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NUCLEAR WEAPON RELIABILITY EVALUATION METHODOLOGY

Donald L. Wright and Rene L. Bierbaum

Prepared by
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Albuquerque, New Mexico 87185 and Livermore, California 94550

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ABSTRACT

This document provides an overview of those activities that are normally performed by Sandia National Laboratories to provide nuclear weapon reliability evaluations for the National Nuclear Security Agency. These reliability evaluations are first provided as a prediction of the attainable stockpile reliability of a proposed weapon design. Stockpile reliability assessments are provided for each weapon type as the weapon is fielded and are continuously updated throughout the weapon stockpile life. The reliability predictions and assessments depend heavily on data from both ground simulation tests and actual flight tests. An important part of the methodology is the opportunities for review that occur throughout the entire process that assure a consistent approach and appropriate use of the data for reliability evaluation purposes.

PREFACE

This document presents an overview of the methodology used by Sandia National Laboratories (SNL) in performing reliability evaluations of nuclear weapons. It supersedes SAND93-0704, "Nuclear Weapon Reliability Evaluation Methodology", June 1993. Various information has been updated in this version, including organization numbers, references, and recent stockpile management developments. The information presented has been extracted from a companion document, the Nuclear Weapon Reliability Evaluation Methodology Guide. This Guide documents the policies, practices and processes of SNL reliability evaluation organizations. The Guide is reviewed and revised periodically to reflect current practices and is maintained by the SNL Reliability Assessment Department. For further information or detail concerning the implementation of the methodology described by this report, please contact:

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List of Acronyms

Acronym	Definition
AGM	Air-to-Ground Missile
CEP	Circular Error Probability
CRE	Component Reliability Engineer
DE	Damage Expectancy
DoD	Department of Defense
D-Test	Destructive Test
E-Test	Environmental Test
HOB	Height of Burst
ICBM	Intercontinental Ballistic Missile
JTA	Joint Test Assembly
LLCE	Limited Life Component Exchange
MC	Military Characteristic
MLE	Maximum Likelihood Estimate
NMSEP	New Material and Stockpile Evaluation Program
NNSA	National Nuclear Security Agency
PD	Probability of Damage
PLS	Pre-launch Survivability

Acronym	Definition
PTP	Probability to Penetrate
REST	Retrofit Evaluation System Test
RRP	Reliability Review Panel
SFI	Significant Finding Investigation
SIOP	Single Integrated Operational Plan
SLBM	Submarine-Launched Ballistic Missile
SNL	Sandia National Laboratories
SRE	System Reliability Engineer
STS	Stockpile-to-Target Sequence
UCL	Upper Confidence Limit
USSTRATCOM	United States Strategic Command
WR	War Reserve
WRR	Weapons Reliability Report
WSR	Weapon System Reliability

NUCLEAR WEAPON RELIABILITY EVALUATION METHODOLOGY

1 Mission and Philosophy

1.1 Mission and Scope

Sandia National Laboratories (SNL) is tasked per Reference 1 to perform a periodic review of all applicable test data and to evaluate the reliability of the nuclear weapon systems for the National Nuclear Security Agency (NNSA). The purpose of this document is to describe the reliability analysis methodology for nuclear weapon ordnance as employed by SNL. The methodology presented is based upon either a complete weapon development program or an upgrade to an existing weapon through the Phase 6.X process. Both of these processes are defined in Reference 2. The methodology for a non-traditional development program is adapted from the methodology presented to provide the applicable reliability analysis elements to support the reliability evaluation needs. The methodology presented can also be modified to meet the needs of non-nuclear weapon analyses.

Unless otherwise noted, weapon refers to that entity of a nuclear weapon for which the NNSA has been assigned design and procurement responsibility. These entities are generally referred to either as warheads or bombs. The NNSA responsibility encompasses the design contributions from SNL, Los Alamos National Laboratory, and Lawrence Livermore National Laboratory. For certain weapons in which the NNSA portion is integrated with the Department of Defense (DoD) portion, SNL participates in joint NNSA/DoD reliability evaluations and reports the results of these joint studies.

1.2 Analysis Context

The NNSA weapon reliability definition and assessment methodology were carefully constructed to integrate appropriately into the larger DoD weapon system assessment and planning process. The integration of NNSA weapon reliability occurs in the calculation of Damage Expectancy (DE) performed by USSTRATCOM to support the development of the Single Integrated Operational Plan (SIOP). The DE calculation addresses the end-to-end mission and includes the complete complement of NNSA and DoD hardware and DoD operational procedures used to execute the mission.

The four major terms in the DE calculation are illustrated in Figure 1.

- Prelaunch Survivability (PLS)
- Weapon System Reliability (WSR)
- Probability to Penetrate (PTP)
- Probability of Damage (PD).

These terms are all conditional probabilities - e.g., the WSR is calculated assuming a successful prelaunch. NNSA weapon reliability is part of the WSR term. The PD term is a function of discrete variables including yield, accuracy (both Height of Burst and Circular Error Probable), and target hardness, and it assumes these yield and accuracy values have been achieved. All performance information for NNSA material in the DE calculation is thus captured in the WSR and PD terms. The weapon yield and accuracy values used in the PD term provide the context for assessing weapon reliability. Figure 2 shows what functions are included in the WSR term by weapon system type. DoD and NNSA are both responsible for various elements of the WSR term. The NNSA Weapons Reliability Report, as denoted in Figure 2, is the source of NNSA inputs.

Figure 1: Damage Expectancy Probability Model

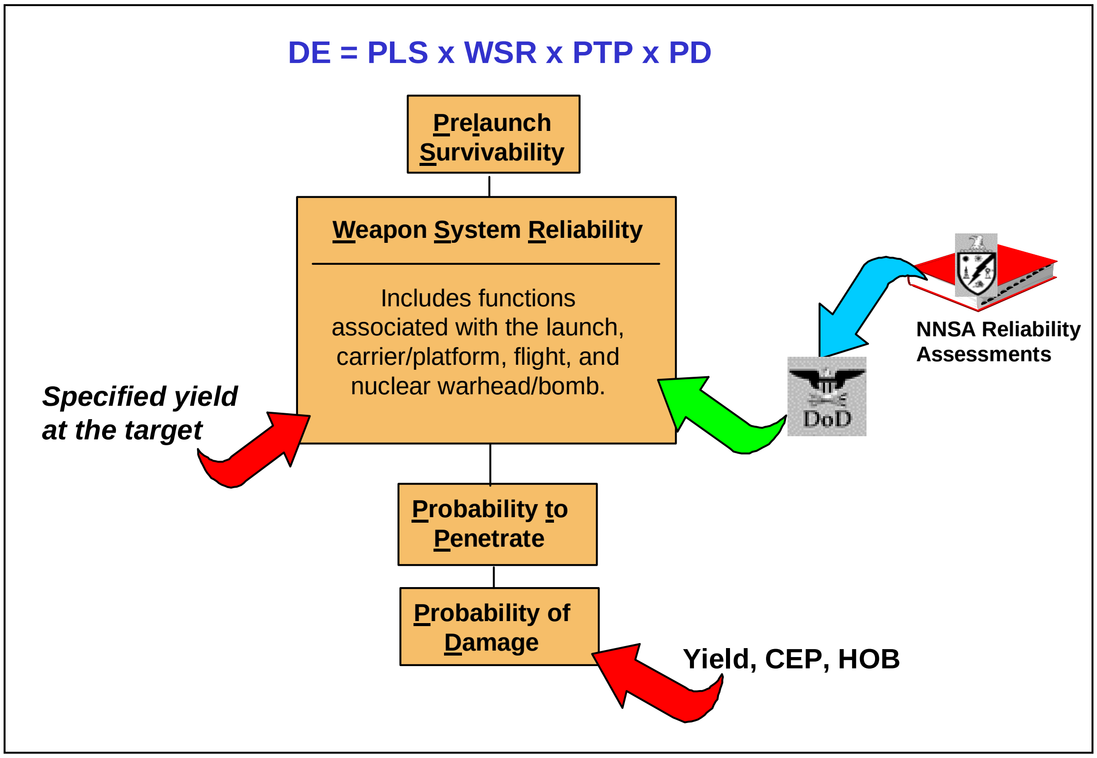
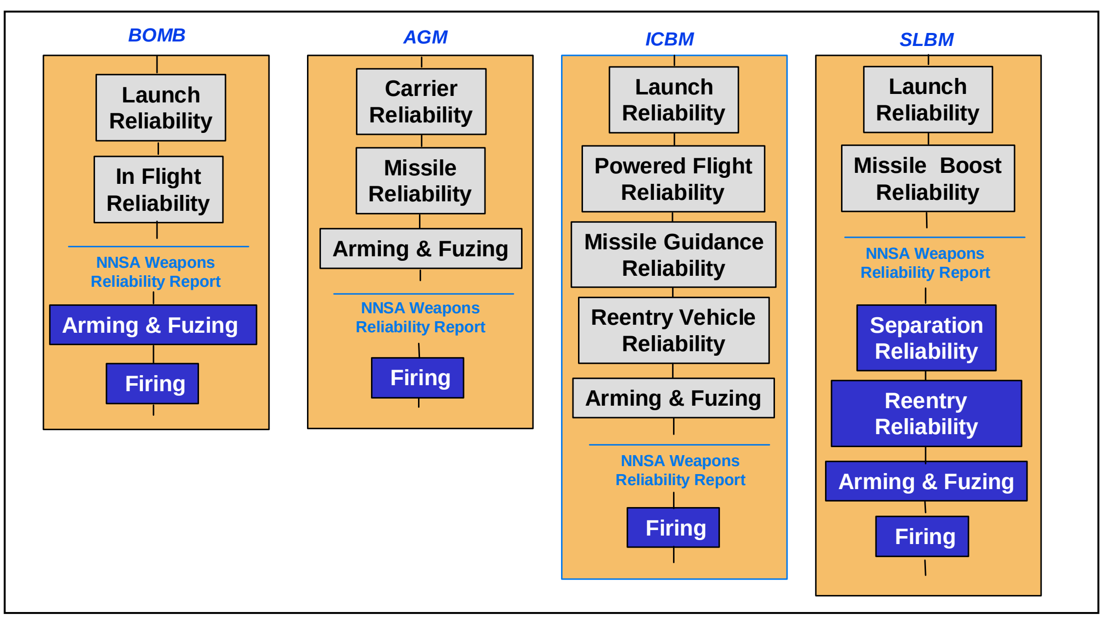


Figure 2: Weapon System Reliability Elements



1.3 Definition of Nuclear Weapon Reliability

Functional nuclear weapon reliability is defined as the probability that during the stockpile life of the weapon and over the envelope of normal environments defined in the Stockpile-to-Target Sequence (STS), the specified nuclear yield at the target will be achieved. The reliability definition is described in detail in Reference 3.

The reliability requirements and specifications for nuclear weapons are contained in Military Characteristics (MCs) and Stockpile-to-Target Sequence (STS) documents. These documents are provided by the DoD and define the required weapon functions and the envelope of environmental conditions to which the weapon may be subjected in the normal course of stockpile storage and conflict usage. These documents also specify certain requirements for the weapon in the event of or following exposure to "abnormal" or accident environments. It is assumed that weapon functionality is not assured during or following exposure to any environment beyond the normal environment envelope. Thus, the evaluation methodology described in this document assumes only "normal" environment situations.

A functional reliability requirement for differing delivery and/or firing options may be specified individually in the MCs. Certain improper operations such as higher-than-selected nuclear yield may also have probability requirements of occurrence or non-occurrence specified. The functional reliability and premature probability requirements associated with certain use-control functions may be specified. Each of these requirements (both functional and premature) is evaluated using the methodology described in this document.

For evaluation purposes, the stockpile life of a weapon is assumed to include the most severe combination of dormant storage and delivery normal environments specified, including maximum dormant storage time. There are several undesirable weapon behaviors that can occur during weapon stockpile life. Figure 3 illustrates the relationship of various behaviors in the weapon total mission time domain, including dormant stockpile storage. Weapon success can occur only in a small window of the actual use life of the weapon. The remaining time windows can have certain undesirable weapon behaviors that preclude success. The reliability of the weapon can be estimated by mathematical combination of the probabilities of occurrence of these undesirable behaviors which are described below. The probability associated with each individual behavior is not analyzed separately, but becomes part of the overall weapon reliability evaluation.

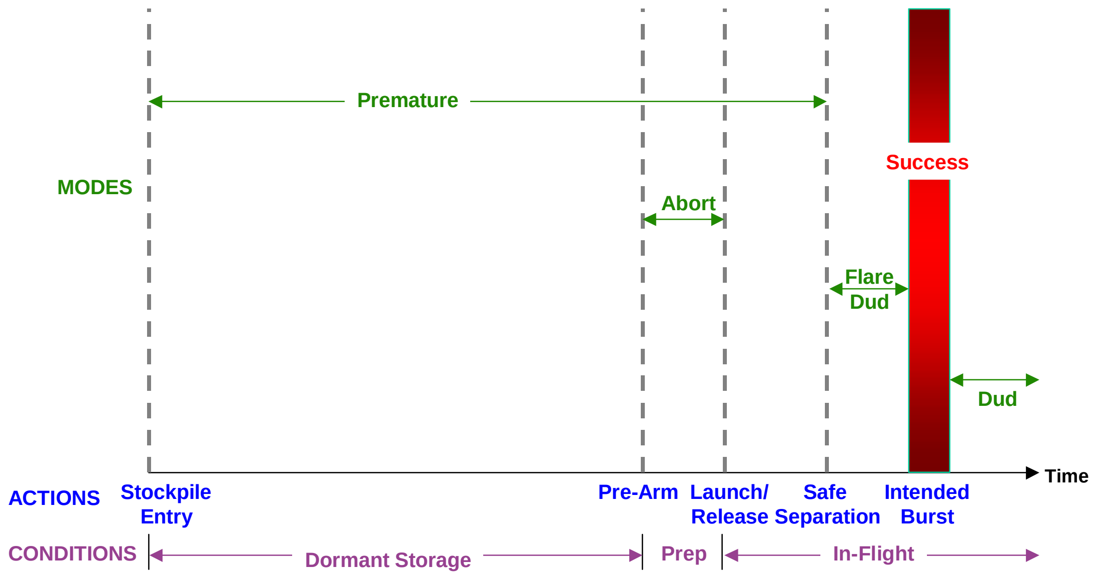
a. Premature - an unintended nuclear detonation that occurs in the normal environment prior to safe separation from the carrier. This is also a concern from the standpoint of nuclear safety along with detonation resulting from an accident environment. The normal environment premature behavior is included in the STS normal environment reliability evaluation.

b. Abort - cancellation of use of the weapon after it is "committed" to the mission, due to evidence that it would result in a failure.

c. Flare Dud - an early nuclear detonation that results in reduced target damage, but is not hazardous to friendly forces.

d. Dud - the failure to provide the prescribed function at the proper time, given proper inputs at the time of release/launch or during flight.

Figure 3: Nuclear Weapon Failure Behaviors



$$\text{RELIABILITY} = (1- P_{Premature}) \times (1- P_{Abort}) \times (1- P_{Flare\ Dud}) \times (1- P_{Dud})$$

A reliability estimate derived by the methodology presented in this document is based on the data currently available from various test programs and involves the mathematical combination of multiple probabilities. Both statistical and non-statistical types of inferences are involved in the evaluation process and have uncertainties associated with each. While statistical uncertainties can be measured by statistical confidence statements, there is no generally accepted method of measuring the non-statistical uncertainties related to the diversity of the test programs involved. Because the overall uncertainty cannot be measured, confidence limits are not associated with the reliability statements based on this methodology.

Because of the wide spectrum of expected weapon deployment and potential use conditions, reliability assessments are generally not restricted to nominal conditions or any specific weapon stockpile age. Thus, unless otherwise stated, the reliability assessments represent realistic lower bound estimates that apply over the STS, and the assessments are assumed applicable throughout the remaining intended stockpile life. By this we mean that the reliability assessment applies to the extremes of the design environments and may be better at nominal or benign conditions. An example exception to the stockpile life reliability lower bound is if unanticipated age degradation mechanisms are detected, the reliability statement will reflect a current "snapshot" of the stockpile reliability with additional notes that may project the expected rate of degradation. Note that if a Limited Life Component Exchange (LLCE) addresses aging, generally there is no impact to the system reliability assessment since it is assumed that the component will be replaced prior to affecting reliability.

2 Implementation

Reliability assessments for one-shot devices, such as nuclear weapons, must be based on statistical analysis of the results of tests of a sample of the stockpile. Furthermore, the complexity and expense of many nuclear weapon subsystems are such that large numbers of weapon tests are not feasible. Thus, subsystem-only test results must be combined with those from the weapon level testing. The evaluation methodology employs mathematical models that reflect the probabilistic contribution of various system elements to the success (or failure) of the weapon. The elements are generally evaluated in terms of their failure probability and are typically reported with two significant non-zero digits. The individual probabilities are mathematically combined and the resultant weapon success probability or reliability is typically rounded to two decimal places (similar to the reliability requirement). Because current scenarios for nuclear weapon use include deployment of small numbers of weapons, a reliability estimate is assigned to each weapon serial number to allow for identification of units with a higher likelihood of success when problems affecting a subpopulation of the stockpile are identified.

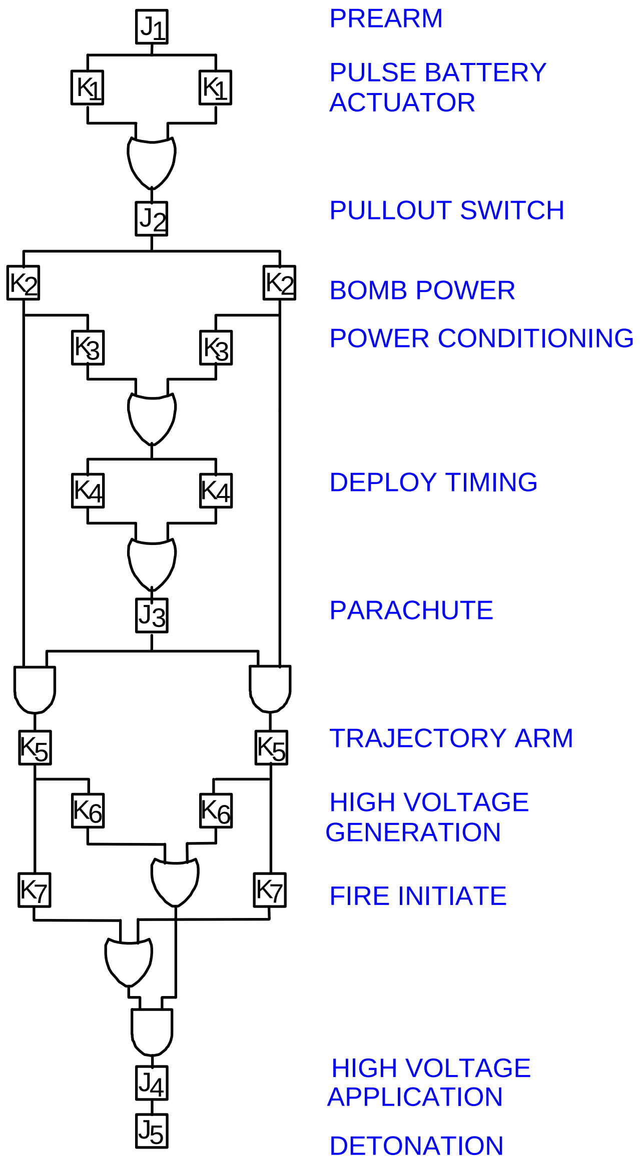
Reliability or failure probability statements are sometimes referred to as either predictions or assessments. For the purpose of this document, predictions refer to statements that rely primarily on inference or extrapolation from similar if not directly applicable data. Assessments on the other hand are based on actual test data. The methodology employed for both the assessment and prediction analysis processes is essentially identical. Thus, the term "prediction" can generally be substituted whenever "assessment" is used to discuss the general methodology.

The following three sections cover the three primary elements of the evaluation methodology: reliability modeling, failure event probability quantification, and system reliability estimation. This process is used both for new weapon development and for Phase 6.X activities.

2.1 Reliability Modeling

A System Reliability Engineer (SRE) is assigned weapon reliability evaluation responsibilities early in the weapon proposal or development phase. The SRE's first step is to represent the major functions of the weapon design in terms of expected and desired subsystem and component behaviors. This process is referred to as modeling and the usual result is a diagrammatic representation of the interrelating component and subsystem behaviors and a set of reliability mathematical equations. Various assumptions affect the accuracy of the mathematical equation and its evaluation. Figure 4 gives an example reliability block diagram model. Successful weapon function requires successful operation of all events listed. Some operations are represented by single blocks while others have two blocks, either of which can provide the needed operation. These functional relationships lead to a mathematical expression (see Figure 4) relating the weapon reliability to the failure probabilities for the component or subsystem behaviors. The reliability block diagram (and associated mathematical equation) is a means of expressing the required weapon reliability logic in terms of component and subsystem behavior probabilities. The individual terms of the expanded mathematical expression for the block diagram represent the behaviors (or events) of interest.

Figure 4: Example Block Diagram



$$R \approx \left[\prod_{i=1}^{5} (1 - J_i) \right] \times \left[1 - \left(\sum_{i=1}^{7} K_i^2 + 2K_2 \left(K_3 + \sum_{i=5}^{7} K_i \right) + 2K_5 (K_6 + K_7) \right) \right]$$

The reliability model is an integral part of a series of analyses performed throughout the weapon development, production, and stockpile phases until the weapon system is retired from stockpile. The initial analysis is an estimate of the reliability assessment expected to be attainable by a weapon system that has completed the necessary development phases and production acceptance testing. The results are used to compare competing design architectures and for allocating subsystem or component reliability design goals. When the weapon enters the stockpile, the model continues to serve as the analysis framework and does so for the entire lifetime of the system.

Working with the SRE are Component Reliability Engineers (CREs) assigned to have and maintain in-depth knowledge of individual subsystems and components used in a variety of weapons. It is the responsibility of the CREs to monitor the design, development, production, and stockpile activities of their assigned subsystem and component product lines to support the SRE in developing, maintaining, and evaluating the weapon reliability model.

2.2 Failure Event Probability Quantification

There are two types of failure event quantifications – predictions and assessments. They are similar in that both are data-driven estimates of event probabilities. These two types of estimates differ in the data sources and amount of data available for each. The following sections will describe each type and the circumstances under which each is used.

2.2.1 Reliability Prediction

Reliability predictions begin as preliminary estimates performed to provide information for both the reliability that may be achieved and the potential of alternate designs. The weapon design or architecture is based on requirements from the Military Characteristics (MC) and Stockpile-to-Target Sequence (STS) documents provided by the Department of Defense (DoD). These weapon requirements are translated into subsystem requirements such that the required system functions are achieved. The initial reliability predictions for the subsystems may cause further development of the weapon architecture in order to achieve the weapon design requirements.

Predictions are initial estimates of event probabilities generally derived from historical data and experience with similar components or subsystems. This history is used by means of extrapolation to obtain an event probability estimate for a newly specified weapon application. Other databases and sources of data are also employed as needed. These predictions are the best event probability estimates available until adequate data are generated from directly applicable testing to refute or corroborate them.

As the weapon development program progresses, development test results are compared with the initial predictions which may cause adjustments to the predictions. Significantly more data become available for further comparisons during subsystem production testing for War Reserve (WR). These data provide a final confirmation of the prediction validity. Figure 5 illustrates the prediction methodology in relation to the weapon definition and design phases.

Figure 5: Reliability Prediction Data Sources

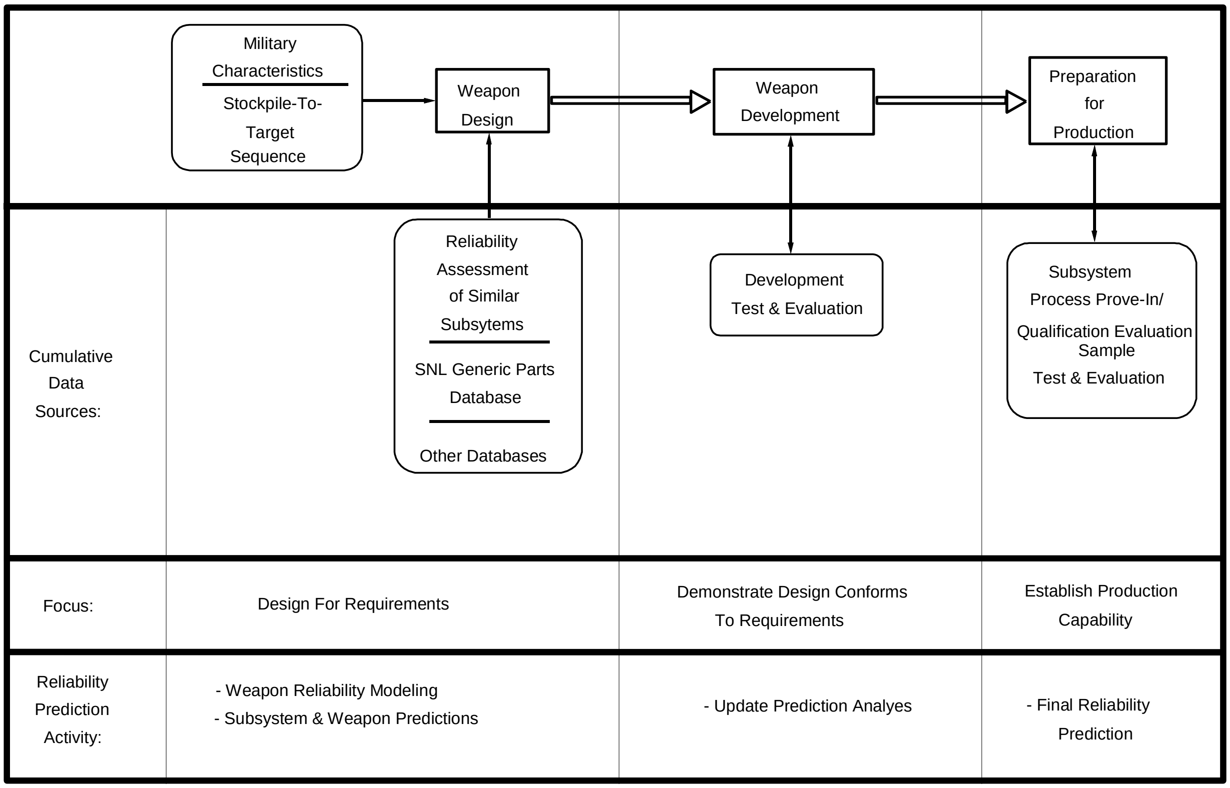


Figure 6 presents the steps of the reliability prediction process summarized below.

a. Understand proposed design and application.

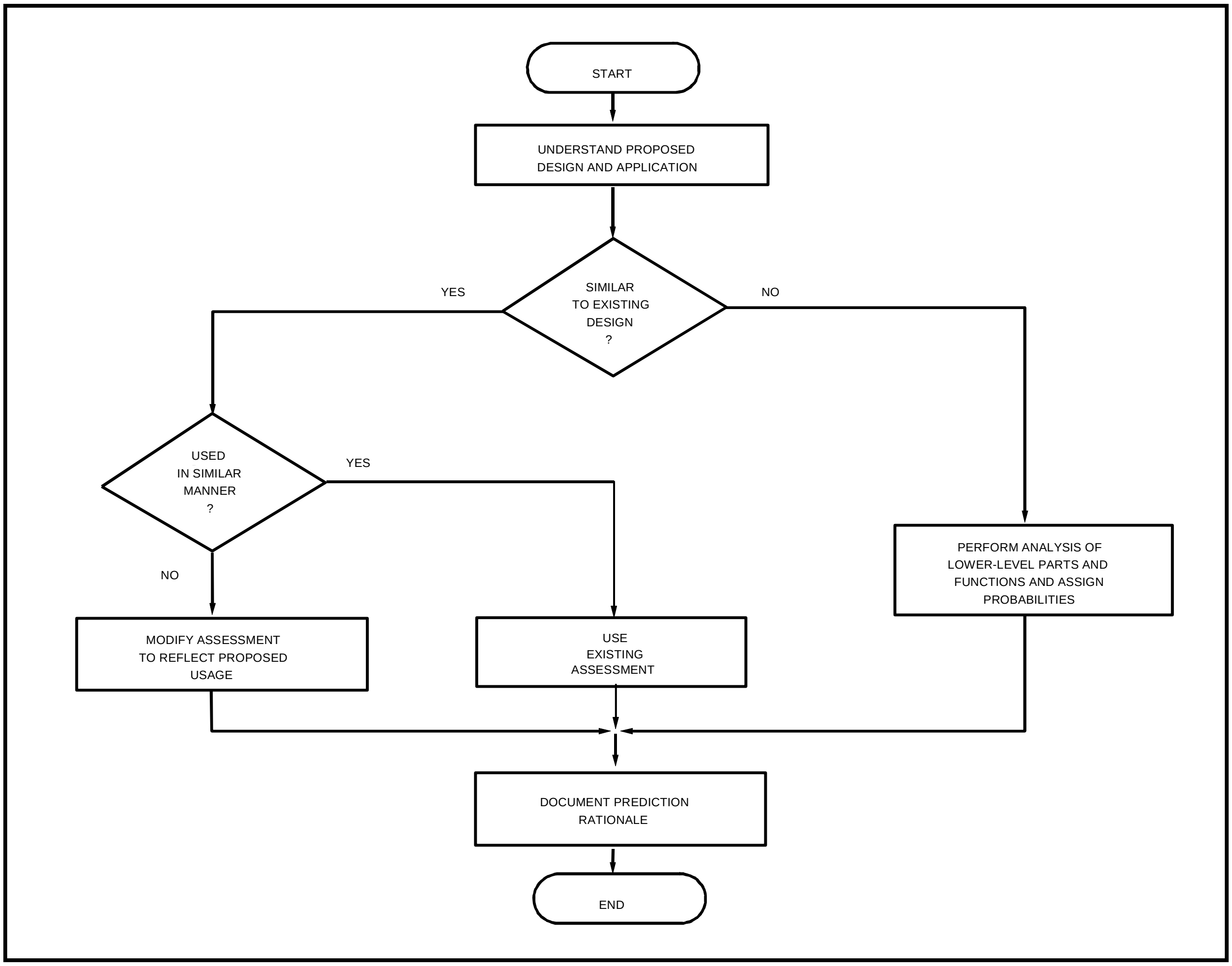
b. Search for similar designs that can provide a basis for predicting the final capability of the proposed design.

   i. If a similar design exists, consider effect of differences between proposed design and application with the reference unit.

   ii. If no similar design exists, combine elemental part failure mode probabilities so as to form a prediction for the assembly.

c. Document prediction rationale.

Figure 6: Component Reliability Prediction Process



2.2.2 Reliability Assessment

While predictions may be extrapolated from historical data, directly applicable test data are used for reliability assessments. The failure events must be precisely described and must be defined such that applicable tests are conducted so as to detect event occurrence and thus allow the proper identification of the outcome of each trial or test. A sample of such trials results in data that are called statistics. Reliability statistics can be broadly divided into two categories, continuous and discrete. Outcomes of trials that can be characterized by an infinite number of values are referred to as continuous variables. Trials that result in outcomes that have only two discrete states (e.g., pass/fail) are known as Bernoulli trials. The data from Bernoulli trials are sometimes referred to as attributes data. Nuclear weapon functions are generally treated as discrete events.

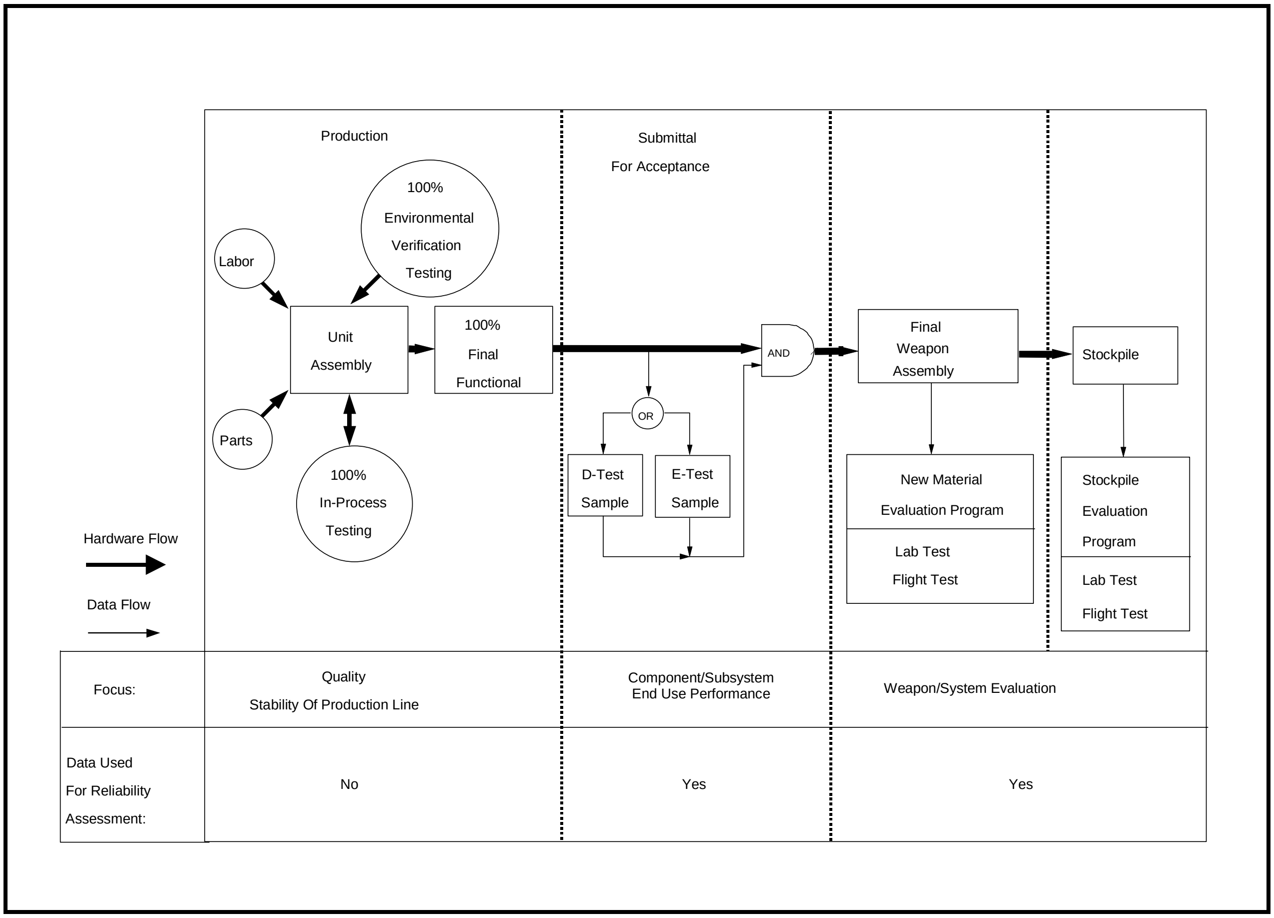
The component event assessment methodology is based on a complementary set of test programs from which test data are derived for assessment purposes. Figure 7 illustrates this methodology and the relationships of the primary test programs for each component or subsystem.

If it is assumed that the probability of occurrence of either state remains the same for all trials, the properties of the Binomial distribution can be used to estimate the parameter, probability of failure occurrence (p), as follows (Reference 4):

$$\hat{p} = (\text{Number of failures/Number of trials}).$$

The “^” over the p indicates this is an estimate of this Bernoulli parameter. This estimate is the Maximum Likelihood Estimate (MLE) and has proven desirable statistical properties.

Figure 7: Reliability Assessment Data Sources



For events having low probabilities of occurrence, a considerable number of trials may be conducted without observing a failure. The MLE estimate of p, based on these trials, will likely be zero. Although this is a strictly valid estimate, standard practice at Sandia is to use a more conservative estimate for the case of zero observed failures. In this case, the estimate is calculated as that value of the binomial parameter p that would yield 50% probability of zero failures in the relevant number of trials. Due to the discrete nature of the Binomial distribution this is called the 50% upper confidence limit for p and is calculated as such (Reference 4):

$$\hat{p}_{(50\%\,UCL)} = 1 - (0.5)^{1/(\text{Number of trials})}.$$

Although the Binomial distribution is truly correct only when the sample is drawn randomly from an infinite population, it provides a useful approximation in most instances. However, if the number of samples is large relative to the population size (e.g., greater than 10% to 20%), the more exact Hypergeometric (Reference 4) should be assumed to be the underlying distribution and used to calculate a 50% upper confidence limit.

As noted before, the reliability is estimated for a range of environmental and operational conditions, over the lifetime of the system. No single test source is capable of checking all of these features. It is only by combining data from all of these test sources that a comprehensive reliability assessment can be performed. The key reliability assessment challenge is one of using all applicable data (and recognizing and rejecting all data that are not applicable) in a valid and consistent manner such as to satisfy the reliability definition. Thus, data from many sources are evaluated, combined, and used as a basis for a data-driven assessment. Lack of data from any of these test sources may jeopardize or degrade the assessment methodology. The degree of applicability of data from different test sources varies, as does the manner in which the data are applied. Determining the applicability of the data may involve both statistical methodology and engineering judgment. Specific considerations in determining applicability include the following:

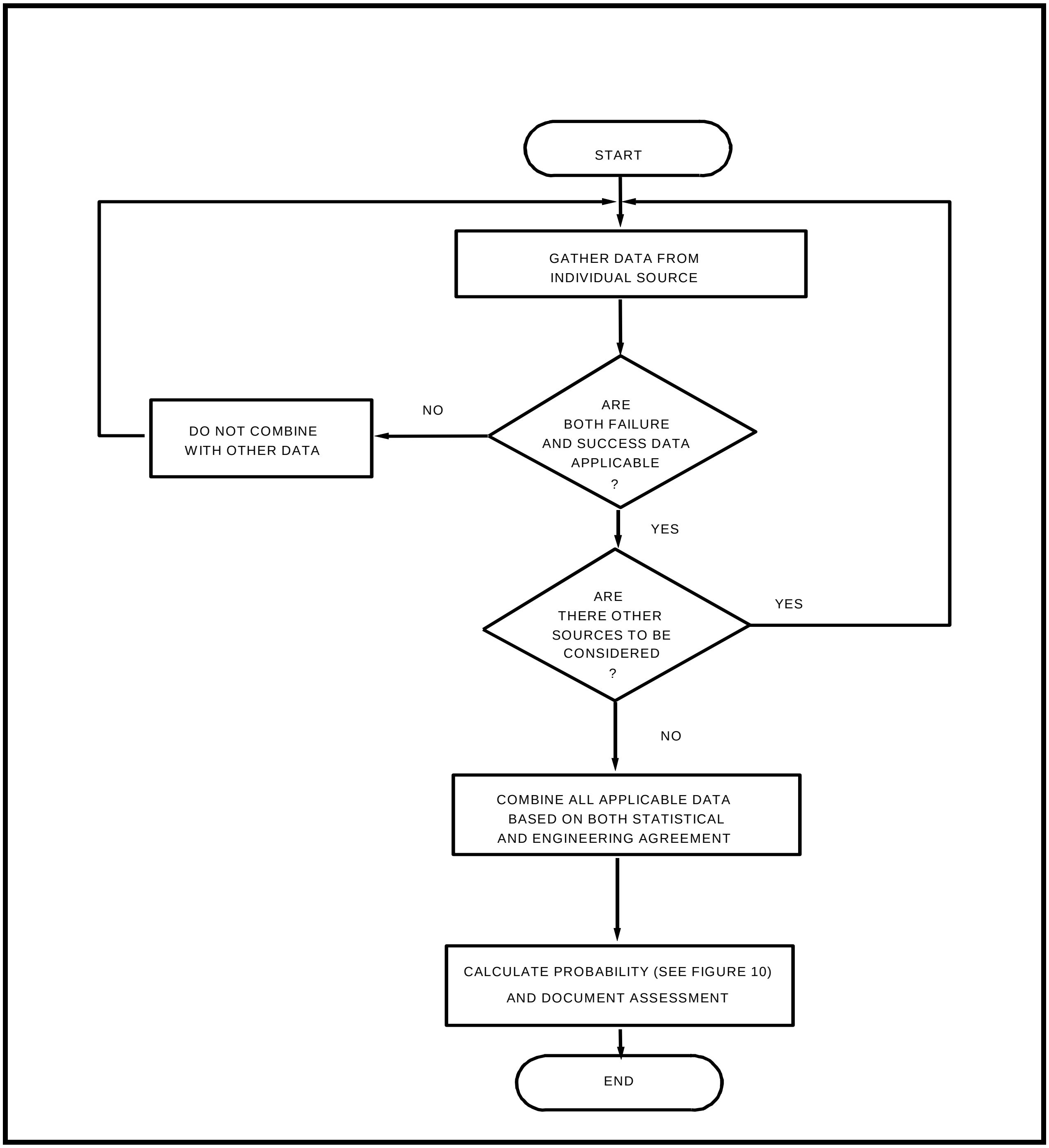
(1) Failure events to which the data pertain. A test may only be capable of detecting certain failure mechanisms and thus is not applicable to all defined failure events.

(2) Test item configuration representative of the stockpile. The test item should be of a quality that is representative of the fielded product. However, hardware or configuration changes may preclude the applicability of certain test results for assessing all events. Also, identified aging phenomena in a specified component type may preclude directly combining these data since age stratification may be necessary.

(3) Test condition representation of critical use conditions and environments. The test conditions should conform to normal environments specified for the weapon in the Stockpile-to-Target Sequence (STS). Specific environments may be required for some critical event behaviors to be detected.

Figure 8 presents the steps of the component reliability assessment.

Figure 8: Component Reliability Assessment Process

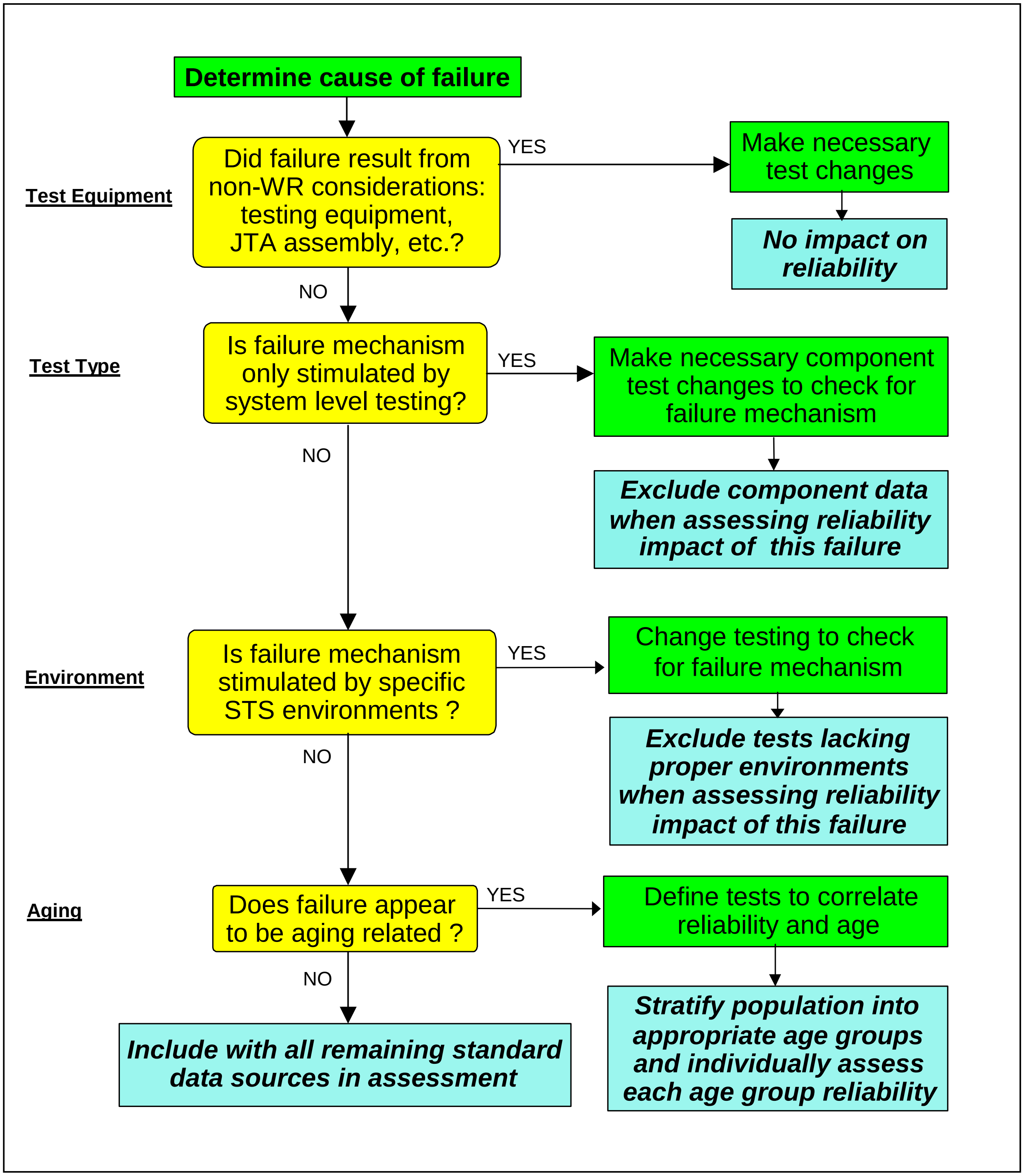


A basic premise of the methodology is that a conservative approach in deriving the assessment must be practiced in situations where uncertainty exists in judging the applicability of data. The exclusion of data that would cause an increase of the assessed failure probability must be thoroughly justified and documented. Similarly, the inclusion of data that significantly decreases the assessed failure probability must also be justified. An example of the latter is inclusion of data from a test in which all failure occurrences are or could be judged as not applicable (e.g., overtests or a test that lacks a necessary condition for failure). This data source would result in only successes and tests that are not applicable (no-tests) and should not be used.

In some cases, data from various sources can be used by simple combination. The simple combination is made on the basis that the present stockpile is of the same manufacture and design as the test sample units, the test results were not affected by differences in the tests from the various sources, and the test conditions properly simulate use environments. The total number of countable failures and the corresponding total number of trials can be used to estimate the event probability as described above.

In many instances, the problem of deciding which data can be properly combined is more complex. The complexity arises because a single event failure can depend on the presence of a number of mechanisms or physical phenomena. Because so many situations can occur, no general rules for combining data are feasible. The process for determining data applicability often depends upon an engineering knowledge of the mechanism of failure and the manner in which it responds to various stimuli. Figure 9 shows the process by which this determination is often made during the course of Significant Finding Investigations following detection of an anomaly.

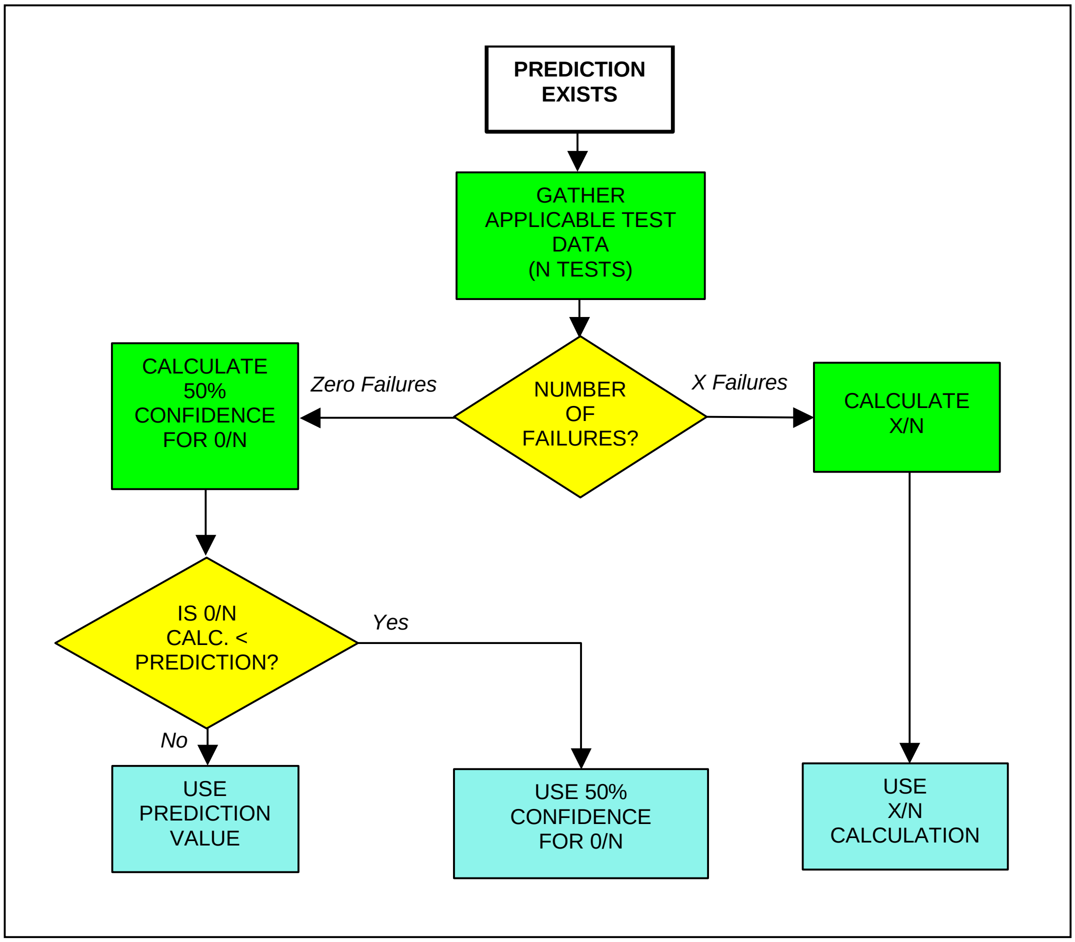
Figure 9: Data Relevance Flow Chart



2.2.3 Prediction/Assessment Usage

The prediction value is used as the basis for the early assessment until it is refuted by the directly applicable test data. The data can indicate either that the prediction value is too low or that the prediction value is too high. Figure 10 depicts the transition in the component reliability analysis process that occurs as data are aggregated over the life of the weapon.

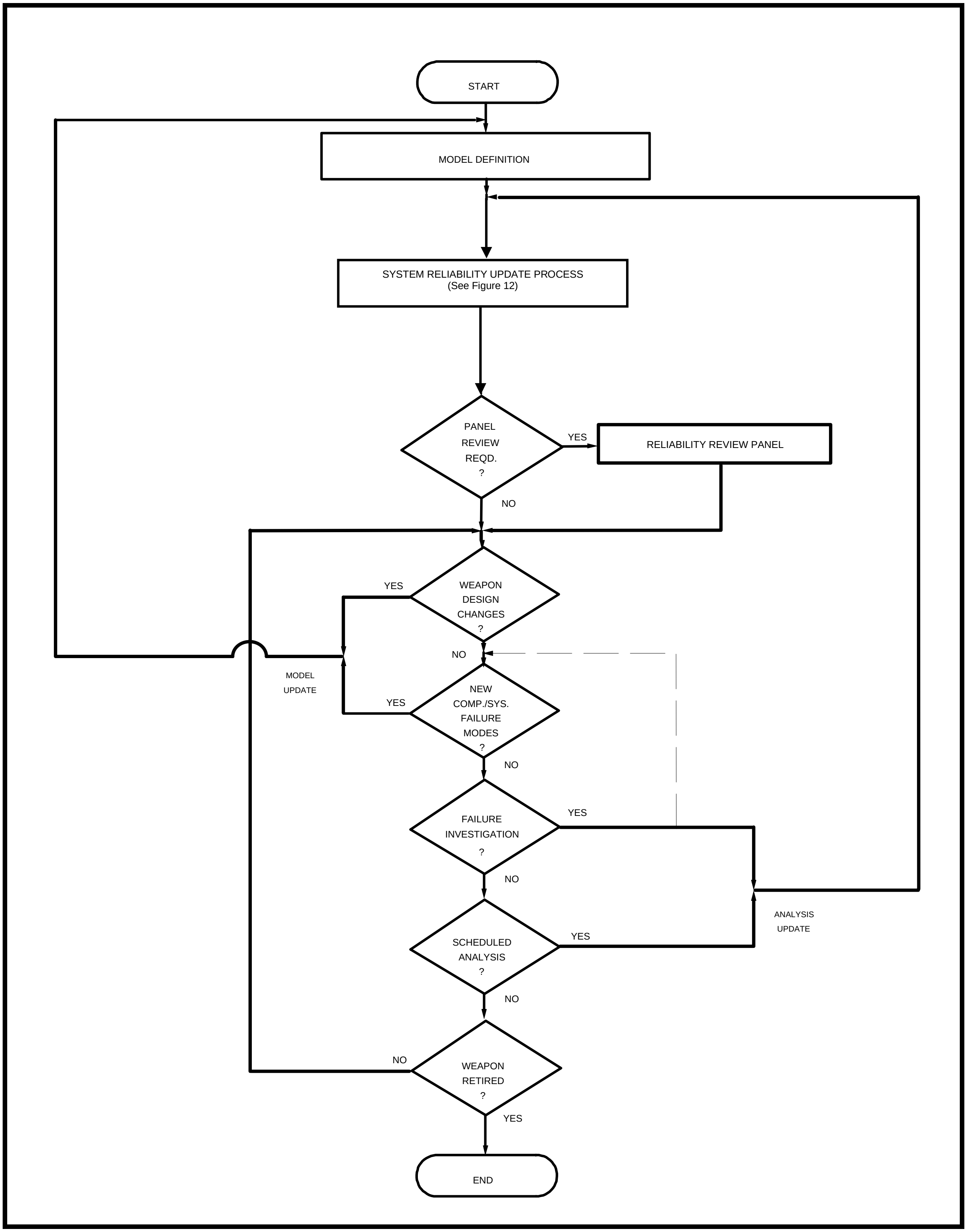
Figure 10: Component Reliability Analysis Process



2.3 System Reliability Analysis

A process has been established that provides a means for continual refinement of both the model and the reliability analysis throughout the weapon design, development, production, and stockpile life. Figure 11 illustrates this evaluation process that is applied throughout the weapon lifetime. A part of this evaluation process is the system reliability update process that is illustrated in Figure 12. This process will be discussed later.

Figure 11: Life Cycle System Reliability Analysis Process



The Life Cycle System Reliability Analysis Process includes a number of decision points, shown as diamonds in Figure 11, which could trigger an update to the weapon reliability assessment. For instance, the model is revised as appropriate when design changes are implemented or as additional failure modes are revealed. These can occur as the weapon design evolves during development or be the result of modification or retrofit during the weapon production or stockpile phases. Another stimulus for update is the discovery, investigation, and assignment of failure probability for an observed test anomaly. The potential reliability effect of every observed failure is evaluated. The investigation may reveal a new failure mode that needs to be defined as an event and included in the model. The dashed line in Figure 11 indicates the resultant revision of the model and an update of the analysis.

A scheduled analysis is also a stimulus for update, as shown in Figure 11. These may be prediction analyses to support various development activities or assessments of the stockpiled weapon. Reassessments are performed periodically after a weapon enters the stockpile and are referred to as updates in that any appropriate new data are included with the existing data to support the assessment. Typically, these types of reassessments are scheduled yearly while a weapon is in production, and then biennially until the weapon is retired from the stockpile. Supplying inputs for the semi-annual NNSA Weapons Reliability Report are also scheduled activities (Reference 1), as are analyses to support joint DoD and NNSA evaluation activities.

The life cycle analysis process described above provides a continuous means of adjusting reliability assessments that may be high (i.e., by including new failures or failure modes when they are observed), and a periodic means of correcting reliability assessments that may be low (i.e., by the addition of recent successes).

The System Reliability Update Process block is presented in Figure 12. This process is initiated by request of the SRE to the appropriate CREs (or other agencies) for a reliability update of component events. The CREs gather and analyze test results preparing a Component Reliability Prediction/Assessment for each of the defined events in the mathematical equation. These analyses are documented in reports, usually by component or subsystem, and may be applicable to more than one configuration of a weapon family (referred to as Mods). The SRE collects the individual prediction/assessment analyses and uses these probabilities to evaluate the weapon reliability using the mathematical equation and the current weapon status and composition data for the stockpile. Weighted-average system reliability assessments are calculated for specified Mod, yield, and use options for both the active and inactive stockpiles. The system reliability analysis and results are documented by the SRE.

Figure 13 summarizes the key weapon reliability activities relative to the NNSA weapon development Phases and Stockpile Life Extension Program (Phase 6.X) processes. The development of the reliability mathematical equation and the initial reliability predictions may begin in Phase 1 (or Phase 6.1) as shown by the dotted line. However, this must be completed early in Phase 3 (or Phase 6.3) in order to support the component allocation and prediction requirement. The refinement and update of the prediction and model continue throughout the development phases along with the evaluation of test anomalies. Periodic assessment updates and continuous evaluation of both production and stockpile surveillance test anomalies continue until the weapon is retired from the active stockpile. Peer review is also an integral part of the process. Discussion of peer reviews and the Reliability Review Panel (RRP) process can be found in Section 3.4.

Figure 12: System Reliability Update Process

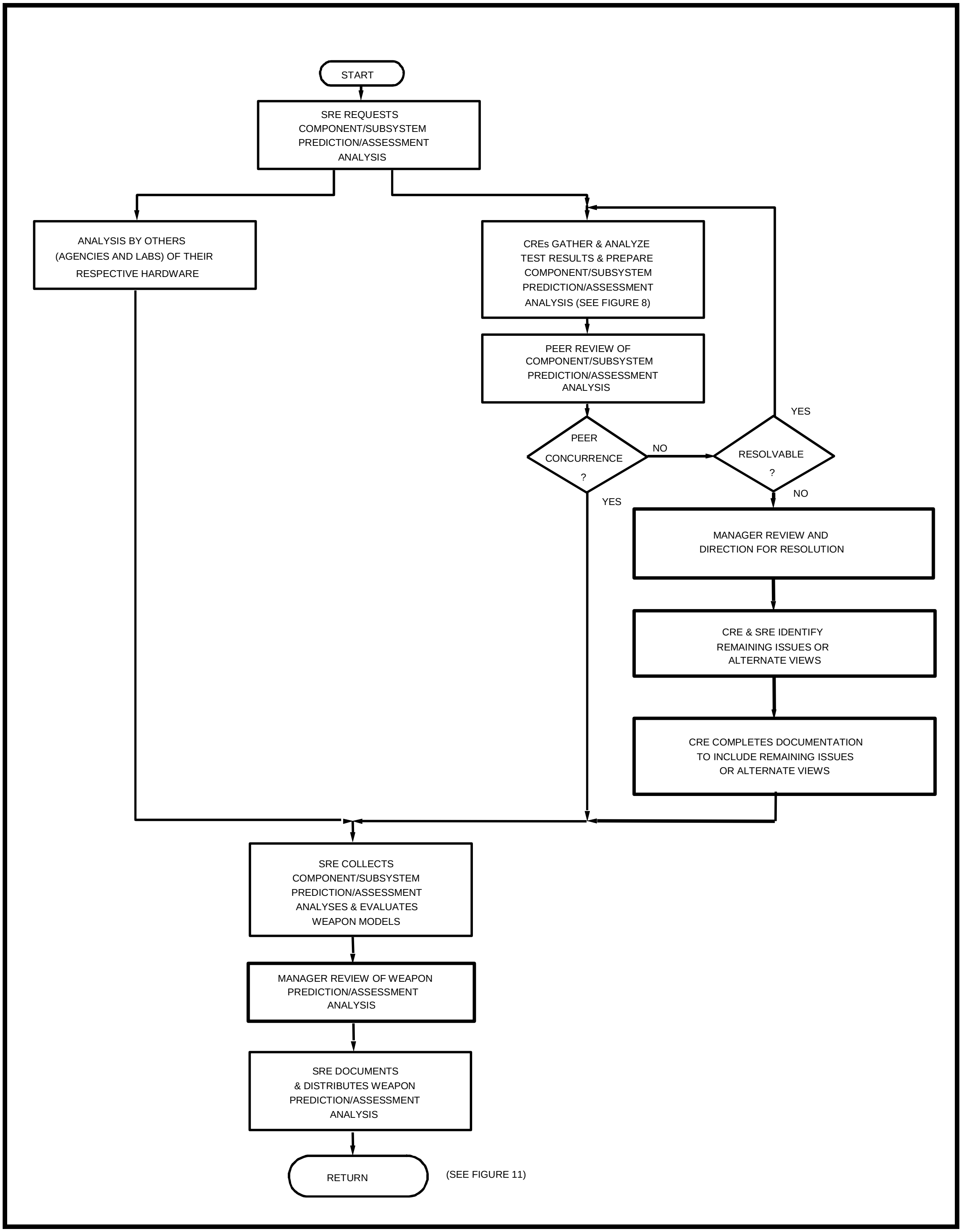
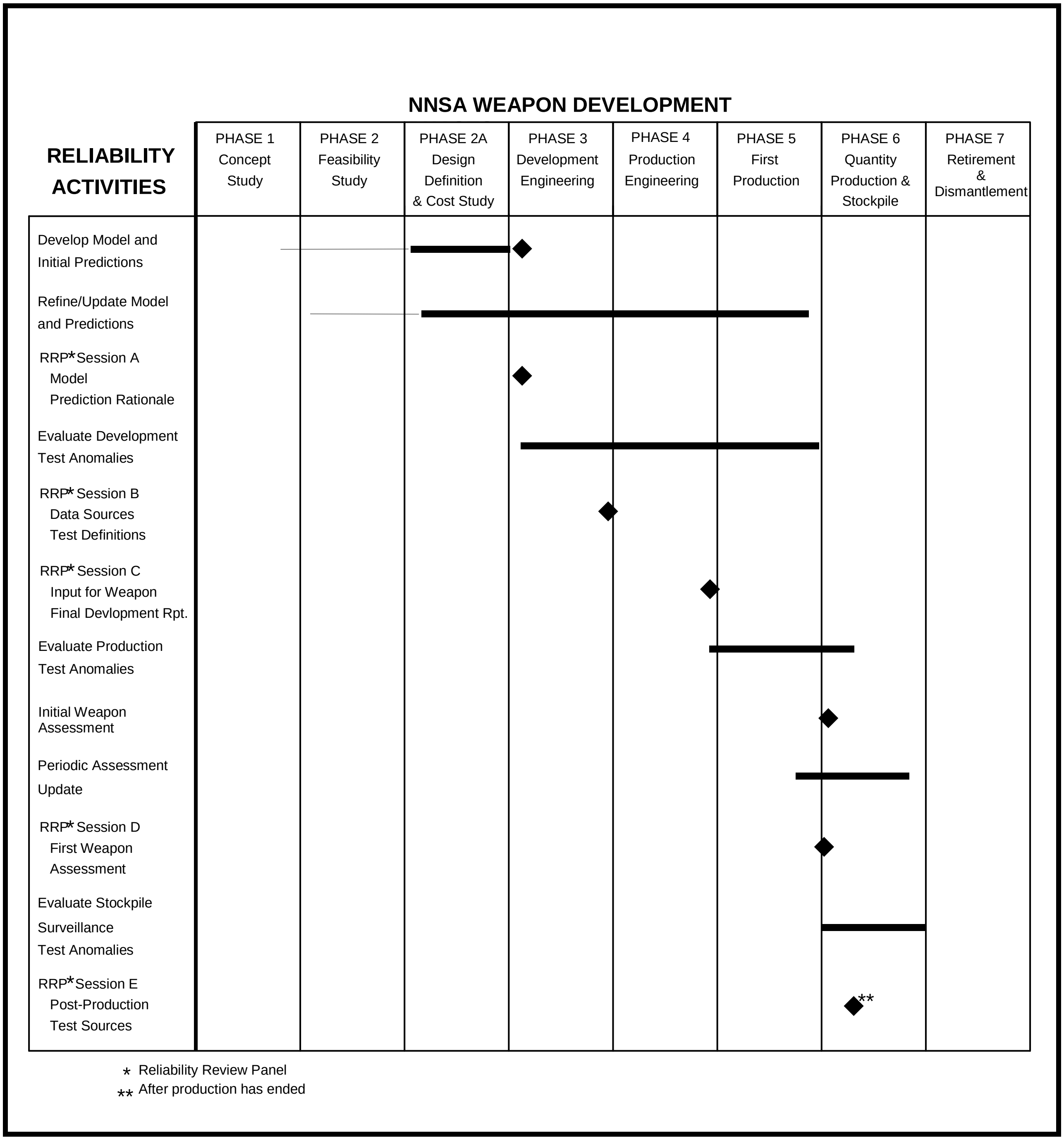


Figure 13: Life Cycle Reliability Activities



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3 Key Supporting Processes

3.1 Reliability Design

The SNL design and development organizations are ultimately responsible for the reliability of the SNL designed portion of the nuclear weapon. Developing and providing weapon systems with high reliability involves many activities during design, development, production, and the stockpile period. The design organizations follow the principle that meeting the reliability requirements is one of their primary functions. Adherence to this principle provides the framework for the test and evaluation programs and prevents dependence on tenuous assumptions in the reliability analysis. Typically, the MCs provide guidance to the designers concerning the priority of reliability relative to competing characteristics such as safety, yield, operational simplicity, command and control, etc., as well as programmatic concerns such as cost and schedule.

The desirable elements for attaining reliable product are:

1. Design to the worst case environmental conditions of the MCs and the STS and demonstrate the design capability by:

   a) Thorough modeling and model-based simulation that defines the response of the system and components under the extremes of environmental conditions,

   b) A variety of laboratory and flight tests to validate the modeling, to demonstrate performance to the MC requirements, and to determine adequate design margin exists.

2. Establish controlled manufacturing processes to assure process variation and human errors do not degrade design intent.

3. Demonstrate continued production process performance through sample testing at the environmental extremes.

4. Evaluate all failures for their cause and effect and implement appropriate corrective action.

A well-conducted design process is a necessary activity for assuring the end-use reliability of the product. This assurance activity is a vital element that supports the reliability assessment methodology.

3.2 Test Programs

As noted in Section 2, component reliability estimates rely upon a variety of data sources. The major sources are described below. Important characteristics of the combined test program are diversification of test conditions and configurations (to provide a variety of means to detect defects) and duration (testing is performed throughout the lifetime of the weapon).

3.2.1 Product Acceptance Sample Testing

The production process involves many operations and generally a large amount of in-process and 100% acceptance testing is performed. However, these tests are generally not considered useful for direct use in the event assessment calculation; rather, they provide means of assuring the quality of the product and the stability of the production processes.

Submittal for product acceptance requires the selection and test of random samples from the production quantity. The results of these tests, designed to subject the units to use conditions and to meet use performance requirements, are used to determine continued acceptance of the product. Sample testing considered to be degrading or destructive is labeled D-Test. Non-degrading sample testing is labeled E-Test. This sample testing is a standard data source for reliability assessment purposes.

The device or component may become a part of a next assembly that undergoes another similar production and submittal process. This next assembly sample testing may also be used in the assessment.

3.2.2 Stockpile Surveillance Program

The SNL Stockpile Surveillance organization is responsible for the definition and execution of a New Material and Stockpile Evaluation Program (NMSEP) consisting of complementary laboratory and flight tests (References 5 and 6). This test program is important for confirming the validity of development and product acceptance test results. These tests provide for continuing surveillance of the stockpile reliability and compatibility and allow for detection of unsuspected age degradation. The investigation of all failures and anomalies for cause and effect through the Significant Finding Investigation (SFI) process provides the basis for corrective actions, modifications, and improvements necessary to maintain the stockpile.

There are two major elements of the NMSEP. First, final weapon assembly production units are randomly sampled through the New Material program. The goal of this program is to discover significant failure mechanisms associated with operational function, use control, and safety features of a weapon, soon enough for corrective action implementation to avert serious consequences. The program also establishes a baseline for comparisons with later test results to detect degradation in the stockpile. This program provides both component and weapon-level data early in the weapon stockpile cycle and is one of the standard data sources for reliability assessment purposes.

The second element of the NMSEP is the Stockpile Surveillance program. Weapons are randomly sampled from the stockpile over the entire life of the weapon. These units are converted to test units for subsequent operational flight tests or laboratory simulation tests. These are units that have been subjected to normal stockpile handling and dormant storage. This program is a standard data source and provides a continuing means of evaluating the stockpile for failure mechanisms induced during design, production, field handling, and by long-term dormant storage.

In cases where retrofits are incorporated into the stockpile (e.g., as part of a Phase 6.X activity), a Retrofit Evaluation System Test (REST) program may be defined in order to assure early identification of defects that may have been introduced by the retrofit.

3.2.3 Other Data Sources

Product acceptance testing and stockpile surveillance testing form the basis of the data for assessing reliability and are standard data sources. Non-standard data sources may be used if they are judged to be applicable and the standard sources are not available or sufficient. Examples of these other data sources are: Process Prove-In, Environmental Screens, Special Test Series, and Shelf-Life Programs. Applicability and combinability issues are especially relevant for non-standard data sources. In certain data-limited situations, the use of modeling to evaluate performance may be employed.

3.3 Documentation

3.3.1 Component Reliability Assessment

The Component Reliability Assessment report focuses on an individual component and contains all of the defined and assessed events for a given weapon application. The CRE is responsible for preparing this report. Occasionally, multiple weapons (or Mods) have the same defined events and can be covered by a single component assessment report.

The Component Reliability Assessment report includes the following elements:

- Component description
- Events and assessments
- Assessment rationale
- Data summary
- Failure descriptions
- Assessment history
- Data Assessment Comparison Chart

3.3.2 System Reliability Assessment

The SRE is responsible for documenting the weapon system reliability assessment. The format and extent of documentation required is dependent upon the type of analysis completed. The most extensive analysis is the one that incorporates assessments (or reassessments) of all of the events for a weapon. This is sometimes referred to as a “complete” or a “general” assessment (reassessment), and the analysis results are documented in a System Reliability Assessment report. Preliminary System Reliability Assessment reports done prior to production should be styled in a like manner as appropriate. Documentation of ad hoc analyses, such as those that might result from an SFI or an update for the NNSA Weapons Reliability Report may not be as extensive as a general reassessment, but should be referenced to the latest System Reliability Assessment report.

Content of a System Reliability Assessment report includes the following elements:

- Reliability assessments summary table
- Reason for changes since the last report
- Issues of increased uncertainty
- Test and stockpile composition basis for the analysis
- System description
- Major contributors to unreliability and corrective actions planned
- Known aging problems
- Assessment History
- Methodology summary
- The block diagram(s) and equations and results for the system

Copies of the appropriate Component Reliability Assessment reports are included with the system report in either an appendix or as a separate referenced document.

3.3.3 NNSA Weapons Reliability Report

The NNSA Weapons Reliability Report (WRR) is the major deliverable of the SNL reliability departments. This report serves as the principal NNSA report on reliability for the DoD and nuclear weapon community. The content includes the following:

a. Executive Summary: issues and reliability changes

b. Active Stockpile Section
- Introduction - definitions, limitations, ground rules
- Reliability Overview Chart (comparison with reliability requirements and other weapons)
- Individual system assessments for NNSA material
- Reliability assessment by option
- Comparison to MC reliability requirements
- Additional reliability assessments (e.g., Use Control)
- Recent assessment activities (SFIs)
- Issues of increased uncertainty
- System-level laboratory and flight test totals

c. Inactive Stockpile Section
- Introduction
- Overview chart
- System assessments different from Active Stockpile

SREs are required to provide input every six months to update the WRR. The basis for the system reliability assessment is the latest System Reliability Assessment report or general reassessment update. However, all assessment changes due to subsequent SFI activities are included along with the current stockpile weapon status and composition information.

3.4 Peer Review

Peer review is considered an important element of the overall system reliability process. There are a variety of means to ensure that analyses are consistent, complete, and well documented. These are described below.

3.4.1 Component and System Reliability Assessment Report Reviews

As part of the component prediction/assessment process, another reliability engineer who is familiar with either the component or the weapon usage reviews the Component Reliability Assessment report. This peer review is intended to assure consistent and supportable data usage and rationale. In the instance that peer review concurrence is not attainable, a management review and resolution process is implemented. Documentation of issues and alternate views that arise from this review process is included in the component reliability assessment report by the CRE.

The SRE's Department Manager reviews the System Reliability Assessment report before it is published. The purpose of this review and approval step is to assure the consistency and accuracy of the analysis and the documentation.

3.4.2 Reliability Review Panel

A process known as a Reliability Review Panel (RRP) has been defined to provide formal and comprehensive peer reviews of reliability activities associated with specific weapon programs. The panel membership includes reliability engineers, system designers, surveillance engineers from both SNL and the nuclear laboratories, and representatives from NNSA. Through this RRP process the reliability activities are reviewed for currency, completeness, and consistency. The review panel activities are accomplished in a number of different sessions that are related to specific nuclear weapon programmatic milestones, both for new development and for Phase 6.X activities (see Figure 13). The issues reviewed throughout this process include, but are not limited to, examination of the mathematical equation representation of weapon functions, failure event descriptions, event prediction rationale, adequacy of data sources for assessment purposes, and interpretation of anomalies. Action items resulting from the RRP are documented and tracked.

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4 SUMMARY

Sandia National Laboratories has been tasked for many years to estimate the reliability of the nuclear weapons in the stockpile. The reliability evaluation methodology has been developed based upon the experiences and knowledge acquired during this extensive history. Another key factor influencing the methodology is the need to support a very specific definition of reliability. This definition is based upon the requirement to integrate the Sandia nuclear weapon reliability estimate into the larger DoD context of Damage Expectancy. The current methodology for evaluating nuclear weapon reliability has been summarized in this report. The philosophy, implementation, and supporting processes continue to be refined to meet the evolving needs of the overall nuclear weapon management structure and processes. On-going peer review is an important element to ensure consistency and completeness.

References

1. "Development and Production Manual", NNSA, AL 56XB, Chapter 8.1.

2. Technical Business Practice TBP-DEF, "Technical Business Practices Definitions".

3. SAND99-8240, "DOE Nuclear Weapon Reliability Definition: History, Description, and Implementation", April 1999.

4. Norman L. Johnson, et. al., "Univariate Discrete Distributions", Second Edition, 1992, John Wiley & Sons.

5. Stockpile Evaluation Manual, Department 2950, SNL, August 2001.

6. Technical Business Practice TBP-801, "Laboratory and Flight Test Material".

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