Forecasting Atmospheric Storage Tank Bottom Corrosion Failure

R Code and Data Sets for Storage Magazine 3 Part Article Published XXX

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The following information is the complete R code as well as data sets used in preparing the above articles. They are available at

Datasets

|  |  |  |  |
| --- | --- | --- | --- |
| Parameter |  | Estimate | Range[[1]](#footnote-2) |
| Exponent: |  | 0.37 | 0.31 - 0.44 |
| Scale: (mils) |  | 21 | 19 - 24 |
| intensity[[2]](#footnote-3) (mils/year) | n of Tanks | Estimate | Range |
| A1 | 2 | 1.7 | 0.9 - 3.3 |
| A2 | 10 | 6.1 | 5.4 – 7.0 |
| A3 | 2 | 6.5 | 5.0 - 8.5 |
| A4 | 20 | 7.1 | 6.6 - 7.8 |
| A5 | 7 | 9.9 | 8.8 - 11.2 |
| A6 | 2 | 2.7 | 1.6 - 4.8 |
| A7 | 2 | 6.8 | 5.3 - 8.7 |
| A8 | 3 | 9.7 | 8.0 - 11.8 |
| A9 | 3 | 3.6 | 2.7 - 4.8 |
| A11 | 5 | 10.2 | 8.9 - 11.8 |
| A12 | 9 | 5.7 | 5.0 - 6.5 |
| NBS | 102 | 7.2 | 6.6 - 7.9 |

Table 1. Estimated power, scale, and intensity parameters.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Years in Service | Survival Probability | | | | |  |
| Site 2 | Site 4 | Site 5 | Site 11 | Site 12 | NBS |
| 1 | 100.0 | 100.0 | 99.9 | 99.9 | 100.0 | 100.0 |
| 5 | 99.9 | 99.7 | 98.5 | 98.2 | 99.9 | 99.7 |
| 10 | 99.5 | 99.0 | 94.2 | 93.0 | 99.7 | 98.9 |
| 15 | 98.9 | 97.6 | 87.8 | 85.7 | 99.3 | 97.5 |
| 20 | 98.1 | 95.9 | 80.4 | 77.3 | 98.7 | 95.6 |
| 25 | 97.1 | 93.7 | 72.5 | 68.6 | 98.0 | 93.2 |
| 30 | 95.8 | 91.1 | 64.7 | 60.2 | 97.2 | 90.6 |
| 35 | 94.4 | 88.3 | 57.2 | 52.3 | 96.2 | 87.6 |
| 40 | 92.7 | 85.3 | 50.3 | 45.2 | 95.0 | 84.5 |
| 45 | 91.0 | 82.2 | 43.9 | 38.9 | 93.8 | 81.2 |
| 50 | 89.1 | 78.9 | 38.3 | 33.3 | 92.5 | 77.8 |
| 55 | 87.2 | 75.7 | 33.2 | 28.4 | 91.0 | 74.4 |
| 60 | 85.1 | 72.3 | 28.8 | 24.2 | 89.5 | 71.0 |
| 65 | 83.0 | 69.0 | 24.8 | 20.6 | 87.9 | 67.6 |
| 70 | 80.9 | 65.8 | 21.4 | 17.4 | 86.3 | 64.2 |
| 75 | 78.7 | 62.6 | 18.5 | 14.8 | 84.6 | 60.9 |
| 80 | 76.5 | 59.5 | 15.9 | 12.5 | 82.9 | 57.7 |
| Intensity(mpy) | 6.14 | 7.13 | 9.89 | 10.24 | 5.69 | 7.22 |
| n[[3]](#footnote-4) | 10 | 20 | 7 | 5 | 9 | 102 |

Table 2. Survival table for sites with 5 or more inspections.

# Annex 2: R Programs

## Censored Gamma Regression

gamma\_censored\_mu\_scale <- function(y, x, censored, var=TRUE) {

#########################################################

# Syntax; fit <- gamma\_censored(y,x,censored)

# y is a positive-valued dependent variable

# x is a design matrix with the same number of rows as y

# censored has the same number of rows as y; coded: -1 = left, 0 = none, 1 = right

# the y value for each censored observation is the upper or lower bound

# of the unobserved value of y

############################################################

# Censoring

left <- which(censored==-1)

obs <- which(censored==0)

right <- which(censored==1)

# Design matrix

n <- length(y)

p <- ncol(x)

labels <- c(colnames(x),"scale")

# Log-likelihood function

ll.f <- function(f.theta) {

f.betas <- f.theta[1: p]

f.b <- f.theta[p + 1]

ll <- sum(dgamma(x = y[obs], log = TRUE,

shape = exp(x[obs,] %\*% f.betas - f.b), scale = exp(f.b))) +

sum(pgamma(q = y[left], log.p = TRUE,

shape = exp(x[left,] %\*% f.betas - f.b),

scale = exp(f.b),lower.tail=TRUE)) +

sum(pgamma(q = y[right], log.p = TRUE,

shape = exp(x[right,] %\*% f.betas - f.b),

scale = exp(f.b),lower.tail=FALSE))

return(-ll)

}

# Maximize log-likelihood

llmax <- nlminb(objective = ll.f, start = c(rep(0, p), 1),

lower = c(rep(-Inf, p), 1e-6))

theta.hat <- llmax$par

names(theta.hat) <- labels

ret.list <- list(theta.hat = theta.hat)

# Estimate variance-covariance matrix

if (var) {

hessian.mat <- pracma::hessian(f = ll.f, x0 = theta.hat)

varcov <- solve(hessian.mat)

colnames(varcov) <- rownames(varcov) <- labels

ret.list$varcov <- varcov

}

# Add AIC and nlminb object to return list

ret.list$aic <- 2 \* (p + 1 + llmax$objective)

ret.list$nlminb.object <- llmax

return(ret.list)

}

## Gamma Regression of Corrosion Data

####################################################################

# Gamma\_Regression\_of\_Corrosion\_Data.R

####################################################################

# The input data must be in the same directory as this program

# and must contain these variables:

# site.name: storage facility names

# yrs: years in service at inspection

# max.pit.depth: maximum pit depth at inspection

# censored: -1 = left censored, 0 = not censored, 1 = right censored

# left censored pit depth = maximum possible value

# right censored pit depth = minimum possible value

# uncensored pit depth = value as reported

# Other variables can be included but are not analyzed

###################################################################

# Output is in .csv files in the same directory as this program

# raw\_estimates.csv: estimates, standard errors and +/- se

# ranges of beta, log(max.pit.depth) at 20 years, log(sigma)

# model\_parameters.csv

# The R program "gamma\_cenored\_mu\_scale.R" must be in the same

# directory as this program

###################################################################

source("gamma\_censored\_mu\_scale.R",local=TRUE)

Cdata <- read.csv("Corrosion\_Data.csv")

n.obs <- nrow(Cdata)

n.per.site <- as.vector(table(Cdata$site.name))

#########################################################################

# dependent variable, design matrix, and censoring for gamma regression

#########################################################################

y <- Cdata$max.pit.depth

ln.yrs <- as.vector(log(Cdata$yrs/20))

site <- factor(Cdata$site.name)

x.site <- model.matrix(lm(y ~ -1 + factor(site)))

df.sites <- ncol(x.site)

n.chars.to.chop <- regexpr('site',colnames(x.site)[2])[1]+5

colnames(x.site) <- substr(colnames(x.site),n.chars.to.chop,100)

x <- ln.yrs

X <- cbind(x,x.site) # Design matrix

colnames(X)[1] <- "exponent"

df.mod <- ncol(X)

censored <- Cdata$censored

######################################################################

# gamma regression with contstant scale

fit <-gamma\_censored\_mu\_scale(y = y, x = X, censored=censored)

######################################################################

# assemble estimates into tables

# theta vector is (beta,log(20-yr-pit.depth),log(sigma))

######################################################################

theta <- as.data.frame(as.numeric(fit$theta.hat))

rownames(theta) <- c(colnames(X),"ln.sigma")

colnames(theta) <- c("estimate")

# varcov is the covariance matrix of theta

# std.err is the standard errors of theta

# cormat is the correlation matrix of theta

varcov <- as.matrix(fit$varcov)

std.err <- as.vector(sqrt(diag(varcov)))

cormat <- round(diag(1/std.err)%\*%varcov%\*%diag(1/std.err),3)

theta$std.err <- std.err

# +/- std.err ranges of estimates

theta$lower <- theta[,1]-std.err

theta$upper <- theta[,1]+std.err

theta$n <- c(n.obs,n.per.site,n.obs-df.mod)

write.csv(theta,"raw\_estimates.csv")

# Convert estimates to gamma process parameters

# n.theta is the number of observations supporting each coefficient

n.theta <- c(n.obs,n.per.site,n.obs-df.mod)

# A = intensities and scale

model.parms <-

rbind(theta[1,],exp(theta[2:(df.mod),])/20,exp(theta[df.mod+1,]))[,c(1,3,4)]

model.parms$n <- theta$n

rownames(model.parms)[1] <- "beta"

rownames(model.parms)[df.mod+1] <- "sigma"

colnames(model.parms)[1] <- "estimate"

write.csv(model.parms,"model\_parameters.csv")

# Pairwise z-values for sites

est <- theta[2:df.mod,1]

sort <- order(-est)

est <- est[sort]

est.names <- rownames(model.parms)[2:df.mod][sort]

vcm <- varcov[2:df.mod,2:df.mod][sort,sort]

df.site <- df.mod-1

z <- matrix(nrow=df.site,ncol=df.site-1)

z[1,1] <- NA

for (r in 2:df.site) {

for (c in 1:(r-1)) {

z[r,c] <- round((est[c]-est[r])/sqrt(vcm[r,r]-2\*vcm[r,c]+vcm[c,c]),2)

}

}

rownames(z) <- est.names

colnames(z) <- est.names[1:(df.site-1)]

z <- cbind(model.parms[2:(df.site+1),"estimate"][sort],z)

colnames(z)[1] <- "A estimate"

write.csv(z,"pairwise.z.csv")

# Survival Table

yrs.in.service <- c(1,seq(5,80,5)) # Years In Service

beta <- as.numeric(model.parms[1,1])

scale <- model.parms[df.mod+1,1]

surv.table <- as.data.frame(yrs.in.service)

for(i in c(1:df.sites)){

row = i+1

A <- model.parms[row,1]

shape <- 20\*A\*(yrs.in.service/20)^beta/scale

surv <- round(100\*pgamma(250,shape=shape,scale=scale),1)

surv.table <- cbind(surv.table,surv)

}

colnames(surv.table) <- c("Year",rownames(model.parms)[2:(df.sites+1)])

write.csv(surv.table,"Survival\_Table.csv")

lower.surv.table <- as.data.frame(yrs.in.service)

for(i in c(1:df.sites)){

row = i+1

A <- model.parms[row,"upper"]

shape <- 20\*A\*(yrs.in.service/20)^beta/scale

surv <- round(100\*pgamma(250,shape=shape,scale=scale),1)

lower.surv.table <- cbind(lower.surv.table,surv)

}

colnames(lower.surv.table) <- c("Year",rownames(model.parms)[2:(df.sites+1)])

write.csv(lower.surv.table,"lower\_Survival\_Table.csv")

############ End ############

## Output Files

Table 3. model\_parameters.csv

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  | estimate | lower | upper | n |
| Exponent | beta | 0.375 | 0.311 | 0.439 | 167 |
| Corrosion Intensities for Sites | NBS | 7.22 | 6.64 | 7.86 | 102 |
| Site 01 | 1.75 | 0.94 | 3.27 | 2 |
| Site 02 | 6.14 | 5.41 | 6.98 | 10 |
| Site 03 | 6.49 | 4.98 | 8.45 | 2 |
| Site 04 | 7.13 | 6.56 | 7.75 | 20 |
| Site 05 | 9.89 | 8.76 | 11.16 | 7 |
| Site 06 | 2.73 | 1.56 | 4.78 | 2 |
| Site 07 | 6.80 | 5.31 | 8.72 | 2 |
| Site 08 | 9.69 | 7.98 | 11.77 | 3 |
| Site 09 | 3.58 | 2.66 | 4.81 | 3 |
| Site 11 | 10.24 | 8.91 | 11.78 | 5 |
| Site 12 | 5.69 | 4.98 | 6.51 | 9 |
| Scale | sigma | 21.0 | 18.7 | 23.7 | 154 |

Table 4. Expected Survival Functions for NBS and 11 Tank Farms

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Year | NBS | Site 01 | Site 02 | Site 03 | Site 04 | Site 05 | Site 06 | Site 07 | Site 08 | Site 09 | Site 11 | Site 12 |
| 1 | 100 | 100 | 100 | 100 | 100 | 99.9 | 100 | 100 | 99.9 | 100 | 99.9 | 100 |
| 5 | 99.7 | 100 | 99.9 | 99.8 | 99.7 | 98.5 | 100 | 99.8 | 98.7 | 100 | 98.2 | 99.9 |
| 10 | 98.9 | 100 | 99.5 | 99.4 | 99.0 | 94.2 | 100 | 99.2 | 94.7 | 100 | 93.0 | 99.7 |
| 15 | 97.5 | 100 | 98.9 | 98.6 | 97.6 | 87.8 | 100 | 98.2 | 88.9 | 99.9 | 85.7 | 99.3 |
| 20 | 95.6 | 100 | 98.1 | 97.5 | 95.9 | 80.4 | 100 | 96.8 | 82.0 | 99.9 | 77.3 | 98.7 |
| 25 | 93.2 | 100 | 97.1 | 96.1 | 93.7 | 72.5 | 100 | 95.0 | 74.6 | 99.8 | 68.6 | 98.0 |
| 30 | 90.6 | 100 | 95.8 | 94.4 | 91.1 | 64.7 | 99.9 | 93.0 | 67.1 | 99.8 | 60.2 | 97.2 |
| 35 | 87.6 | 100 | 94.4 | 92.6 | 88.3 | 57.2 | 99.9 | 90.7 | 59.9 | 99.7 | 52.3 | 96.2 |
| 40 | 84.5 | 100 | 92.7 | 90.5 | 85.3 | 50.3 | 99.9 | 88.2 | 53.1 | 99.6 | 45.2 | 95.0 |

Table 5. One standard error lower survival bounds.

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Year | NBS | Site 01 | Site 02 | Site 03 | Site 04 | Site 05 | Site 06 | Site 07 | Site 08 | Site 09 | Site 11 | Site 12 |
| 1 | 100 | 100 | 100 | 100 | 100 | 100 | 99.9 | 100 | 100 | 99.8 | 100 | 99.8 |
| 5 | 99.7 | 99.6 | 100 | 99.8 | 99.4 | 99.6 | 97.2 | 100 | 99.2 | 96.2 | 100 | 96.2 |
| 10 | 98.9 | 98.2 | 100 | 99.1 | 97.4 | 98.4 | 89.5 | 99.9 | 97.0 | 86.5 | 99.9 | 86.5 |
| 15 | 97.5 | 96.1 | 100 | 97.9 | 94.3 | 96.4 | 79.3 | 99.7 | 93.4 | 74.3 | 99.7 | 74.2 |
| 20 | 95.6 | 93.2 | 99.9 | 96.3 | 90.3 | 93.7 | 68.4 | 99.5 | 88.8 | 61.9 | 99.5 | 61.8 |
| 25 | 93.2 | 89.8 | 99.9 | 94.3 | 85.7 | 90.5 | 57.9 | 99.2 | 83.6 | 50.6 | 99.2 | 50.5 |
| 30 | 90.6 | 86.0 | 99.9 | 92.0 | 80.8 | 86.9 | 48.4 | 98.9 | 78.1 | 40.8 | 98.8 | 40.7 |
| 35 | 87.6 | 82.0 | 99.8 | 89.5 | 75.6 | 83.0 | 40.1 | 98.5 | 72.5 | 32.6 | 98.4 | 32.5 |
| 40 | 84.5 | 77.8 | 99.7 | 86.7 | 70.4 | 79.0 | 33.0 | 98.0 | 66.9 | 25.9 | 97.9 | 25.8 |

# Annex 3. Corrosion Data

Table 6. Tank Data

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| site.name | yrs | max.pit.depth | censored | site.name | yrs | max.pit.depth | censored |
| Site 1 | 9.4 | 45 | 0 | Site 5 | 16.4 | 250 | 1 |
| Site 1 | 10.8 | 18 | -1 | Site 5 | 29.5 | 250 | 1 |
| Site 2 | 10.8 | 20 | 0 | Site 5 | 30.4 | 250 | 1 |
| Site 2 | 11.4 | 70 | 0 | Site 5 | 32.4 | 192 | 0 |
| Site 2 | 11.5 | 70 | 0 | Site 5 | 33.5 | 150 | 0 |
| Site 2 | 11.8 | 20 | 0 | Site 5 | 37.6 | 165 | 0 |
| Site 2 | 12.6 | 132 | 0 | Site 5 | 39.7 | 240 | 0 |
| Site 2 | 30.8 | 250 | 1 | Site 6 | 4.8 | 82 | 0 |
| Site 2 | 31.8 | 143 | 0 | Site 6 | 7.4 | 18 | -1 |
| Site 2 | 31.9 | 140 | 0 | Site 7 | 29.5 | 180 | 0 |
| Site 2 | 33.8 | 241 | 0 | Site 7 | 36 | 132 | 0 |
| Site 2 | 33.9 | 250 | 1 | Site 8 | 16.8 | 136 | 0 |
| Site 3 | 18.8 | 138 | 0 | Site 8 | 17.4 | 132 | 0 |
| Site 3 | 31.6 | 125 | 0 | Site 8 | 18.9 | 250 | 1 |
| Site 4 | 3.5 | 100 | 0 | Site 9 | 9.9 | 50 | 0 |
| Site 4 | 9.8 | 120 | 0 | Site 9 | 12.7 | 20 | 0 |
| Site 4 | 10.9 | 110 | 0 | Site 9 | 38.7 | 140 | 0 |
| Site 4 | 11.7 | 140 | 0 | Site 11 | 26.6 | 225 | 0 |
| Site 4 | 14.9 | 150 | 0 | Site 11 | 28.9 | 160 | 0 |
| Site 4 | 15.1 | 220 | 0 | Site 11 | 29.6 | 250 | 1 |
| Site 4 | 16.6 | 80 | 0 | Site 11 | 31.3 | 250 | 1 |
| Site 4 | 19.1 | 100 | 0 | Site 11 | 39.8 | 200 | 0 |
| Site 4 | 25.1 | 70 | 0 | Site 12 | 11.3 | 240 | 0 |
| Site 4 | 26 | 200 | 0 | Site 12 | 18.7 | 18 | -1 |
| Site 4 | 28.2 | 170 | 0 | Site 12 | 18.9 | 30 | 0 |
| Site 4 | 28.2 | 170 | 0 | Site 12 | 19.3 | 100 | 0 |
| Site 4 | 29.9 | 110 | 0 | Site 12 | 27.7 | 250 | 1 |
| Site 4 | 29.9 | 90 | 0 | Site 12 | 30 | 222 | 0 |
| Site 4 | 29.9 | 312 | 1 | Site 12 | 33.4 | 165 | 0 |
| Site 4 | 30.6 | 70 | 0 | Site 12 | 33.9 | 162 | 0 |
| Site 4 | 31 | 110 | 0 | Site 12 | 39 | 132 | 0 |
| Site 4 | 33.3 | 250 | 1 |  |  |  |  |
| Site 4 | 34.9 | 220 | 0 |  |  |  |  |
| Site 4 | 36.8 | 150 | 0 |  |  |  |  |

Table 7. NBS Data

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| site.name | yrs | max.pit.depth | censored | site.name | yrs | max.pit.depth | censored |
| NBS | 1.1 | 61.8 | 0 | NBS | 7.6 | 66.1 | 0 |
| NBS | 1.1 | 65 | 0 | NBS | 7.6 | 68.9 | 0 |
| NBS | 1.1 | 38.2 | 0 | NBS | 7.7 | 94.1 | 0 |
| NBS | 1.2 | 28 | 0 | NBS | 7.7 | 161 | 0 |
| NBS | 1.2 | 28 | 0 | NBS | 7.7 | 57.1 | 0 |
| NBS | 1.3 | 46.9 | 0 | NBS | 7.7 | 66.1 | 0 |
| NBS | 1.4 | 42.1 | 0 | NBS | 7.8 | 61.8 | 0 |
| NBS | 1.4 | 29.1 | 0 | NBS | 7.9 | 83.9 | 0 |
| NBS | 1.5 | 79.1 | 0 | NBS | 8 | 68.1 | 0 |
| NBS | 1.7 | 46.9 | 0 | NBS | 8 | 216.1 | 0 |
| NBS | 1.9 | 85.8 | 0 | NBS | 8 | 178 | 0 |
| NBS | 2 | 59.8 | 0 | NBS | 8 | 68.1 | 0 |
| NBS | 2 | 44.9 | 0 | NBS | 8 | 96.1 | 0 |
| NBS | 2 | 68.1 | 0 | NBS | 8 | 98.8 | 0 |
| NBS | 2 | 90.2 | 0 | NBS | 8 | 92.9 | 0 |
| NBS | 2 | 42.1 | 0 | NBS | 8 | 135.8 | 0 |
| NBS | 2 | 61.8 | 0 | NBS | 8 | 133.9 | 0 |
| NBS | 3.7 | 50 | 0 | NBS | 9.6 | 68.1 | 0 |
| NBS | 3.7 | 59.8 | 0 | NBS | 9.7 | 78 | 0 |
| NBS | 3.8 | 57.1 | 0 | NBS | 9.8 | 64.2 | 0 |
| NBS | 3.8 | 74 | 0 | NBS | 9.8 | 157.9 | 0 |
| NBS | 3.8 | 52 | 0 | NBS | 9.9 | 92.9 | 0 |
| NBS | 3.8 | 48.8 | 0 | NBS | 9.9 | 142.1 | 0 |
| NBS | 4 | 61.8 | 0 | NBS | 9.9 | 103.9 | 0 |
| NBS | 4 | 70.1 | 0 | NBS | 9.9 | 155.1 | 0 |
| NBS | 4 | 18.1 | 0 | NBS | 10 | 70.9 | 0 |
| NBS | 4 | 109.8 | 0 | NBS | 10 | 70.9 | 0 |
| NBS | 4.1 | 90.2 | 0 | NBS | 10 | 178 | 0 |
| NBS | 4.1 | 90.2 | 0 | NBS | 10 | 85.8 | 0 |
| NBS | 4.1 | 92.1 | 0 | NBS | 10.1 | 79.9 | 0 |
| NBS | 4.1 | 46.1 | 0 | NBS | 10.1 | 114.2 | 0 |
| NBS | 4.1 | 85 | 0 | NBS | 10.1 | 129.1 | 0 |
| NBS | 4.1 | 79.1 | 0 | NBS | 10.2 | 163 | 0 |
| NBS | 4.3 | 133.9 | 0 | NBS | 10.2 | 79.9 | 0 |
| NBS | 5.1 | 96.1 | 0 | NBS | 11.6 | 85 | 0 |
| NBS | 5.6 | 61.8 | 0 | NBS | 11.6 | 70.9 | 0 |
| NBS | 5.7 | 59.1 | 0 | NBS | 11.7 | 70.1 | 0 |
| NBS | 5.8 | 77.2 | 0 | NBS | 11.7 | 124 | 0 |
| NBS | 5.8 | 153.1 | 0 | NBS | 11.8 | 127.2 | 0 |
| NBS | 5.8 | 79.9 | 0 | NBS | 11.8 | 111.8 | 0 |

Table 7. NBS Data (continued)

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| site.name | yrs | max.pit.depth | censored | site.name | yrs | max.pit.depth | censored |
| NBS | 5.8 | 52 | 0 | NBS | 11.9 | 88.2 | 0 |
| NBS | 6 | 81.9 | 0 | NBS | 12 | 85.8 | 0 |
| NBS | 6 | 72.8 | 0 | NBS | 12 | 216.1 | 0 |
| NBS | 6 | 90.2 | 0 | NBS | 12 | 74 | 0 |
| NBS | 6 | 81.1 | 0 | NBS | 12 | 127.2 | 0 |
| NBS | 6 | 59.1 | 0 | NBS | 12 | 90.9 | 0 |
| NBS | 6 | 88.2 | 0 | NBS | 12 | 125.2 | 0 |
| NBS | 6 | 85.8 | 0 | NBS | 12 | 78 | 0 |
| NBS | 6.1 | 48 | 0 | NBS | 12 | 79.9 | 0 |
| NBS | 6.2 | 129.9 | 0 | NBS | 12.1 | 83.9 | 0 |
| NBS | 6.2 | 131.9 | 0 | NBS | 12.1 | 177.2 | 0 |

1. Estimate ± std error [↑](#footnote-ref-2)
2. Corrosion rate (mils/year) at age 20. [↑](#footnote-ref-3)
3. Number of tanks inspected at or before 40 years in service. [↑](#footnote-ref-4)