Accelerated Aging of the M74A1 Simulator

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ABSTRACT

This paper addresses the storage requirement, shelf life and the reliability of the M74A1 Simulator. Experimental conditions have been determined and the data analysis has been completed for the accelerated testing of the system. A method for evaluation of shelf life of the M74A1 as a function of the storage time, temperature and relative humidity is presented.

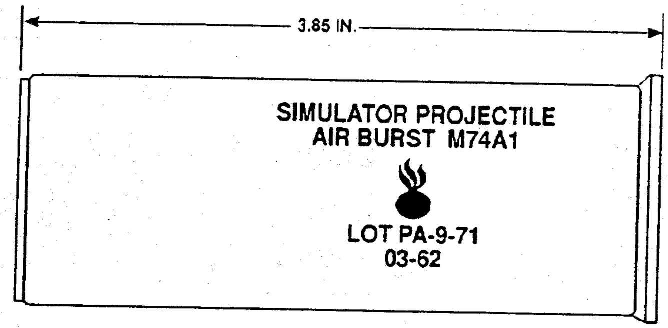
BACKGROUND

The M74A1 is a projectile air burst simulator. It has a one-piece aluminum case and resembles a shotgun shell. The case contains a percussion primer mounted in the base, a black powder propelling charge, a delay fuze, and an inner case containing a flash charge. The simulators are fired from a pyrotechnic pistol. The firing pin of the pistol strikes the primer that ignites the propelling charge. The propelling charge expels the self-contained flash charge from the case while igniting the igniting charge. The igniting charge contains a delay fuze that burns in two to three seconds. At 45 degrees elevation, the height of burst is about 100 feet.

It is shown in Figure 1. In this paper experimental data are presented in which the aging process has been accelerated. The experimental data have been acquired at temperatures ranging from 200 to 260 °F and .4% to 85% relative humidity.

<u>M74A1 Subassembly Chemical Compositions</u>

The chemical compositions of each of the subassemblies used in the M74A1 are shown in Tables I through V. There are many ingredients sensitive to heat and moisture including black powder and Boron. The primer mixture, itself, may be vulnerable to degradation. In general, the compositions contain fuels and oxidizers. In an experimental procedure such as the one used in this investigation, the exact subassembly that caused the item to fail cannot be determined. Individual subassembly accelerated aging functional tests would have to be done to determine the failure distributions for each subassembly



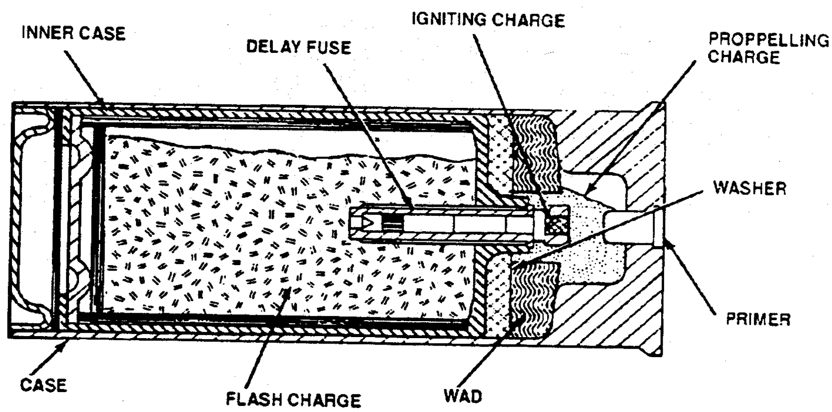


Figure 1. M74A1 Simulator Cutaway View

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Table I – Primer Mixture for M39A1 Percussion Primer

Constituent	Weight Percent
Potassium Chlorate Technical Grade A, Class 2, MIL-P-150	37.05 +/- 2. %
Lead Thiocyanate (Sulphocyanate), JAN-L-65	38.13 +/- 2.0 %
Trinitrotoluene (TNT), Type I, Mil-T-248	5.69 +/- 0.5 %
Barium Nitrate, MIL-B-162	8.68 +/- 1. %
Ground Glass (60-100 MESH), JAN-G-479	10.45 +/- 1. %

Table II – Black Powder (MIL-P-00223C (AR)) Propelling Charge
(Also used in igniting charge for the delay fuse)

Constituent	Weight Percent
Potassium Nitrate, JAN-P-156	74.0 +/- 1.0
Sulfur, Mil-S-14929	10.4 +\- 1.0
Charcoal, JAN-C-178	15.6 +\- 1.0

Table III– Fuse Powder (MIL-P-633, Type I)

Constituent	Weight Percent
Potassium Nitrate, Mil-P-00223C	74.0 +/- 2.0
Sulfur, Mil – S- 14929	10.4 +\- 1.5
Charcoal, JAN-C-178	15.6 +\- 1.5

Table IV– Delay Composition

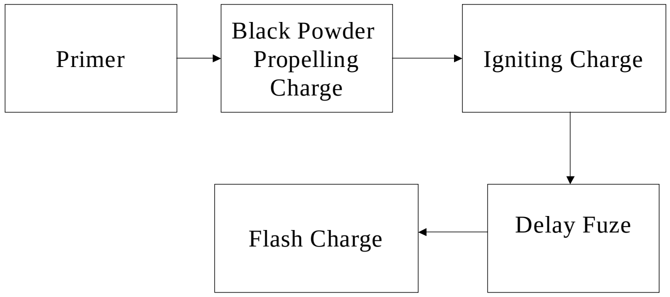
Constituent	Weight Percent
Barium Chromate, Grade C, MIL-B-550	95.0 +\- 0.2 %
Boron, MIL-B-51092	5.0 +\- 0.2

Table V– Flash Charge

Constituent	Weight Percent
Black Powder, Class 7, MIL-P-223	91. +/- 1. %
Aluminum Powder, Dark Pyro, 9276874	9. +/- 1. %

M74A1 Reliability Block Diagram

The reliability block diagram for the M74A1 is shown in Figure 2. There are five elements including the primer, the propelling charge, the igniting charge, the delay assembly and the flash charge. As indicated by the reliability block diagram, any one of the components in the diagram can cause the item to fail since they are all in series.



M74A1 Reliability Block Diagram

Figure 2. M74A1 Reliability Block Diagram

Degradation Mechanisms

The degradation mechanisms can only be deduced from the probable reactions based on known chemical properties of the ingredients and components. For example, the room temperature decomposition of Barium Chromate can release a small amount of oxygen into the system. The room temperature decomposition of Barium Chromate starts at as low as 60 ºC. However, even at 1015 ºC the weight loss is less than 1.0 weight percent (AMCP 706-187). Another source of oxygen is the air.

Any fuels that come in contact with oxygen will undergo some oxidation. Surface oxidation will in general make the fuels less reactive. In the case of a delay (which is already a slow burning mixture) oxidation of the boron can cause failure.

EXPERIMENTAL

Raw Data

The dud rates shown in Table VI include failures due to any of the components in Figure 2. Table VI shows the conditioning temperature and relative humidity, exposure time and dud rate for the items tested.

TableVI. Experimental Reliability Data for the M74A1

Temperature (°F)	Relative humidity	exposure time (days)	Dud Rate
200	85%	9	0/10
200	85%	20	10/10
200	85%	30	7/10
200	85%	40	9/10
200	85%	50	10/10
200	85%	60	6/10
200	85%	70	14/15
200	85%	81	15/15
220	85%	5	0/4
220	85%	10	0/4
220	85%	15	0/4.
220	85%	21	1/4
240	50%	6	1/4.
240	50%	10	2/4.
240	50%	15	4/4.
240	50%	20	3/4.
220	50%	6	0/4
220	50%	9	0/4
220	50%	15	0/4
220	50%	20	1/4.
260	.4%	12	4/4
260	.4%	16	4/4.
260	.4%	21	4/4.

*Data at 220 ºF (50% RH and 85% RH) were combined and are reported as 220 ºF and 67.5% RH. Data at 260 ºF and 21 days was not used in the maximum likelihood estimation of the distribution parameters.

Data Analysis Methodology

The data analysis methodology uses applied life data analysis (Nelson, 1990, 1982) to estimate the service life of the M74A1 based on the experimental data. Data must be available at a number of temperature and relative humidity conditions for accurate life prediction. In this study the data were available at four temperature/humidity conditions.

Modeling of Data

The lognormal cumulative distribution function for the population fraction failing by age y is

$$F(y,T,\%RH) = \Phi \{ [\ln(y) - \mu(T,\%RH)]/\sigma\}, y>0 \quad (1)$$

In equation (1), $\Phi(\ )$ is the standard normal cumulative distribution function. The parameter $\mu(T,\%RH)$, is the mean of the log of life and is called the log mean and σ is the log standard deviation. Note that the failure distributions determined in this study are a function of temperature and relative humidity as are the log means.

Since the data are time censored (samples are pulled out at certain times), maximum likelihood methods are used to estimate the parameters in the lognormal probability distributions from the data. These solutions are approximate for time-censored data and exact for failure-censored data. A summary of the log means and standard deviations obtained in this experiment is shown below in Table VII

Table VII. Maximum Likelihood Results for the Log means, log standard deviations and medians at each test temperature and relative humidity for the M119

Temperature (T) and % RH	Log Mean $\mu(T,\%RH)$	Log Standard Deviation (σ)	Median Life ($\tau_{.50}$) in days
200 °F – 85.0% RH	3.933	.4791	51.041
220 °F – 67.5% RH	3.056	.0351	21.252
240 °F – 50.0% RH	2.697	.3802	14.832
260 °F – 85% RH	2.628	.1438	13.856

The survival function, reliability function and the cumulative distribution function at a particular temperature and humidity are related by the equation below:

$$R(y) = S(y) = (1 - F(y)) \quad (2)$$

In equation (2) R(y) represents the reliability function which is also called the survivability (S(y)), and F(y) is the cumulative distribution function given in equation (1) A plot of the survivability is shown in Figure 3 for the 50%RH and 240 ºF experiment.

M74A1 Failure Distribution at 240 Degrees F and 50% Relative Humidity

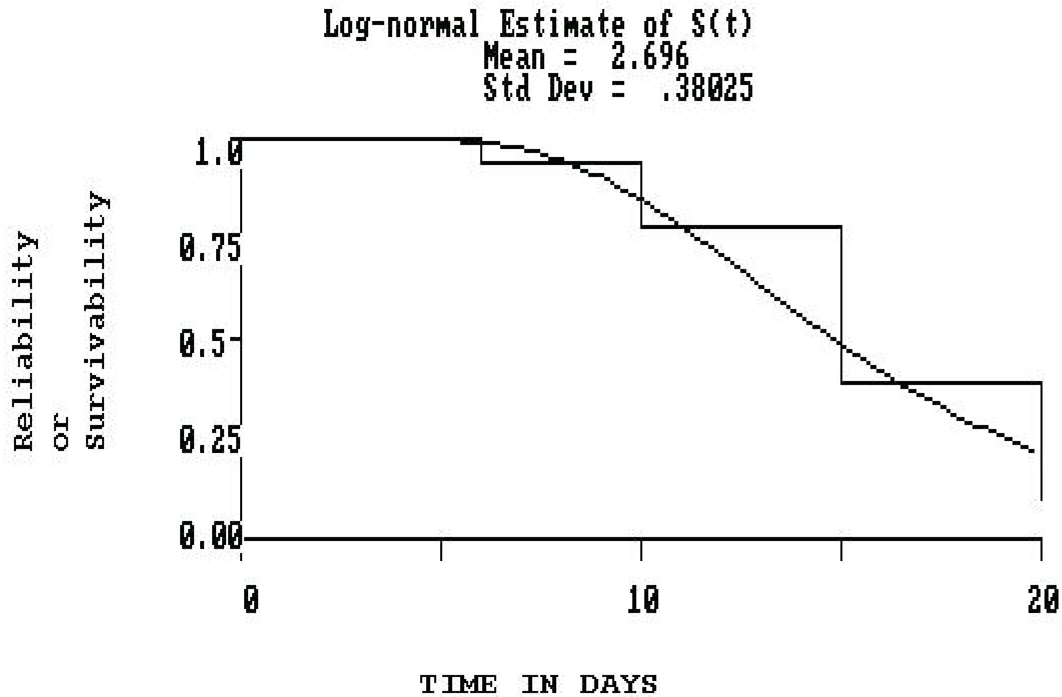


Figure 3. Survivability (reliability) of the M74A1 at 50 % Relative Humidity and 240 degrees F. Failure data was modeled using a lognormal distribution. Parameters have been estimated using maximum likelihood techniques.

<u>Eyring Equation for correlation of the log means with temperature and humidity</u>

A form of the Eyring equation is used to correlate the log means of each failure distribution with temperature and humidity. The equation is shown below:

$$\mu(T,\%RH) = A' + E_A/T + B*(\%RH) \quad (3)$$

In equation (3) $\mu(T,\%RH)$ is the log mean at temperature, T, and T is the absolute temperature in Rankine and %RH is the relative humidity at temperature T. A', E_A and B are constants. The median service life at 70 °F is calculated by exponentiation of equation (3):

$$(\tau_{.50}) = \exp\{\mu(T,\%RH)\} \quad (4)$$

Substitution of equation (3) into equation (4) results in the expression for $(\tau_{.50})$, the median service life:

$$(\tau_{.50}) = A \exp(E_A/T)\exp(B*[\%RH]) \qquad (5)$$

In equation (5) the symbol A has been used to represent exp (A’). The values of A, E_A, and B in equation (5) are obtained by non-linear regression using a Marquardt algorithm. The values of these parameters are shown in Table VIII.

Table VIII Estimated parameters for the M74A1 for Equation (5)

A	3.281e-012 days
E_A	20855 Rankine
B	-.015018 /%RH

Substitution of the parameters in Table VIII into Equation (6) results in the estimate of the median service life at 70 °F and 10 % RH. This estimate is 354,701 days or about 971.8 years. A plot of Equation (5) for 10, 50 and 90 % RH is shown in Figure 4.

In Figure 4 the median lifetime is on the ordinate (y axis) and temperature on the abscissa (x axis). The three lines represent the predicted lifetimes at three values of the relative humidity. The longest lifetime (top line) corresponds to the 10 % RH condition. As can be seen, even a 100 ºF increase in temperature (170 °F and 10% RH) results in a dramatic shortening of the lifetime to about 683 days. Although the humidity effect exists, the degradation is primarily temperature driven. The experimental data points are also shown. Note that the experimental data fit nicely on the predicted lines.

SUMMARY

A methodology for estimating service life based on attribute data has been presented. The methodology is based on experimental data which is used to estimate the parameters of a lognormal failure distribution at different temperature and humidity conditions. The log means are correlated with temperature and humidity using the Eyring equation. The results indicate that the storage life of the M74A1 rapidly degrades as storage temperature increases.

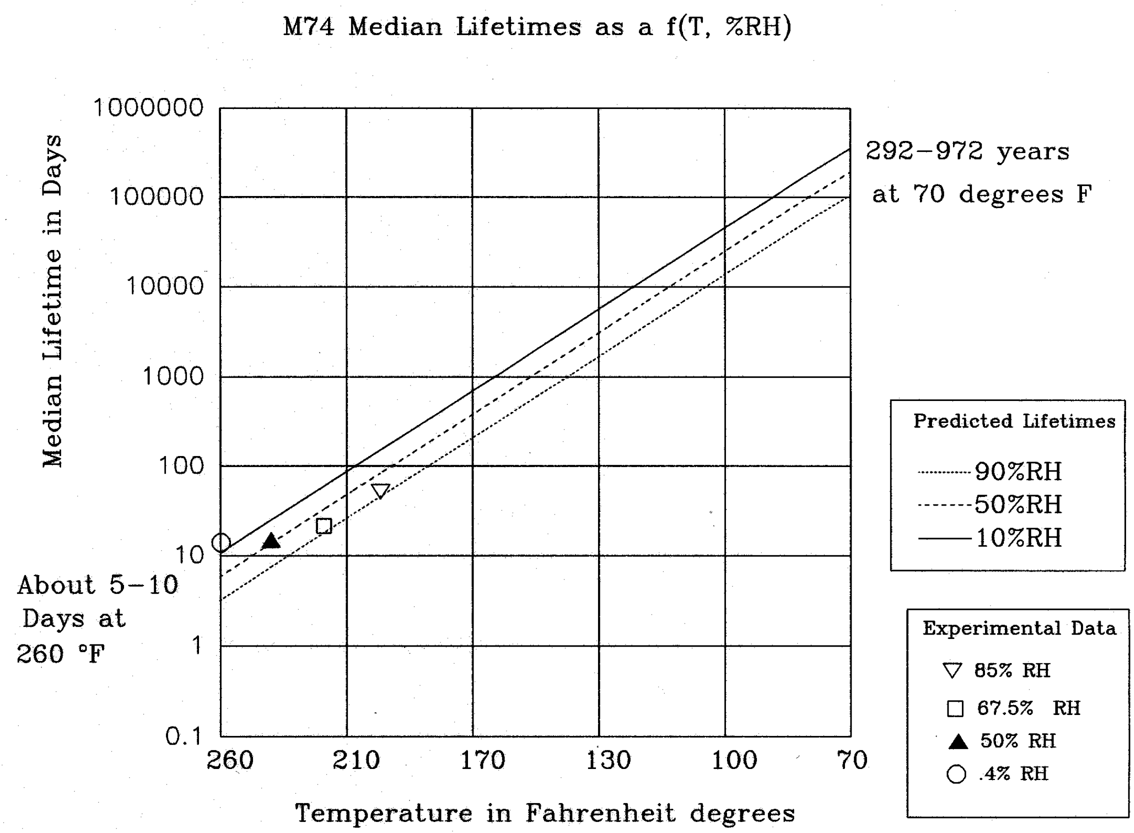


Figure 4. Plot of the Median Lifetimes of the M74A1 as a function of temperature and humidity.

FUTURE WORK

In order to estimate the experimental error variance in this type of methodology it is desirable to repeat the experiment. This would supply a statistical measure of the variance associated with the predicted lifetimes. Detailed theoretical failure mechanisms for each component can be further developed using chemical reactions and physical modeling (burn rate models, heat transfer and other techniques) to model potential degradation mechanisms. Experiments could be designed to validate these failure mechanisms. Data for each of the components in Figure 2 could be obtained by accelerated aging of the individual components. The results can be used to develop new designs for the M74A1 that are not so temperature sensitive and which have enhanced reliability and storage life.

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