CCF events.
The integrated analysis tool (RSAT) is specially designed for solving large PSA model and offers MCS (Minimal Cut Set), Sensitivity, Importance and Time dependent Analysis. Risk Spectrum PSA also includes the Risk Spectrum MCS editor and an advanced Post Processing function.

8.1.3. Using RS PSA in this project.

As shown in previous, there are many applications and huge use for Risk Spectrum Program as a software, but in this part contains only the importance of RS Program. During this project, which RS program is used for two basic processes, one at the beginning of the project, which is the essential program to extract and get all the failure events for our Nuclear power plant. This was done by RS PSA program by choose Analyses and Results as shown below in Figure 4 and then choose the consequence Analysis case and change the uncertainty Analysis specification to (yes) and finally run the program[24].

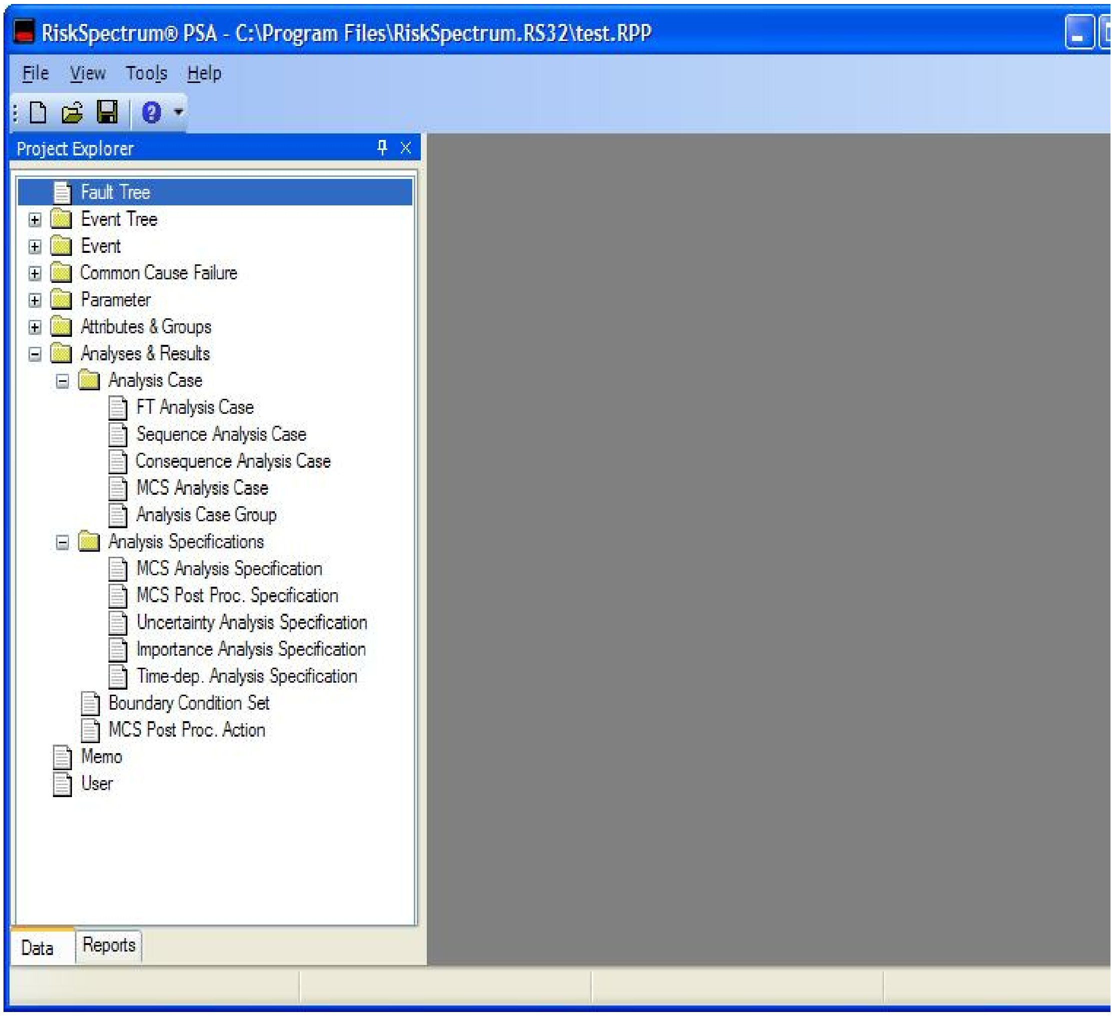

Figure 4: Analyses and results in Project Explorer.

The other applications for RS PSA Program in this project was in case of recalculating the CDF (core Damage Frequencies), which must be modified to be more accurate in NPP operations in the future. RS was used as the first case above, but next Parameter list and FR (Failure Rate), run it again to get the new modifying values as will show in next pages.

8.2. Minitab 17 Program

Minitab played a very important role in this project through two tasks. First task was comparing between Bayesian and MLI Techniques by hypothesis test method and gave the mean standard deviation ratio for each failure event at various time periods. As it shown in next pages and from the appendices book, which huge calculations were done by this program, which run it by this way, which it must choose from the list (calculation).Then, select (Random Data) with will be in this project (Gamma or Beta) then choose another list called (Stat), then select (basic statics) and (Variance 2) as following and finally select (each sample is in its own column). The result for mean standard deviation ration will appear clearly and put it in table and see the relationship between ST.Dev Ratio for both BAY and MLI and MLI and MLI as well with time progression as shown in tables. The below figure 5 show the basic page for Minitab 17 program.

The other task for Minitab 17 program was extract statistical distribution graphs for various MLI values and BAY values in one graph to see the width distribution between two shapes as it will shown in next pages for Data analysis. In order to know, which technique is more appropriate for each basic events and then know if the preliminarily hypothesis were correct or not and hence, make a methodology for these statistics values[25] .

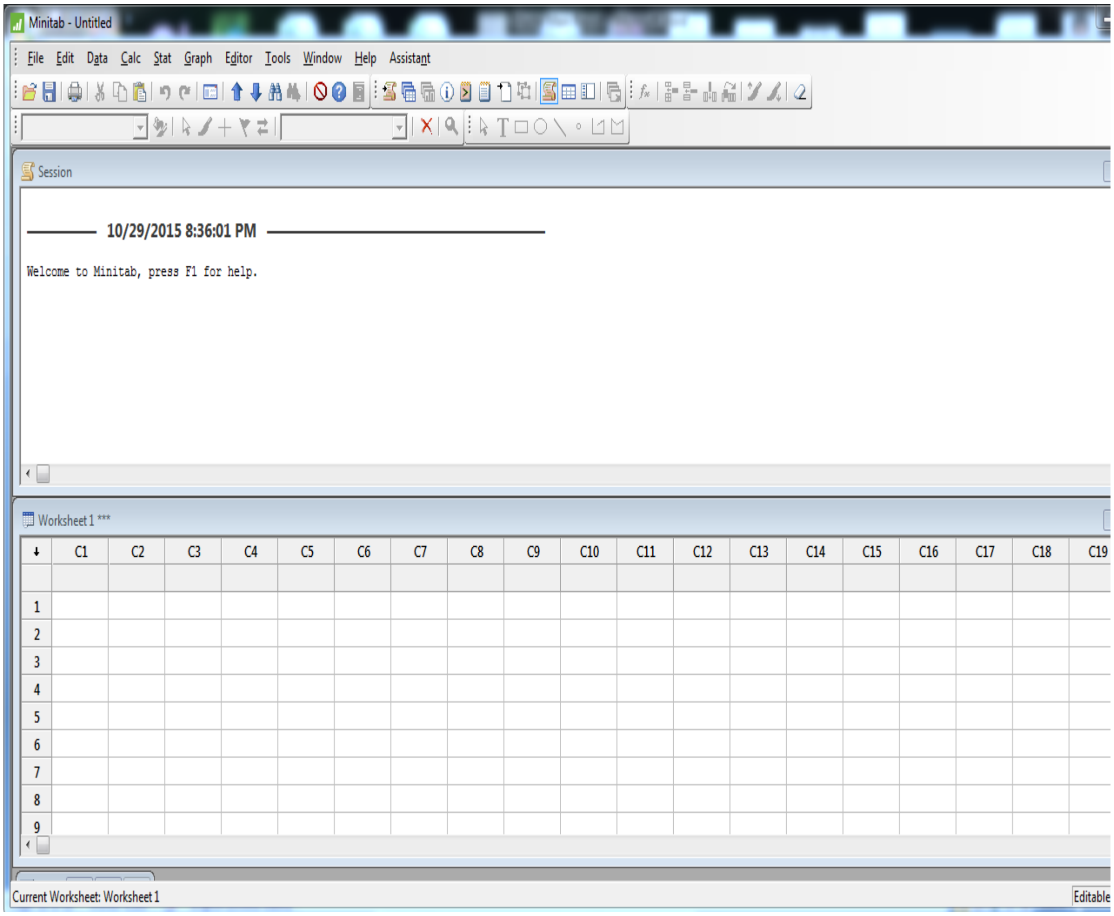

Figure 5: Basic Page for Minitab 17 program

9. Results Discussions

In this part, the most important results in our research will be discussed accurately in details within their tables and graphs to be able to achieve the main goal of this project, which is evaluate the feasibility of a methodology to help in making decision which technique is more appropriate. Hence, feasibility study must use Standard deviation ratio to explain that.

Therefore, Five different basic events will be selected randomly to study their mean standard deviation ratio and determine which technique is more appropriate for each one.

9.1 MLI/Bayesian Events at constant MLI zero value.

The hypothesis on this study will depend on using MLI Technique to estimate the failure rate, if MLI standard deviation was almost the same Bayesian standard deviation. Otherwise, more details must be required to make MLI standard deviation much closer to Bayesian standard deviation. If MLI and Bay could not be almost the same, so Bayesian technique still using to estimate failure rates.

9.1.1 Basic event 1THCAT9A3F.

This table explains the different values for basic event 1THCAT9A3F, which increasing with time per hours at constant origin MLI (indicates to number of failures), some of these values can be found directly from NPP document or from Tables B above such as alpha and beta values for origin MLI, Generic and Bayesian as shown below. Other alpha and beta values for MLI and Bayesian must be calculated by following equations:

- For alpha MLI values: $MLI)_{alpha} = MLI0)_{alpha} + MLI0)_{mean}$ X Time (Eq. 8.1.1)
- For beta MLI values: $MLI)_{beta} = MLI0)_{beta}$ + Time (Eq. 8.1.2)
- For alpha BAY values: $BAY)_{alpha} = Generic0)_{alpha} + New\ MLI)_{alpha}$ (Eq. 8-1.3)
- For beta BAY values: $BAY)_{beta} = Generic0)_{beta} + New\ MLI)_{beta}$ (Eq. 8-1.4)
- All scale values are inverse beta values for each column. All mean values equal alpha value/beta value for each column.

Then, the new mean values at each time for this failure event standard deviation (MLI/BAY) can be determined by Minitab 1.7 program as shown below in the green cells for each time.

Next, the following table was done below to show the relationship between MLI time beta in hours (indicates to the components operating time) versus mean standard deviation ratio for MLI/BAY and then see it as a graph drawing.

Time β MLI (h)	ST.Dev Ratio
4093051.65	0.952
4293051.65	0.948
4493051.65	0.955
4693051.65	0.952
4893051.65	0.958
5093051.65	0.954
5293051.65	0.963
5493051.65	0.965
5693051.65	0.96
5893051.65	0.972
6093051.65	0.965
6293051.65	0.964
6493051.65	0.965
6693051.65	0.969
6893051.65	0.968

Table4- for basic event 1THCAT9A3F for MLI/BAY

The following graph show the relationship between mean Standard deviation for MLI and BAY and MLI time in hours. From the graph, it is clear that mean standard deviation ratio is almost stable at one with time progressing in hours for basic event 1THCAT9A3F. That means MLI can be used effectively for this basic event.

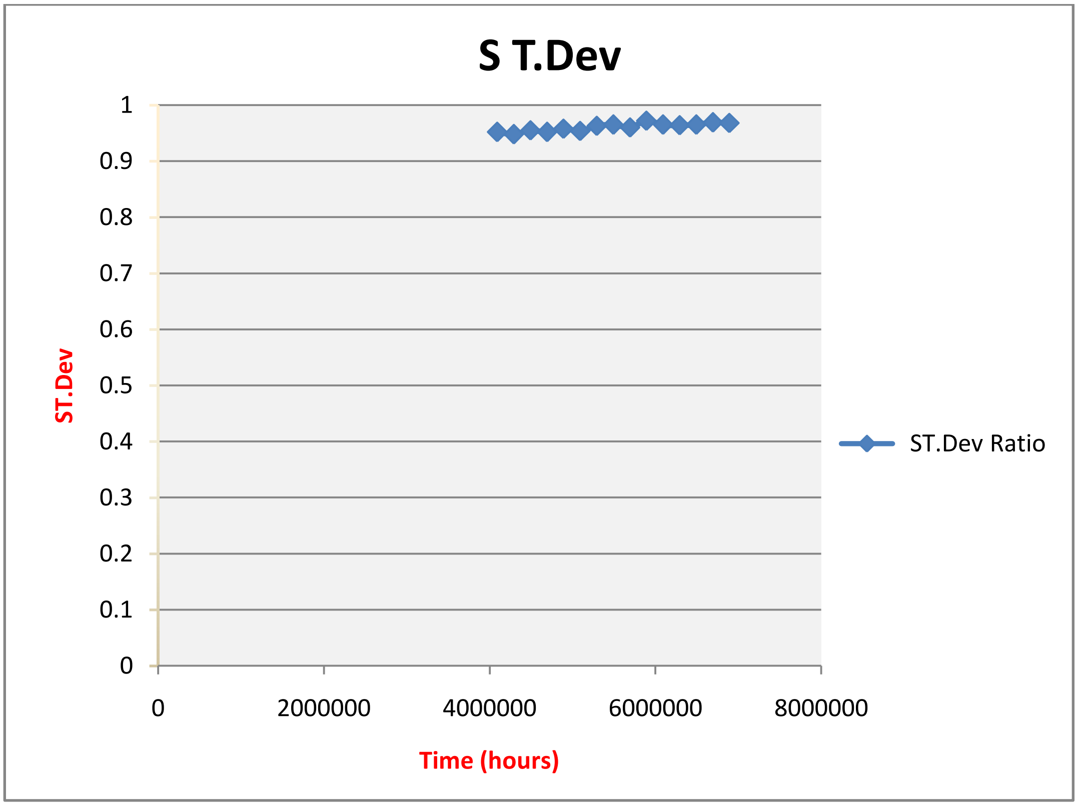

Figure 6– show the relationship for basic event 1THCAT9A3F for MLI/BAY

9.1.2 Basic Event 1VE81052AR

- Next, the following table was done below to show the relationship between MLI time beta in hours versus mean standard deviation ratio for MLI/BAY at constant origin MLI and then see it as a graph drawing.

Time β MLI (h)	ST.Dev Ratio
10854.52	3.924
20854.52	2.822
35854.52	2.197
85854.52	1.566
135854.52	1.375
185854.52	1.275
210854.52	1.241
410854.52	1.124
610854.52	1.088
810854.52	1.069
1010854.52	1.054
1210854.52	1.043
1410854.52	1.033
1610854.52	1.03
1810854.52	1.026
2010854.52	1.023
2210854.52	1.021
2410854.52	1.02
2610854.52	1.02
2810854.52	1.019
3010854.52	1.014

Table5 -for basic event 1VE81052AR for MLI/BAY at Constant MLI0

-The following graph show the relationship between mean Standard deviation for MLI and BAY at constant origin MLI value and MLI time in hours. From the graph, it is clear that mean standard deviation ratio is decreasing gradually to one with time progressing in hours for basic event 1VE81052AR. That means MLI cannot be used for this basic event and should remain using Bayesian.

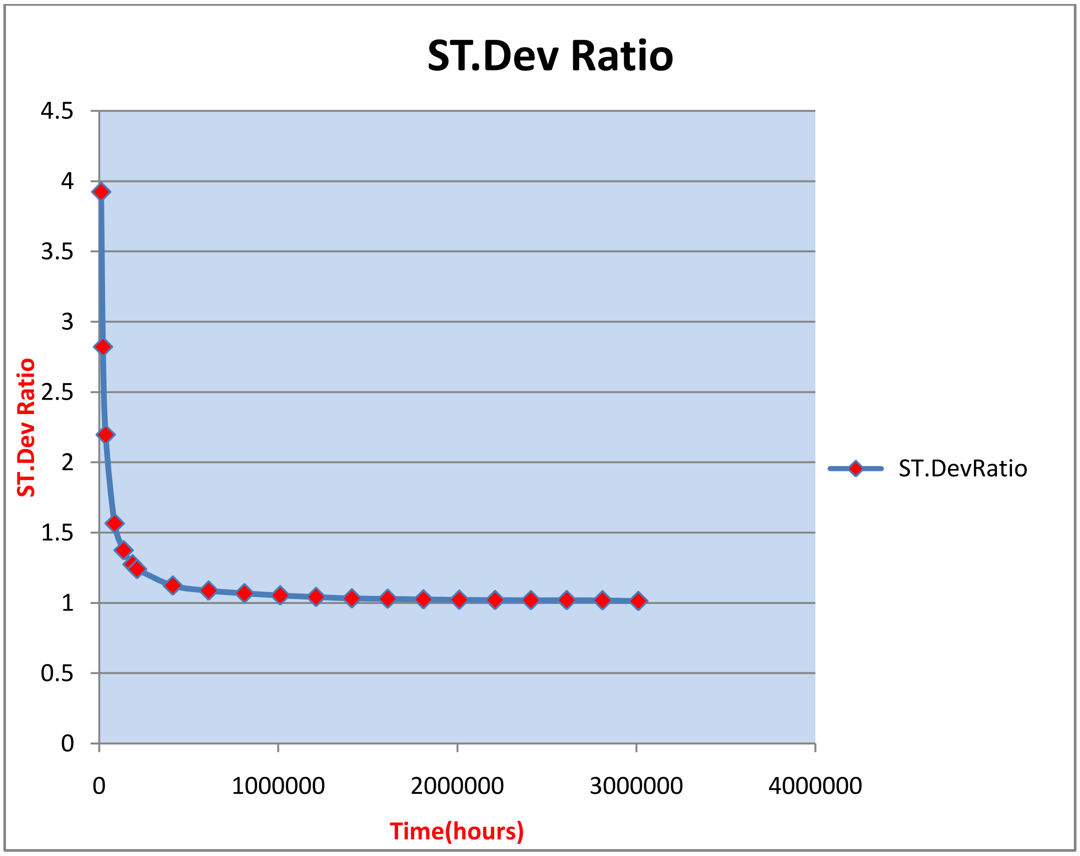

Figure 7 - show the relationship for basic event 1VE81052AR for MLI/BAY at constant MLI

9.1.3 Basic event 1VK360001O

The following table was done below to show the relationship between MLI time beta in hours versus mean standard deviation ratio for MLI/BAY at constant origin MLI and then see it as a graph drawing.

Time β MLI (h)	St.Dev Ratio
1002554.7	11.47
1202554.7	9.735
1402554.7	8.604
1602554.7	7.721
1802554.7	6.954
2002554.7	6.392
2202554.7	5.95
2402554.7	5.499
2602554.7	5.156
2802554.7	4.903
3002554.7	4.627
3202554.7	4.513
3402554.7	4.191
3602554.7	4.018
3802554.7	3.858
10802555	2.03
30802555	1.365
100802555	1.109
200802555	1.057

Table 6- for basic event 1VK360001O for MLI/BAY at Constant MLI0

- The following graph show the relationship between mean Standard deviation for MLI and BAY at constant origin MLI value and MLI time in hours. From the graph, it is clear that mean standard deviation ratio is decreasing gradually to one with time progressing in hours for basic event 1VK360001O. That means MLI cannot be used for this basic event and should remain using Bayesian.

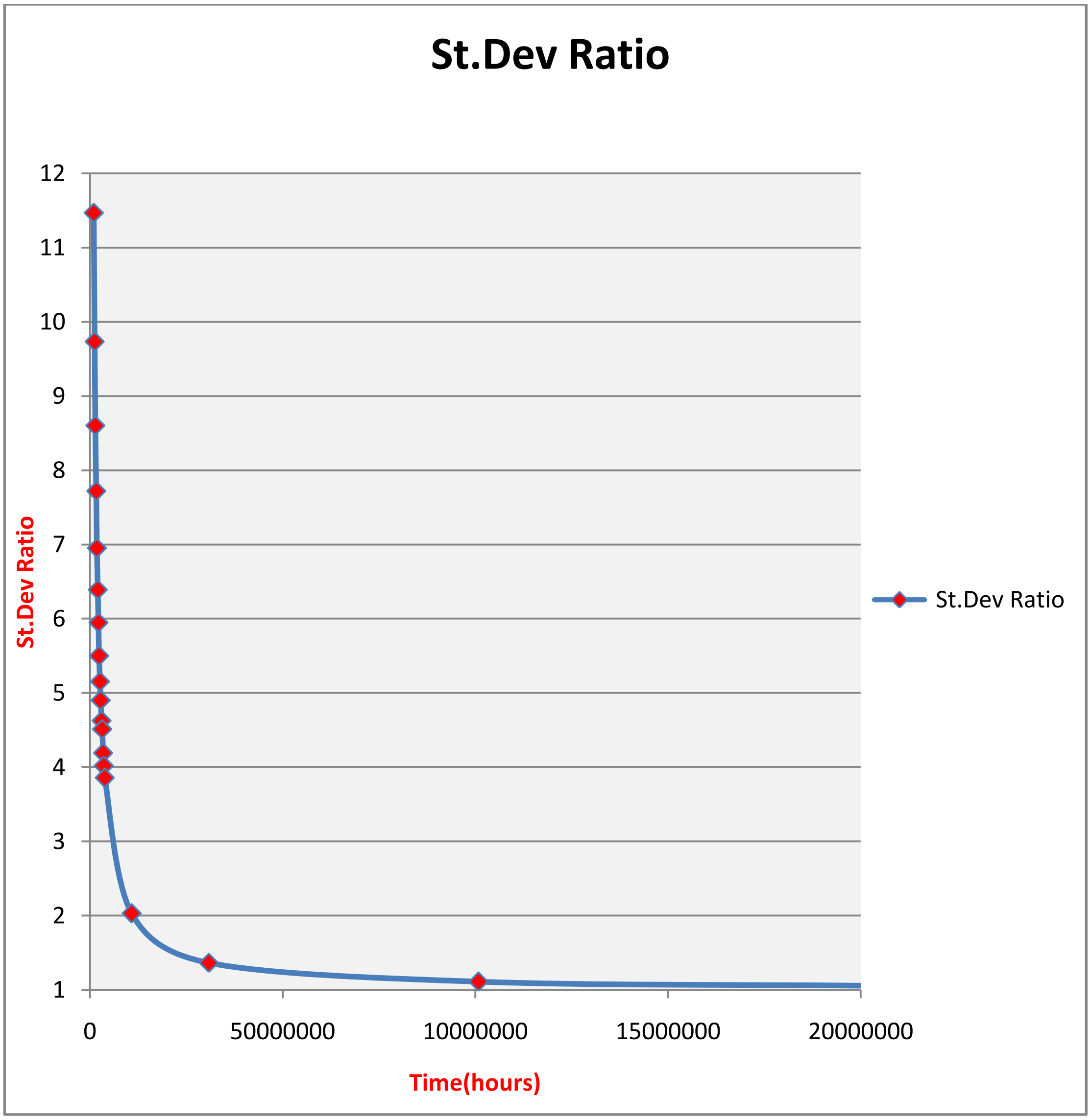

Figure 8 show the relationship between for basic event 1VK360001O for MLI/BAY at Constant MLI0

9.3.4 Basic Event 1REPK602AE.

the following table was done below to show the relationship between MLI time beta in hours versus mean standard deviation ratio for MLI/BAY at constant origin MLI and then see it as a graph drawing

Time β MLI (h)	St. Dev Ratio
22694466.67	1.77
22894466.67	1.749
23094466.67	1.761
23294466.67	1.756
23494466.67	1.75
23694466.67	1.739
23894466.67	1.718
24094466.67	1.717
24294466.67	1.716
24494466.67	1.709
24694466.67	1.704
24894466.67	1.702
25094466.67	1.701
25294466.67	1.7
25494466.67	1.693
32494466.67	1.559
72494466.67	1.265
122494466.7	1.159
172494466.7	1.089
222494466.7	1.089

Table 7 - for basic event 1REPK602AE for MLI/BAY at constant MLI0

- The following graph show the relationship between mean Standard deviation for MLI and BAY at constant origin MLI value and MLI time in hours. From the graph, it is clear that mean standard deviation ratio is decreasing gradually to one with time progressing in hours for basic event1REPK602AE. That means MLI cannot be used for this basic event and should remain using Bayesian.

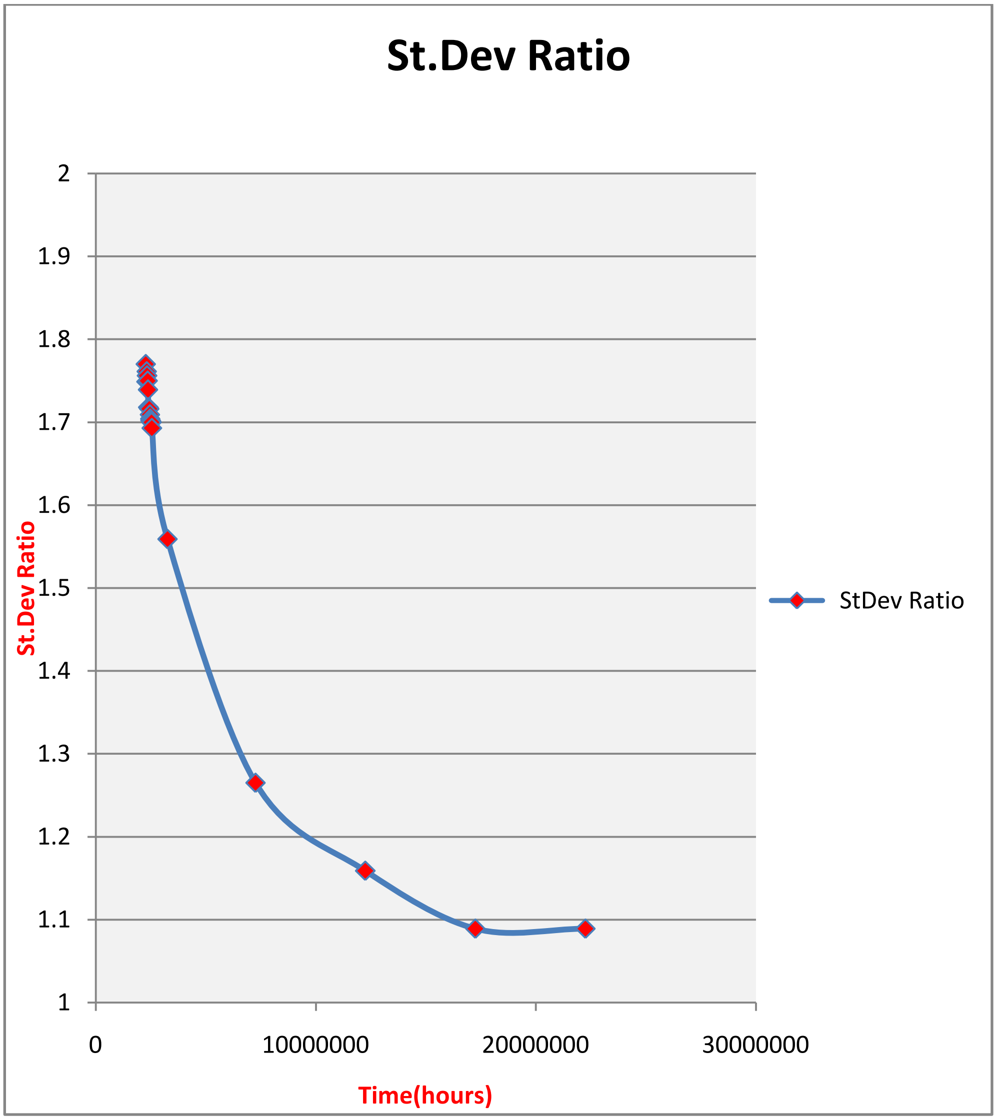

Figure 9 – show the relationship for basic event 1REPK602AE for MLI/BAY at constant MLI0

9.1.5 Basic Event 1EN81B06AR

Time β MLI (h)	Ratio GEN	S Ratio BAY
211274.47	2.043	2.234
261274.47	1.747	1.991
311274.47	1.531	1.783
361274.47	1.432	1.751
421274.47	1.296	1.634
441274.47	1.266	1.628
451274.47	1.229	1.57
456274.47	1.227	1.582
459274.47	1.213	1.552
460274.47	1.22	1.57
461274.47	1.222	1.55
462274.47	1.231	1.578
463274.47	1.238	1.592
466274.47	1.216	1.557
471274.47	1.203	1.542
481274.47	1.186	1.529
501274.47	1.154	1.521
521274.47	1.132	1.512
541274.47	1.108	1.48
561274.47	1.098	1.494
581274.47	1.053	1.423
601274.47	1.044	1.453
611274.47	1.03	1.437
661274.47	0.987	1.388
711274.47	0.95	1.398
761274.47	0.91	1.369
811274.47	0.882	1.331
861274.47	0.844	1.297
911274.47	0.821	1.308
961274.47	0.799	1.263
1211274.47	0.699	1.222
1461274.47	0.631	1.17

Table 8 –For basic event 1EN81B06AR for MLI/Gen and for MLI/BAY

- The following graph show the relationship between mean Standard deviation for MLI and BAY at constant origin MLI value and MLI time in hours. From the graph, it is clear that mean standard deviation ratio is decreasing gradually to one with time progressing in hours for basic event . That means MLI cannot be used for this basic event and should remain using Bayesian.

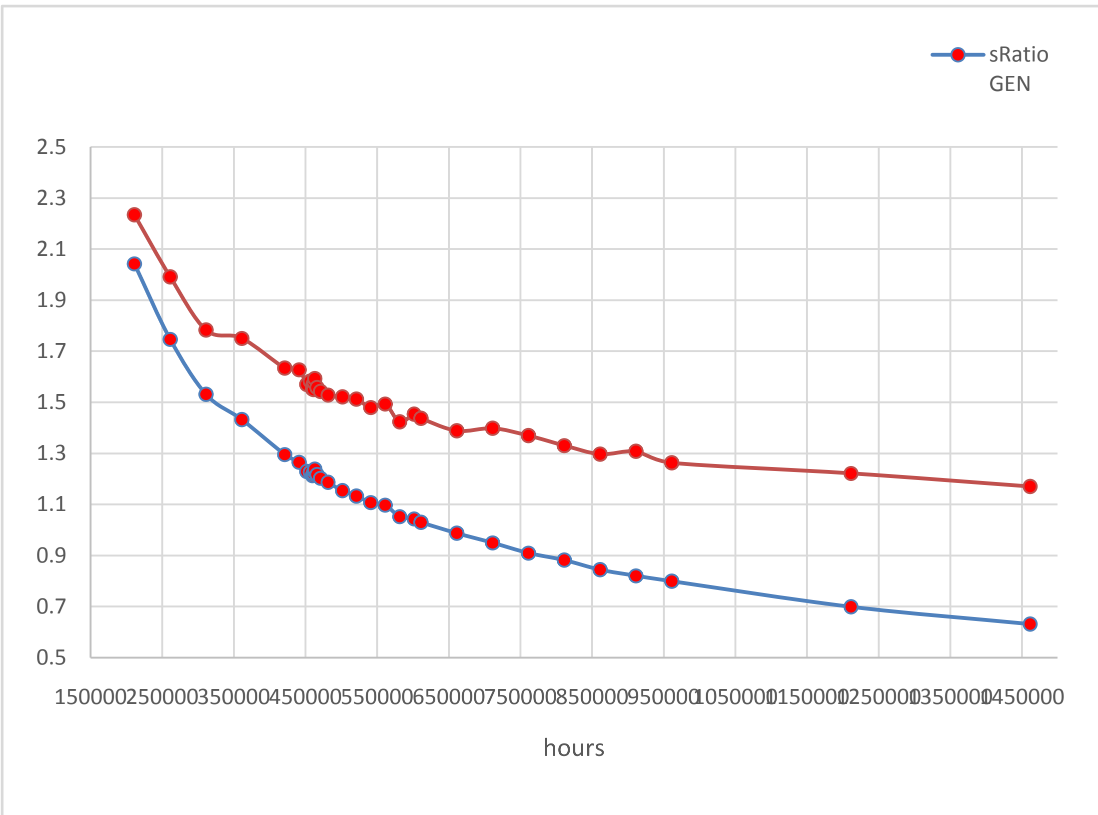

Figure 10–Show the relationship for MLI/BAY at const MLI0 and Gen 0

9.2 MLI/MLI Events at constant MLI Zero value

The hypothesis on this study will depend on using MLI Technique to estimate the failure rate, if MLI standard deviation was almost the same Bayesian standard deviation. Otherwise, more details must be required to make MLI standard deviation much closer to Bayesian standard deviation. If MLI and Bay could not be almost the same, so Bayesian technique still using to estimate failure rates.

9.2.1 Basic event 1THCAT9A3F

- Next, the following table was done below to show the relationship between MLI time beta in hours versus mean standard deviation ratio for MLI/MLI and then see it as a graph drawing

Time β MLI	ST.Dev Ratio
4093051.65	1.027
4293051.65	1.018
4493051.65	1.017
4693051.65	1.031
4893051.65	1.024
5093051.65	1.027
5293051.65	1.056
5493051.65	1.017
5693051.65	1.021
5893051.65	1.017
6093051.65	1.028
6293051.65	1.02
6493051.65	1.007
6693051.65	1.014

Table 9- for basic event 1THCAT9A3F for MLI/MLI

The following graph show the relationship between mean Standard deviation for MLI and MLI time in hours. From the graph, it is clear that mean standard deviation ratio is almost stable at one with time progressing in hours for basic event 1THCAT9A3F. . That means MLI can be used effectively for this basic event.

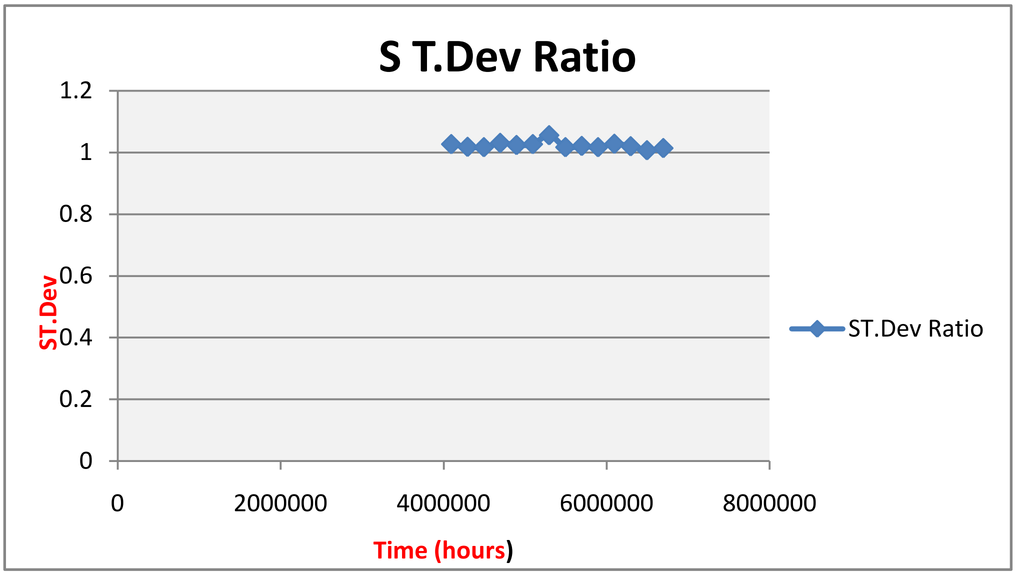

Figure 11 – show the relationship for basic event 1THCAT9A3F for MLI/MLI at constant MLI0

9.2.2 Basic event 1VE81052AR

- The following table was done below to show the relationship between MLI time beta in hours versus mean standard deviation ratio for MLI/MLI at constant origin MLI and then see it as a graph drawing.

Time β MLI	St.Dev Ratio
210854.52	1.39
410854.52	1.218
610854.52	1.156
810854.52	1.112
1010854.52	1.097
1210854.52	1.07
1410854.52	1.069
1610854.52	1.058
1810854.52	1.051
2010854.52	1.051
2210854.52	1.047
2410854.52	1.042
2610854.52	1.034
2810854.52	1.022

Table 10 - for basic event 1VE81052AR for MLI/MLI at Constant MLI0

- The following graph show the relationship between mean Standard deviation for MLI and MLI at constant origin MLI value and MLI time in hours. From the graph, it is clear that mean standard deviation ratio is decreasing gradually to one with time progressing in hours for basic event1VE81052AR.That means MLI cannot be used for this basic event and should remain using Bayesian.

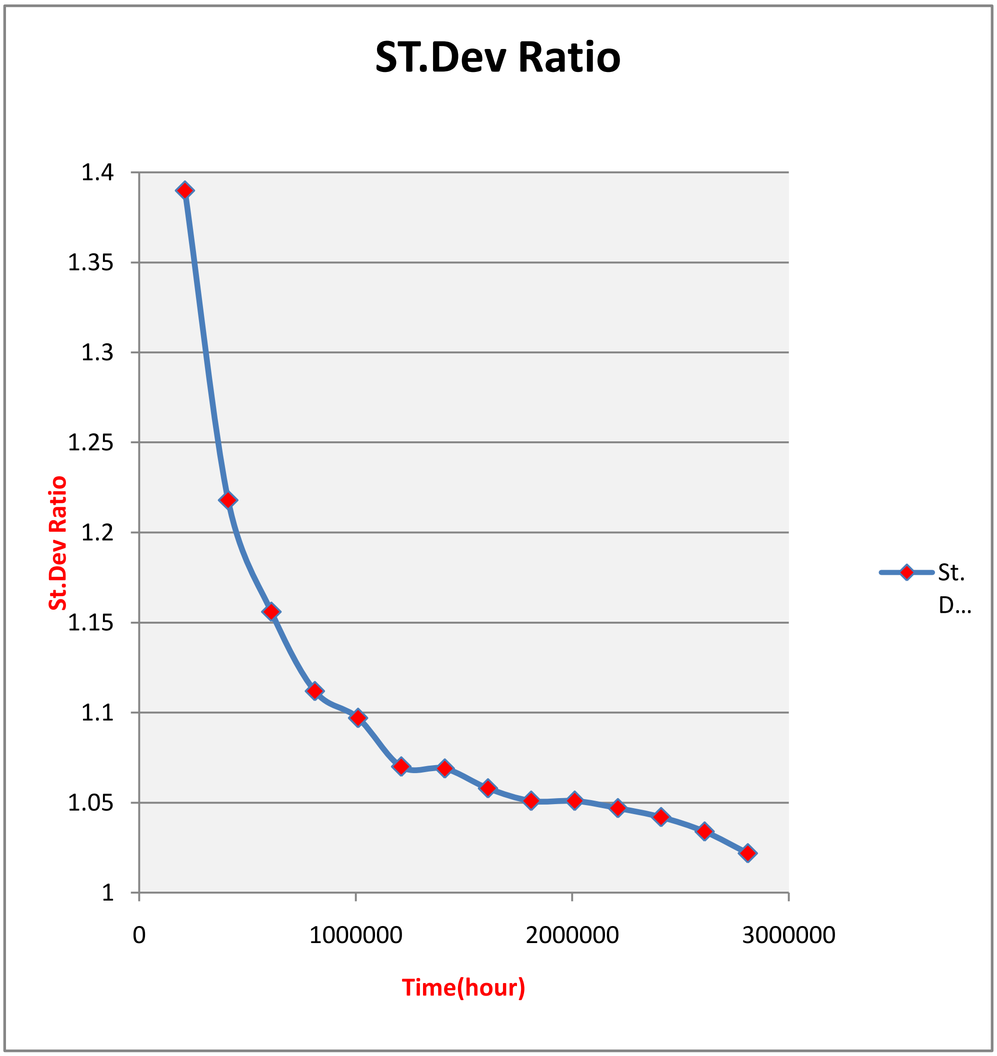

Figure 12 - show the relationship for basic event 1VE81052AR for MLI/MLI at constant MLI

9.2.3 Basic event 1VK360001O

Next, the following table was done below to show the relationship between MLI time beta in hours versus mean standard deviation ratio for MLI/MLI at constant origin MLI and then see it as a graph drawing.

Time β MLI	ST.Dev Ratio
1002554.7	1.094
1202554.7	1.079
1402554.7	1.075
1602554.7	1.068
1802554.7	1.053
2002554.7	1.049
2202554.7	1.042
2402554.7	1.042
2602554.7	1.04
2802554.7	1.038
3002554.7	1.038
3202554.7	1.028
3402554.7	1.033
3602554.7	1.029

Table 11 - for basic event 1VK360001O for MLI/MLI at Constant MLI0

The following graph show the relationship between mean Standard deviation for MLI and MLI at constant origin MLI value and MLI time in hours. From the graph, it is clear that mean standard deviation ratio is stable at one with time progressing in hours for basic event 1VK360001O.That means MLI can be used for this basic event effectively.

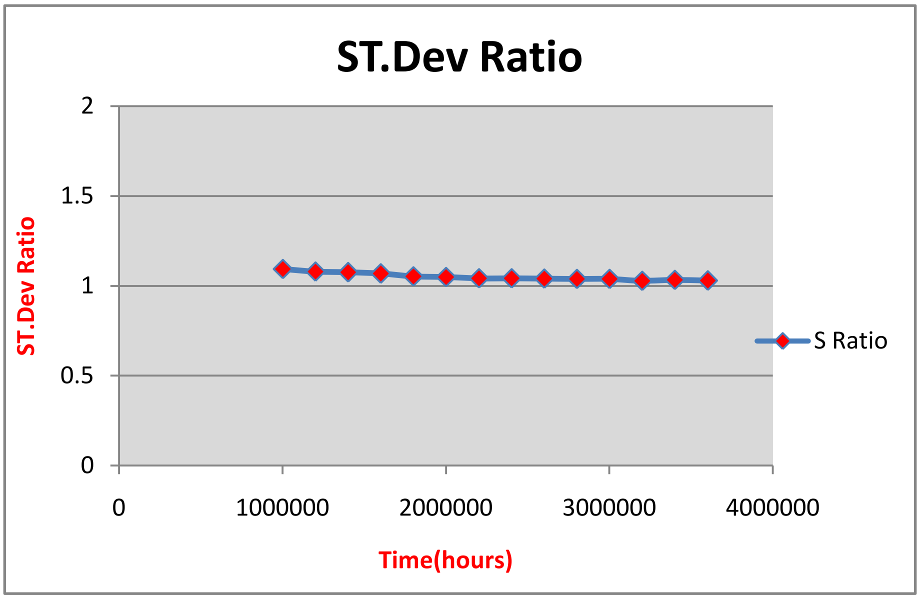

Figure 13 show the relationship for basic event 1VK360001O for MLI/MLI at constant MLI 0

9.2.4 Basic event 1REPK602AE.

- Next, the following table was done below to show the relationship between MLI time beta in hours versus mean standard deviation ratio for MLI/MLI at constant origin MLI and then see it as a graph drawing.

Time β MLI	St.Dev Ratio
22694466.67	1.009
22894466.67	1.006
23094466.67	1.008
23294466.67	1.006
23494466.67	1.006
23694466.67	0.996
23894466.67	1.001
24094466.67	1.003
24294466.67	1.001
24494466.67	1.001
24694466.67	1.004
24894466.67	1.002
25094466.67	1.002
25294466.67	1.001

Table 12- for basic event 1REPK602AE for MLI/MLI at Constant MLI0

- The following graph show the relationship between mean Standard deviation for MLI&MLI at constant origin MLI value and MLI time in hours. From the graph, it is clear that mean standard deviation ratio is stable at one with time progressing in hours for basic event 1REPK602AE.That means MLI can be used for this basic event effectively.

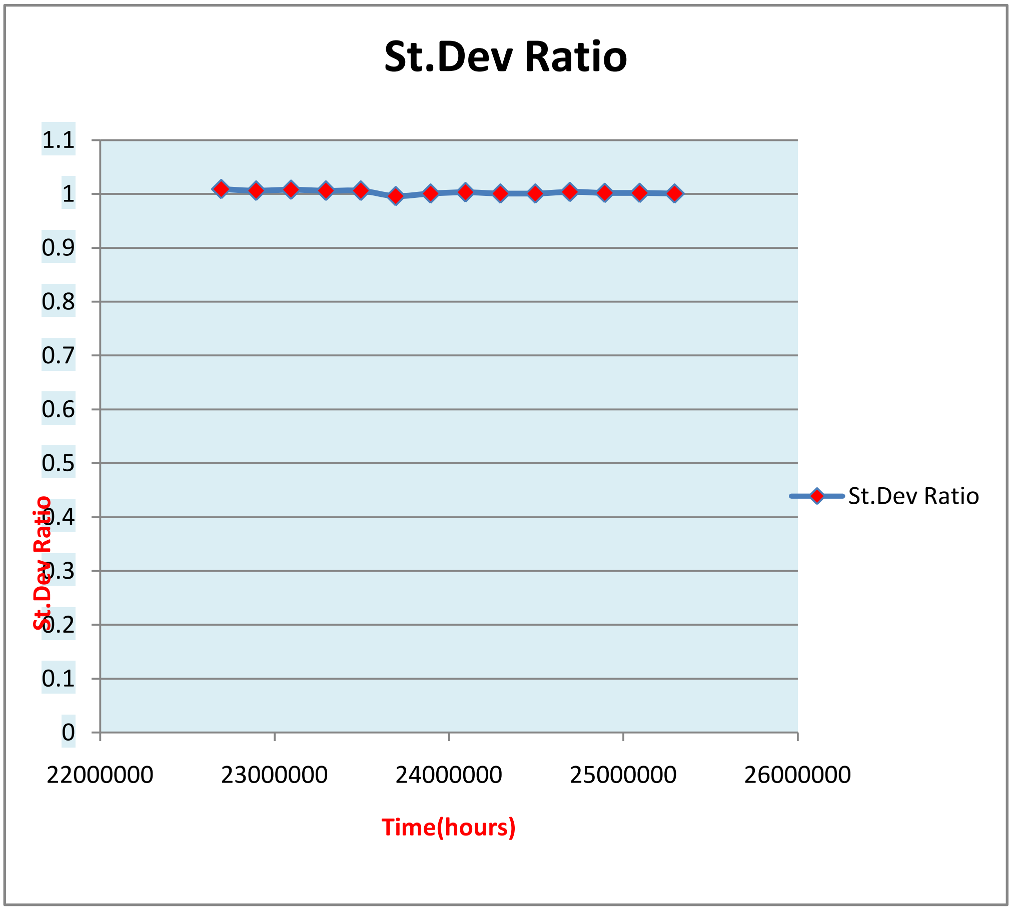

Figure 14 show the relationship for basic event 1REPK602AE at MLI/MLI at constant MLI 0

9.2.5 Basic event (1EN81B06AR)

for MLI/Gen and for MLI/BAY

Time β MLI (h)	sRatioGEN	sRatio BAY
211274.47	2.043	2.234
261274.47	1.747	1.991
311274.47	1.531	1.783
361274.47	1.432	1.751
421274.47	1.296	1.634
441274.47	1.266	1.628
451274.47	1.229	1.57
456274.47	1.227	1.582
459274.47	1.213	1.552
460274.47	1.22	1.57
461274.47	1.222	1.55
462274.47	1.231	1.578
463274.47	1.238	1.592
466274.47	1.216	1.557
471274.47	1.203	1.542
481274.47	1.186	1.529
501274.47	1.154	1.521
521274.47	1.132	1.512
541274.47	1.108	1.48
561274.47	1.098	1.494
581274.47	1.053	1.423
601274.47	1.044	1.453
611274.47	1.03	1.437
661274.47	0.987	1.388
711274.47	0.95	1.398
761274.47	0.91	1.369
811274.47	0.882	1.331
861274.47	0.844	1.297
911274.47	0.821	1.308
961274.47	0.799	1.263
1211274.47	0.699	1.222
1461274.47	0.631	1.17

Table 13–For Distinguish basic event for MLI/Gen and for MLI/BAY

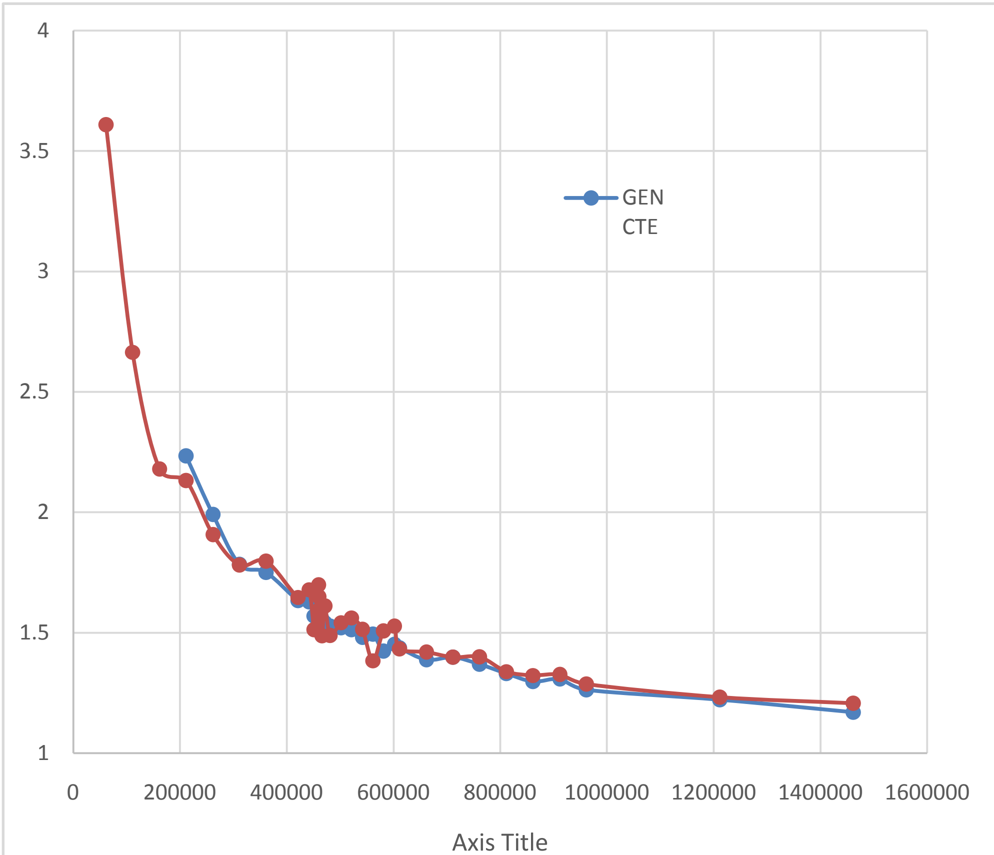

Figure 15 - show the relationship MLI and Generic with mean standard deviation ratio

- The following graph show the relationship between mean Standard deviation for MLI and MLI at constant origin MLI value and MLI time in hours. From the graph, it is clear that mean standard deviation ratio is decreasing gradually to one with time progressing in hours for that basic event. That means MLI cannot be used for this basic event and should remain using Bayesian.

9.3 Distribution graphs Results

In this section, the comparison between MLI technique and Bayesian technique will be evaluated throughout distribution graphs, which are included distribution shape, distribution width and the probability density functions.
IF the MLI and Bayesian distribution shape and its width are close to each other, then we can use MLI technique for that certain basic event definitely.

IF not so close enough to each other through those distributions, then we must remain using the Bayesian technique for those basic events.

Therefore, the same five previous cases for basic events will be mentioned here again for studying its distribution graphs and then determine which technique is more appropriate.

9.3.1 Basic event 1THCAT9A3F

This section presents the probability density functions for the gamma distributions of MLI and Bayesian in different situations and as shown in the graph, the blue line represents MLI and the red line represents Bayesian and their distribution width are nearly the same, so we can use MLI in this basic event.

- Data origin MLI vs Data origin Bayesian

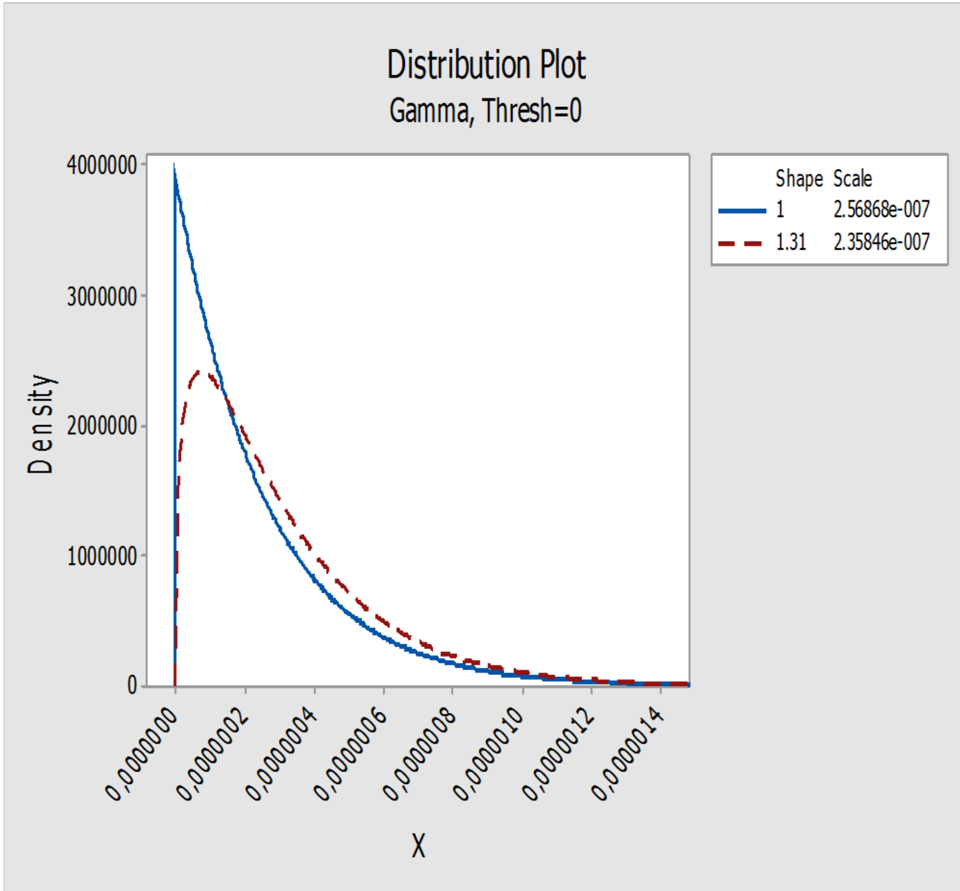

Figure 16- – probability density for basic event 1THCAT9A3F

- Data origin MLI vs Last time studied Bayesian

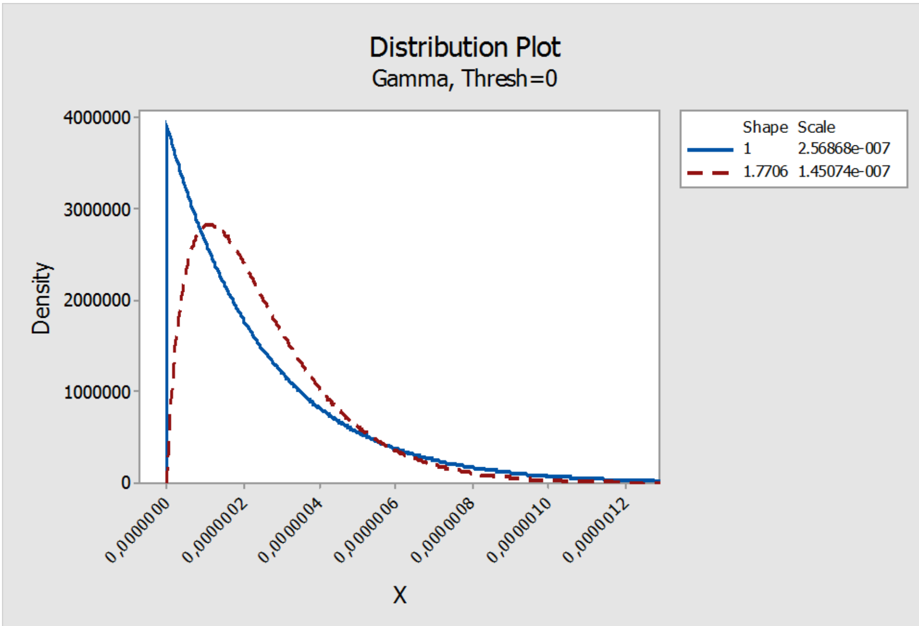

Figure17 – Probability density for basic event 1THCAT9A3F

- Last time studied MLI Vs Last time studied BAY

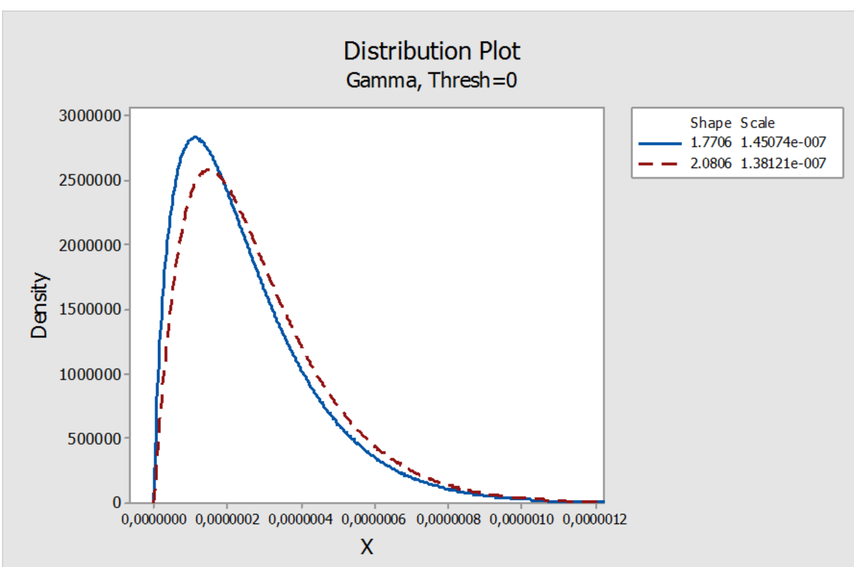

Figure- 18 - Probability density for basic event 1THCAT9A3F

9.3.2 Basic event 1VE81052AR

- This section presents the probability density functions for the gamma distributions of MLI and Bayesian in different situations and as shown in the graph, the blue line represents MLI and the red line represents Bayesian and their distribution width are not the same, so we cannot use MLI in this basic event.

- Data origin MLI Vs Data origin BAY

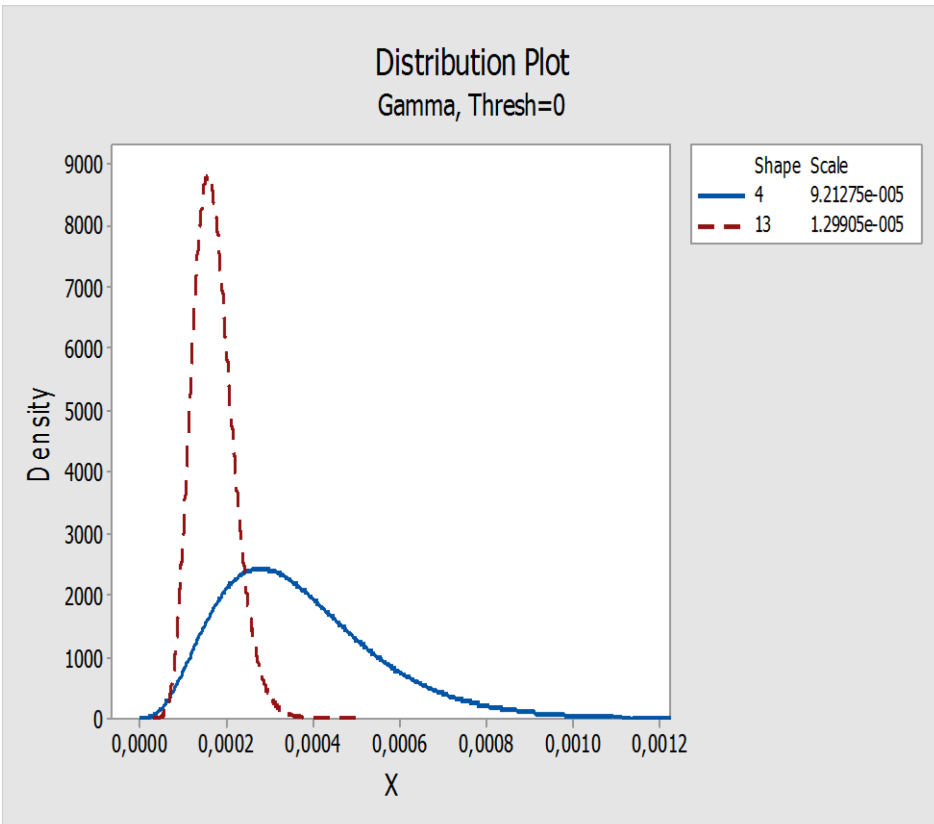

Figure 19 – probability density for basic event 1VE81052AR

- Data origin MLI VS Last Studied BAY

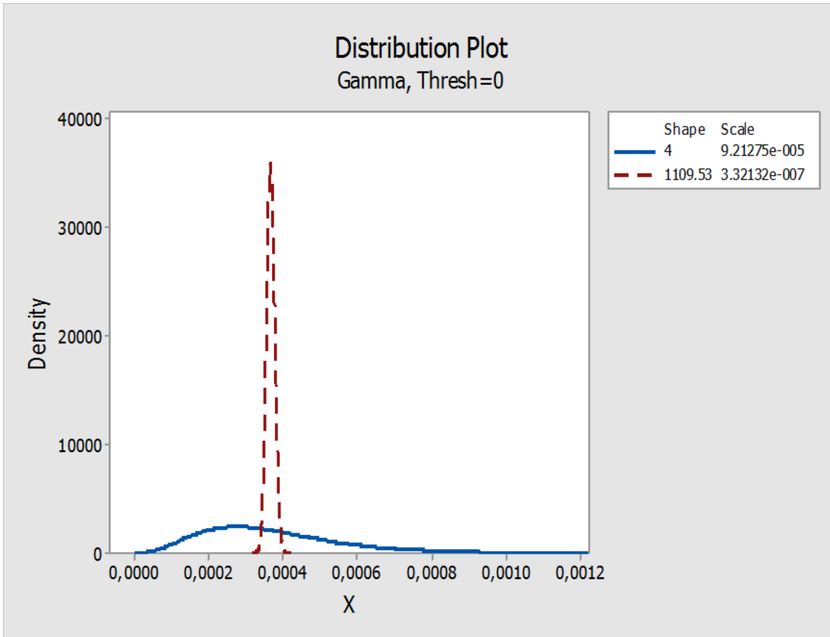

Figure 20 – Probability density for basic event 1VE81052AR

- Last studied MLI vs Last studied Bayesian

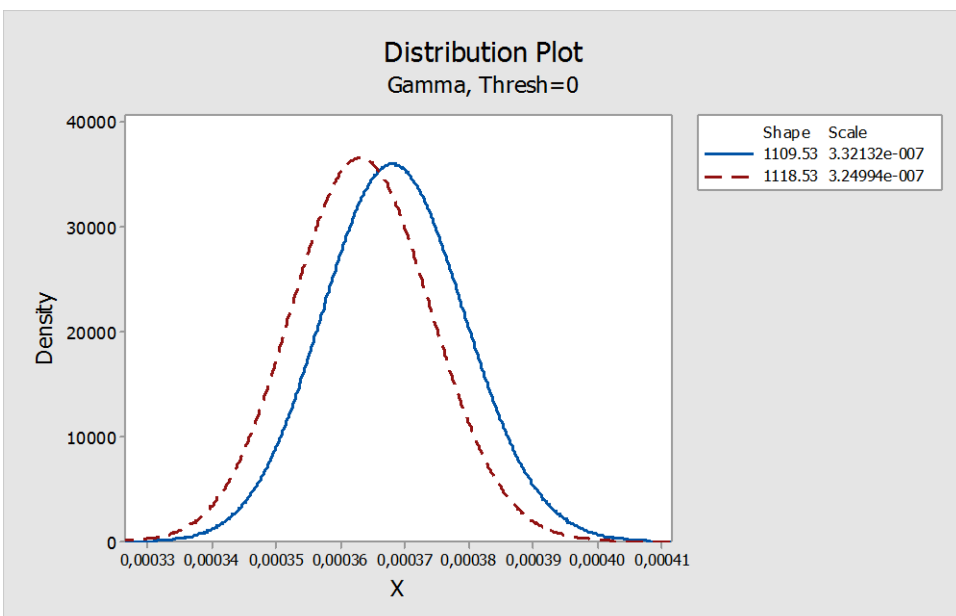

Figure 21 – Probability density for basic event 1VE81052AR

9.3.3 Basic event 1VK360001O

This section presents the probability density functions for the gamma distributions of MLI and Bayesian in different situations and as shown in the graph, the blue line represents MLI and the red line represents Bayesian and their distribution width are very different, so we cannot use MLI in this basic event.

- Data origin MLI & Data origin BAY

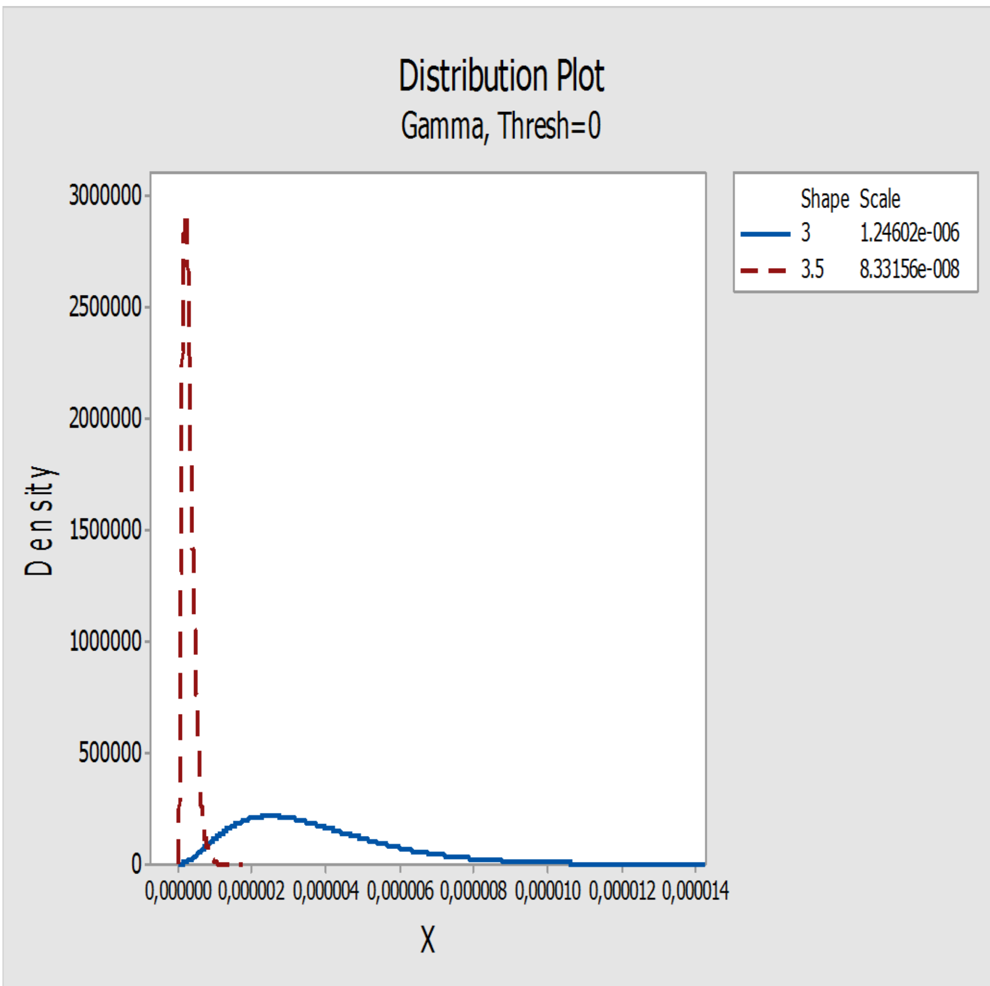

Figure 22 - Probability density for basic event 1VK360001O

- Data origin MLI Vs Last time studied MLI

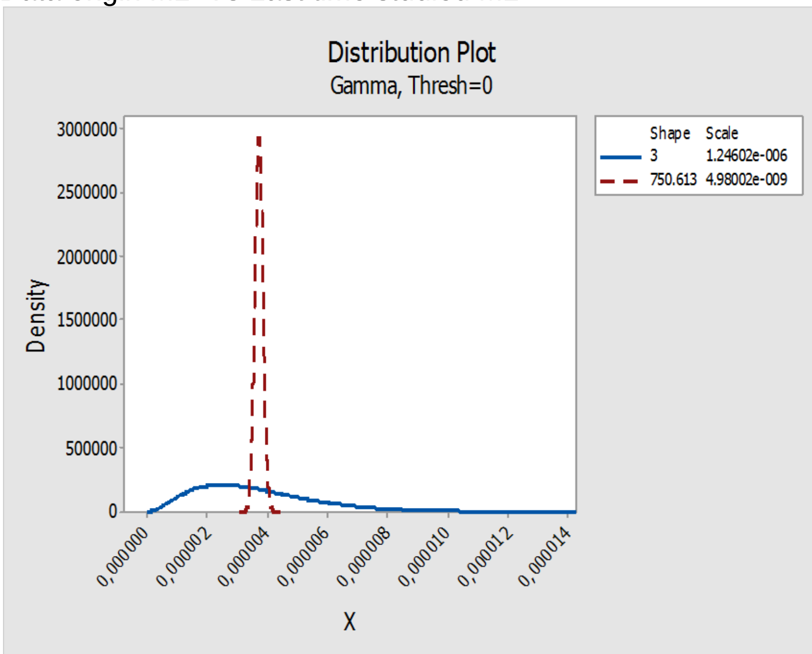

Figure 23 - Probability density for basic event 1VK360001O

- Last studied MLI Vs Last studied BAY

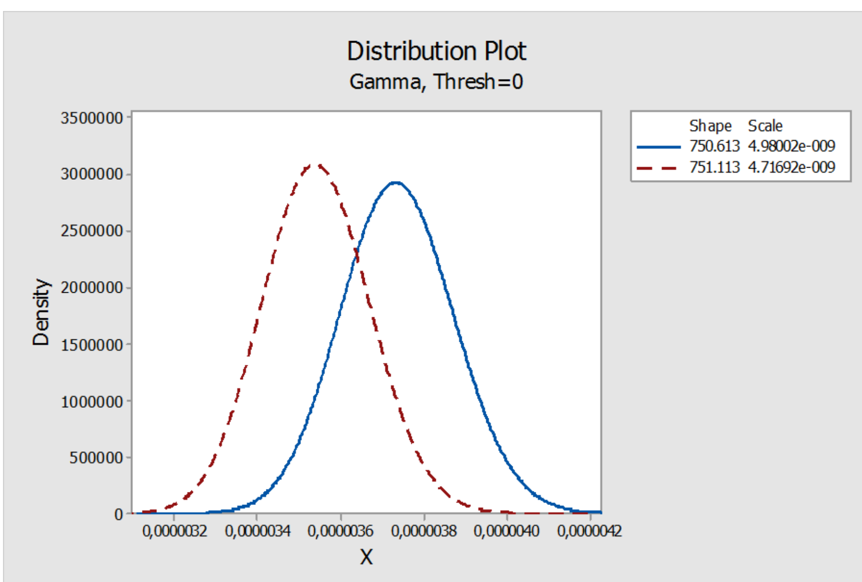

Figure 24-Probability density for basic event 1VK360001O

9.3.4 Basic event 1REPK602AE

- This section presents the probability density functions for the gamma distributions of MLI and Bayesian in different situations and as shown in the graph, the blue line represents MLI and the red line represents Bayesian and their distribution width are nearly the same, so we can use MLI in this basic event.

- Data origin MLI Vs Data origin BAY

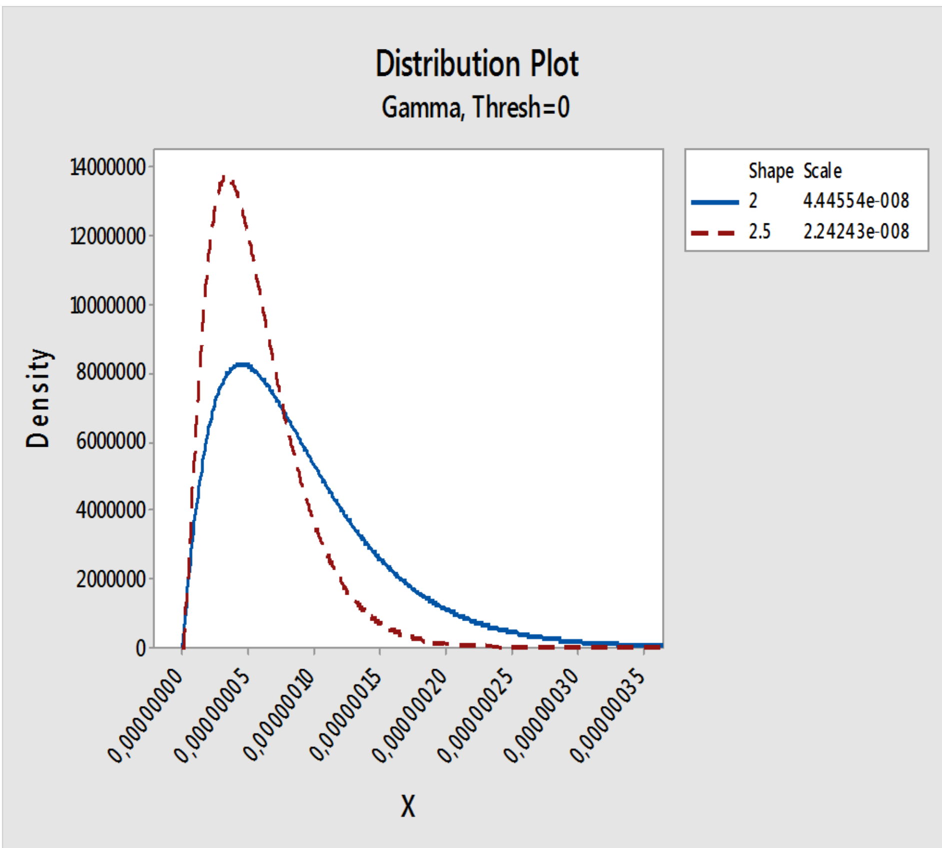

Figure 25 – Probability density for basic event 1REPK602AE

Data origin MLI Vs Last studied MLI

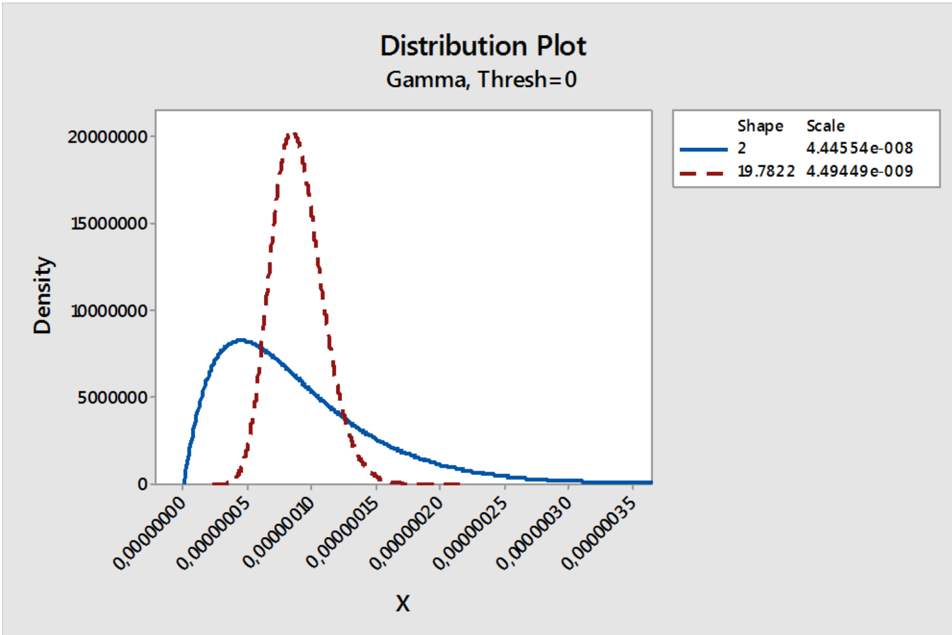

Figure 26– probability density for basic event 1REPK602AE

- Last studied MLI Vs Last studied BAY

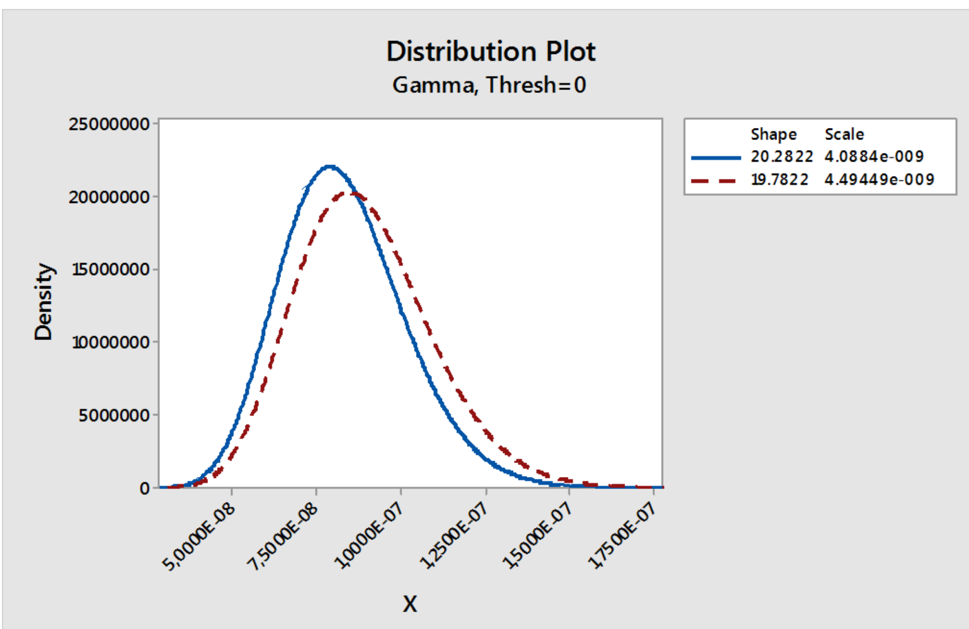

Figure 27 – probability density for basic event 1REPK602AE

9.3.5 Basic event (1EN81B06AR)

This section presents the probability density functions for the gamma distributions of MLI and BAY in different situations and as shown in the graph, the blue line represents MLI and the red line represents Bayesian and their distribution width are so different, so it could not be use MLI in this case.

- Data origin MLI Vs Data origin BAY

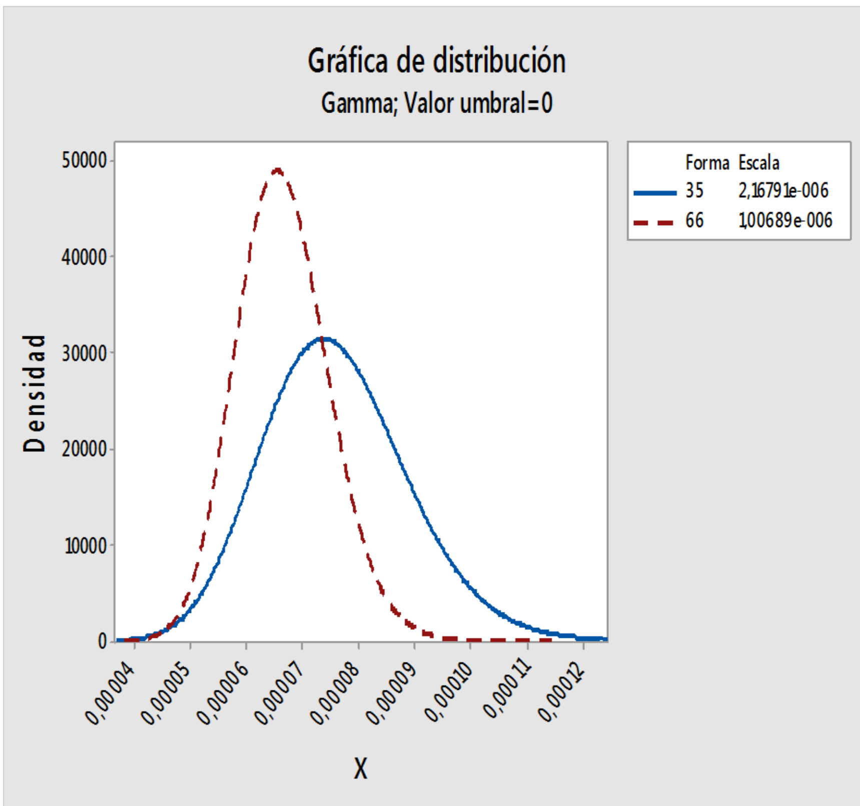

Figure 28 – Probability density for distinguish basic event

- Data Origin MLI Vs Last studied BAY

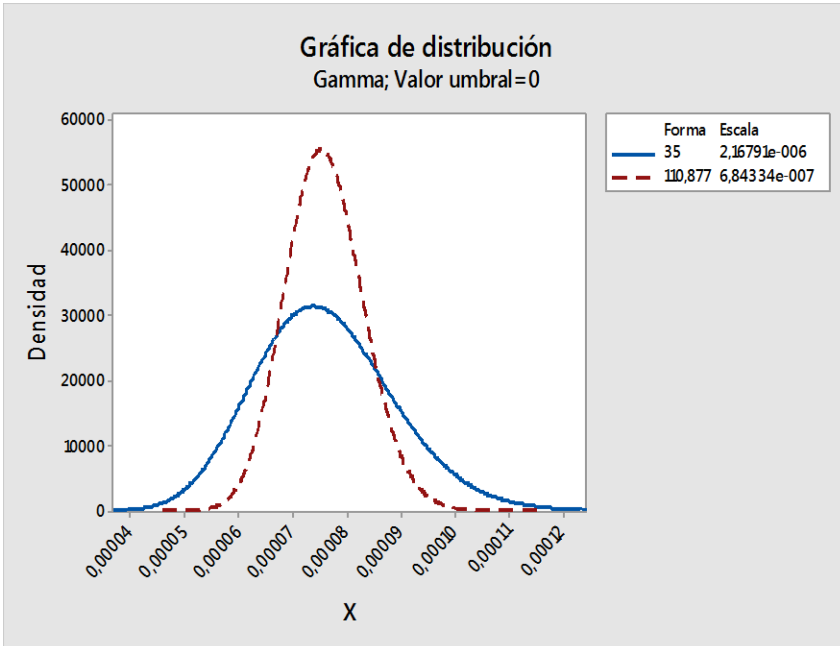

Figure 29 – Probability density for distinguish basic event

- Last studied MLI Vs Last studied BAY

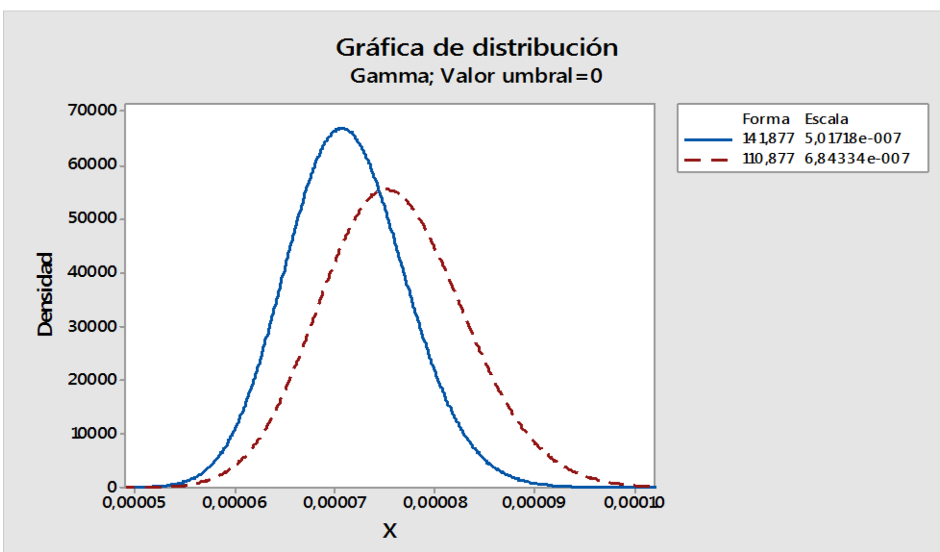

Figure 30– probability density for distinguish basic event

10. CDF calculations for the modified basic events

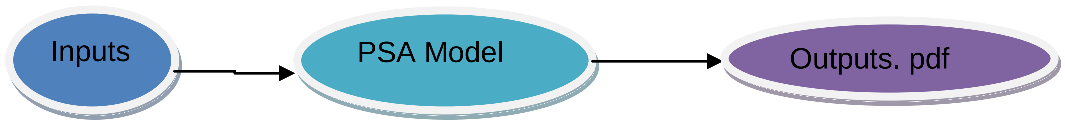

Figure 31 – Diagram shows the project processes

In this section, Core damage Frequencies will be recalculated for the previous basic events which were not accurate with the MLI technique in compare with Bayesian technique. CDF was calculated by using Risk Spectrum Program again to get these results from it directly and these results are considered the main practical application for our project and it must send to the NPP safety committee to put it in their consideration in future time for these basic events mentioned here, which are not the same core damage frequencies were mentioned before in Data document, which is the main reference in our project. These modifications were carried out by using the Bay inputs instead of MLI inputs and use RS PSA model to recalculate CDF.

These modifications will help to determine the priorities components in our reactor that needs to maintenance activities and then assuring the budget of maintenance will be consumed in optimal way, which also lead to minimize the accidents during operation and prevents shutdowns the reactor as less as it can.

ID	Calculation Type		MCS Results	UNC Mean	5%	Median	95%
FDN	EQUATION core damage(E-9)	F	1.10E-05	1.07E-05	3.69E-06	8.48E-06	2.40E-05
FDN (1VK360001O)	EQUATION core damage(E-9)	F	9.91E-06	1.04E-05	3.26E-06	7.47E-06	2.36E-05
FDN (1VE81052AR)	EQUATION core damage(E-9)	F	1.03E-05	1.00E-05	3.42E-06	7.87E-06	2.24E-05
FDN (1VK360001F)	EQUATION core damage(E-9)	F	1.06E-05	1.11E-05	3.60E-06	8.15E-06	2.52E-05
FDN (1EN81B06AR)	EQUATION core damage(E-9)	F	1.10E-05	1.07E-05	3.69E-06	8.48E-06	2.40E-05

Table 14- Modification calculations

Conclusion

Throughout this research and technical working, mean Standard deviation ratios for basic events must be used to evaluate the feasibility of a methodology to help in making decision which technique is more appropriate. Firstly, performed the required calculations for ten cases of basic events as shown in details in Appendix book from page 38. Therefore, just five basic events were chosen randomly from ten and mentioned here in this main report.

For Technical applications, the table 14 is show the most critical results from this study, which can be applied in real plant. For instance, the minimal cut set result was (9.91E-06) for basic event (1VK360001O) as shown in Table-14, with the MCS reference (1.10E-05), so it is lower than the reference MCS. Hence, the system will become more vulnerable, which means that Minimal cut sets can be used to understand the structural vulnerability of a system. The lower a minimal cut set is, the higher vulnerable system (or top event in fault trees) is to that combination of events such as basic events (1VE81052AR) and(1VK360001F), which have longer MCS than the reference basic events (1.03E-05) and (1.06E-05) respectively. Hence, the failure rates for their scenarios are higher. This final calculation is considered the main applicable part for that project.

This project is a continuing point, for this reason both methodology and results could be improved and used in future developments, not only in nuclear field, but in a lot of industries where the failure rate and the risk can be important as well.

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Thanks Allah for being with me in the hardest moments in my life and protect me from the worst actions. I will never walk alone.

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