



Presented to:
RAM VI Workshop

***Optimizing the Non-Destructive Test Program
for a Missile Inventory***

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- **The Stockpile Reliability Program (SRP)**
- **Developing a Testable Reliability Requirement**
- **Predicting Inventory Testable Reliability**
- **Optimizing the Annual Non-Destructive Test Quantity**
- **Application Assumptions**
- **Summary & Conclusion**

NOTE: Document research has not identified an approach similar to the one presented herein. Therefore, unique variables were generated to describe the approach, and the equations derived were not validated based on existing technical references.

SRP Background

Data

■ Component Testing



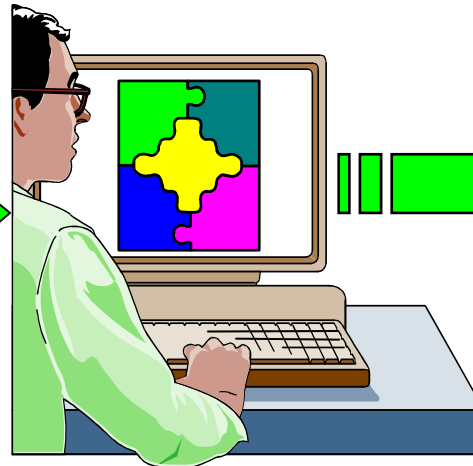
■ Flight Testing



■ Surveillance



■ Training/Tactical Firings



Analysis

**IDENTIFY
TRENDS:**

**RELIABILITY,
SAFETY &
PERFORMANCE**

**Shelf Life
Extension
or
Recertification
Decision**

**Missiles with expired shelf life or not recertified
are RESTRICTED FROM ISSUE OR USE.**

■ Component Testing



■ Flight Testing



■ Surveillance



■ Training/Tactical Firings



- (1) Identify and segregate failing missiles,
- (2) Collect parametric data for reliability and performance trend analyses,
- (3) Determine degradation trends associated with specific populations of the inventory.

DISADVANTAGES:

- (1) Cost,
- (2) Inventory availability,
- (3) Over-testing,
- (4) Induced failures.

NDT across the life of a system should be at the minimum level required to meet the user's reliability requirement.

TESTABLE RELIABILITY (R_T): The observed reliability during NDT. For example, if 1% of missiles processed through NDT are failing, then $R_T = 0.99$

FLIGHT TEST RELIABILITY (R_{FT}): All missiles undergo NDT prior to flight tests during development, production, or SRP, yet flight failures are still experienced. This flight test reliability represents the un-testable failure modes.

USER RELIABILITY REQUIREMENT (R_U): Usually a specified value, sometimes referred to as System Reliability, described generally as;

“the probability that a missile, randomly issued/selected from the inventory, will pass user pre-flight check-out, successfully launch, fly to target, and detonate.”



Establishing a Minimum Testable Reliability Requirement



The product of demonstrated values of R_T and R_{FT} provide an estimate of the user reliability being demonstrated by the system:

$$R_{U \text{ Dem}} = R_T * R_{FT}$$

If the system is demonstrating that it is meeting the user requirement, then:

$$R_T * R_{FT} > R_U$$

And likewise, a system meeting the user requirement would have an observed minimum testable reliability of:

$$R_{T \text{ Min}} > R_U / R_{FT}$$



Establishing a Minimum R_T



EXAMPLE

A system is demonstrating flight test reliability of 0.96 in SRP tests.

The user reliability requirement, to include pre-flight check-out, successful launch, flight, and detonation is 0.94.

Therefore, the minimum testable reliability that the system should be demonstrating is:

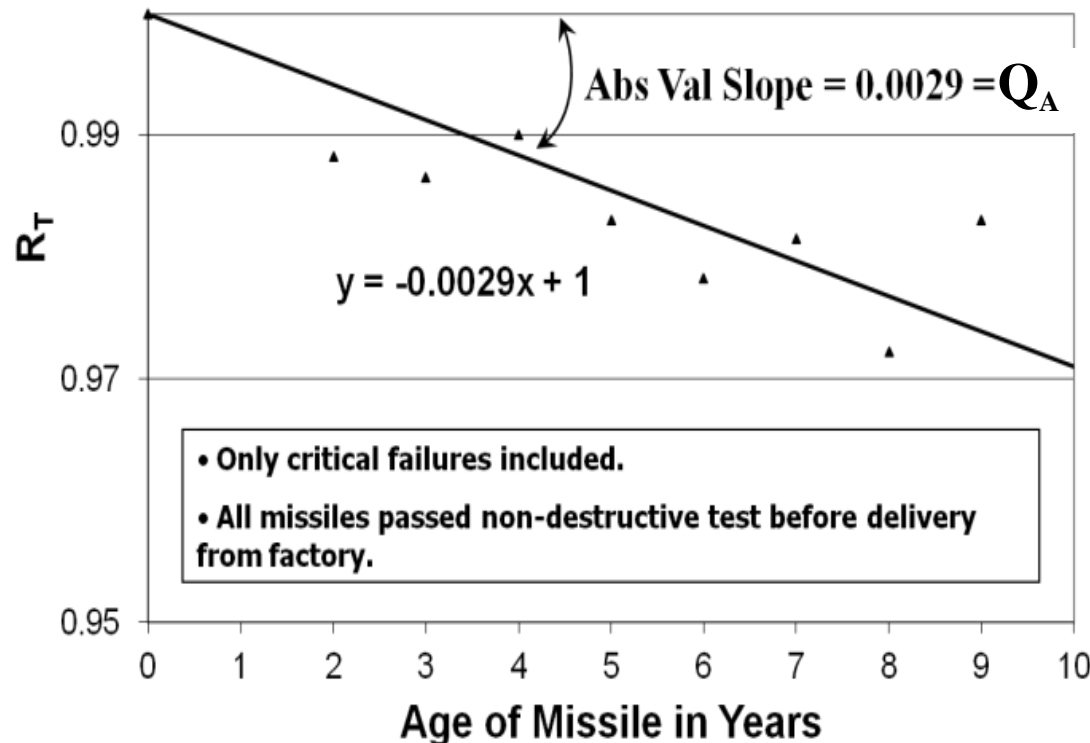
$$R_{T \text{ Min}} = 0.94 / 0.96 = 0.979$$

In other words, if more than 2.1 percent of missiles being processed through NDT are failing, then the system is no longer meeting the user reliability requirement.

****This example $R_{T \text{ Min}}$ of 0.979 will be used in the other examples throughout the remainder of this presentation.**

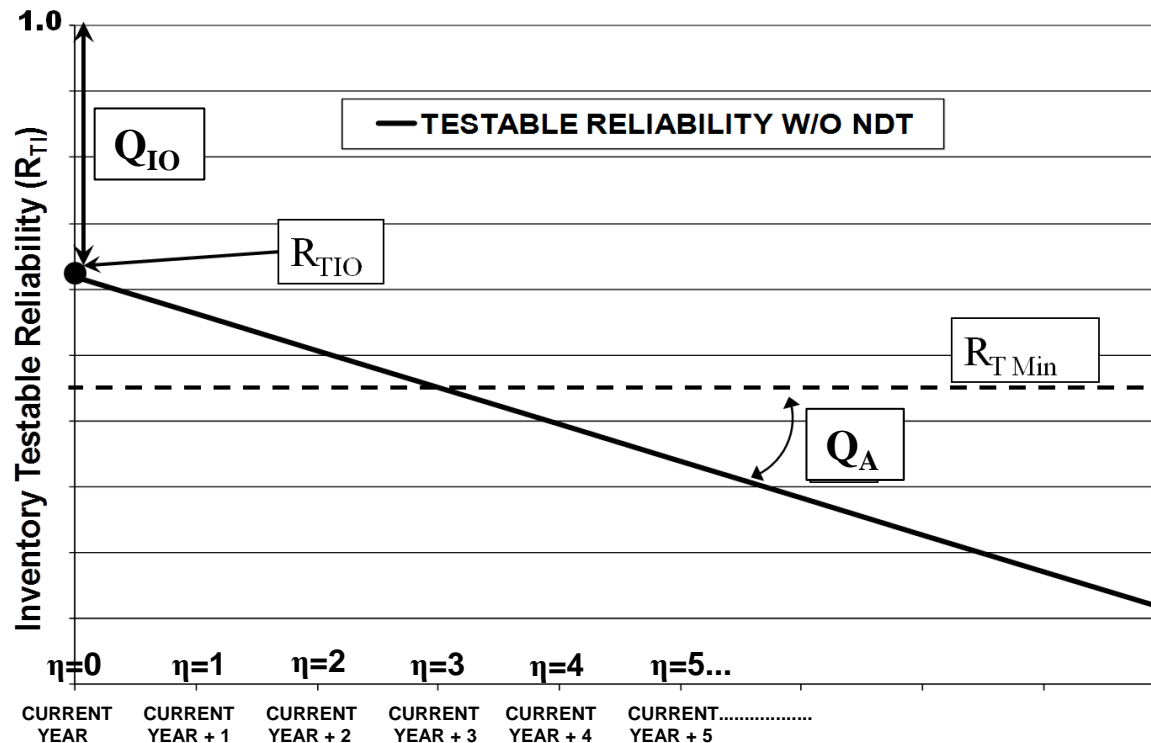
Historically, during the majority of their operational life, missile systems experience a constant failure rate. The associated NDT testable unreliability versus age can be estimated using test data:

EXAMPLE



Predicting Inventory Testable Reliability (R_{TI}) w/o NDT

Since the failure rate is constant, if the inventory's current year testable reliability R_{TIO} can be estimated, then the predicted testable reliability by calendar year (R_{TI}) without any NDT can be estimated by plotting a line with slope Q_A from the point of R_{TIO} .



The predicted inventory's testable failure probability is:

$$Q_I = Q_{IO} + \eta * Q_A$$

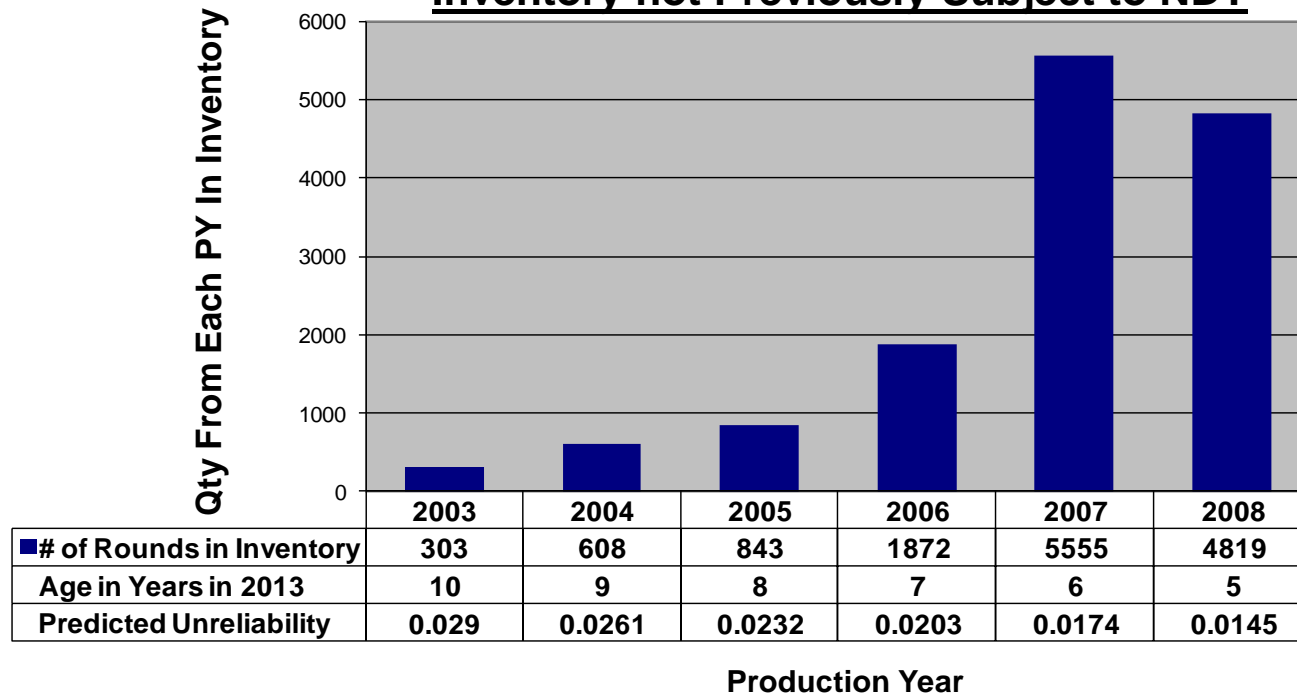
Where η is the number of years from current year.

Systems are produced over multiple years.

Therefore, Q_A by itself, does not provide an estimate of the inventory's current year testable reliability/unreliability (R_{TIO}/Q_{IO}).

EXAMPLE

Inventory not Previously Subject to NDT

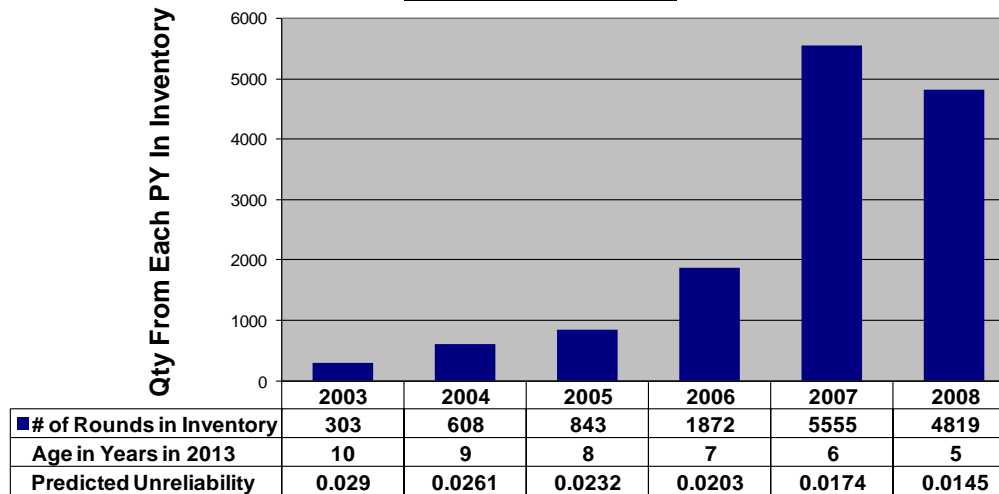


Estimating Current Year Inventory Testable Failures

If A_{PYN} is the age of the missiles in production year N and N_{PYN} is the quantity of missiles in production year N, the following equation sums the estimated number of testable failures in each production year group:

$$Q_A[(A_{PY1} * N_{PY1}) + (A_{PY2} * N_{PY2}) \dots + (A_{PYN} * N_{PYN})]$$

EXAMPLE



Production Year

$$0.0029[(10*303)+(9*608)+(8*843)+(7*1872)+(6*5555)+(5*4819)] = 249$$

This inventory is estimated to have 249 failing missiles that could be identified with NDT.

Dividing the estimated number of testable failures by the total quantity in the inventory (N_I) provides the current year testable unreliability, Q_{IO} :

$$Q_{IO} = Q_A[(A_{PY1} * N_{PY1}) + (A_{PY2} * N_{PY2})... + (A_{PYN} * N_{PYN})] / N_I$$

And likewise,

$$R_{TIO} = 1 - Q_{IO}$$



**Estimate of inventory's
current testable reliability.**

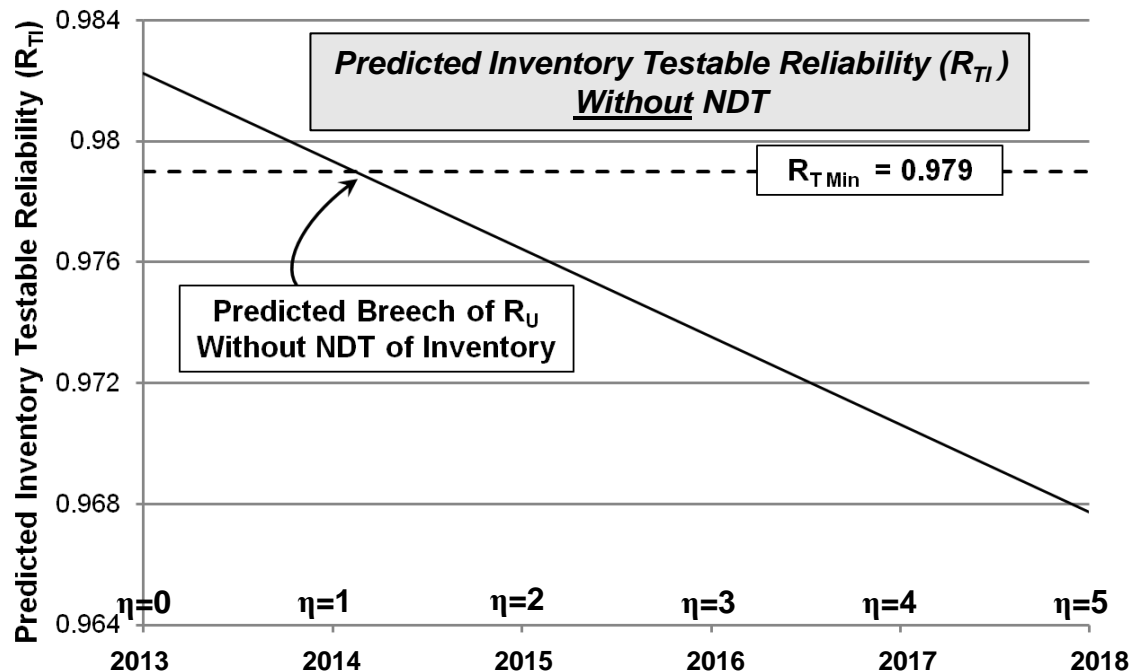
Example of Predicting R_{TI}

Utilizing the example inventory: $Q_{IO} = (249/14000) = 0.0178$

$$Q_I = 0.0178 + \eta * 0.0029$$

And,

$$R_{TI} = 1 - (0.0178 + \eta * 0.0029)$$



Without NDT his inventory is predicted to fall below the user's reliability requirement in 2014.

Predicting Inventory Testable Reliability if NDT is Instituted at $\eta=0$

Once NDT is instituted the inventory is developing subpopulations of missiles: untested, and tested. That is, when a group of missiles undergoes NDT, the testable failures in that group are 'reset' to zero, and the quantity of untested missiles in the inventory is reduced.

The unreliability of an inventory subject to NDT (Q_{IT}) is the sum of predicted failures in the untested population (N_{FU}) and failures in the tested population (N_{FT}) divided by the total inventory quantity:

$$Q_{IT} = (N_{FU} + N_{FT}) / N_I = (N_{FU} / N_I) + (N_{FT} / N_I)$$

This equation is simplified to the two terms that are derived in the following charts; failure probability for the untested population (Q_U), and failure probability for the tested population (Q_T):

$$Q_{IT} = Q_U + Q_T$$



Unreliability of the Remaining Un-tested Inventory Q_U



The quantity remaining in the untested population is being reduced by the product of number of years of NDT (η) and the number tested annually (N_T) - assuming a constant annual test quantity.

Thus the equation for Q_U is provided by:

$$Q_U = [(N_I - \eta * N_T)(Q_{IO} + \eta * Q_A)] / N_I$$

Unreliability of the Tested Inventory Q_T

The failure probability for missiles that have undergone NDT has been 'reset' to the number of years since NDT (η) was performed on those missiles. For example, the following equation captures the failure probability of the tested population at year four (Q_{T4}):

$$Q_{T4} = (N_T * Q_A * 3 + N_T * Q_A * 2 + N_T * Q_A) / N_I = (N_T * Q_A * 6) / N_I$$

The following equation was generated to represent an inventory at any year η :

$$Q_T = [N_T * Q_A \sum_{1}^{\eta} (\eta - 1)] / N_I$$

Equation for Predicting Inventory Testable Reliability

Since the unreliability of an inventory subject to NDT (Q_{IT}) is:

$$Q_{IT} = Q_U + Q_T$$

Thus, the unreliability of an inventory subject to NDT is provided by:

$$Q_{IT} = [(N_I - \eta * N_T)(Q_{IO} + \eta * Q_A) + N_T * Q_A \sum_{1}^{\eta} (\eta - 1)] / N_I$$

This assumes NDT is started in $\eta=0$, and a constant quantity N_T is tested annually.

And likewise,

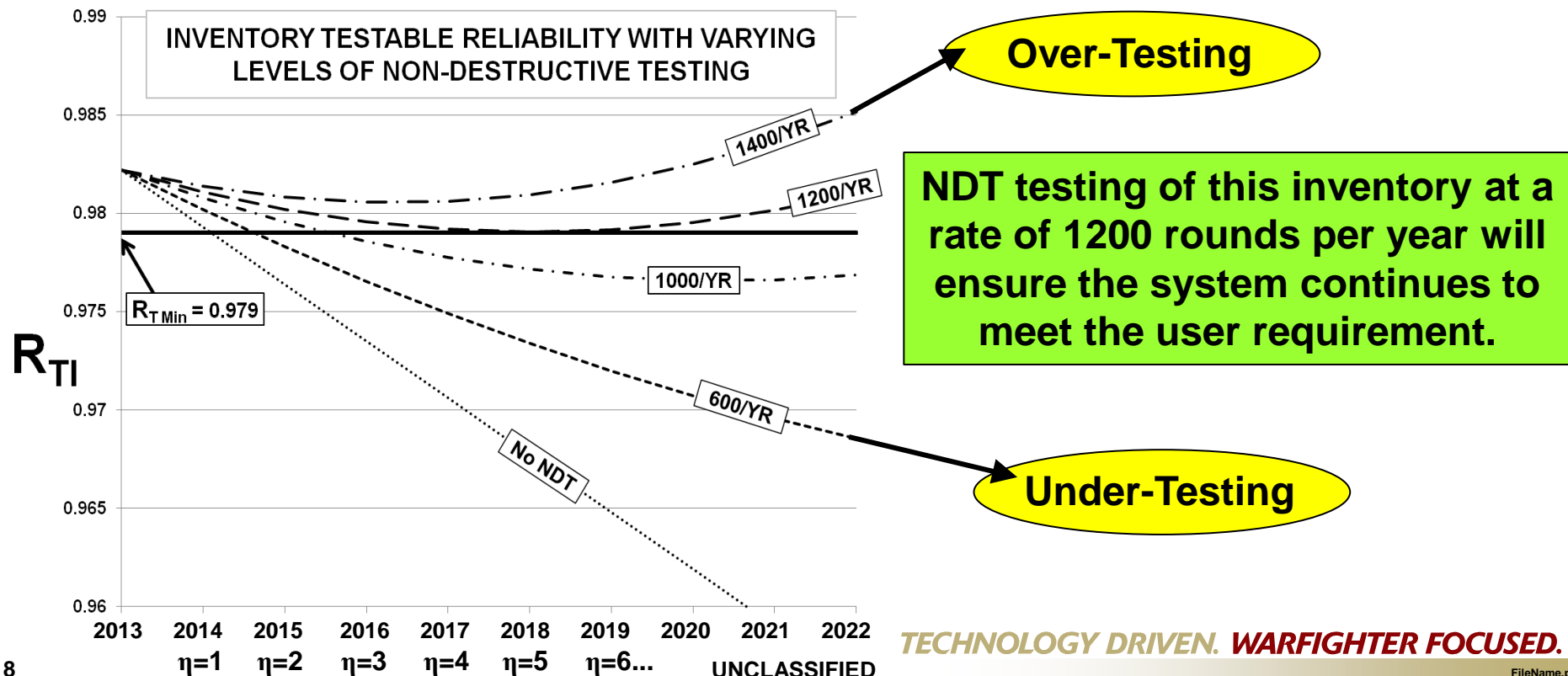
$$R_{TI} = 1 - Q_{IT}$$



Prediction of an inventory's testable reliability if annual NDT testing of a constant quantity of missiles is tested annually.

The equation for Q_{IT} can be set up in spreadsheet format, and R_{TI} for varying levels of annual NDT testing (N_T) can be plotted. Utilizing the information developed for the example system, the equation for Q_{IT} would be:

$$Q_{IT} = \frac{[(14000 - \eta * N_T)(0.0178 + \eta * 0.0029)] + [N_T * 0.0029 \sum_1^{\eta} (\eta - 1)]}{14000}$$



Limitation/Assumption: Missiles Previously Subject to NDT

The equations provided do not take into account missiles that have been subject to NDT prior to $\eta=0$. If the quantity is small compared to the size of the inventory then the equations provide a good approximation.

An improvement on this approximation is to subtract the quantity of failures that have already been observed (N_{FO}) prior to $\eta=0$ from the numerator when estimating the current year testable unreliability, Q_{IO} :

$$Q_{IO} = \{Q_A[(A_{PY1} * N_{PY1}) + (A_{PY2} * N_{PY2})... + (A_{PYN} * N_{PYN})] - N_{FO}\} / N_I$$

This approximation does not take into account the 'resetting' of tested missiles. If the number subject to NDT is larger and/or NDT has been ongoing for a longer period, the engineer will need to analyze historic data to adjust the estimate for Q_{IO} . This is a feasible effort, but emphasizes the value of performing this analysis early in the lifecycle.

- Inventory is in operational life phase (constant failure rate).
- NDT is performed on a cross-section of the available inventory
 - $N_{PYNT} = N_T (N_{PYN}/N_I)$
 - Reasonable assumption for a medium to large inventory stored worldwide
- Equations assume a constant annual NDT quantity
 - Reasonable assumption for budgeting and executing a continuous-level-of-effort SRP
- Equations assume items are repaired
 - Easily modified in spreadsheets by reducing N_I by the predicted quantity of failed items removed
- Does not address retest point (where 100% of inventory has been tested and rounds are undergoing retest)
 - If done early in system life the process optimizes before retest point

The methodology provided can be used to determine the approximate quantity of missiles that need to be non-destructively tested annually in order to sustain inventory reliability above the user's reliability requirement.