Dogs of Chernobyl:
The Effects of Radiation on Nutrition

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Abstract

This project aimed to find a recommended diet for the dogs that are living in the Exclusion zone due to the Chernobyl accident. In the project we analyzed fecal and hair samples that were collected by Clean Future Funds, which were then transported from Chernobyl to the United States. The data acquired from these test were then reported in the report and multiple types of dog food brands were compared to determine which was the best diet for the dogs. The usage of Prussian blue dissolved in water was also discussed. With the recommended diet, which was designed to minimize the biological half-life of cesium, it is expected that the rate of excretion of radiocesium will accelerate.

Acknowledgments

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Executive Summary

Project Background

In April 26, 1986 the Chernobyl nuclear disaster took place. The disaster happened when the plantation was conducting an experiment to test the electrical system in the event that the main electrical system would fail (Smith, 2005). However, due to poor communication and poor misjudgment the nuclear power plant exploded from a failure in the pressurized cooling water system (Smith, 2005, pp.2). Around 134 emergency personnel who responded to the incident suffered from acute radiation poisoning with 28 being fatal (United Nations Scientific Committee on the Effects of Atomic Radiation, 2011). Also, 118,400 people who lived around the power plant had to be evacuated and during the evacuation they had to leave behind most of their belongings including pets (Clean Future Funds, 2018).

Radionuclides were dispersed throughout Chernobyl and neighboring areas. Many of these radionuclides were dispersed throughout the soil and vertically migrated downwards where it could be potentially absorbed by vegetation (Smith 2005). This therefore increased the plants internal radioactivity, which could be harmful to organism that feed on these plants. The dogs from Chernobyl were left behind by their owners and were forced to fend for themselves therefore they scavenge for food and this includes eating vegetation from the affected soil.

Project Objective and Methodology

The goal of this report is to analyze the fecal samples from these dogs in order to determine the radioactive levels that inhibit in them. As well as to find an appropriate diet for them that will help maintain their health and to potentially diminish their internal radioactive levels.

The workers of the Clean Future Funds organization collected the samples from Chernobyl dogs. The samples were then transported back to the United States in order for us to be able to analyze them by using scintillation detectors. These detectors are typically sensitive to one type of radiation. The detectors that were used in these experiments were sodium iodide detectors, which pick up gamma rays and not alpha or beta radiation (Zoomie, 2015). With the detector we can find out which radionuclides are active in the samples that were tested. The instrument finds these values by measuring the energy of the gamma that is released and captured by the sodium iodide crystal (Zoomie, 2015). The process of capturing these energies is either called the gamma spectroscopy or multi-channel analyzer (MCA) (Zoomie, 2015). The results of these tests were then recorded and later used in order to see the significance of the radioactivity.

Project Findings

From the data that was acquired from the tests we could then calculate and analyze the radioactivity from the samples. In the samples we received a numerous amount of hair samples from dogs that were prepped for surgery. We also received a very limited amount of dog fecal samples (not enough to make a conclusive statement). The hair samples came back with little to no significant activity while the fecal samples came back with average activity of 1.42 Bq/g. In taken in this value one had to keep in mind that in organisms cesium gets mostly extracted through the urinary tract. Therefore the urinary to fecal ratio of cesium being found is about 2.5:1 to 10:1 (these are numbers derived from human studies) (Agency for Toxic Substances and

Disease Registry, 2004). Thus the numbers given from the fecal samples is not an accurate representation of the organism as a whole.

Recommendations

The recommended diet for the dogs after deliberating various form of dry dog food for adults was found to be Blue Buffalo brand. This was chosen due to its nutritional values and low fillers. Also Blue Buffalo is one of the cheaper and nutritional dog foods in the market with an approximate price of $1.57 per pound (1 pound = ~0.45 kilograms). The worst dog food in terms of nutritional value was found to be Purina. Purina was found to have mostly fillers and the first ingredient on the package is grain and not meat.

Another recommendation that was made was to place a low trough of water outside one of the facilities around the Exclusion zone with 2.5 grams of Prussian blue per liter. The Prussian blue will accelerate the process of extracting the Cesium by binding to it. It has been studied that with the usage of Prussian blue the biological half-life of radiocesium goes down by 45% for younger dogs, by 63% for adult dogs and by 45% for senior dog (Melo et al., 1998). Increasing the concentration of Prussian blue in the water seems to not affect the rate of which radiocesium is excreted from the body. With the implementation of this diet to the dogs of Chernobyl is expected that they will be able to process the radiocesium in much quicker time than if they were to process it naturally.

Authorship

Giselle Sosa wrote all sections of the paper. The methodology, results and the findings sections were written with the aid of Taylor Trottier's paper. The analyzing and prepping of the samples were conducted by the team, which consisted of Joseph LeBlanc, Giselle Sosa, and Taylor Trottier.

Table of Contents

List of Figures

List of Tables

Chapter 1: Introduction

In the Exclusion zone, in Chernobyl, there are countless of strays that have been left behind due to the evacuation that occurred after the explosion at the Chernobyl nuclear plant (Clean Future Funds, 2018). After the explosion soldiers were sent to the Exclusion zone in order to cull the pets that roamed the area, however they were not able to kill all of the dogs (Clean Future Funds, 2018). Now the dogs have been breeding rampantly with each other. They also started to heavily rely on the workers who work around the area for scraps of food. Which most likely do not contain the necessary proteins for them to stay healthy.

Figure 1: Stray dogs relying workers for scrap – (Clean Future Funds, 2018)

The issue with the feeding of scraps to the dogs is that the dogs are not satiated enough with just the scraps and therefore they will turn to vegetation that may have absorbed radiation via the soil. If the dogs eat the contaminated plants then they would also potentially increase their internal radiation alongside with it. Which is why a better diet plan is needed for the dogs.

The goal of this project is to be able to come up with a better diet plan that may benefit the whole population of dogs in the Exclusion zone. With the implementation of a new diet we hope to have the majority of the dogs run around healthy and without need to go foraging for contaminated vegetation. The new diet will also allow for the dogs to not heavily rely on the workers for food. Therefore, with a better diet the dogs will have a better recovery and start to dwindle down their internal radiation much quicker than if they were not to implement the new diet.

Figure 2: Pack of dogs from Chernobyl – (Clean Future Funds, 2018)

Chapter 2: Background

2.1 Chernobyl

2.1.1 Events at Chernobyl

The Chernobyl nuclear disaster occurred when the plantation was conducting an experiment to test the electrical system in the event that the main electrical system would fail (Smith, 2005). In order to conduct the experiment the "thermal power output [of the reactor] had to be reduced to 700 – 1,000 MegaWatts (MW), about 25% of its maximum power output" (Smith, 2005, pp.2). The plant operators reduced the power output to 720 MW, however, 30 minutes later the power output rapidly declined to 30 MW (Smith, 2005). The power declined at a rate of 23MW per minute. The automatic controls rods, which controlled the power of the nuclear reactor, were believed to have caused this extreme drop (Smith, 2005). Therefore, the plant workers removed some of the control rods in order to stabilize the reactor, which then successfully increased the power to 200 MW (Smith, 2005). As the experiment was being conducted, the flow of water was varied in the coolant system, which resulted in significant changes "in temperature of the inlet water" (Smith, 2005, pp.2). At this point the reactor was extremely unstable, causing an automatic warning to be issued but the operators ultimately ignored it and continued on (Smith, 2005). The power was increasing rapidly and in order to conduct an emergency shut down the control rods that were taken out were then immediately put back into place (Smith, 2005). Not long after, the power of the reactor exponentially started to increase "leading to a failure in the pressurized cooling water system", and eventually the reactor exploded due to the steam and not from a nuclear reaction (Smith, 2005, pp.2). As a result many small fires ignited around the premises and firemen were dispatched to deal with them, however the fire at the plant burned for around 10 days (Smith, 2005).

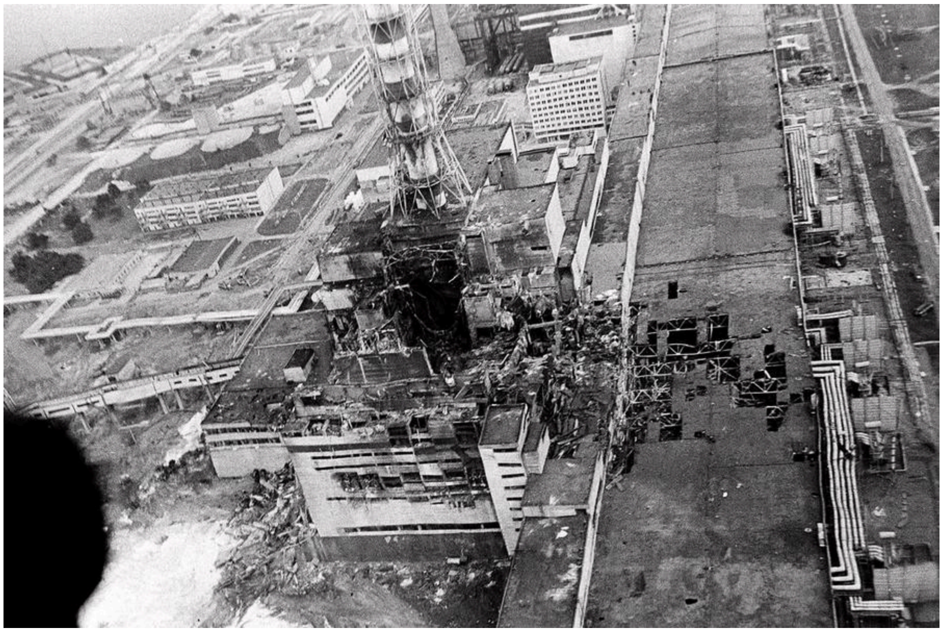

Figure 3: Aerial shot of the nuclear plant few days after the accident – (Taylor, 2011)

2.1.2 Response to the Accident

First responders and plant operators were exposed to large amounts of radiation. Around 134 of the personnel that were present in the immediate aftermath were suffering from acute radiation poisoning with 28 being fatal (United Nations Scientific Committee on the Effects of Atomic Radiation [UNSCEAR], 2011). Acute radiation occurs when a person is exposed to high levels of radiation. Symptoms that are associated with acute radiation syndrome are “nausea, vomiting, headache, and diarrhea”, and serious cases, like the 28 who perished, can result in death (CDC, 2014). More than anything, the event affected the people who lived around the plantation the most, with around 118,400 people being evacuated (United Nations Children's Fund [UNICEF], 2002). The evacuees were only allowed to bring whatever they could carry; therefore many dogs and cats were abandoned (Clean Future Funds, 2018).

2.1.3 Temporary Solutions

There were various radionuclides that were released from the explosion. A concrete shielding, the "sarcophagus", was made over the destroyed reactor in order to diminish the release of more radioactive materials (Smith, 2005). The sarcophagus was completed in November 1986, and in 1999 it was reinforced (Smith, 2005). Of course the damage has been done and there is relatively nothing one can do to clean up the mess. The majority of the radionuclides had very short half-lives therefore, the radiation levels drastically decreased in only a few months (Smith. 2005). The radionuclides that are still present are the ones with long half-lives. One radionuclide that is of importance is Cesium-137, which has a half-life of approximately 30 years (EPA, 2017).

Figure 4: Newest version of the sarcophagus being built in 2015 – (RT News, 2015)

2.2 Radiation

2.2.1 Basics of Radiation

In order to understand the concerns surrounding the dogs of Chernobyl, we must first understand what radioactivity is. Radioactivity is a process that occurs in unstable atoms (Australian Radiation Protection and Nuclear Safety Agency [ARPANSA], 2018a). An atom is considered stable when the forces "among the particles [neutrons and protons] that makeup the nucleus are balanced" (ARPANSA, 2018a). This means that it is more difficult to break apart the nucleus of a stable atom, due to it having a greater binding energy (Orecity, 2007). The binding energy of a nucleus is the energy required to separate the nucleus to its components (Orecity, 2007). An atom is unstable when the nucleus is unbalanced due to an excess of neutrons or protons (ARPANSA, 2018a). And since the atom is unstable it is easier to break apart the nucleus, because the binding energy of the nucleus is not as strong compared to the nucleus of a stable atom (Orecity, 2007). This then allows the unstable atom to discharge its neutrons and protons, thus causing it to release nuclear energy in the form of alpha or beta particles, which is then "often accompanied by gamma rays" (ARPANSA, 2018a).

Alpha particles are slow and heavy compared to other forms of radiation (ARPANSA, 2017a). They are emitted from the atom's nucleus during the process of alpha decay (ARPANSA, 2017a). As the alpha particle is released, it can cause multiple ionizations in short distances (ARPANSA, 2017a). Ionization is when an atom loses or gains electrons (ARPANSA, 2017a). By being able to make multiple ionizations it can, in turn, create more biological damage, however because they are so ionizing they cannot penetrate the dead cells on the surface of our skin (ARPANSA, 2017a). In order, for alpha particles to have a dangerous effect on our health, it needs to have an entry into the body. It can enter the body by ingestion or through an open wound (ARPANSA, 2017a).

There are two types of beta particles: beta minus particles and beta plus particles (ARPANSA, 2017b). Beta minus particles are electrons that are ejected by the nucleus, while beta plus particles are positrons that are ejected by the nucleus (ARPANSA, 2017b). Atoms that have a lot of neutrons try to stabilize themselves through beta decay, by ejecting these beta particles (ARPANSA, 2017b). In general, beta particles are less ionizing than alpha particles, thus they travel farther distances and create less biological damage (ARPANSA, 2017b). Exposure to beta radiation may cause burns and if ingested it can damage the internal organs and soft tissue (ARPANSA, 2017b).

During gamma decay, gamma rays, the stronger emission from the three, are produced (Lawson, 1999). A gamma ray is “a packet of electromagnetic energy emitted by the nucleus” of an atom (ARPANSA, 2017c). They are highly energetic and are able to penetrate through a lot of different types of materials, including human skin (ARPANSA, 2017c). If the gamma rays do pass through the skin “they can cause ionizations that damage tissue and DNA” (United States Environmental Protection Agency [EPA], 2018).

The intensity of radioactive emissions decreases exponentially overtime and sometimes changes to atoms of a different element with a lesser charge (Lawson, 1999). The time it takes for an element to decrease to half of its original value is the element's half-life (Bewick, 2017). This can be found using the following equation:

$$A_t = A_0 * e^{-\ln(2) * \frac{t}{t_{\frac{1}{2}}}}$$

Where $t_{1/2}$ is the time the half-life of the atom, A_t is the activity at time t, and A_0 is the initial activity (Lawson, 1999).

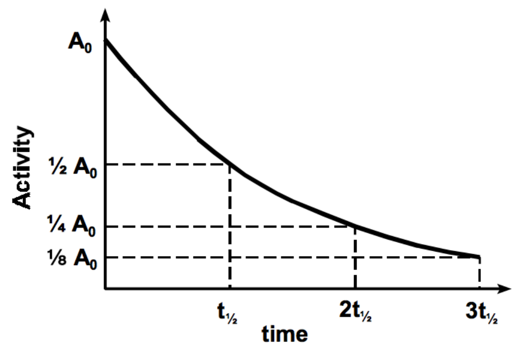

Figure 5: Graphical representation of exponential decay of activity – (Lawson, 1999)

The element of interest is Cesium-137 (Cs-137). The type of emissions Cs-137 emits are beta particles and gamma rays; it also has a half-life of approximately 30 years (EPA, 2017). We can find Cs-137 around places where nuclear reactor accidents happened (EPA, 2017).This is due to fact that Cs-137 is a byproduct of the nuclear fission of Uranium that is used to make the fuel rods at a nuclear power plant (Centers for Disease Control and Prevention [CDC], 2015). Overtime Cs-137 decays through beta decay to an excited Barium-137, and then it eventually goes through gamma decay into a stable ground state Barium-137 (ARPANSA, 2017a).

2.3 Radiation in the Environment

2.3.1 Deposition of Radionuclides in the Environment

In order to understand the effects the accident had on the environment we first need to understand the way radionuclides disperse throughout the environment. Radionuclides can be dispersed throughout the environment in dry conditions or during precipitation (Smith 2005). When radionuclides are deposited in dry conditions it is referred to as 'dry' deposition while when it is deposited through precipitation it is referred to as 'wet' deposition (Smith 2005). It is important to know these different forms of dispersing because it indicates how impactful the radiation is towards the Earth. In general, wet deposition is a bit more effective than dry deposition when it comes to being absorbed into the soil (Smith 2005). The amount that gets absorbed into nearby vegetation/plants depends on the amount of foliage that is around during radioactive fallout and the foliage can intercept the dry deposition of radionuclides. More specifically trees have the perfect amount of foliage to intercept these radionuclides (Smith 2005). Therefore this means that in parts that were heavily guarded by trees (i.e. the forest) had some protection against the radioactive fallout as a result of the accident.

The initial dispersing of radioactivity in the soil is mostly due to wet deposition in result of rain (Smith 2005). After the rainwater hit the surface of the soil, the "vertical migration" of the radionuclides in the soil is slowed down due to the "fallout [being] sorbed to the soil matrix" (Smith 2005, p.41). What this means is that the radionuclides that were transported through the rainwater have a bit more difficulty of moving deeper into the soil because the soil absorbs the fallout really well. We are interested in the vertical migration of the radionuclides because it means that it can become in contact with the "plant's rooting zone" and could result in being absorbed into the vegetation itself (Smith 2005 pg.41). Thus increasing the vegetation's internal radioactivity, which could become harmful to whatever organism consumes it, which can also ultimately affect the animals that consume those plant-eating organisms. Vertical migration of radionuclides is also essential in determining the external radiation dosage that people may encounter in more radioactive areas (Smith 2005). This is because the more the soil matrix absorbs the less the external radiation would be.

In terms of the affects of the Chernobyl accident, there were measurements conducted in the soil during the summer of 1986 and they found that most of the radionuclides should be dispersed in the top 8 cm of the soils, while the maximum of the activity should be found at around 1.5 cm deep (Ivanov et al., 1997). This is not a significant number. The lack of radionuclide migration can be attributed to the fact that fuel particles from the reactor were the cause of the deposition, which would lead to a decrease of vertical migration (Smith 2005). Despite the shallow measurement from 1986, one has to keep in mind that Cesium-137 tends to linger around the soil at depth of up to 10 cm for very long periods of time (Smith 2005). This could be attributed to Cesium-137's long half-life. The figures shown below (Figure 4,5) show where the radionuclides were found in the soil that was 18 km away from the reactor and in what depth the most activity took place (Boulyga, Zoriy, Ketterer, & Becker, 2003). The graphs show approximately the same trend as what was discussed in Ivanov et al. study.

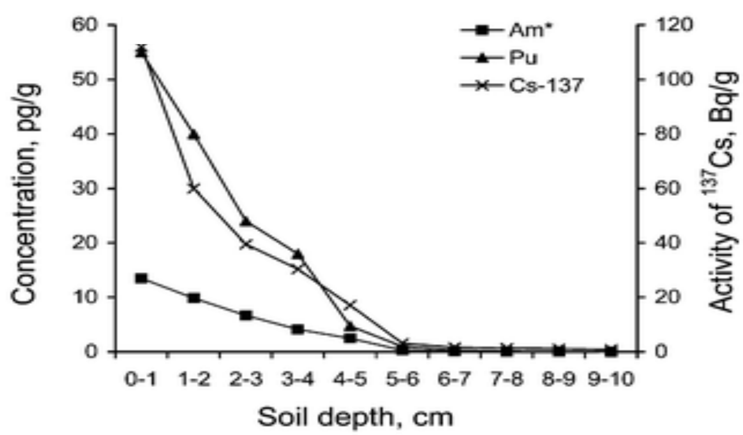

Figure 6: The approximate depths at which radionuclides were found 18km away from reactor– (Boulyga, Zoriy, Ketterer, & Becker, 2003)

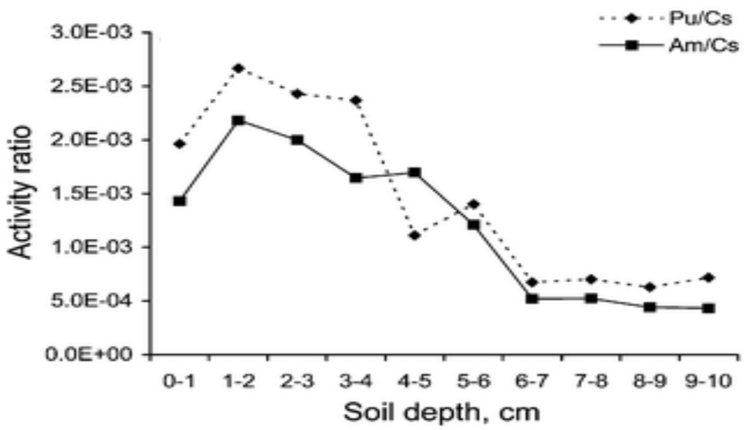

Figure 7: The depths where the most activity was found in the soil 18km away from reactor– (Boulyga, Zoriy, Ketterer, & Becker, 2003)

In the first year after the accident, most of the radionuclides were measured to be at the surface of the soil (Smith 2005). Later on the radionuclides redistributed throughout the soil and vertically migrated deeper into the soil matrix, which leads to the expectation that the top 15 cm layer of the soil will be directly affect by the radionuclides (Smith 2005). Plants (at 15 cm deep) have the potential of processing the affected soil. Therefore it is a probable that the vegetation that is consumed around the reactor has been affected by the radionuclides and can lead to an increase of internal dosage of the organisms that consume it. In an outlook of a few years the bioavailability of the radiocesium around the power plant is largely controlled by the uptake from soil by the roots of plants (Smith 2005). Changes in radiocesium in the environment are really slow (Smith 2005). This made the absorption of radionuclides by the roots as one of the main pathways to living organism (Smith 2005).

2.3.2 Effects of Radiation on the Environment

The dogs of Chernobyl have been foraging for food in the exclusion zone or by being fed by the workers there (see Figure 6). We can clearly see that this is not the best diet for the dogs and therefore, perhaps some of them are malnourished or are not as healthy as the dogs that are kept in first world countries. This is all a result of the Chernobyl disaster.

Figure 8: Dogs crowding around workers to get food – (Clean Future Funds 2018).

After the events of the Chernobyl accident, various radionuclides were deposited in the environment surrounding the nuclear reactor. The part that affects the surrounding wildlife the most is the water supply and the vegetation that grows on the affected soil. This is a cause for concern for the dogs of interest because they do not have their owners to rely on and therefore need to scavenge for food (which also includes plant matter) in order to stay alive. Therefore, one would believe that the affected vegetation would increase the internal radioactivity of the dogs. This thought was later investigated more in order to see the effects that food may have in an organism's (specifically mammals) internal radiation dosage.

2.4 Radiation Effects in the Body

2.4.1 Health Effects from Radiation in Humans

Naturally occurring Cesium typically is not hazardous to life; it can be found throughout the environment in rock, and soil (CDC, 2015). Cesium is dangerous to our health when we are around places where nuclear accidents, like the Chernobyl incident, have happened (CDC, 2015). When in the environment Cs-137 behaves as a chloride salt and has the potential to become airborne, be dispersed through water, and to be soaked up in the soil (EPA, 2017). Overall, it is not likely for one to be exposed to high levels of radioactive Cesium unless one was to reside around areas where nuclear accidents have happened.

If we were to be exposed to high levels of radioactive Cesium, we could run the risk of contracting various health complications. For example, radioactive Cesium can damage the cells on ones body just by standing near a place of high radioactive activity (CDC, 2015). The risk of developing cancer and birth defects increases when exposed to Cs-137 (EPA, 2017). External burns and acute radiation syndrome (ARS) can also be a result of exposure to Cs-137 (EPA, 2017). ARS can cause nausea, vomiting, and diarrhea (CDC, 2014). It can also destroy the bone marrow, "which results in infections and internal bleeding", thus possibly resulting in death (CDC, 2014). The recovery for someone who was affected by ARS can "last from several weeks up to two years" (CDC, 2014).

Radioactive cesium may enter the body through the ingestion of food that was grown in contaminated soil, and/or drinking contaminated water from water sources where cesium has dissolved (CDC, 2015). It can also enter the body by breathing in contaminated air (CDC, 2015). Once cesium enters the body it distributes itself throughout soft tissues until it is filtered and excreted by the kidneys (CDC, 2015). It is then released from the body mostly through urination, while a smaller portion of the cesium gets released through defecation (CDC, 2015). The time it takes for half of the cesium to be excreted is about 110 days (Müller, n.d.).

2.4.2 Radiocesium in other Organisms

Radiocesium in general disperses itself evenly throughout the animal's organs (Smith 2005). This is most likely due to the case that radiocesium likes to interact just like how potassium would in the body. The government tries to decrease the effects of radiation in the body by setting ground rules of what an acceptable dosage of radioactivity is safe to consume in foodstuff (Smith 2005). This ground rule is better known as the "intervention level". When the level is high above the accepted level then the regulation authorities will place a ban on whatever foodstuff is dangerous to consume (Smith 2005). In terms of Chernobyl the levels of radioactivity is unsafe for humans to consume and may lead to (as mentioned before) cancer (Smith 2005).

In general mammals are very sensitive to radioactive materials (Smith 2005). However, humans are more radiosensitive and have higher instances of developing cancer unlike others animal (like dogs). In the 30-km zone around the reactor the radiation levels are considered unsafe to humans. Radiation is only considered a threat to a human if by being in the presence of such radioactivity has a significant probability of causing cancer later in life (Smith 2005). Just because the radiation levels are too high for human living does not mean that it is too high for animal living. Animals are much more resistant to higher levels of radiation (Smith 2005). Therefore they do not procure cancer because cancer (in the animal kingdom) is a disease of the old and many animals in the wild do not live long enough to develop cancer (Smith 2005). This explains why for animals the onsets of cancer are a minuscule problem. Since, animals are more focused on staying alive from potential predators and from not starving to death.

2.6 Overall Ecological Effects

One may think that the result of the accident was an overall negative towards the ecological system around the exclusion zone. However, that is just not the case, in the contrary the wild nature in Chernobyl is thriving. Of a result of the removal of humans the animals do not have a main predator in their midst (Smith 2005). The populations of wolves are a main problem that they are facing and they have become abundant in the area (Smith 2005). Interestingly enough the diversity of the plants has increased and can be compared to natural park reserves (Smith 2005). So overall, the implications of the removal of humans have in general made a "net positive effect" in the environment of Chernobyl (Smith 2005 pp.280). Yes, it is true that the ecological system did have an immediate negative reaction towards the nuclear reactor accident, however overtime nature had a positive reaction towards the absence of humans (Smith 2005). There are some radiation damage occurring towards the organism that live there, however the incidents of these are relatively minor and do not have much of an impact in their health (Smith 2005). The exclusion zone and the surrounding areas now have an abundance of wildlife ranging from "wild boar, wolves, and many bird species" (Smith 2005, pp. 295). And the increase of wildlife means trouble towards the more domesticated animals that were left behind (i.e. dogs). Which is why the dogs were forced to move into the exclusion zone in order to survive the ever-increasing numbers of wolves (Clean Future Funds 2018).


Figure 9: Pack of wolves at Chernobyl eating their prey – (Dadiverina, 2017)

2.7 Goal for the Dogs of Chernobyl

For Clean Future Funds the main goal for the dogs is to be able to bring their ever growing numbers down by spay or neutering them. Since the populations of the strays that are free to mate have started to increase to around over 30,000 (Clean Future Funds 2018). The nuclear plant has tried to diminish these numbers by culling the strays, which is a very unethical (Clean Future Funds 2018). This is why it is necessary for there to be ever growing support and donations to the organization in order for they can continue maintaining the dogs by providing them vaccines, and spay or neuters (Clean Future Funds 2018). However, nutrition should also be a big part of helping the dogs to maintain their health and to potentially help decrease their internal radiation levels.

Chapter 3: Methodology

3.1 Process of Collecting Samples

The samples that were analyzed during the project came directly from Chernobyl and collected by Clean Future Funds. There were a collection of both hair samples and fecal samples. More hair samples were analyzed compared to fecal samples. This was due to the complications that arose during collection. The opiates in the tranquilizer guns that were used to gather the dogs caused unprecedented constipations on the dogs (M. Kaltofen, personal communication, August 16, 2017). Due to the constipation the dogs were not able to provide the expected amount of fecal samples that we initially were looking forward to. There were, however ample amounts of washed hair samples of the dogs. Hair samples were collected before spay and neuter surgeries that were conducted by workers of Clean Future Fund.

3. 2 Preparation of the Hair and Fecal Samples

Prior to analyzing the samples in the detector, the samples were prepared. More specifically the fecal samples were dried out in order to reduce the moisture that can interfere with the accuracy of the readings of the gamma spectroscopy instrumentation. While transferring the fecal samples from the original packing to the Whirl-Pak bags, proper attire was worn with the people handling the samples wearing gloves. Precautions were taken in order to make sure the samples were not contaminated by other sources and therefore separate people were designated different tasks (i.e. the transferrer, the note taker). After the fecal samples were placed in Whirl-Pak bags, they were then left to dry up in a fume hood with permission of one of the staff members in the institution. The fume hood was well ventilated and allowed for the samples to dry evenly while also not causing any discomfort to whomever was working in the same space.

There were not any prior preparations for the hair samples since they were already dry and did not need any further drying. The samples were placed in petri dishes when they were ready to be analyzed by using scintillation detectors (Trottier, 2018). During the analyzing time the samples were both weighed down by a cylindrical weight in order to pack the materials closer to each other and to make them denser (Trottier, 2018).

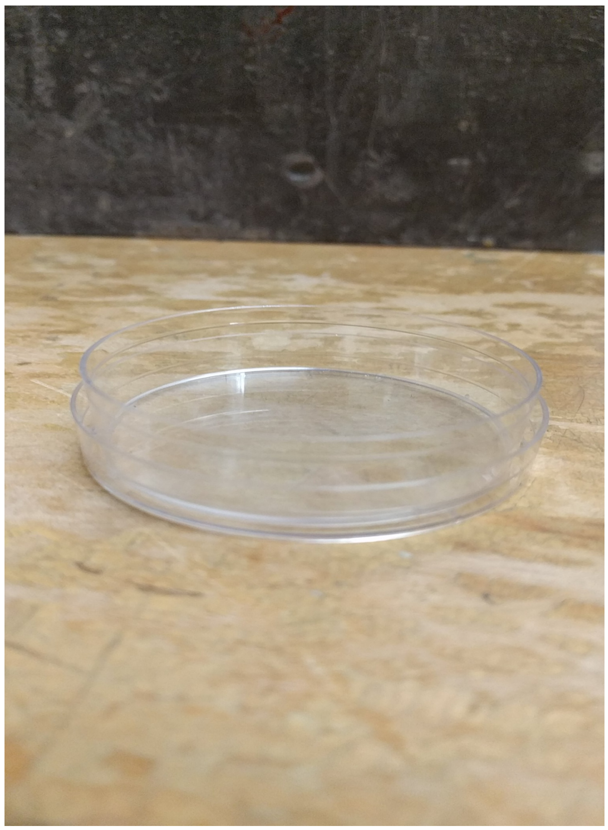

Figure 10: Example of the petri dish used during analyzing – (Trottier, 2018)

3. 3 Instrumentation and Measurements

There were two different scintillation detectors that were used in the acquisition of the data: the Canberra Lynx NaI and the Canberra Osprey (Trottier, 2018). Scintillation detectors are typically sensitive to one type of radiation. The sodium iodide detectors (the detectors that were used) pick up gamma rays and not alpha or beta radiation (Zoomie, 2015). With the detector we can find out which radionuclides are active in the samples that were tested, which in our case we were interested in finding Cs-137 activity. The instrument finds these values by measuring the energy of the gamma that is released and captured by the NaI crystal (Zoomie, 2015). The process of capturing these energies is either called the gamma spectroscopy or multi-channel analyzer (MCA) (Zoomie, 2015).

In order for us to find the Cs-137 peak we first had to calibrate the detector software by using a small Cs-137 sample that was available in the laboratory where the tests were conducted (Trottier, 2018). And after the system is calibrated then we can properly identify the gamma energies released from the samples. In our data we specifically were expecting. in our gamma ray spectrum, for a peak at around 662 keV, since that is the gamma energy Cs-137 releases (Zoomie, 2015).

Figure 11: Canberra Osprey Detector – (Hofstra Group, n.d.)

Figure 12: Lead Shield of Canberra Lynx NaI Detector – (Canberra, n.d.)

Chapter 4: Results and Discussion

4.1 Results

4.1.1 Activity found from Hair

As previously stated, there were a considerable amount of hair samples that were brought back from Chernobyl. In the beginning, we hypothesized that there would be very little Cs-137 gamma energies emitted from the samples. Therefore, we did not expect to find anything significant from the data acquisition. This was most likely because the dogs prior to their surgeries were washed and then shaved, and this may have altered the results because any radiated components that may have been in the hair may have washed away (M. Kaltofen, personal communication, August 16, 2017). Thus making the samples that we were given a poor representation of the living conditions that the dogs live in. Overall, there were no measurable activities attained from the hair sample analysis (Trottier, 2018) (refer to Appendix C).

4.1.2 Activity found from Feces

The Feces, on the other hand, did have some activity unlike the hair samples. What we attained from the fecal samples is that even though we did get some activity it was not that significant. We hypothesized that the fecal samples would show greater activity than the hair sample, however the magnitude of that activity was not clear to us in our initial hypothesis. The results show that most of the fecal samples had activity of less than 1 Bq/g (remember that one Bq is equal to one decay per second) (Trottier, 2018). However samples numbered 4 and 5 had activity that was greater than 1 Bq/g (Trottier, 2018).

Table 1: Fecal samples acquired peak data with counts accounted for geometry – (retrieved from Trottier, 2018)

Samples	Mass [g]	Peak [keV]	FWHM [keV]	CPS	CPS/g
1	2.6	654.39	630.4	0.5381	0.152
2	3.85	658.39	46.03	1.693	0.450
3	5.65	658.39	46.03	6.168	1.12
4	10.2	655.39	45.02	30.44	3.03
5	9.97	654.39	45.02	55.98	5.71
6	5.01	653.39	624.4	0.7122	0.16
7	3.02	654.39	623.4	0.2933	0.08
9	5.12	652.39	44.02	3.121	0.63

4.2 Discussion

4.2.1 The effects of Radiation in Fecal Data

It is pretty likely that the results of the fecal scans were due to what the dogs were consuming in their environment (not the food they get from the workers). The dogs were definitely consuming some sort of vegetation since in some of their fecal samples because there was undigested plant matter in them. The plants that they have digested most likely were contaminated with radionuclides such as Cesium-137. Thanks to the vertical migration of these radionuclides (as discussed before) the soil gets contaminated which in the process contaminates the plants that rely on that soil. The radionuclides further traveled down the soil matrix even more due to rainwater (Smith, 2005). However as radiocesium concentrations start depleting then the bioavailability of the soil will also go down at the same rate resulting in vegetation that has lower levels of radiation (Smith, 2005).

4.2.2 Determining the Diet for the Dogs

In general dogs have the capability of consuming both meat and plant matter; however if the balance between these two foodstuffs are not appropriate then it can cause diet-induced disorders in dogs (Baldwin et al., 2010). This is a concern towards the dogs that live in the exclusion zone.

In order to properly know the diet that should be placed to feed the population dogs we have to come up with the average body condition score (BCS –evaluation of canine body fat) and the average muscle condition score (MCS – evaluation of canine muscle mass) of the dogs in the exclusion zone. If we want to further tailor the diet we should get the average scores of the dogs under one year of age, the average scores of the dogs between 1 and 7 years of age, and the average scores of the dogs over 7 years of age. The overall preferred BCS for dogs is around a 4.5 in the 9–point scale (refer to Appendix A). This means that the dogs should have a healthy enough diet where the ribs are palpable and when the pelvic bones and ribs are not excessively prominent. In testing for muscle mass, a scale like the one for the BCS is not currently available, however in order to have a better understanding of the severity of muscle loss one has to palpitate the bony areas of the dog (i.e. pelvic region) in order to get an approximate measurement of severity (Baldwin et al., 2010). By palpitating the pelvic region one is getting a rough estimate of how much muscle has been decayed. The more the muscles has decayed the more one can feel the bone but the more healthy the dogs is then the muscle serves as a wedge between the skin, fat, and bone (refer to Appendix B). If there is a cause of concern in these areas then a diet plan should be implemented for the dogs.

Chapter 6: Recommendations

6.1 Improved Diet for the Dogs

6.1.1 Nutritional Need of Dogs

An appropriate diet for the dogs can further speed up the process of diminishing the internal radiation dosage that was analyzed in the fecal samples. The recommended intake of nutrients for adult dogs are around 30 – 70 percent carbohydrates, 18 – 25 percent protein, and 10 – 15 percent fat (PetMD, n.d.). Although these percentages are for adult dogs mainly, it should still be effective towards all other age groups. Therefore, a diet for an average adult dog should be relatively fine for the whole population. By supplying uncontaminated food we can take away one of the sources of radiation that affects the dogs. It would also help in maintaining a healthy weight.

6.1.2 Comparison of on the Shelf Dog Foods

Dog food companies need to follow the basic guidelines of nutrition in order to be served to dogs. They need to contain all the nutritional needs that a dog needs in order to survive (Baldwin et al., 2010). However, reaching a basic guideline does not mean that it is the best form of nutrition. Many dog food brands (especially the cheaper kind) are substituted with a lot of fillers that are composed of mostly carbs (Dog Food Guide, 2018). As mentioned earlier, the recommended intake percentages of carbohydrates are around 30-70%; however, these brands are composing their dog food with carbohydrates in the higher percentage. Therefore it is preferred that the dog food that should be fed to the dogs at Chernobyl are evenly balanced with carbohydrates in the lower percentage, and with a higher percentage of protein and fat. One way to determine if a dog food is more meat based is by looking at the first ingredient on the ingredient list. If the first ingredient is meat then that brand is much preferred unlike a brand that has grain as the first ingredient. Another factor that one wants to keep an eye out is if the dog food includes vegetables or fruits. This is because (as mentioned before) dogs can be omnivorous creatures, and by including fruits and vegetables one is introducing more ways where vitamins can be incorporated into their diet. Fillers should be taken into account too, because the only purpose of fillers is to add more "bulk" into the diet and they are mostly non-nutritious. Therefore they are essentially taken up space where more vitamins and nutritional components could have been used. The pricing is also a main factor for choosing which dog food brand to choose since Clean Future Funds is mostly running through donations, and are distributing those donations towards things as well like vet care and vaccines.

Table 2: Comparison of On the Counter Dry Food – (data retrieved from PetMed)

Dog Food Brands*	Meat First Ingredient	Contains Vegatable or Fruit	Free of Fillers	All Natural	Price [USD]
Purina	✖	✖	✖	✖	~$1.17 / lb
Blue Buffalo	✓	✓	✓	✓	~$1.57 / lb
Iams	✓	✖	✖	✓	~$1.03/ lb
Merrick	✓	✓	✓	✓	~$2.00 / lb
Holistic	✖	✓	✖	✓	~$1.93 / lb
Eukanuba	✓	✖	✖	✓	~$1.30 / lb
Dick Van Patten's	✓	✓	✖	✓	~$1.73/ lb

* Dog food brands chosen especially made for adult dogs of all breeds and sizes

As seen by Table 2 the dog food brands with the best qualities were down to Blue Buffalo and Merrick. Blue Buffalo is around .50 cents cheaper per pound compared to Merrick therefore it would be the best dog food for the dogs. The worst dog food from the dog brands that were compared was Purina. Purina (although cheap) would not be the best form of nutrition due its high carb percentage.

6.2 Incorporation of Prussian blue

6.2.1 Prussian blue in Humans

In humans, one of the main ways of accelerating the biological half-life of cesium is to administer Prussian blue orally. Prussian blue is a crystal lattice that exchanges the cesium that is inside the body with potassium (Thompson & Church, 2001). It does this by binding to the cesium that is inside the body in the inside of the intestines; it aids and flushes out the radiocesium until it is excreted through the person's excrements (Thompson & Church, 2001). This study has been conducted on both human adults and children. The findings show that Prussian blue is an effective way of reducing the biological half-life by 43% (Thompson & Church, 2001).

Prussian blue works rather well with people and increasing the amount does not make the treatment more effective than the minimum amount (which is 3g per day for humans). Although effective in cutting down biological half-life, Prussian blue can be detrimental to a person's health if they are constipated. This is because during constipation the contaminated feces have more time to interact with the intestines and can be potentially more detrimental to their health (Thompson & Church, 2001).

6.2.2 Prussian blue in Dogs

Melo et al., conducted experiments on multiple beagle dogs on the effectiveness of Prussian blue. In their study, they separated dogs by age groups: puppies, adult dogs, and senior dogs. Water was given to the dogs with Prussian blue dissolved in it with a concentration of 2.5 grams per liter. The dogs were allowed to drink the water whenever they want (Melo et al., 1998). The end result was that the biological half-life of radiocesium of the younger dogs was cut down by 45%, for adult dogs it was cut down by 63%, while for senior dogs it was cut down by 45% (Melo et al., 1998). Therefore it seems that Prussian blue is as effective as it was for humans. Due to these findings I would recommend including Prussian blue alongside the dogs improved diet with some minor adjustments.

6.2.3 Incorporation of Prussian blue in Diet

One way Prussian blue can be incorporated into the diet of the dogs is to give them water treated with Prussian blue. By following the study from Melo et al. the water should have a concentration of 2.5 grams per liter. The water would be preferred to be under a type of shading on one of the outside facilities in order for the rain to not dilute the concentration of Prussian blue in the water. The water should be placed in the side of a local facility with a low trough in order for most dogs can reach the water supply. Hopefully by doing so the activity found in the dogs feces will dwindle down much quicker than it would without the assistance of Prussian blue.

Chapter 7: Conclusion

The goal of this project was to come up with an improved diet for the dogs at Chernobyl. In the project a team conducted experiments and analyzed the fecal and hair samples of dogs that resided around the Exclusion zone. With the results we were then able to conclude that there was some internal radiation in the dogs, which may have been a result of the vegetation that the dogs consumed. The results of the hair samples however did not provide any valuable input to the condition of the dogs due to them being washed beforehand.

The recommended diet for the dogs that was determined was to feed the dogs a dry kibble diet of Blue Buffalo as their main food source. As well as to leave a trough of water that they can readily reach. The water was recommended to have a concentration of 2.5 grams of Prussian blue per liters. The Prussian blue would help in accelerating the recovery of the dogs by cutting down the biological half-life of radiocesium in their system by at least 45%. The project did have its limitations because of the issues that arose when collecting the fecal samples. In the future due to the knowledge of what the tranquilizer does to the dogs we should try collecting fecal samples a few more weeks or months in advance in order for their to be a substantial amount of fecal samples to analyze. Thus perhaps resulting in a study with results that are more conclusive.

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Appendix A – Body Condition System

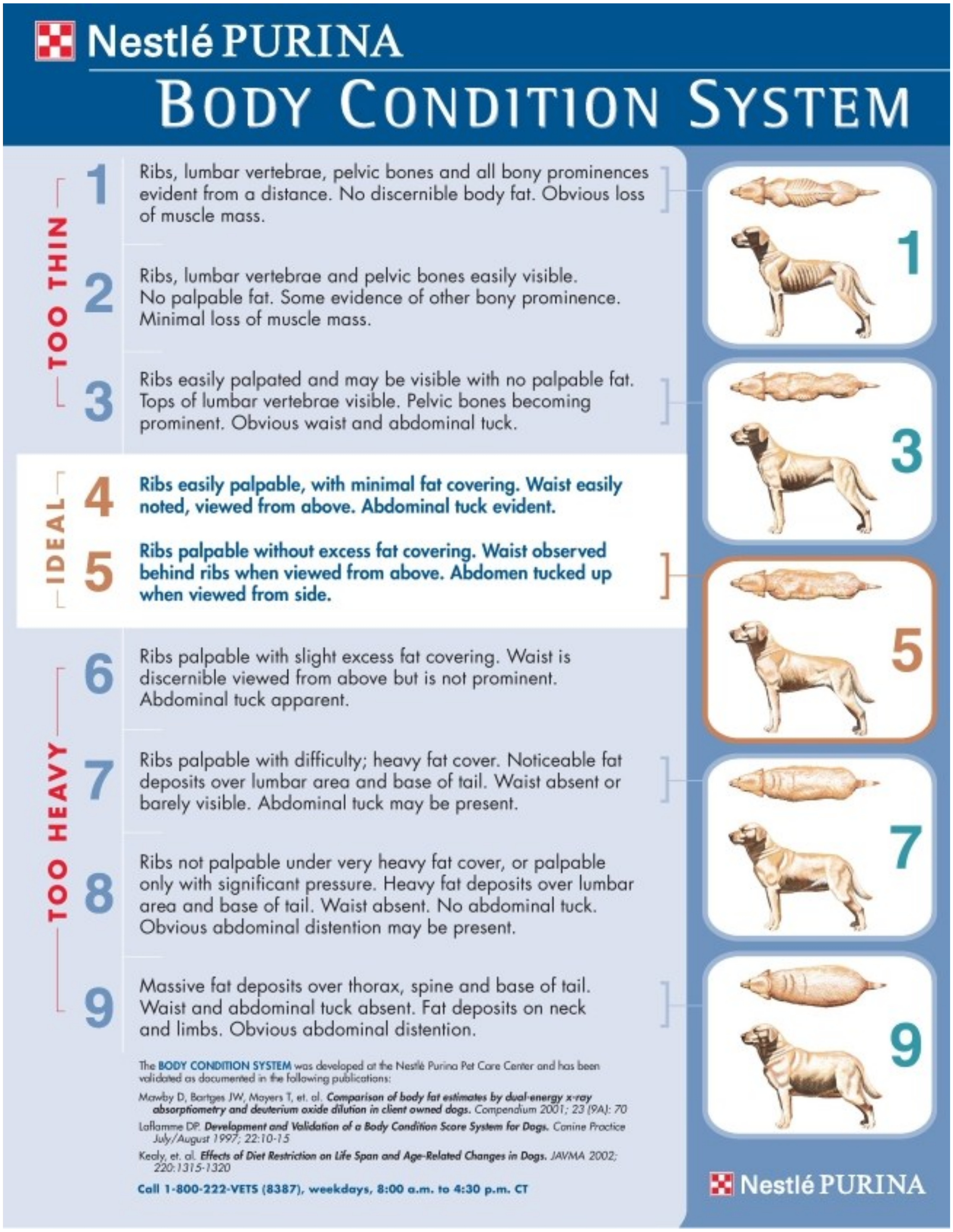


Figure 13: Body condition system chart to determine the BCS score of dogs – (Nestle Purina, 2012)

Appendix B – Muscle Condition System

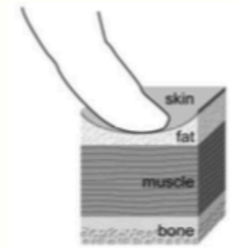
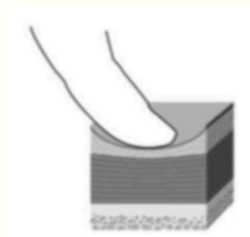
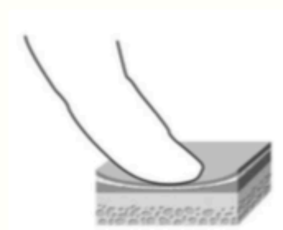
Description	Figure
No muscle wasting, normal muscle mass	
Mild muscle wasting	
Moderate muscle wasting	
Marked muscle wasting	

Figure 14: Recommended way to test for MCS – (Baldwin et al., 2010)

Appendix C – Hair Sample Scan Data Table

Table 3: Hair Sample Acquired Scan Data – (retrieved from Trottier, 2018)

Sample	Pre Cal	Post Cal	Drift %	Empty Mass	Full Mass	Mass
Y001	662	660.54	0.22	7.54	9.08	1.54
Y002	662.18	663.72	0.23	7.74	8.46	0.72
Y003	661.99	664.24	0.34	7.63	8.61	0.98
Y004	662.07	663.4	0.20	7.84	8.85	1.01
Y005	661.9	662.12	0.03	7.54	9.04	1.5
Y006	662	660.5	0.23	7.51	8.67	1.16
Y007	661.82	660.28	0.23	7.54	8.89	1.35
Y008	662.09	664.68	0.39	7.79	9.12	1.33
Y009	662	664.97	0.45	7.63	9.34	1.71
Y010	661.72	664.21	0.38	7.57	8.36	0.79
Y011	661.96	664.68	0.41	7.57	8.76	1.19
Y012	661.98	657.28	0.71	7.9	9.07	1.17
Y013	662.01	658.21	0.57	7.89	9.32	1.43
Y014	662.09	659.96	0.32	7.82	9.12	1.3
Y015	662	661.72	0.04	7.58	8.99	1.41
Y016	662.03	664.23	0.33	7.58	8.84	1.29
Y017	661.8	662.49	0.10	7.55	8.75	1.2
Y018	661.9	665.6	0.56	7.6	8.68	1.08
Y019	662.03	662.27	0.04	7.7	8.81	1.11
Y020	661.92	658.7	0.49	7.6	8.78	1.18
Y021	662	660.29	0.26	7.61	8.51	0.9
Y022	661.98	658.21	0.57	7.55	8.75	1.2
Y023	662.04	663.65	0.24	7.7	9.02	1.32
Back-T-24	662.07	666.52	0.67	0	0	0
Back-23-24	662	659	0.45	0	0	0
Back-T-48	662.08	656	0.92	0	0	0
Back-23-48	661.9	660.5	0.21	0	0	0
O-35	661.93	662.96	0.16	7.59	7.84	0.25
O-36	661.96	662.8	0.13	7.74	7.89	0.15
O-37	661.92	660.42	0.23	7.55	8.45	0.9
O-38	661.82	662.4	0.09	7.79	7.91	0.12
O-39	662.05	660.63	0.21	7.57	7.92	0.35
O-40	661.97	659	0.45	5.81	5.86	0.05
O-42	661.95	659.04	0.44	5.9	6.05	0.15
O-44	662.15	657	0.78	5.89	6.03	0.14
O-45	661.98	662.1	0.02	5.96	7.03	1.07
O-46	662.12	667	0.74	5.86	6.51	0.65
O-47	662.06	665.2	0.47	5.86	6.14	0.28
O-48	661.9	667	0.77	6	7.02	1.02
O-49	662.1	666	0.59	5.81	6.16	0.35
O-50	661.9	659	0.44	5.89	7.49	1.6