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Internal Dosimetry Assessment of the Olfactory Recess for Search and Rescue Canines in the Event of an Am-241 Release

by

Andrew Turner

A thesis

submitted in partial fulfillment

of the requirements for the degree of

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To the Graduate Faculty:

The members of the committee appointed to examine the thesis of Andrew Turner find it satisfactory and recommend that it be accepted.

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Internal Dosimetry of the Olfactory Recess for and Rescue Canines in the Event of an Am-241 Release
Thesis Abstract – Idaho State University (2018)

The work within examines data provided via Lovelace Respiratory Research Institute (LLRI). The goal of this thesis is to examine the canine olfactory recess and determine if it should be considered when performing compartmental modeling of inhalation. However, the olfactory recess was not collected during the study performed by LRRI. The olfactory recess was able to be mathematically accounted for and justified as an important compartment to be considered when performing inhalation modeling of Am-241. A linear regression analysis was conducted to determine if a time-dependent clearance model of the olfactory recess could be developed. An ANOVA was also conducted on the data set. The analysis showed the p-value of time to be 0.038. The low p-value demonstrated time was an important parameter in modeling clearance of radioactive material from the olfactory recess. A temporal clearance model was developed from the analysis.

Key Words: internal dosimetry, health physics, modeling, canines, search and rescue, Am-241

Chapter 1: Introduction

1.1 Problem Statement

The focus of this research is to examine the inhalation pathway of intake in beagles. Developing a compartmentalized lung model for search and rescue dogs is the end objective. However, the pathway of intake must be understood before a compartmentalized model is developed. Therefore, the goal of this research is to obtain a clear understanding of the inhalation pathway of canines concerning aerosolized Am-241. The compartmentalized model developed will eventually be used to study various chelation therapy systems intended to help mitigate the effects of harmful airborne radionuclides, specifically, Am-241. A model will pro- vide a means to predict translocation of radioactive material throughout a canines physiological systems. Various breeds of canines have been used to research topics of human health including blood circulation, drug administration, diabetes, and genetics research (ORI, 2003). However, Canis lupus familiaris (beagles), have been the dog breed of choice for various animal studies since the 1960s. The small size of beagles along with their docile nature have made them a popular choice for researchers (ORI, 2003). Beagles were recently the subject of an internal dosimetry study at Lovelace Respiratory Research Institute (LRRI). The beagles were exposed to various radionuclides such as Am-241 and Cs-137. The methods of intake included inhalation and intravenous (IV) injection. This research focuses on Am-241 intake via inhalation.

1.2 Service Dogs as an Asset

Service dogs have been in military use since 1939. They are credited with saving a substantial amount of lives. The United States (U.S.) military doubled the number of service dogs shortly after the events of 9/11. Each dog cost about 3,100 USD and the value goes up to approximately 11,000 USD, after training. The price continually increases with ongoing upkeep costs. (Maryann, 2003). “I don’t think you can put a real price on their heads because of the peace of mind that they give the troops with their capability of detection/deterrence,” - Major Frank W. Schaddelee, commander of the 341st Training Squadron (Maryann, 2003). Service dogs are considered an invaluable asset. Prolonging the life of service dogs will help increase the return on investment for the organization using them because it will help keep the animal in service longer and lower up keep costs. (Maryann, 2003).

A dog has about 125 to 250 million smell receptors where a human typically has 5 to 15 million. The olfactory portion of the brain is about four times larger in canines. Canines also make use of a highly developed olfactory recess, an organ lacking in primates. An olfactory recess is a complex airway network located towards the rear of the nasal cavity. The olfactory recess aids in odorant transport and influences olfactory airflow (Craven and Settles, 2009). These characteristics allow dogs to detect scents as little as 1 to 2 ppt with about 98 percent success (Craven and Settles, 2009, Maryann, 2003). Dogs can quickly be trained to detect new smells and they can be trained to sniff out specific biological and chemical agents (Maryann, 2003).

One of the goals of this project is to develop a higher level of radiation protection for service dogs. This will be accomplished by using the data obtained from the LRRI experiments. A better understanding of the amount of intake, translocation and clearance of radioactive materials in service dogs would enhance the stewardship options and decision making with respect to these assets.

1.3 Research Objectives

A goal of this research is to develop a compartmentalized inhalation model relevant to Search and Rescue (SAR) dogs. The model will be based on experimental beagle dog data. An extrapolation from Beagles to other dogs will need to be made and justified. The extrapolation will need to be completed because search and rescue dogs are typically Border Collies, German Shepherds, Retriever, etc. These breeds are physiologically different from Beagles due to their size differences (Rovia et al., 2008).

The ICRP 66 Human Respiratory Tract Model (HRTM) will serve as an initial basis, for this objective, but will be modified to meet the goals of this effort. The model will be modified based on relevant data and canine physiology. The need for the development of the HRTM was based on different areas of the respiratory tract having different radiosensitivities. The scope of this research is to investigate the areas of ET_1 and ET_2. ET_1 and ET_2 refer to the anterior and posterior nasal cavities, respectively. The scope of this research also includes better defining the areas of ET_1 and ET_2 for canines. The nose of a canine is physiologically unique, due to its sizable surface area and the existence of an olfactory recess. Canines also have a horizontal orientation. These features are different from those used in the ICRP 66 HRTM developed for humans.

1.4 Hypothesis Testing

The clearance model of the olfactory recess will be modeled temporally. The null hypothesis states the clearance of radioactive material cannot be modeled temporally. The alternative hypothesis states the clearance of radioactive material can be modeled temporally. An ANOVA will be conducted during the analysis to determine the p-value of time. The p-value of time will determine if time is an important factor in modeling clearance of radioactive material from the olfactory recess. The alternative hypothesis will be accepted if the p-value of time is less than 0.05. The alternative hypothesis will be rejected if the p-value of time is greater than 0.05. The models will be evaluated using R2-predicted. R2-predicted will be used to determine how well the model fits the data and predictability of the model. (Derryberry, 2014)

Chapter 2: Literature Review

2.1 A Review of Relevant Canine Dosimetry Studies

Canine dosimetry research has been conducted in the past. Inhalation studies using alpha emitting radionuclides such as Am-241 and Pu-239 have been examined However, these studies have been done by injection into the blood stream (Alomairy et al.). Studies have also been done on canines to find dose conversion factors. However, these dose conversion factors are used for external exposure and internal gamma exposure (Stabin et al., 2015). Beagle dogs were used to study the long-term non-radiological effects of Pu-239. The studies examined intake via inhalation, ingestion and dermal exposure. The studies were not conducted for the purposes of compartment modeling. No long term studies found any non- radiological long-term hazards associated with Pu-239 (DHHS, 2010).

Few research efforts have considered the radiation exposure consequences possibly experienced by search and rescue canines. One recent study focuses on external gamma and beta radiation. The identified the shortcomings of previously developed dose conversion factors, namely they are intended for use at a height of one meter. The height of search and rescue canines on average is 0.40 meters. The dose conversion factors were developed through use of the point-kernal integration technique. The dose conversion factors found in the study were found to be higher than original estimates (Trevino and Marianno, 2018). It appears prior researchers have yet to address Am-241 intake via inhalation in canines. An examination previous literature shows canine dosimetry, specifically search and rescue canine dosimetry research can be improved upon. The focus of this research is to develop a canine inhalation compartment model for Am-241.

2.2 Overview of Amercium-241 and Radiological Terrorism

Americium-241 is created via thermal neutron activation (Chu et al., 1994) when Plutonium-241 decays by emitting a beta particle. Americium-241 presents a relatively low hazard unless ingested or inhaled. Americium-241 has a half-life of 432.2 years. Americium-241 is used within commonly available household smoke detectors. Unfortunately, Am-241 can be used for nefarious activities such as radiological terrorism. Specifically, Am-241 is a possible component of a radiological dispersal devices(RDDs), more commonly known as a dirty bomb. A RDD is a device using conventional explosives, such as dynamite, to disperse radioactive material (Medalia, 2011). Americium-241 is of concern because it is among most dangerous (Hosik et al., 2011) radionuclides to be used in an RDD. Cobalt-60 and Cs-137 are other possible candidates to use in an RDD. A study made using basic assumptions, such as minimal wind, showed one Curie of Am-241 can achieve the same level of toxicity as 100 Ci of Co-60 or Cs-137 (Hosik et al., 2011). The RDD simulation study done for a metropolitan area found the maximum total effective dose equivalent (TEDE) for one curie of Am-241 was 0.702 Person Rem (Hosik et al., 2011). This value was higher than any other radionuclide studied during the simulation, including those using 100 Ci or more (Hosik et al., 2011).

Potential RDDs would distribute Am-241 into the air where it could be inhaled or ingested by the public. RDDs pose more than just a risk to public health. The cost of clean up after detonation of a RDD could be tens of thousands of dollars (Medalia, 2011). This cost includes limiting dose to the public and emergency personnel responding to the event along with environmental decontamination. How- ever, terrorist face various difficulties when creating RDDs. These include getting materials, remaining undetected, and designing a working weapon (Medalia, 2011). A majority of the prevention of RDDs is a result of the United States Nuclear

Regulatory Commission (NRC)'s security regulations were increased after 9/11. There is still a possibility of a radiological terrorism event even with NRC safeguards. Therefore, governments have additional precautionary measures (Medalia, 2011), including developing infrastructure for the preparation and recovery from a RDD. Nevertheless, with all precautions in place an attack using an RDD can still occur.

2.3 Response to an RDD

There are three phases when responding to an RDD. They are the early, intermediate and late phase. The early phase has a short time span of a few hours and focuses on immediate response and protection. Early phase actions include sheltering the public, administrative medical counter measures, decontamination, access control and victim extraction (Management, 2016). The impact of this work would affect the early phase of recovery and involves victim extraction through Search and Rescue (SAR) personnel and canines. Emergency response personnel will be called in when a dirty bomb goes off. The personnel will be informed of the current hazard before starting operation. The need for immediate search and rescue will depend on the severity of the explosives used in the RDD. SAR dogs may need to be used to find people in the wreckage left by the bomb. Human SAR personnel have the capability of wearing protective equipment, including respirators. SAR canines cannot use respirators as it would block their nose and limit their ability to find injured people. Therefore, it becomes necessary to know how long a SAR canine can be used in contaminated environments post detonation before they become compromised. Radiation protection philosophy in general suggests the canine's exposure level should be kept as low as reasonably achievable to avoid veterinary cost and to keep the canine in service.

2.4 Canine Olfactory Anatomy and Physiology

Canines have four legs, horizontal orientation and poses an extra organ not found in primates. This organ is the olfactory recess and is located in the rear of the canine's snout. A cross-sectional image of a canine's olfactory recess is shown in Figure 2.1, below

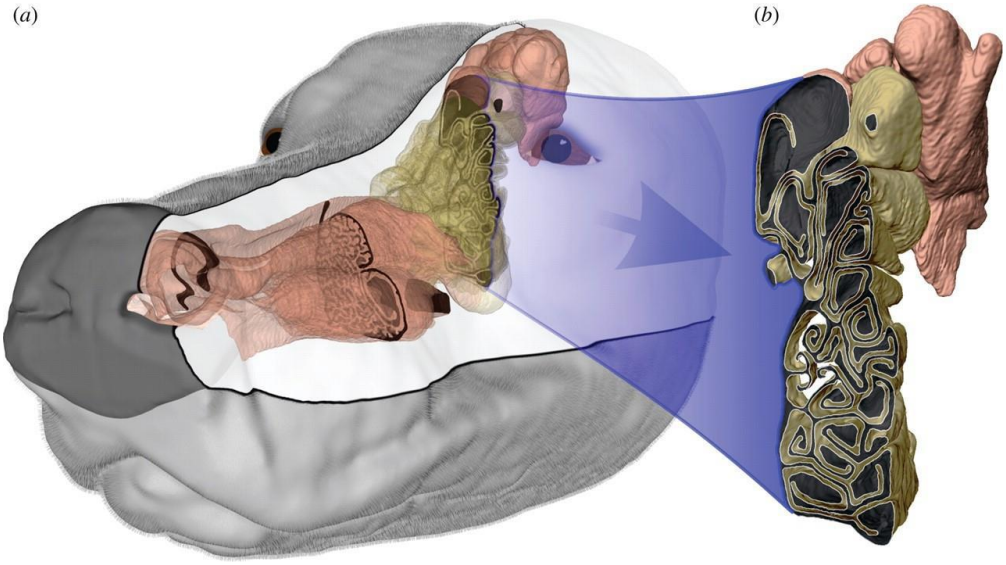

Figure 2.1: A canine's snout (a) and olfactory recess (b) (Craven and Settles, 2009).

The olfactory recess serves the canine in a few different ways. The most important one is to filter out scents. This allows canines to find items and people by smell. The olfactory recess is best described as a series of convoluted airways (Craven and Settles, 2009). Odor molecules, once deposited, will be transported from the nostrils to the olfactory recess as the canine inhales. The odor molecules will re- main seated in the olfactory recess, even as the canine exhales. The deposition of odor molecules reflects the physiology of the olfactory recess (Craven and Settles, 2009). The canine's nasal area is high vascularized, with venous structures connecting to the olfactory recess. The high vascularization of the nasal area allows for materials to be easily taken up by the blood (Wang and Mary, 2003).

The actions of sniffing and inhaling are different for a canine. When a canine sniffs its nostrils will flare. The flaring of the nostrils opens their nasal cavity allowing more odor molecules to enter. Canines are also capable of essentially taking two air samples at once, one per nostril. This ability gives canines a sense of direction through their nose, allowing them to track people and items. Canines also regulate their sniffing. Canines perform two types of sniffing. The types of sniffing are known as long and short bouts. A short bout is essentially one large extended sniff. A long bout consists of shorter sniffs over an extended amount of time. (Craven and Settles, 2009)

2.5 ICRP 66 Human Respiratory Model

The International Commission on Radiological Protection (ICRP), publication 66 (ICRP 66), refers to the human respiratory tract model. ICRP 66 discuses radioactive material deposition, distribution, and clearance from the human respiratory tract (ICRP, 1994). Currently, there is no such model in existence for canines or any other animal. However, the document contains important ideas, concepts, and techniques related to internal dosimetry of respiratory tract modeling.

Modifying human deposition models begins with considering the differences be- tween canines and humans in the extrathoracic region. Humans have four extrathoracic compartments. The compartments are known as ET_1, ET_2, ET_{seq}, and LN_{ET}. Compartments ET_1 and ET_2 refer to the anterior nasal passages and the Naso-Oropharynx/Larynx regions, respectively. ET_{seq} represents the region where particles become sequestered within the extrathoracic region. Sequestered particles will be moved to the lymph nodes, represented by ET_{seq}. Particles deposited on the epidermis lining ET1 are assumed to be returned to the environment (ICRP, 1994). A basic break

down of the ICRP 66 model with all of its compartments is shown below in Figure 2.2. Figure 2.3, demonstrates how the compartments of the model match with their anatomical structures.

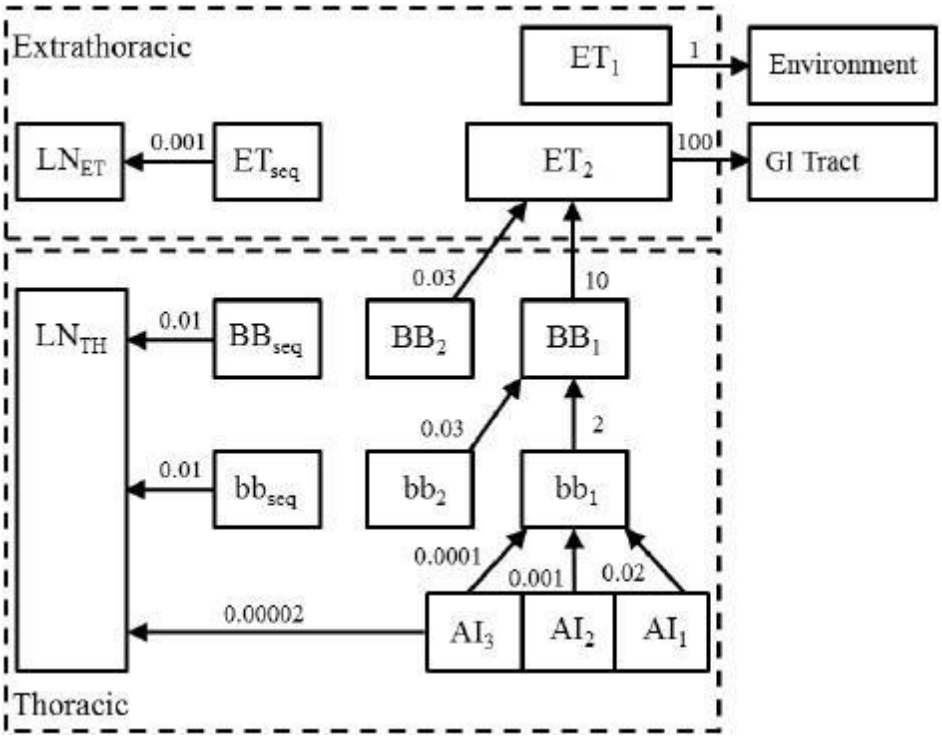

Figure 2.2: A basic representation showing compartments of the ICRP 66 Human Respiratory Tract Model (ICRP, 1994).

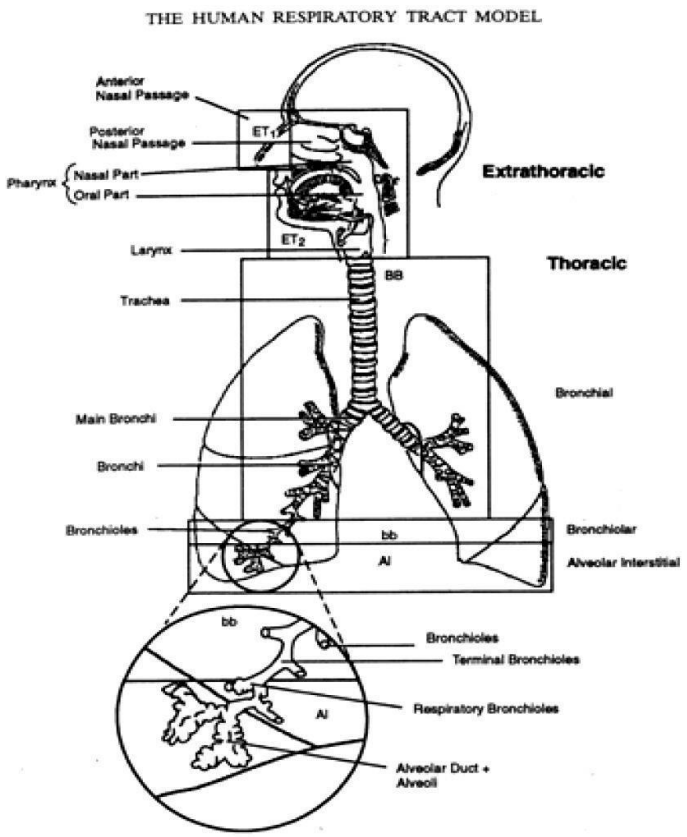

Figure 2.3: The ICRP Human Respiratory Tract with anatomy also shown (ICRP, 1994).

ICRP 66 represents the respiratory tract as a series of equivalent particle filters. The fraction of tidal air reaching the final filter during inhalation is dependent on the number of filters, tidal flow, and the volume of the previous filter. This idea is demonstrated mathematically in Equation 2.1 shown below.

$$\phi_j = 1 - f\frac{1}{V_T}\sum_{jj=0}^{j-1} v_{jj}\,, for\ all\ j \in \left[1, \frac{N+1}{2}\right] \tag{2.1}$$

N represents the number of filters

V_T represents tidal flow

ϕ_j represents the fraction of tidal air reaching the last filter

v_{jj} represents the volume of a preceding filter (filter jj)

A successively smaller portion of air passes through each filter during inhalation and the fraction reaching the last filter is determined by all other filters in Equation2.1. The deposition of particles in the filters is represented by Equation 2.2, below.

$$I_0 = C_A t B \tag{2.2}$$

I_0[Bq] represents the intake of particles

C_A[Bq m−3] represents the concentration of activity in air

t represents the time duration in hours

B[m^3 h^{-1}] represents the breathing rate

ICRP 66 states absorption into the blood is a two stage process. First, the material will be dissociated into particulates capable of being absorbed into the blood. An uptake of the particulates occur in the blood. Uptake by the blood can be a fast or slow process (ICRP, 1994).

2.6 Application

The existence of an olfactory recess in canines' anatomy calls for a different model than the one used in humans. It appears one filter representing the olfactory recess would collect most of the particulate matter. A second mathematically symmetrical but not identical filter would be used to represent exhalation. Another consideration in modeling is with how canines' sniffing differs from breathing. ICRP66 was developed for humans and assumes an upright bipedal position. However, canines have a horizontal orientation. The horizontal orientation means a particle, as a function of aerodynamic diameter, will not move as far through the canine's respiratory tract due to gravitational settling. The horizontal orientation along with the capacity for particles to get stuck in the olfactory recess suggests modeling through a system of sequential filters would need significant modification. The main modifications would be accounting for the olfactory recess in the inhalation pathway and accounting for uptake in the blood. Other modifications can be based on relevant data.

SAR canines find people during an event through a process of sniffing them out. This activity implies a canine will have a higher breathing rate while sniffing for people. Once an RDD has gone off the air concentration of radioactive material will remain relatively constant during the time immediately after the event. A canine cannot regulate its rate of sniffing. Therefore, the only variable to control is the amount of time in the area.

Chapter 3: Materials and Methods

3.1: Overview of Data

Data has been provided by LRRI. The data set consists of 32 beagles, 16 male and 16 female. The beagles were separated into eight different research groups. The research groups are composed of two males and two females. The research groups are defined by eight different sacrifice times. The sacrifice times range from one hour to 28.0 days. The canines were aged 11.2 ± 0.7 months old and weighed 9.2 ±1.1 kg. Canines were given an adjustment period of 24 hours within their cages. The animals were observed to have normal behavior within the 24 hour adjustment period. Canines were placed in a latex mask to limit external contamination while connected to a nose only exposure system. A simplified diagram is shown below in Figure 3.1 (Weber, 2011).

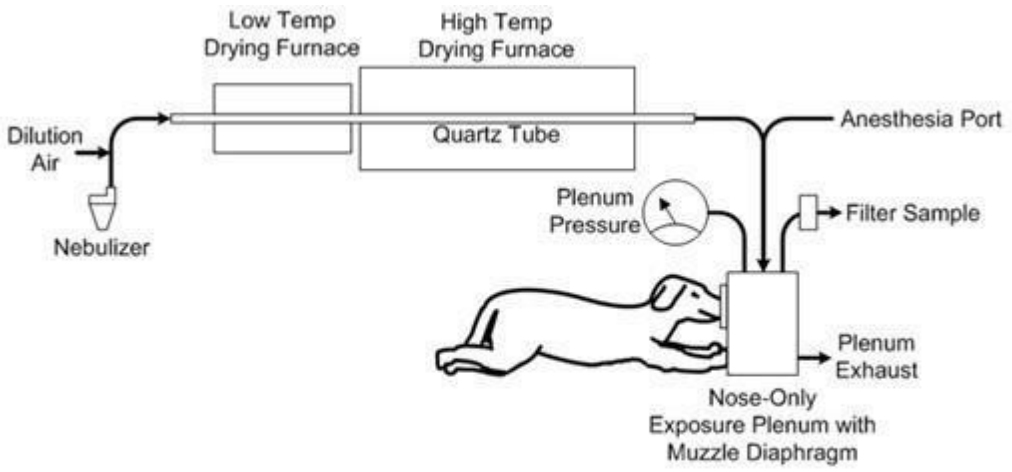

Figure 3.1: A simplified diagram of the study conducted by LRRI (Weber, 2011).

All animals were exposed for eight minutes. Animals were observed two times a day. No unusual behavior was observed throughout the study. Urine and fecal samples were collected on a daily basis. Cages were washed daily to collect any residual excretion matter. All canines underwent a full necropsy upon sacrifice. The liver, spleen, lungs/trachea, muscle, GI tract, gonads/ovaries, femurs, lumbar vertebrae were collected during necropsy. No subjects exhibited any unusual behavior during the study. The data shows only about 50 percent of the activity is recovered with sacrifice times of less than a day. However, at later sacrifice times it is possible to recover 100% of administered activity. It is possible to account for this discrepancy with the olfactory recess (Weber, 2011).

3.2 The Olfactory Recess

All particles entering the canine inhalation pathway via the nose must pass through the olfactory recess. The olfactory recess was not collected during the inhalation study. However, it is possible to account for the olfactory recess. This is accomplished by subtracting the amount of recovered activity from the amount of administered activity, see Equation 3.1. The values obtained from Equation 3.1 can then be plotted against sacrifice time. Equation 3.1 gives the percentage of activity accounted for when the olfactory recess is considered.

$$Olfactory\ Recess\ Percentage = 1 - \left(\frac{Recovered\ Activity}{Administered\ Activity} * 100\right) \qquad (3.1)$$

3.2 Model Fitting

The statistical software R allows for fitting of models to data with certain functions. The function used in this research is the linear model function. A formula relating a dependent variable and an independent variable can be placed into the linear model function. Useful information such as the sum of square errors and p-values can be extracted from the linear model function. The variables placed into this function can also be modified to allow consideration of logarithmic and exponential relationships. Various uses of the linear model function are shown, below.

```
#linear relation
fit<-lm(y~x)
#log dependent variable
fit<-lm(log(y)~x)
#log independent variable
fit<-lm(y~log(x))
#log both variables
fit<-lm(log(y)~log(x))
```

Listing 3.1: The linear model function

3.4 Statistics and Using R^2 Predicted

The percentage of activity recovered from the olfactory recess can be fitted as a function of time. The statistical software R was used to complete a regression analysis of the data. The various models were evaluated using R^2 predicted. The test statistic, R^2 tends to over predict and over fit data and is not examined within this research. The over fitting of R^2 can be countered by examining the variants of R^2. The variants of R^2 are R^2 predicted, pseudo R^2 predicted, and R^2 adjusted. The tests statistic, R^2 is typically of larger magnitude than any of its variants. The R language provides subroutines used to calculate the value of these parameters. The algorithms used to access R^2 and its variants are shown below. The models were assessed for normality and subsequent residual distributions were analyzed. This assessment will be done graphically. Normality was assessed using the qqnorm function provided in R. Residual distributions were assessed by plotting the fitted values against the residuals for each model.

It is possible using a linear model will not provide a valid fit of the data. Alternatively, a non-linear model function may be used. The software package R provides a nonlinear least squares function for fitting data in this case. The nonlinear least squares allows the user to input an equation and then evaluate the utility of those variables in the prediction of observed data. The values obtained from the nonlinear least squares function cannot be used to calculate R^2 predicted. However, the quantity pseudo R^2 predicted can be calculated. Pseudo R^2 predicted will reasonable approximate R^2 predicted. (Derryberry, 2014)

```
function(y,fit){

    SSE<-sum(fit$resid^2)
    SYY<-(var(y))*(length(y)-1)
    inf<-influence(fit)#influence
    h<-inf$hat #hat vector
    new_resid<-fit$resid/(1-h)
    PRESS<-sum(new_resid^2)
    R_2_pred<- 1-(PRESS/SYY)

    if(R_2_pred<0){
        return(0)
    } else {
        return(R_2_pred)
    }
}
```

Listing 3.2: R^2 predicted function

```
resid<- y - fitted #residuals
SSE <- sum(resid^2) #sum of square error/residual
SYY <- var(y)*(n-1) #n is number of number of data points
PRESS <- SSE*(n/n-p)^2 #p is number of compartments modeled
R2_pred <- 1-PRESS/SYY #psuedo R2 predicted

}
```

Listing 3.3: Pseudo R^2 Predicted Function

```
#Only valid if summary is available
summary(fit)$adj.r.squared
```

Listing 3.4:R^2 Adjusted Method

```
#if summary is available
summary(fit)$r.squared

#if summary is not avaible
R2<-1-SSE/SYY
```

Listing 3.5:R^2 Method

R2 and pseudo R2 predicted are cross validated numbers. The values are validated through a process known as leave-one-out cross validation (LOOCV). LOOCV works through an iterative process by removing data points and fitting a line when each point is removed. This method can be viewed as splitting the data into sets of n-1 and 1, n number of times. This climates the need for performing data splitting. R2 predicted and pseudo R2 predicted are computed algebraically here so the points do not need to be manually removed each time. (Derryberry, 2014)

Chapter 4: Results

4.1 Model Fitting Results

It was found that the amount of recovered activity increases as a function of sacrifice time. This can be seen in Figure 4.1, below. The olfactory recess was originally not considered during the LLRI study. However, it seems self-evident all material entering the canines lungs must first enter the nostrils and then pass through the olfactory recess. This suggests the quantity of activity not accounted for at earlier sacrifice times is most likely deposited in the olfactory recess before being translocated to the transfer compartment.

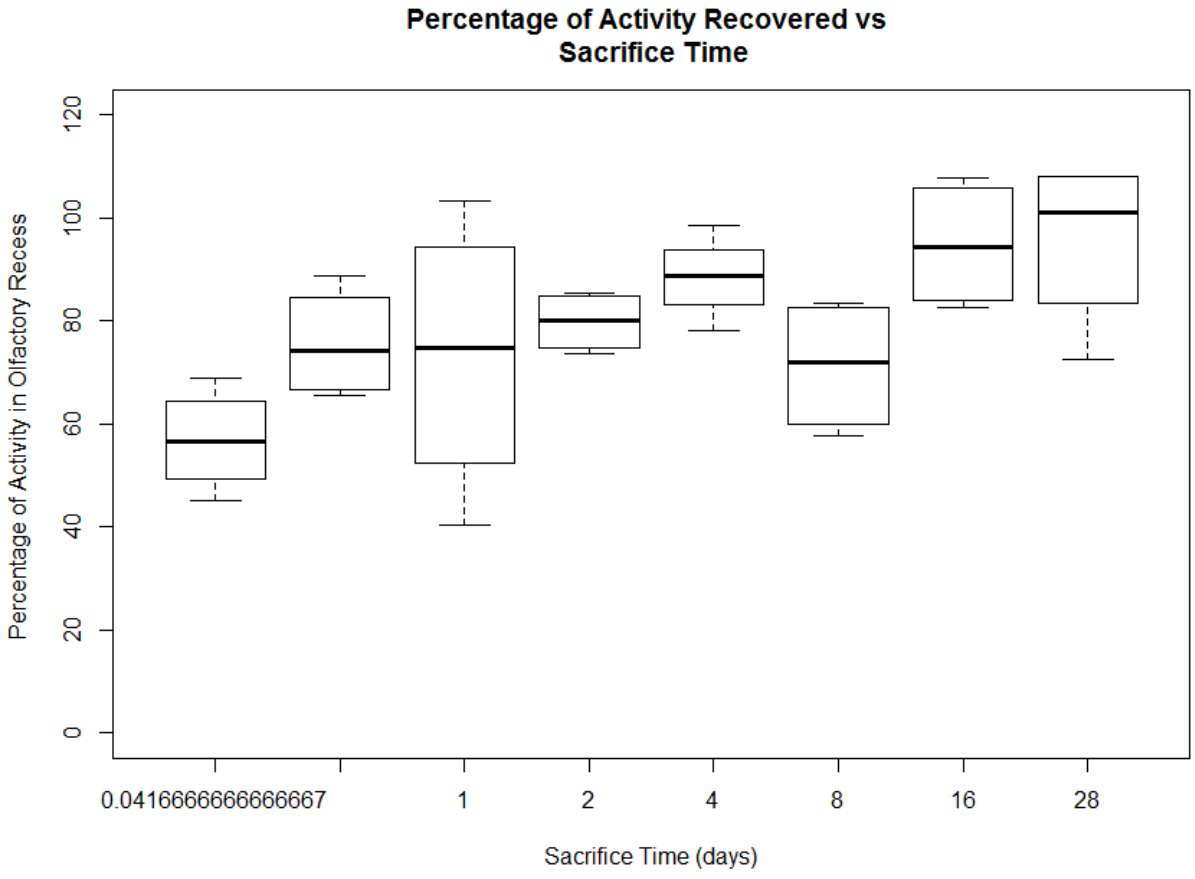

Figure 4.1: Box-plot of recovered activity (%) as a function of sacrifice time (days).

Sacrifice time and amount of radioactive material within the olfactory recess were found to share a log-log relationship using the linear model function in R. The amount of activity within the canine olfactory recess was calculated via Equation 3.1. These values were plotted as a function of sacrifice time. The estimated amount of activity in the olfactory recess exponentially goes to zero over a period of 16 days, on average. The calculated p-value of the natural log of time was found to be 0.038. The p-value is less than 0.05 therefore the alternative hypothesis is accepted. The radioactive material once removed from the olfactory recess will be redistributed throughout the body. The radioactive material translocated via the circulatory system. It is suspected absorption of radioactive material after deposition in the olfactory recess is feasible given the substantial vascularization of this organ. This implies the organ serves as an additional area of entry into the blood. It can be seen from the data the amount material will go to zero around day 16. Figure 4.2 also shows a large spread in the data at day eight and afterwards. This is likely caused by gender differences in the canines. Males retain more activity in the olfactory recess than females.

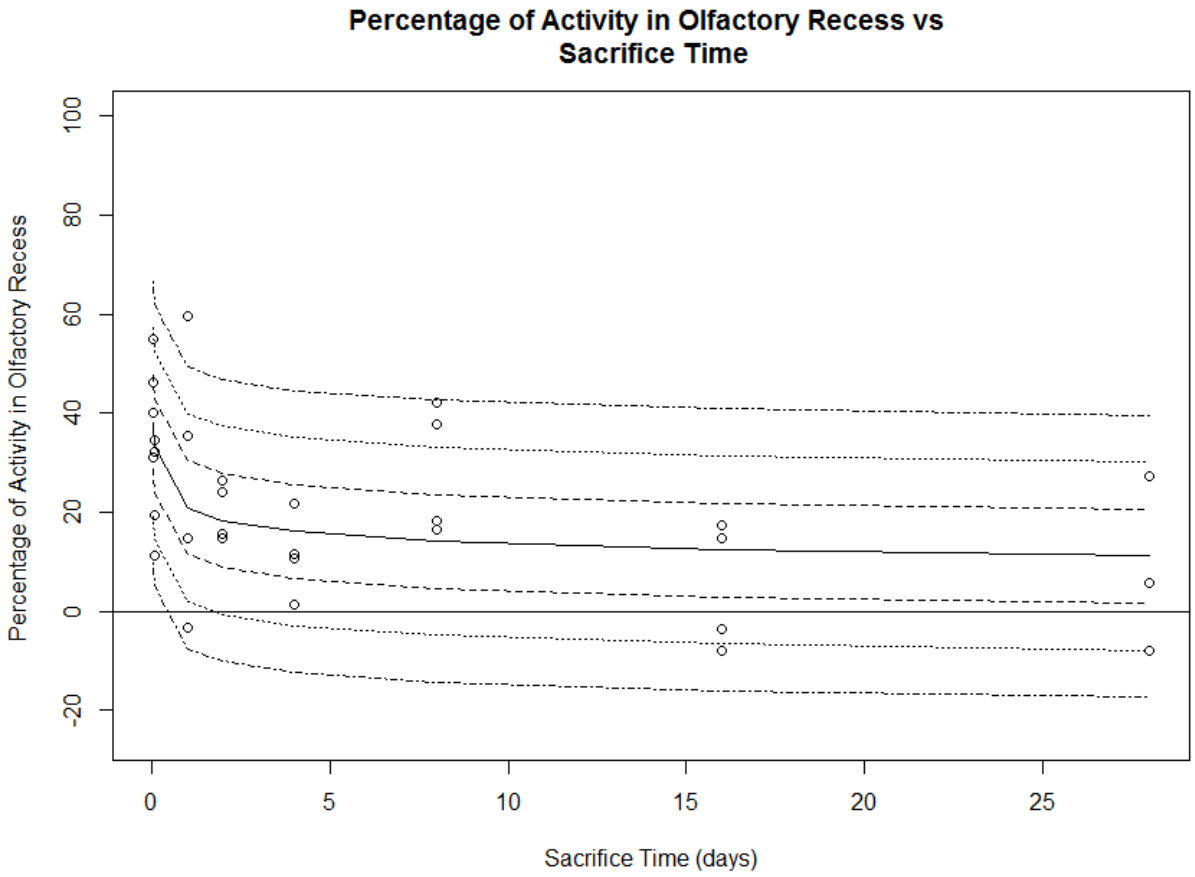

Figure 4.2: Exponential clearance model for the olfactory recess. One, two and three standard deviations are represented by the dashed lines.
Equation: $y = 20.923x - 0.189$

4.2 Proposed Inhalation Model

A schematic of the proposed inhalation is shown below, see Figure 4.3. This model is based on the data provided by LRRI and the observations form this research. The model shows how fast a percentage of inhaled Am-241 will reach each compartment in units of days. A time of zero indicates an immediate intake can be assumed. ET0 represents the olfactory recess. The notation of ET0 was chosen so other compartments can be added if need be in the future. The radioactive material in the lungs/trachea compartment is moved to the gastrointestinal via the mucociliary escalator.

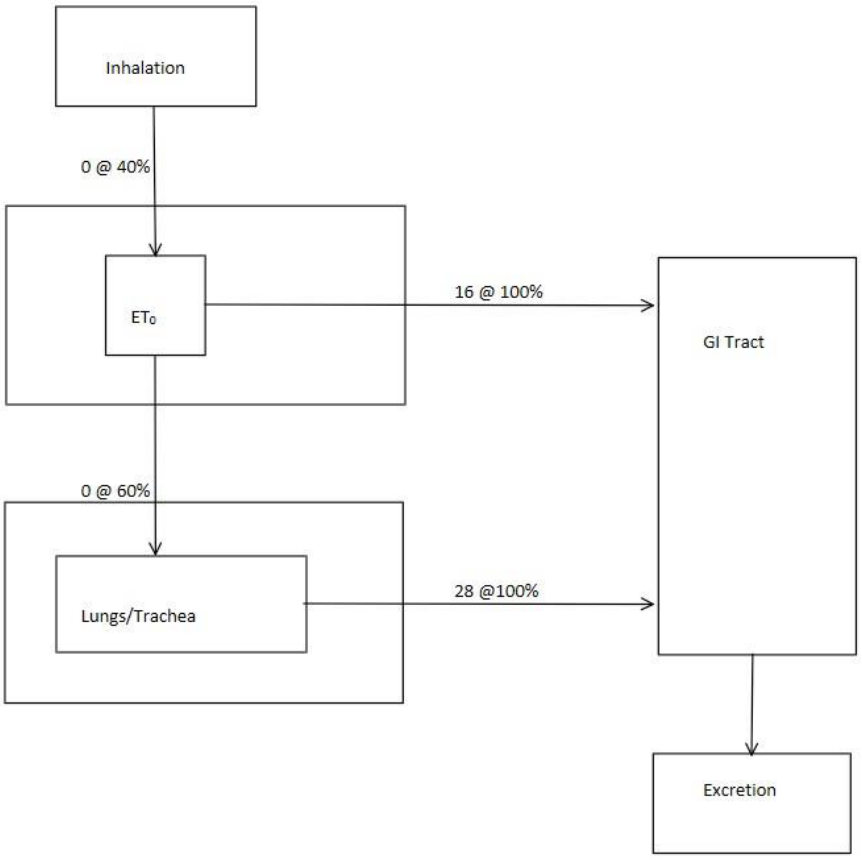

Figure 4.3: Proposed inhalation model based on current data. Numbers listed are in days.

It is interpreted from the plotting the data 40% of inhaled Am-241 will be taken up by the olfactory recess, immediately. The other 60% of radioactive material will challenge the lung/trachea area. The radioactive material will then be redistributed throughout the body via the circulatory system as a function of time. The interpretation of olfactory recess deposition is predicted on the data. Deposition could well occur at this organ where it is cleared into the blood as a function of time. This observation is illustrated in Figure 4.2 the material is cleared from compartment ET0 within 16 days. Further Figure 4.1 shows 100% of activity can be recovered at later sacrifice times. Therefore, the material must be redistributed throughout the body.

4.3 R^2 and R^2 Predicted Results

The parameters R^2 and R^2 predicted were both calculated for the clearance model of the olfactory recess. The parameter R^2 was calculated to be 29.74%. R^2 predicted was calculated to be 20.06%. R^2 predicted is usually lower than R^2. However, R^2 predicted better reflects how well the model will predict a new data set (Derryberry, 2014).

4.4: Normality and Residual Distribution Assessment

The statistical software package R contains a function for creating normality plots based on fitted models. Good normality is demonstrated by the data points falling near the line on the plots. The normality plot can be seen in Figure 4.4. The model shows good normality. The model fitted is the log-log relationship between radioactive material within the olfactory recess and time. A common approach to assess residual distribution is to plot the residuals against the predicted values. The model is supported if no trends are observed in such plots. The assessment was done graphically, see Figure 4.5.

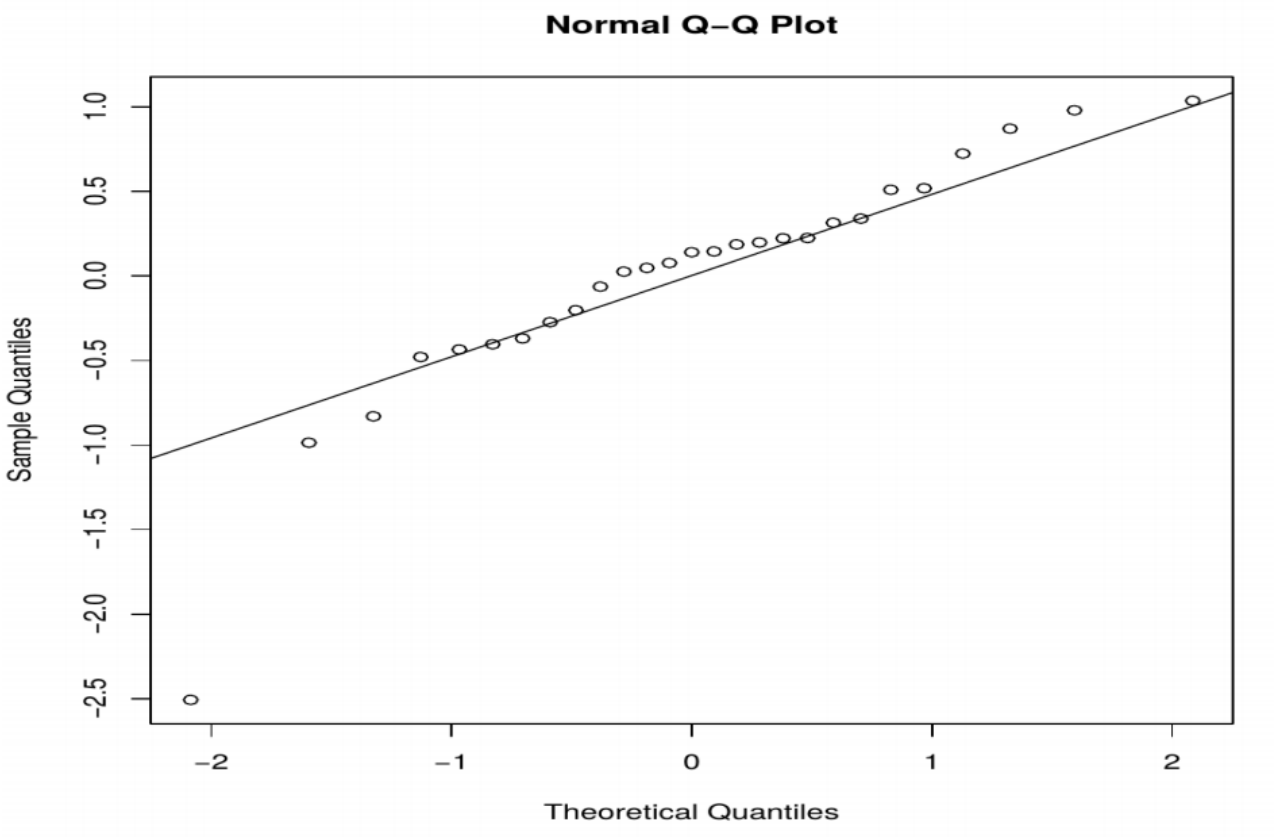

Figure 4.4: Normality plot of all data points.

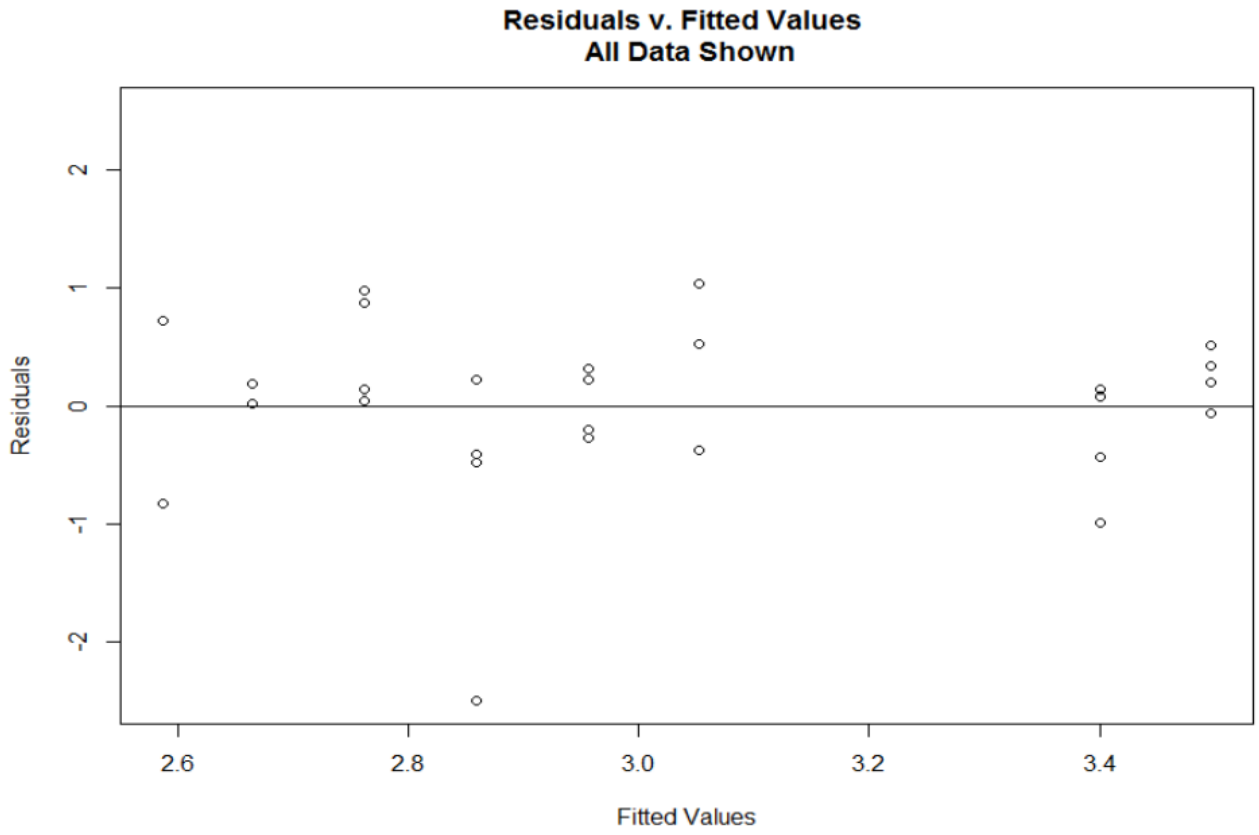

Figure 4.5: Residual distribution plot.

Chapter 5: Conclusion

5.1 Discussion

The research group with a sacrifice time of eight days has a lower recovery given analysis of mass balance. The supported interpretation by the analysis is the issue with short term recovery caused by and accounted by possible deposition in the olfactory recess with eventual clearance by absorption into the transfer compartment. The spread in the model at eight days and after can be accounted for by gender differences. The size of the olfactory recess is directly related to the size of the canine. Males on average in the study weighed approximately one to two kilograms more than their female counterparts. The calculated values of the parameters R2 and pseudo R2 predicted were 29.74% and 20.06%, respectively.

5.2 Future Work

The research accomplished within this thesis is only the beginning of what could be accomplished in regards to SAR canine dosimetry. Future work would involve expanding research on the filtration and deposition models of canines. Future work may also involve improvement of canine studies. Canine studies in the future should consider collecting the olfactory recess and blood. Blood collection would better information for canine absorption studies. Future efforts might focus on further model development. This for instance could include more research into GI tract modeling, addressing gender differences and more accurate inhalation modeling. Dose conversion factors should be developed for canines, currently the amount of activity inhaled is the only quantity capable of being grossly estimated. Finally, an amount of time a canine can be used in an environment with airborne Am-241 before suffering health effects should be determined.

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