Heating Device for μPET/CT Machine

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<u>Table of Contents</u>

Abstract

During medical imaging, specifically μPET/CT scans, small animals are anesthetized to ensure their lack of motion. Under anesthesia these animals, oftentimes mice, are subject to a significant decrease in body temperature that can lead to hypothermia or death. It has been proposed to design a heating device capable of providing a constant temperature near that of the subject's body temperature. After careful consideration of three potential design alternatives, a tube heater with the ability to provide hot air flow to a heat delivery system within the μPET/CT scanning chamber has been selected as the best approach to the solution of this problem.

Problem Statement

Metabolism slows down during anesthesia. This can lead to hypothermia and eventual death. For prolonged μPET/CT scans, where animals, often mice, are under anesthesia for an extended period of time, it is important to keep the animals at a steady temperature. Currently, heating lights are used to provide heat to the animal; however, heating lamps lead to non-uniform and poorly controlled temperature regulation. Therefore, it had been proposed to design a heating device that can be used to provide controllable and steady temperature during prolonged μPET/CT scans. Because of the imaging limitations, the heating device cannot contain metal or moving parts within the scanner's field of view.

Motivation

A decrease in the test subject's body temperature during μPET/CT scans has a number of implications. Most notably this temperature loss could lead to hypothermia or even death over the course of an hour long scan. Aside from the fact that this may violate guidelines on the proper treatment of lab animals during research, it also causes many serious setbacks for researchers. Researchers invest a significant amount of time and money implanting and developing specific cancers in these mice. They also spend time devising treatment plans to see how the mice respond to them. Death of a test subject may prevent a researcher from making conclusions that could contribute to the field. In addition to this, varying body temperatures throughout the course of a scan may decrease the scans accuracy, and a variance in temperature from scan to scan may cause inconsistencies in the images. A heating device capable of providing constant temperature could potentially eliminate these inaccuracies and inconsistencies as well as decrease the number of test subjects lost. On a larger scale this could aid in the efficiency of current cancer research.

Client Requirements

The μPET/CT heating device must fulfill four major requirements along with a number of secondary requirements deemed less important by the client. The first main requirement of this device is that a controllable and uniform temperature must be provided to the mouse inside of the μPET/CT machine. This is extremely important as it is the solution to a number of aforementioned difficulties faced by researchers in the field. A mouse's body temperature is around 36.9°C so the device will have to produce a temperature near this to keep the mouse's body temperature constant [5]. The second main requirement for this device is that no metal parts can be located within the μPET/CT machine's field of view while a scan is taking place. Metal parts within the viewing field of a CT scan cause distortions known as artifacts that make it difficult for the researcher to analyze the image. The third main requirement for the device is that it must have effectively no potential to harm the μPET/CT machine because this machine is extremely expensive and is the only one in the world. The fourth main requirement for the device is that the cost of production must be under $500.

In addition, the device should minimize movement inside the μPET/CT machine. Too much movement inside the machine's field of view can distort the image. A physical requirement that must be met is that the portion of the device that delivers heat to the mouse must fit inside the μPET/CT imaging chamber which has a circular opening with a diameter of ten centimeters. The last requirement for this device is that it must be cleanable. At times mice will urinate during scans. Due to the radioactive pharmaceuticals delivered to the mouse for PET scan purposes, the mouse's urine is often radioactive. For this reason, the device must be cleanable to ensure that there are no radioactive isotopes present which would result in a distorted image.

Background Information

PET/CT Imaging

PET/CT imaging is widely used as a technique to track the progress of cancer as well as the effectiveness of cancer treatment plans. Throughout the country, clinical machines are used to provide doctors with useful information about their patient's disease. μPET/CT refers to a smaller version of the machine with a higher resolution on the scale of microns as opposed to millimeters for the clinical machine. This increased resolution is necessary to image small animals for research purposes. PET/CT imaging combines the power of the two previously used techniques to provide a more detailed and beneficial image.

PET or Positron Emission Tomography is a nuclear medicine imaging technology that utilizes positron labeled molecules to measure the intensity and function of biological processes without disturbing the test subject [6]. Prior to a scan the subject is injected with a radiopharmaceutical or tracer, often fluoro-2-deoxyglucose which is an analog of glucose. The radiopharmaceutical travels throughout the body by way of the blood stream. This tracer is consumed by the subject's cells through normal metabolic processes. As the tracer molecules begin to decay by means of these cellular processes they emit positrons which are the antimatter counterpart to electrons. When positrons are emitted they almost instantaneously collide with electrons in a process known as annihilation. The byproduct of this annihilation is a pair of gamma rays which travel in opposite directions until they are detected by a scintillator material. The detection allows the machine to pinpoint the location where the annihilation took place, and through the compiling of thousands of these annihilations create an image. PET images represent the relative activity of the cells. In PET images, cancerous areas show up as bright spots on the image due to their increased metabolic activity [1]. Increased metabolic activity in cancer cells is a result of the uncontrolled cell division that characterizes these cells. Using PET imaging, researchers are able to study the growth of cancerous tumors as well as metastasis, the movement of cancer throughout the body.

CT, or Computed Tomography, is an imaging procedure that uses a series of x-rays to create a three dimensional image of the anatomy of a subject. In computed tomography, x-rays are emitted in a single plane. The CT machine measures the attenuation of the different tissues in the body of the subject by sending these x-rays through the body and then collecting them on the opposite side [10]. CT machines are capable of detecting a difference in tissue density as small as 1%. A large number of two dimensional images known as slices are taken around a single axis of rotation. They are then compiled through a number of techniques, most notably tomographic reconstruction, to create a three dimensional image.

μPET/CT is a machine that combines the technology of PET and CT imaging into one process. The μPET/CT scanner that will house the designed heating device is a product of Siemens and is currently the only operable combined μPET/CT scanner in the

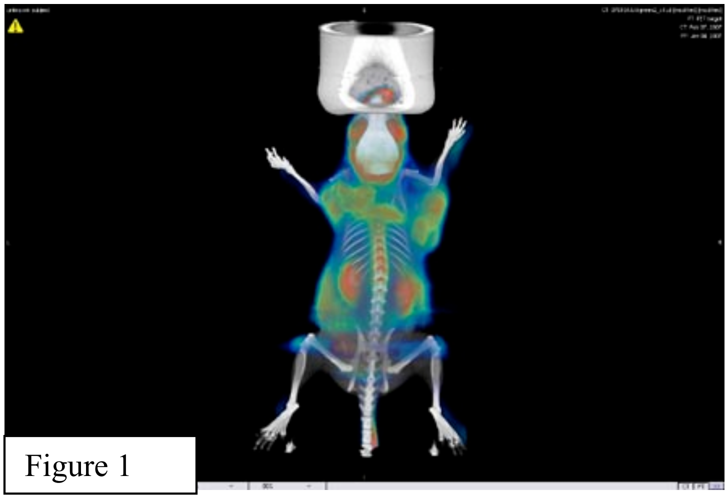


Figure 1

world. The PET portion machine provides the necessary information on cellular activity while the CT portion of the machine provides information on the anatomy of the subject. The PET data, when overlaid with a CT scan, creates a complete image of the cancerous cells within the anatomy of the host. Figure 1 is a μPET/CT image of mouse provided by this project's client Dr. Robert Jeraj.

Mice/Heat Loss

Due to the large surface area to mass ratio of mice as well as their incredibly high metabolic rate, mice lose heat more rapidly than larger animals [2]. As mentioned before, during hour long μPET/CT scans mice can experience hypothermia or even death due to the anesthetic. Anesthesia causes heat loss by sedating the mouse and eliminating muscle activity, a major source of heat production. In addition, under anesthesia, there is a general core to peripheral heat transfer resulting in a substantial heat loss to the environment [3]. The inability to control body temperature is intensified in nude mice that are given this name due to their lack of hair. Nude mice are commonly used in medical research because they possess an inability to reject tumors or transplants of cells from other specimens including humans. This inability to reject foreign cells comes from the absence of a thymus in their body, and, in turn, an absence of T-cells. T-cells are necessary for the immune system to destroy foreign cells that invade the body [8]. Dr. Robert Jeraj uses nude mice to study cancer treatment by first implanting cancerous cells in the mice and then tracking the progress of certain treatment plans using medical imaging techniques such as μPET/CT.

Potential Designs

PVC Tube Heater

One potential design alternative takes advantage of the insulating properties of Polyvinyl Chloride (PVC) as well as the high resistance properties of nichrome wire [7][4]. The first main component of this design is a device that we chose to call a PVC tube heater. To create the heater, we would suspend a nichrome wire inside the PVC tube. Nichrome wire is wire composed of nickel chromium and is known for its high resistance. Manifested in this high resistance is the ability to produce heat. Applying a voltage across the nichrome wire inside the PVC tube would cause the wire to emit heat.

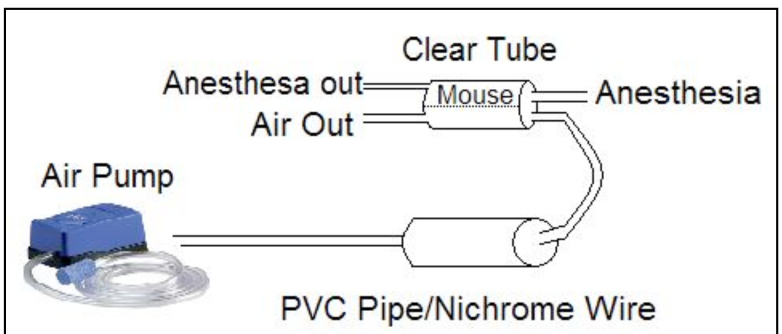
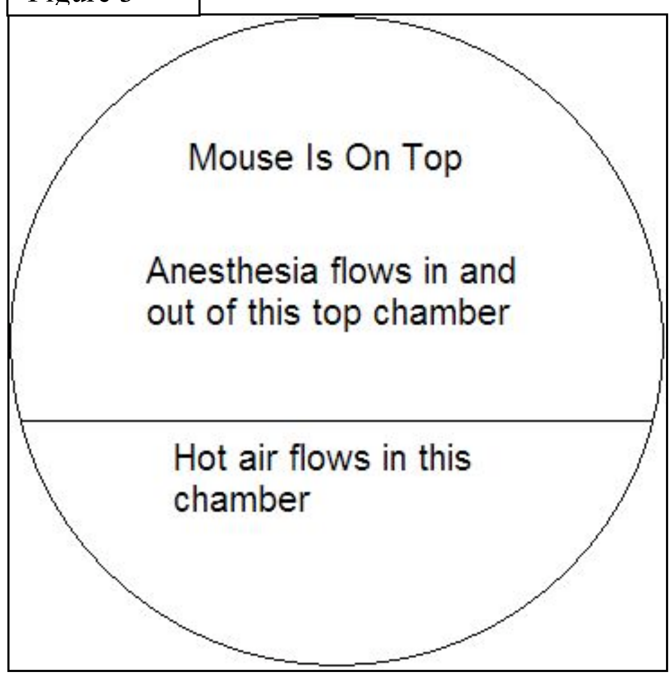


Figure 2

The next component of this design is an air pump. A number of air pumps have been considered for this design including one similar to the pumps used in fish tanks. This air pump would create an air flow which we would connect to one end of our PVC tube heater. Air would pass over the hot nichrome wire, heating up as it flows over the wire. The heated air would flow out of the other end of the PVC tube heater where it would be transported through plastic tubing into the µPET/CT scanning chamber to be delivered to the mouse (Figure 2).

For the heat delivery to the mouse, a cylindrical tube design will be utilized (Figure 3). Inside, the cylinder will be divided into two compartments by a plastic platform. The platform will sit on a ledge forming an air tight seal and will slide out the back of the tube for cleaning purposes. On the bottom half of the cylinder, a heating tube will enter the front side. Hot air will flow in this end and flow out a hole on the opposite side to release the pressure. The heat coming in will transfer to the platform where the mouse will lie and act as a heating pad for the mouse. On the upper half of the cylinder the anesthesia will flow into the chamber to keep the mouse anesthetized. It will flow in the front and exit the opposite side (Figure 3). Because there is limited space within the µPET/CT scanner with the heating cylinder inside, we must loop the anesthesia exit tubing back through the top of the plastic cylinder and out the front of the machine for neutralization. Also, the enclosed upper half will help trap the heat being transferred from the lower half, allowing the generation of less heat by the source.

Figure 3



Since temperature control is such an important aspect of this project, it is important that precise temperature control could be built into this design. There are numerous variables which can be adjusted to obtain the correct air temperature to be delivered to the mouse. The first adjustment that can be made is the amount of nichrome wire that we use to create the PVC tube heater component. Less nichrome wire will result in a lower air temperature and likewise more wire will result in higher air temperature. The second adjustment that we can be made is the amount of voltage that is dropped across the nichrome wire. If more voltage is dropped across the nichrome wire, the current through the wire will increase, thus, increasing its temperature. Finally, the air flow rate produced by the air pump can be adjusted. This will adjust the amount of time that the air spends in the PVC tube heater which changes the amount of heat that the air can absorb.

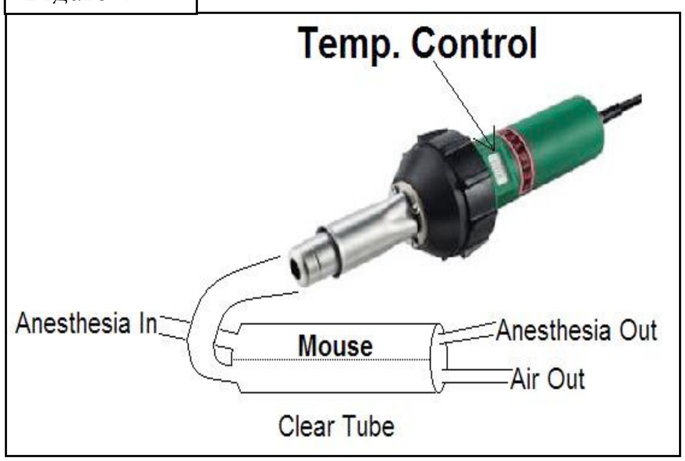
This design has numerous advantages. The first advantage is the fact that there are three variables which can be adjusted to produce the desired temperature. These variables were described in the previous paragraph. The second advantage of this design is that it has a small potential to harm the μPET/CT machine since the heat producing components will be located outside of the machine. The only components inside the machine will be non-heat producing, non-moving, plastic parts which have an extremely low probability of harming the machine. The last major advantage of this design is its production cost. In comparison to the other design alternatives, this design is extremely cost conscious. Most of the parts can be bought from a local hardware store. The estimated cost of this design is under $200.

While this design has numerous advantages, there are also a few disadvantages. Due to the number of variables a complex calibration stage will be required with this design to generate our desired temperature. This will involve tweaking the three aforementioned variables to yield a temperature which will keep the mouse's body temperature constant. Along with this, another disadvantage is that we will eventually have to come up with our own custom power supply which will deliver the correct voltage to the nichrome wire to produce our desired temperature.

Triac PID Heat Gun

Another potential design alternative that would be capable of providing heat to a mouse within the μPET/CT machine is a heat gun design. A heat gun is a device that is capable of providing heat as well as air flow in a single unit. The heat gun considered for this design is the Triac PID from a company called Leister [9]. This device provides controllable temperature and also employs a digital temperature read-out. A number of tips are also available for the gun allowing for use of a range of different plastic tubes. Plastic tubing will connect the gun to the device that will transfer heat to our mouse (Figure 4). The heat gun design would utilize the cylindrical enclosure described in the section containing information on the tube heater design for delivery of heat to the mouse. Refer to *page 10* for more information on this aspect of

Figure 4



the design.

Along with the cylinder delivery system, the heating gun design offers a number of advantages. The onboard temperature control gives the ability to adjust to a desired temperature. With the temperature control it also displays the temperature digitally, which will allow the operator to know what temperature is being delivered to cylinder at all times. Also, this design is simplified due to the heat and air flow coming from one device. Limited calibrations will have to be done upon purchasing.

Some disadvantages also arise when dealing with the temperature adjustability of the heat source. The heat gun only has 10 degree F. temperature increments, so if the body temperature of the mouse doesn't fall on certain temperatures, the mouse may suffer from hypothermia or die. Also, the Triac PID is intended for removing paint and welding plastic at temperatures greater than 200 degrees F. which would likely kill the mouse. The Triac PID is also quite expensive and would be costly if it ever needed to be replaced.

Water Heating System

The third design alternative, a water pump design, comes from the in-floor heating system used in many newer homes. Plastic tubes run through the floors of the house and a water heater equipped with a circulating pump delivers hot water throughout the floors. The heat is transferred from the water through the tubing into the floors heating the floors to a desired temperature. The water heating system design is based on these principles.

A water pump is the main component of this design which will provide continuous flow of water. A circulating pump would be ideal for this design in order to provide this water flow at a constant pressure. A circulating pump will pump water out one of its ends and circulate the water back through its other end. A constant flow of water would aid in delivering a constant temperature to the mouse's body. If possible, a pump with a heater built in would work quite efficiently with the design of this system. If a water pump and heater combination is not available, an in-line water heater would be used as the heating source. This would allow the water to be heated as it flows through the heater and provide a constant temperature flowing to the mouse.

To deliver the heat to the mouse within the μPET/CT machine, tubing would coil around the mouse making a cylindrical tube-like bed (Figure 5). Heat would transfer through the plastic tubing heating the area where the mouse lies. Because the tubing would completely surround the mouse, a warm environment would be easy to maintain.

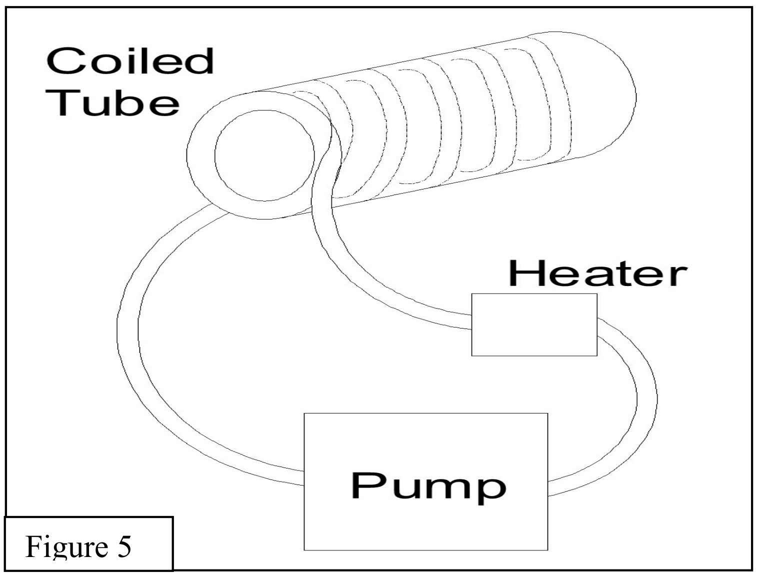


Figure 5

The water pump design offers a number of advantages. Because water pumps are readily available, we would have no problem finding a pump that can be integrated into our design. A pump would provide constant water flow maintaining a constant temperature throughout the system, in turn providing the mouse with a constant body temperature. Because water has a high specific heat, we would not have to worry about heat loss from the water heater to the coil delivery system where the mouse lies.

The water pump design also has a number of disadvantages. Because we are working with a very exclusive and expensive imaging machine, we don't want to take any chances with this design leaking and breaking the μPET/CT scanner. Also, the heat transfer from the coil system may not be efficient enough, since it must transfer heat from the water through the plastic tubing to the mouse. With this uncertainty of the heat transfer, we would also have to adjust the temperature, which has a slower response time relative to the heated air designs. A slow response time could cause images to be inaccurate.

Design Matrix

With all three designs complete, a design matrix was drafted to compare them against one another. The designs were evaluated by the means of categories that we felt were necessary to the success of the device. The criteria we used to evaluate our designs were the result of the design requirements and concerns dictated by our client. Each criterion was assigned a weight value with the weights of all 6 criterion totaling 1.00.

Weights were assigned based on the overall contribution to the success of the device as well as values important to our client. Our client made it clear that, above all, the CT/PET machine needs to be safe. Therefore, it was weighed quite heavily on our matrix. Likewise, our client also emphasized the fact that the device must provide an accurate temperature range otherwise the device will not be able to aid in the production of precise results from scan to scan. Thus, the temperature range category received a substantial weight of 0.25. The same weighing method was used for the remainder of the criteria until the total reached 1.00.

We then went through and rated each of the designs in each of the categories. The best rating a design could achieve in a particular category was the weight for that category. For example, in the cost category the water pump received a score of 0.10 out of a possible .20, the weight for the category. After we went through and tabulated the scores, the PVC heater received the highest score, 0.86 out of 1, while the water pump and the heat gun fell at a far second and third.

Given the results of the design matrix, we decided to pursue the PVC heater design for the rest of the semester.

Category	**Weight**	**Water Pump**	**PVC Heater**	**Heat Gun**
Cost	.20	.10	.20	.05
Temperature Range	.25	.20	.20	.05
Safety of PET/CT Machine	.20	.05	.15	.10
Mouse Surface Stability	.10	.05	.10	.10
Heat Transfer	.10	.05	.08	.08
Temperature Adjustability	.15	.10	.13	.05
TOTALS	**1.00**	**.55**	**.86**	**.43**

Table 1 – Design Matrix

Future Work

A number of steps will need to be taken to construct a working version of the PVC Heater. First of all, parts need to be bought to build a prototype of the design. For the heating element, this includes a PVC pipe, nichrome resistance wire, plastic tubing, and an air pump. Furthermore, the mouse enclosure requires an acrylic clear tube, an acrylic sheet to cap of both ends of the tube, a polyethylene divider, plastic tubing with fittings to circulate heat, and anesthesia through the enclosure. Most of these items are of minimal cost and there should be no problem finding them at a local hardware store. Before anything is built, the materials will need to be scanned by the µPET/CT machine in order to assure that they will not produce artifacts during the scans.

After testing the compatibility of the materials with the scanner, the mouse enclosure will be the first item to be built. It will be constructed with close attention to the dimensions of the PET/CT machine so that it will be able to move freely within the bore and not disturb the machine.

The second element to be built will be the heating system. Since the heating system consists of many different variables, all of which affect the heat, multiple heating elements will be built that differ in amount of nichrome wire, placement of nichrome wire, and length of PVC tube. All of these will need to be powered by a direct current power source which represents another controllable variable. Once the desired temperature range is reached, the heating element should be attached to the mouse enclosure and the temperature should be fine-tuned.

As time permits, a temperature probe will be placed on a sedated mouse that is housed in the mouse enclosure and its temperature will be monitored during the final calibration stages. The correct voltage will need to be acquired so that the temperature of the mouse remains its normal resting body temperature. This may or may not be possible given the fact that our heat is consistently increasing with time. However, the use of a programmable microcontroller with a negative feedback system will fix our problem should the latter be the case.

A microcontroller would, in theory, monitor the body temperature of the mouse and turn off and on the power source accordingly so that a constant body temperature is achieved. This would be quite a big step, and will most likely not be accomplished this semester. However, it should be considered if the project is to be continued the following semester.

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Appendix A

Product Design Specification: Updated March 13, 2007

Team Members:

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Problem Statement:

During anesthesia, metabolism slows down, which can lead to hypothermia and eventual death. For prolonged μPET/CT scans, where animals are kept for an extended period of time under anesthesia, it is important to keep the animals at steady temperature. Currently heating lights are used to provide that; however they often lead to non-uniform and poorly controlled temperature regulation. Therefore, it has been proposed to design a heating device that could be used to provide a controllable and steady temperature during prolonged scans. Because of the imaging requirements, the heating device should not contain metal parts.

Client Requirements:

- Temperature should be near the body temperature of a mouse
- Temperature should be controllable and constant
- Heating should be able to be provided for roughly one hour
- The device should be cleanable

Design Requirements:

- No metal parts within the scanning region of the μPET/CT machine
- Liquid may be used but device must be completely sealed (no leaking)
- Limit the use of moving parts. Slight motion may be acceptable, but significant motion may affect imaging capabilities
- The portion of the device that the mouse is sitting on should be somewhat firm so the mouse does not sink into the device
- The heat delivery portion of the device must fit in a 4 ¾ inch diameter opening

1. Physical and Operational Characteristics

a. Performance Requirement: The device will need to produce temperatures near the body temperature of a mouse. However, the main concern is that the device can maintain a constant temperature.

b. Safety: The device will likely operate at high temperatures; therefore the user should use care when operating the device. The device will require a label warning of this high operating temperature. We should use a temperature fuse to automatically turn off the device if the temperature becomes extremely high. The device may also employ a DC power supply. Standard safety precautions should be followed regarding this electrical unit.

c. Accuracy and Reliability: The device should provide controllable heat accurate within roughly 3-5 degrees Celsius of the temperature desired by the operator. Temperatures should be repeatable to ensure that temperature is a controlled variable across a number of scans spanning an amount of time determined by the researcher.

d. Life in Service: The device should be capable of providing heat for at least one hour, the typical length or a μPET/CT scan. The device should be able to withstand multiple uses within one day. The product life of the device depends on the working parts used in the design.

e. Shelf Life: Shelf life will not likely be an issue with this device

f. Operating Environment: The device will be used at the UW hospital in the room where the μPET/CT scan machine is located. The temperature of this room is approximately 80 degrees Fahrenheit.

g. Ergonomics: The temperature control of the device should be straightforward so that a user can easily shift the temperature up and down without extensive training. Also, the body temperature of the mouse should be highly visible.

h. Size and Shape: The device used to deliver heat to the mouse within the scanning chamber of the μPET/CT machine must fit into a cylindrical space with a circular diameter of approximately 10 cm. The length of this device will likely not be constrained by the length of the μPET/CT scanning chamber. There are no size constraints on any device outside of the scanning chamber.

i. Weight: The weight of this device is not constrained.

j. Materials: The part of the device that goes inside the imaging chamber cannot contain any metal parts. Metal parts may be used on portions of the design that are located outside of the imaging chamber. Also, this device should be cleanable because mice tend to urinate during scans.

k. Aesthetics, Appearance, and Finish: The device should clearly indicate a warning about the high temperatures that the device will be running at. Aesthetics are not a large concern at this point.

2. Product Characteristics:

a. Quantity: One device is required.

b. Target Product Cost: The budget for this project is not concrete. Our goal is to construct a prototype for under $200.

3. Miscellaneous:

a. Standards and Specifications: The device should comply with all regulations established by the FDA for medical instruments. More information can be found on the FDA website.

b. Customer: The customers for this device will be researchers who would like to keep the body temperature of a small animal constant during imaging processes.

c. Patient-related concerns: There are no patient-related concerns at this time.

d. Competition: There is currently no device available that adheres to the requirements set forth by the client.