Vietnam Caves - Radiation Experiments

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OVERVIEW

A series of laboratory experiments were conducted to test if radiation could explain loss of CH4 in caves. The experiments consisted of pumping CH4 into bags with or without an alpha-emitter. The bag was hooked up to a CH4 detector and this continusouly measured CH4 loss over time.

1) SET WORKING DIRECTORY

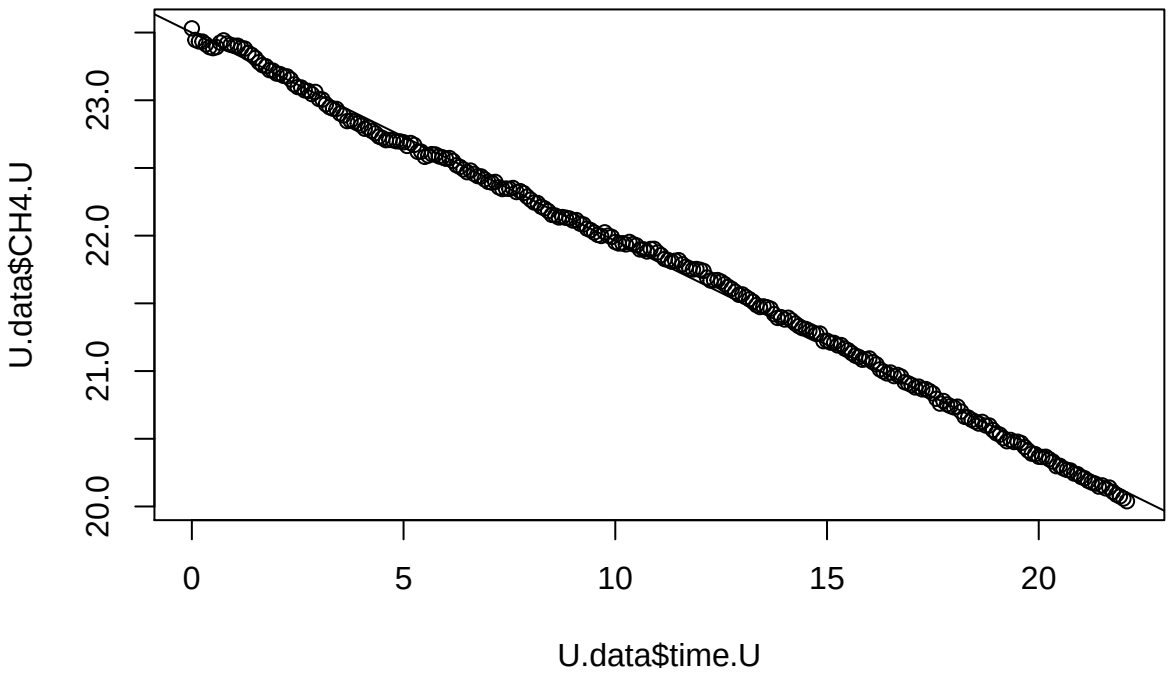
```
rm(list=ls())
getwd()
```

```
## [1] "/Users/lennonj/GitHub/radiolyticCH4/code/uranium"
```

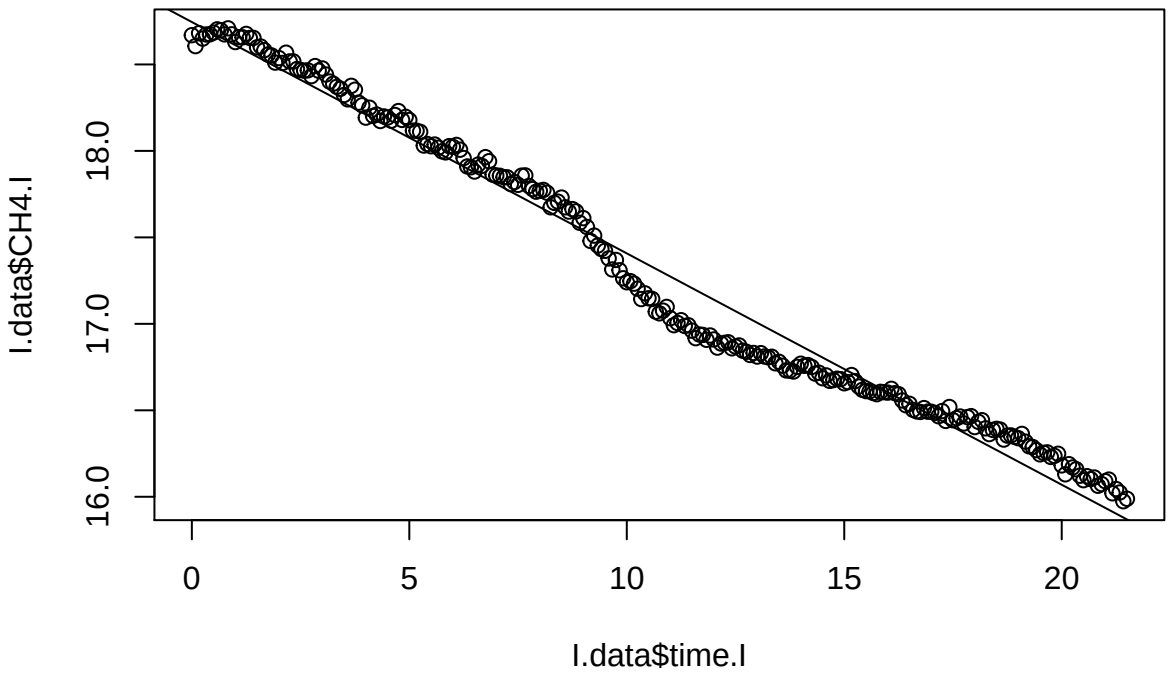
```
setwd("~/GitHub/radiolyticCH4/")
```

2) Load data, perform time conversions

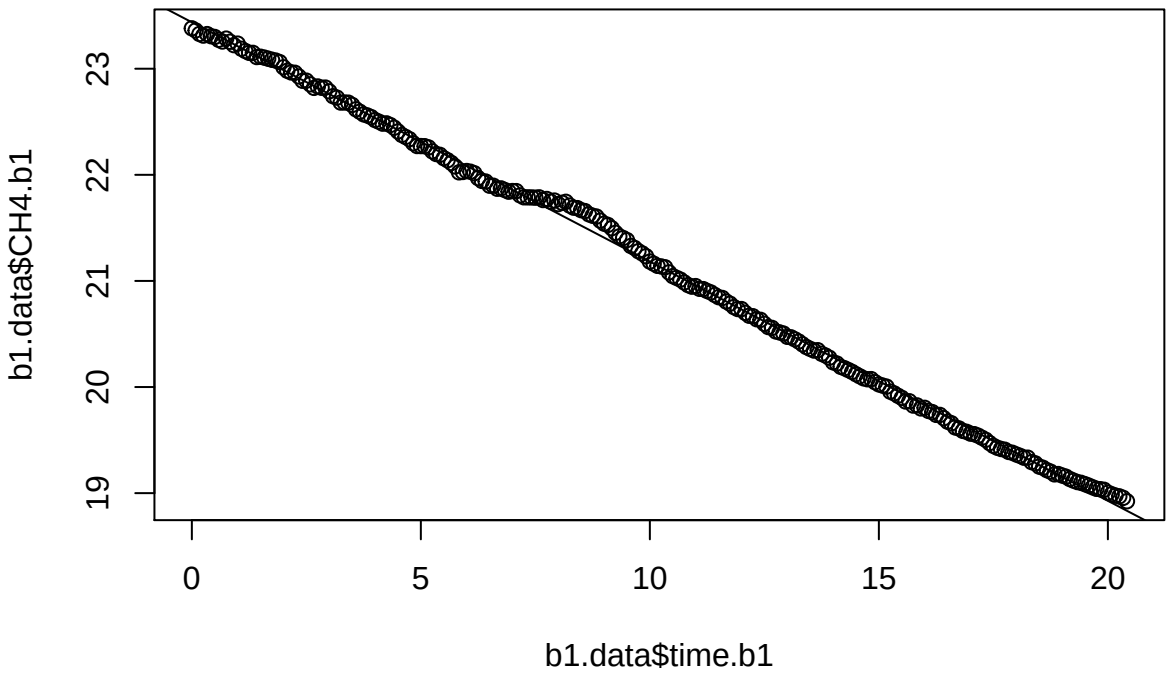
```
# Uranium Bag: contains depleted uranium as source of ionizing radiation
data.U <- read.table("~/GitHub/radiolyticCH4/data/uranium/uranium.bag.txt",
          sep="\t", header=TRUE)
time.U <- data.U[,1]
time.U <- strptime(data.U[,1], "%m/%d/%Y %H:%M")
time.U.hr <- (time.U - time.U[1])/(60*60)
CH4.U <- data.U[,2]
CH4.U.per <- CH4.U/max(CH4.U)
U.data <- as.data.frame(cbind(time.U.hr, CH4.U, CH4.U.per))
U.rate <- lm(U.data$CH4.U ~ U.data$time.U)
plot(U.data$time.U,U.data$CH4.U)
abline(U.rate)
```



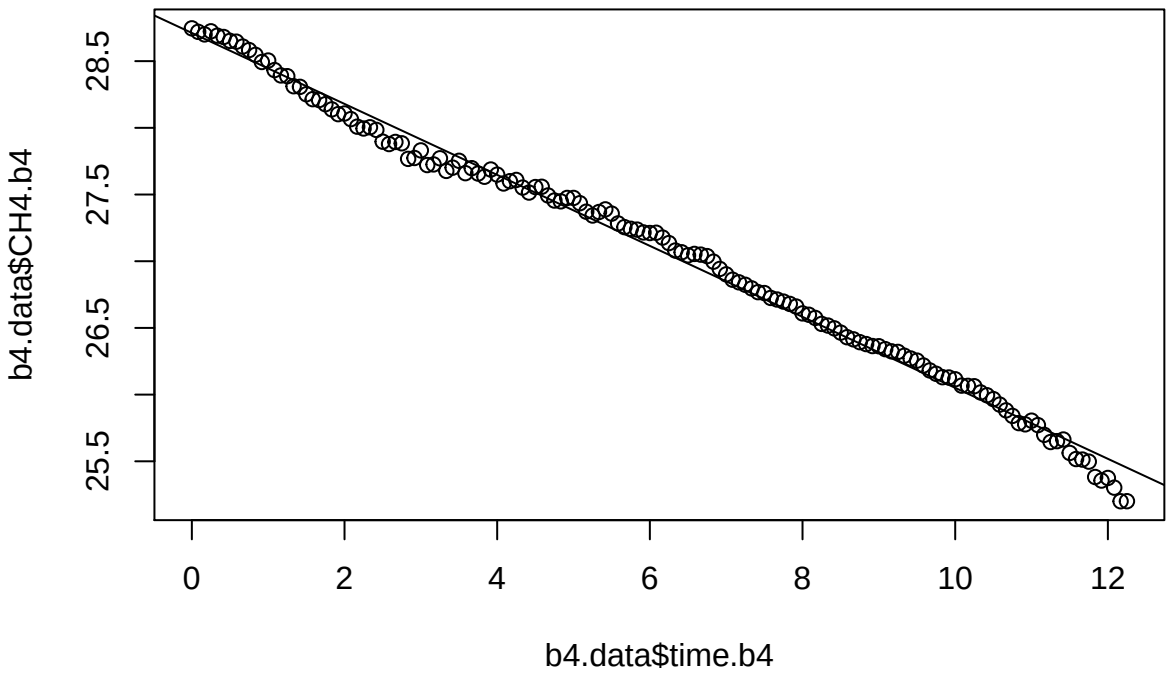

```
# Ions Bag: control bag with no additional source of ionizing radiation
data.I.raw <- read.table("~/GitHub/radiolyticCH4/data/uranium/ion.bag.txt",
          sep="\t", header=TRUE)
data.I <- data.I.raw[seq(1, nrow(data.I.raw), by=5), ]
time.I <- (strptime(data.I[,1], "%m/%d/%Y %H:%M"))
time.I.hr <- (time.I - time.I[1])/(60*60)
CH4.I <- data.I[,2]
CH4.I.per <- CH4.I/max(CH4.I)
I.data <- as.data.frame(cbind(time.I.hr, CH4.I, CH4.I.per))
I.rate <- lm(I.data$CH4.I ~ I.data$time.I)
plot(I.data$time.I, I.data$CH4.I)
abline(I.rate)
```



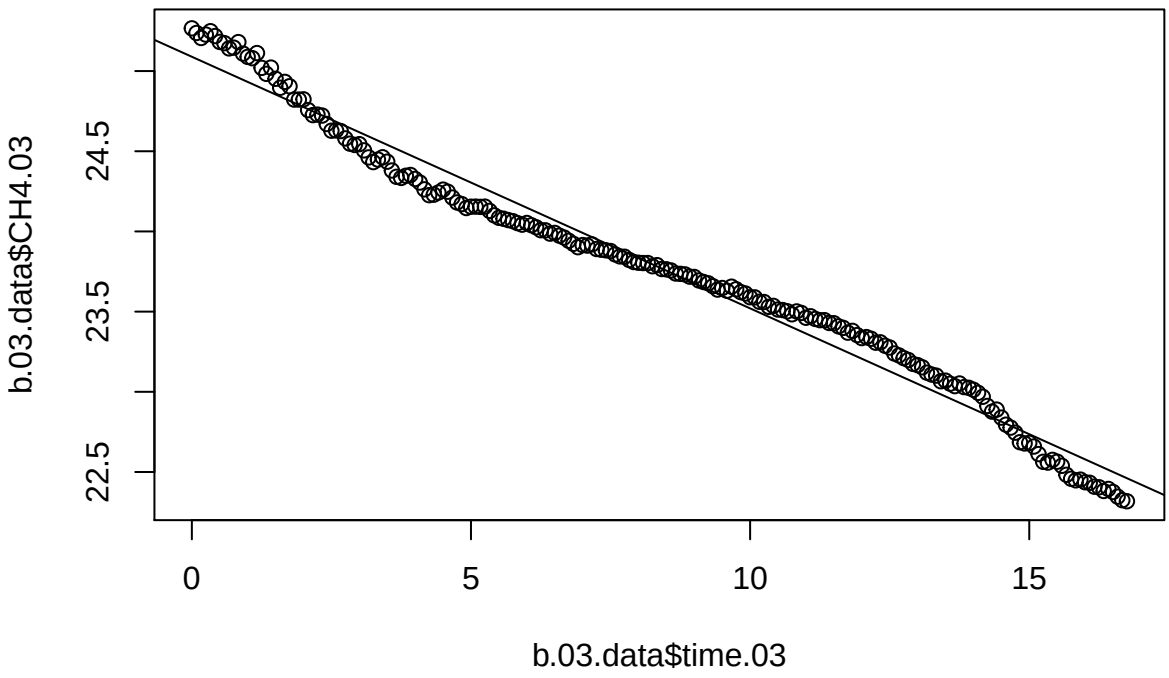

```
# Box 1: : control bag with no additional source of ionizing radiation
data.b1 <- read.table("~/GitHub/radiolyticCH4/data/uranium/box1.bag.txt",
          sep="\t", header=TRUE)
time.b1 <- (strptime(data.b1[,1], "%m/%d/%Y %H:%M"))
time.b1.hr <- (time.b1 - time.b1[1])/(60*60)
CH4.b1 <- data.b1[,2]
CH4.b1.per <- CH4.b1/max(CH4.b1)
b1.data <- as.data.frame(cbind(time.b1.hr, CH4.b1, CH4.b1.per))
b1.rate <- lm(b1.data$CH4.b1 ~ b1.data$time.b1)
plot(b1.data$time.b1, b1.data$CH4.b1)
abline(b1.rate)
```



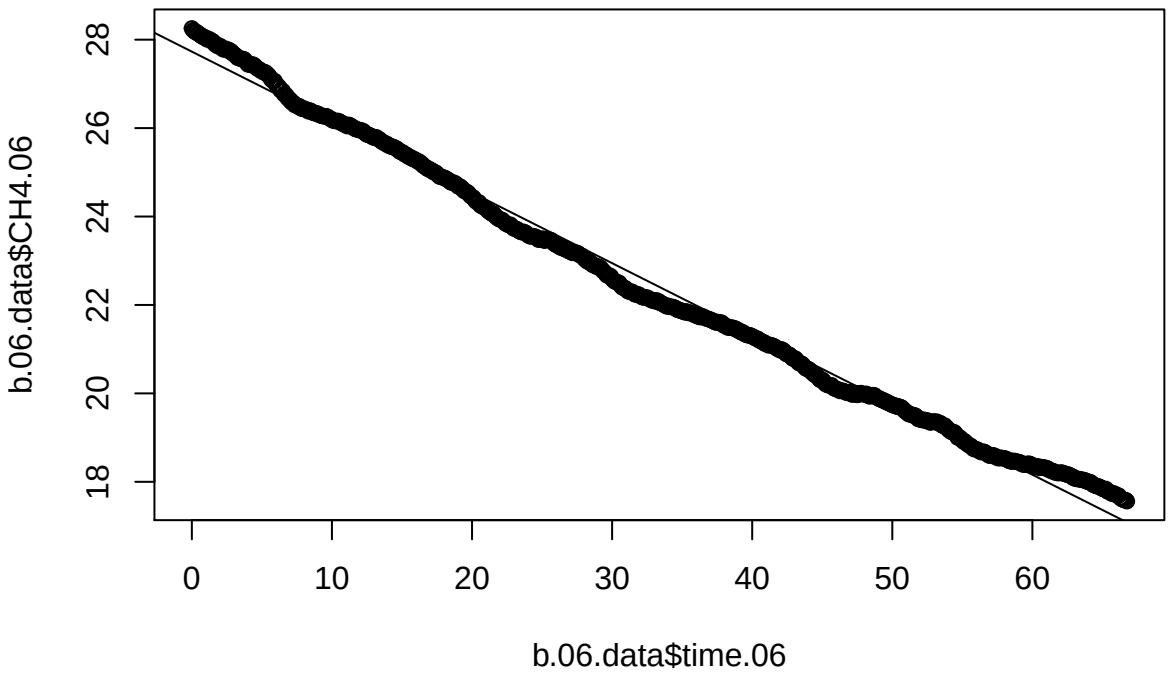

```
# Box 4: : control bag with no additional source of ionizing radiation
data.b4 <- read.table("~/GitHub/radiolyticCH4/data/uranium/box4.bag.txt",
          sep="\t", header=TRUE)
time.b4 <- (strptime(data.b4[,1], "%m/%d/%Y %H:%M"))
time.b4.hr <- (time.b4 - time.b4[1])/(60*60)
CH4.b4 <- data.b4[,2]
CH4.b4.per <- CH4.b4/max(CH4.b4)
b4.data <- as.data.frame(cbind(time.b4.hr, CH4.b4, CH4.b4.per))
b4.rate <- lm(b4.data$CH4.b4 ~ b4.data$time.b4)
plot(b4.data$time.b4, b4.data$CH4.b4)
abline(b4.rate)
```



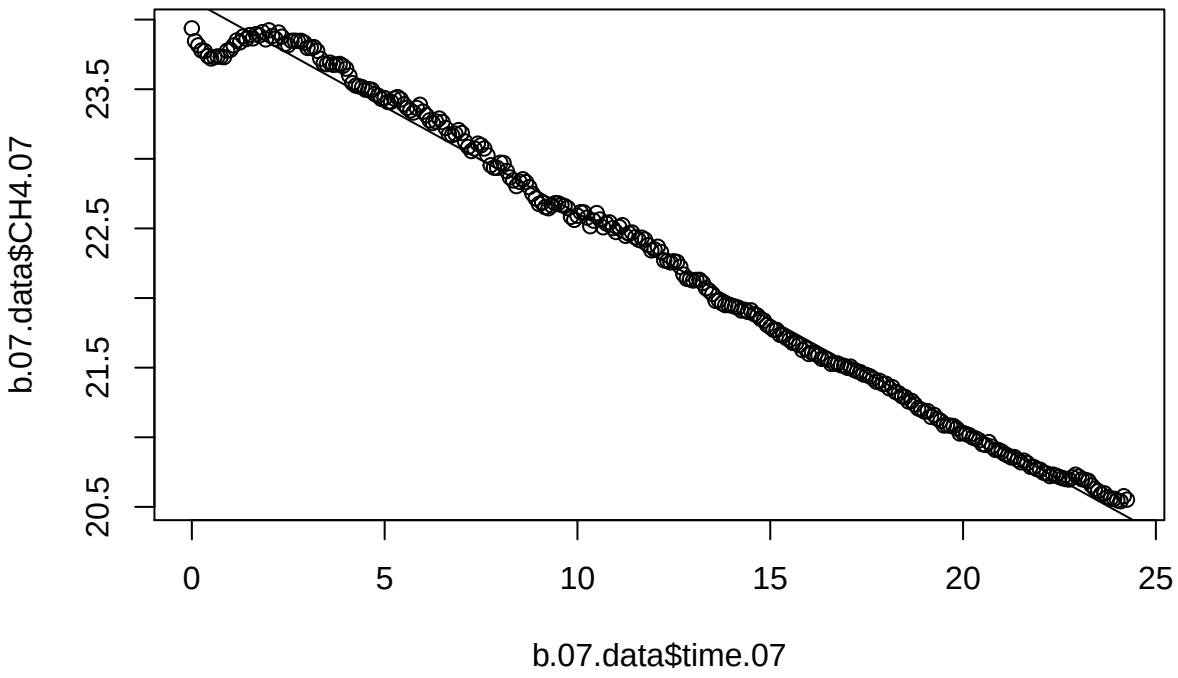

```
# Black bag 0703: control bag with no additional source of ionizing radiation
data.black.03 <- read.table("~/GitHub/radiolyticCH4/data/uranium/black.bag.0703.txt",
            sep="\t", header=TRUE)
time.03 <- (strptime(data.black.03[,1], "%m/%d/%Y %H:%M"))
time.03.hr <- (time.03 - time.03[1])/(60*60)
CH4.03 <- data.black.03[,2]
CH4.03.per <- CH4.03/max(CH4.03)
b.03.data <-as.data.frame(cbind(time.03.hr, CH4.03, CH4.03.per))
b.03.rate <- lm(b.03.data$CH4.03 ~ b.03.data$time.03)
plot(b.03.data$time.03, b.03.data$CH4.03)
abline(b.03.rate)
```



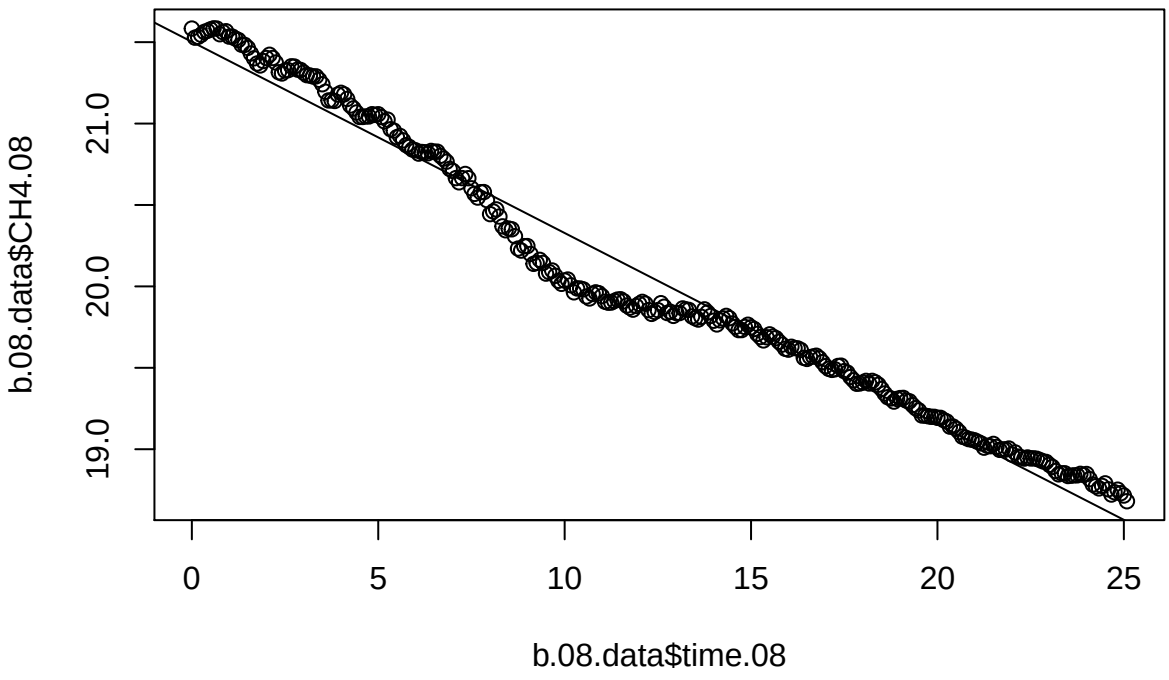

```
# Black bag 0706: control bag with no additional source of ionizing radiation
data.black.06 <- read.table("~/GitHub/radiolyticCH4/data/uranium/black.bag.0706.txt",
              sep="\t", header=TRUE)
time.06 <- (strptime(data.black.06[,1], "%m/%d/%Y %H:%M"))
time.06.hr <- (time.06 - time.06[1])/(60*60)
CH4.06 <- data.black.06[,2]
CH4.06.per <- CH4.06/max(CH4.06)
b.06.data <-as.data.frame(cbind(time.06.hr, CH4.06, CH4.06.per))
b.06.rate <- lm(b.06.data$CH4.06 ~ b.06.data$time.06)
plot(b.06.data$time.06, b.06.data$CH4.06)
abline(b.06.rate)
```




```
# Black bag 0707: control bag with no additional source of ionizing radiation
data.black.07 <- read.table("~/GitHub/radiolyticCH4/data/uranium/black.bag.0707.txt",
              sep="\t", header=TRUE)
time.07 <- (strptime(data.black.07[,1], "%m/%d/%Y %H:%M"))
time.07.hr <- (time.07 - time.07[1])/(60*60)
CH4.07 <- data.black.07[,2]
CH4.07.per <- CH4.07/max(CH4.07)
b.07.data <-as.data.frame(cbind(time.07.hr, CH4.07, CH4.07.per))
b.07.rate <- lm(b.07.data$CH4.07 ~ b.07.data$time.07)
plot(b.07.data$time.07, b.07.data$CH4.07)
abline(b.07.rate)
```




```
# Black bag 0708: control bag with no additional source of ionizing radiation
data.black.08 <- read.table("~/GitHub/radiolyticCH4/data/uranium/black.bag.0708.txt",
              sep="\t", header=TRUE)
time.08 <- (strptime(data.black.08[,1], "%m/%d/%Y %H:%M"))
time.08.hr <- (time.08 - time.08[1])/(60*60)
CH4.08 <- data.black.08[,2]
CH4.08.per <- CH4.08/max(CH4.08)
b.08.data <-as.data.frame(cbind(time.08.hr, CH4.08, CH4.08.per))
b.08.rate <- lm(b.08.data$CH4.08 ~ b.08.data$time.08)
plot(b.08.data$time.08, b.08.data$CH4.08)
abline(b.08.rate)
```



3) Test of the oxidation slopes

```
uranium.rate <- U.rate$coefficients[2]

control.rates <-c(I.rate$coefficients[2], b1.rate$coefficients[2],
      b4.rate$coefficients[2], b.03.rate$coefficients[2], b.06.rate$coefficients[2],
      b.07.rate$coefficients[2], b.08.rate$coefficients[2])

# one-sample t-test: uranium
u.t.test <- t.test(control.rates, mu = uranium.rate)

print(u.t.test)
```

```
##
##  One Sample t-test
##
## data:  control.rates
## t = -0.9682, df = 6, p-value = 0.3704
## alternative hypothesis: true mean is not equal to -0.1537
## 95 percent confidence interval:
##  -0.2222 -0.1241
## sample estimates:
## mean of x
##   -0.1732
```

4) Estimating rates of CH4 loss

```
# Conversion factors
gas.mol <- 22.4 # L occupied by 1 mole of gas
bag.vol <- 43 # L; operating volume of bags
l.m3 <- 1000 # L to m3 conversion
ppm.conv <- 10^-6
m.umol.conv <- 10^6
gfw.ch4 <- 16.042

# Rate calculations
rates.ppm.h <- uranium.rate # rate of oxidation -- mean
se.ppm.h <- sqrt(diag(vcov(U.rate))) # rate of oxidation -- SEM
parms.ppm.h <- c(rates.ppm.h, se.ppm.h[2]) # concatenate mean and SEM
parms.ppm.d <- parms.ppm.h/24 # convert from hours to days
rates.umol.L.d <- (parms.ppm.d * ppm.conv) * (1/gas.mol) *
  bag.vol * m.umol.conv # convert to umol
rates.mg.L.d <- rates.umol.L.d * gfw.ch4 / 1000
rates.ng.m3.d <- rates.mg.L.d * 10^6 /l.m3
```

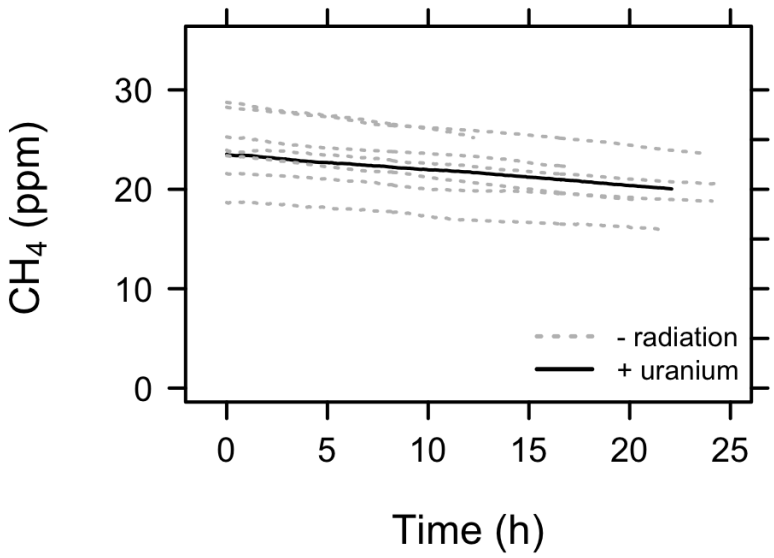
3) Make UR-CH4 concentration plot vs. time

```
png(filename="/Users/lennonj/GitHub/radiolyticCH4/figures/uranium.png",
    width = 1200, height = 900, res = 96*2)

plot.new()
par(mar = c(7, 7, 5, 7))

# Plot Uranium Bag
plot(time.U.hr, CH4.U, xlim = c(-1,25), ylim = c(0, 35), type = "l",
     col = "black", cex = 2, ylab = "", xlab = "",
     cex.lab = 1.5, las = 1, lwd = 2, yaxt = "n", xaxt = "n")
box(lwd=2)

# Plot Ion Bag
points(time.I.hr, CH4.I, type = "l",
       col = "grey", lty = 3, cex = 2, lwd = 2)

# Plot Box 1
points(time.b1.hr, CH4.b1, type = "l",
       col = "grey", lty = 3, cex = 2, lwd = 2)

# Plot Box 4
points(time.b4.hr, CH4.b4, type = "l",
       col = "grey", lty = 3, cex = 2, lwd = 2)

# Plot black bag 0703
points(time.03.hr, CH4.03, type = "l",
       col = "grey", lty = 3, cex = 2, lwd = 2)

# Plot black bag 0706
```

```
points(time.06.hr[1:288], CH4.06[1:288], type = "l",
       col = "grey", lty = 3, cex = 2, lwd = 2)

# Plot black bag 0707
points(time.07.hr, CH4.07, type = "l",
       col = "grey", lty = 3, cex = 2, lwd = 2)

# Plot black bag 0708
points(time.08.hr[1:290], CH4.08[1:290], type = "l",
       col = "grey", lty = 3, cex = 2, lwd = 2)

# Add ticks and tick labels
axis(side = 2, lwd.ticks = 2, las = 1, cex.axis = 1.25,
   labels = c("0", "10", "20", "30"),
        at = c(0, 10, 20, 30))

axis(side = 4, labels = F, lwd.ticks = 2,
   at = c(0, 5, 10, 15, 20, 25, 30))

axis(side = 1, lwd.ticks = 2, cex.axis = 1.25, las = 1, mgp = c(3, 1, 0),
    labels = c("0", "5", "10", "15", "20", "25"), at = c(0, 5, 10, 15, 20, 25))

axis(side = 3, labels = F, lwd.ticks = 2, las = 1, cex.axis = 1.25,
   at = c(0, 5, 10, 15, 20, 25))

mtext(expression('CH'[4]*' (ppm)'), side = 2, outer = TRUE, cex = 1.5,
      line = -3, adj = 0.55)

mtext('Time (h)', side = 1, outer = TRUE, cex = 1.5,
      line = -3.5, adj = 0.5)

legend("bottomright", c("- radiation", "+ uranium"), bty = "n", y.intersp = 1,
       lty = c(3, 1), lwd = 2.5, seg.len = 2.25, col = c("grey","black"), cex = 1)

dev.off()
```

```
## pdf
##   2
```

```
graphics.off()
```


30
20
10
0
CH_4 (ppm)
0
5
10
15
20
25
Time (h)
- radiation
+ uranium