Exubrion Therapeutics

Evaluation of potential dose to members of the public from treatment of dogs with Synovetin OA® containing Sn-117m

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Introduction

Synovetin OA is a colloid containing Sn-117m that can be used to treat osteoarthritic dog elbows. One of the concerns with this treatment is ensuring that dose limits for members of the public will be met. Exubrion Therapeutics, the makers of Synovetin OA, wishes to develop generic release criteria acceptable to the NRC such that individual NRC or Agreement State licensees could successfully submit radioactive materials license applications or amendments using those release criteria. This evaluation analyzes osteoarthritic dog behaviors and establishes the release criteria which may be used to release dogs treated with Synovetin OA in accordance with the dose limits for members of the public.

Canine Osteoarthritis

Radiosynoviorthesis (RSO) to treat chronic pain and inflammation of osteoarthritis (OA) in dogs has been deployed in animal health due to the lack of treatments which veterinarians can turn to in cases where the primary and secondary line of treatments are found to be inadequate. As in human medicine, veterinary practitioners initially treat OA or arthritic pain with prescription non-steroidal anti-inflammatory drugs (NSAIDs), all of which have been developed to address acute pain (Fox 2017). If those drugs fail, veterinary practitioners very often use prescription opioids with their inherent difficulties for both the dog and the caretaker. These therapies are generally easy to use (e.g. oral daily medicines or periodic injections) and dispensed or administered by the general practitioner. If those options fail, dog caretakers faced with treatment failure are left to try various unproven oral nutraceutical and invasive cell therapies, many times with limited success. Ultimately, these dogs are referred to specialists (typically orthopedic surgeons) for treatment of pain associated with OA when these initial type of treatments are found to be inadequate especially when the arthritic pain becomes chronic (Appendix A). These are the more severe cases which includes those dogs that are suffering from OA secondary to elbow dysplasia.

The population of dogs most often affected with OA tend to be large and giant breed dogs such as Labrador retrievers, golden retrievers, bulldogs, St. Bernards, German Shepherds, Bernese mountain dogs, chow chows, bearded collies, boxers, mastiffs, Rottweilers, American Staffordshire terriers and Newfoundland dogs (Racine 2019). In Exubrion Therapeutic's studies in which 92 elbows were treated in 69 dogs selected because they were affected by naturally occurring OA of the elbow, the average weight of the affected dogs was 67.5 lbs. In a recently published peer reviewed journal article, dogs greater than 77 lbs. had a higher OA score indicating more severe OA than those less than 77 lbs. (Gilbert 2019). There is a correlation between size and activity levels of these large breed dogs.

Treatment of Canine Osteoarthritis with Sn117-m

RSO using the Sn-117m colloid targets pro-inflammatory macrophages which engulf the micro particle colloid and causes apoptosis (slow, non-inflammatory death) of the macrophage. Research has shown that different pain receptors are involved with chronic pain associated with OA (Perretti 2017). By targeting the macrophage, multiple inflammatory and pro-inflammatory enzymatic cascades are affected rather than one or two enzymatic pathways as is the case with NSAIDs (Kraus 2016). In short, RSO with Sn-117m colloid provides a broader based approach to reducing inflammation within the affected joint in which the less expensive, easier to administer but more specific enzymatic targeting drugs have proven to be inadequate.

Dosage of Synovetin OA is proportional to dog weight with up to 3 mCi being injected in each joint for the largest dogs. Over 99% of the injected Sn-117m colloid remains within the treated joint (Lattimer et al 2019). Therefore, the biological half-life is not relevant and excretion of the Sn-117m is not a concern. Approximately half the decay energy of the Sn-117m is released by internal conversion electrons with a relatively short range and the remainder is released by gamma rays and X-rays. The predominant gamma ray energy is 158.56 keV.

The presenting signs for OA are exhibited in a variety of ways, including reluctance to exercise, exercise intolerance, inactivity stiffness, lameness, inability to jump (up and down), muscle atrophy, joint swelling, capsular and extracapsular fibrosis, joint effusion, reduced range of motion, crepitus, pain on joint manipulation, and behavioral changes such as aggression (Fox 2017). Signs vary from very mild and intermittent to severe and persistent. External factors such as the amount of exercise performed and the weather may influence the severity of signs that the owner reports. The tendency for most patients is for clinical signs to gradually worsen, although this can occur at a variable rate with interposing periods of remission and flares of disease (Innes 2018).

Dogs to be treated by RSO will be those dogs which are refractive to primary and secondary treatments in the elbow. The 'poster child' for OA in dogs is the middle-aged to older (>4 years), large breed (>50 lb. [22.5 kg]) dog that is overweight to obese. Veterinary instructions for caring for dogs with severe OA include: "Be sure the dog is able to stand on a non-skid surface while eating and drinking. Have the client explore the home for potential 'problem spots.' Steps in and out of house, patio stones, and garage floors can create unintentional challenges for the painful dog. Ramps are recommended for getting into and out of vehicles." (Fox 2017).

This population of lame dogs are reluctant to jump on furniture to sit in a caretaker's lap or to jump up to sleep on an elevated bed.[1] Initially following RSO treatment, it is expected the patient will have a continuing level of pain and lameness until the inflammation of the synovial lining is sufficiently reduced which can take weeks. This initial continuing pain post treatment will continue to limit the patient from jumping on beds and furniture. In 3 studies treating naturally occurring OA subsequent to elbow dysplasia with RSO of the label dose of the Sn-

1 Dr. Steven Fox clinical observations, June, 2019.

117m colloid, the patients showed a gradual improvement of lameness with the caregivers reporting that it took a few weeks to notice an improvement in mobility.

Compliance with Public Dose Limits

There are three criteria that must be met for release of a dog.

- 10 CFR 20.1301(a)(1): The dose to a member of the public shall not exceed 100 mrem in a year.
- 10 CFR 20.1301(a)(2): The dose to a member of the public shall not exceed 2 mrem in any one hour.
- The dog should not create a radiation area, i.e., a dose rate ≥5 mrem in one hour at 30 cm. This is not an actual regulatory requirement but does eliminate the need to comply with posting requirements.

In order to comply with these public dose limits, the use of Sn-117m is governed by three layers of controls:

1. Identify the common human-dog interactions that could potentially cause a person to exceed the public dose limit. As the following analysis shows, the normal interactions people have with most dogs (particularly most severely arthritic dogs) would not cause those people to approach the public dose limit. Therefore, changes in behavior are not required for most dogs. Nevertheless, the following two controls are applied in all cases.
2. Specify those behaviors that could create a risk of excess exposure to a member of the public. Pre-screen all potential patients for those behaviors and determine whether the caregivers can modify those behaviors for the prescribed period of time. If they cannot, the patient will not be offered treatment with Sn-117m.
3. To create an additional margin of safety and to remind the caregivers of any restrictions, caregivers will be given a set of release instructions and asked to sign them immediately prior to treatment to confirm their intent and ability to comply.

The third criteria is met by setting the maximum exposure rate at which a dog may be released at 0.45 mrem/hr. By the inverse square law, this results in a dose rate at a distance of 30 cm that does not exceed 5 mrem/hr and thus does not create a radiation area.

Occupancy factors and human-dog interactions

This evaluation analyzes human-dog interactions and specifically the common behaviors and the times and distances involved. The following analysis is based on: the published literature, interactions with the 69 severely arthritic dogs and their pet owners involved in Exubrion's three studies, discussions with dozens of practicing veterinarians who see arthritic dogs on a daily basis, and countless pet owners (including focus groups conducted to assess pet-pet owner

interactions). In reviewing this material, there are two important distinctions to point out (particularly relevant to the precedent case in cats):

1. The size and weight range of dogs is far greater than cats. As previously noted, size is a major determinant in behavior patterns (what pet owners will do with a 15 lb. dachshund is substantially different from what they will do with a 75 lb. golden retriever).
2. While the literature and most people's perspectives of dog behavior is generally based on healthy dogs, this product is for severely arthritic dogs. That arthritis affects the dog's ability to move and willingness to interact in general.

In this section, we will identify the common groups of behaviors (including times and distances) and will use those in a subsequent section to assess the public dose that would result.

The most comprehensive study of dog-human interactions found was a study by Westgarth (2008). This study found that 83% of large/giant dogs rarely or never lie on a person's lap compared to only 29% for toy/small dogs and 49% for medium-sized dogs and that younger dogs are more likely to exhibit these behaviors than older dogs. 68%, 49%, and 29% of large, medium, and small dogs respectively rarely or never lie on furniture. An important consideration is that these behaviors are for healthy dogs. A dog with osteoarthritis has difficulty with physical activity, like running and especially the jumping which would be required to get onto a person's lap or furniture. Since osteoarthritis is a condition which impacts predominantly older dogs, it can be safely assumed that these dogs are even less likely to lie on a person's lap or on furniture.

This same study found that only 14% of dogs sleep on a human bed. This percentage applied to all dogs in the study and was not broken down by dog size. It is reasonable to assume that, as with the statistics regarding lying on a person's lap or on the furniture, smaller dogs are more likely to sleep on the owner's bed than larger dogs so only some percentage less than 14% of large dogs sleep on their owner's bed.[2] Once again, this percentage applies to healthy dogs. An osteoarthritic dog (also older by definition since the disease develops slowly over time) would have significant trouble jumping up onto an owner's bed and would be even less likely to co-sleep with its owner.

Typical human-dog interactions can be roughly broken down into three groups: standing, sitting, and co-sleeping. Of importance when considering interactions is both the activity and the distance involved.

In the reviewer notes for the December 21, 2001 response to the May 18, 2001 technical assistance request for release criteria for cats treated with radioactive iodine, the NRC states "The distances provided are put into perspective by relating them to distances from the highest activity measured from the cat to the center of the area of the person that NRC defines as the 'whole body'" (NRC 2001) The center of the torso is the center of the area of the person that NRC defines as the "whole body." This concept is further expanded in NRC Regulatory Guide 8.40 (NRC 2010) and used in this evaluation.

2 "Owner" is taken to be any person living in the same household with the dog.

Standing

"Standing" would apply to most waking activities in relatively close proximity to the dog other than a dog next to a seated owner. The most common standing interactions would be feeding, walking, and petting.

When feeding a dog, the amount of time in close proximity to the dog is quite limited. A typical interaction would be a dog expectantly waiting for its food in somewhat close proximity to its owner's legs while its food dish is filled. However, once the dish is filled and the dog begins eating, the distance between the dog and owner is much greater since the owner does not hover over the dog as it eats. The majority of time during this activity is at a distance of approximately 3 feet or more with only a minor portion, much less than a minute, at a distance of 1 foot and the entire process occupies only a couple minutes.

Walking a dog is another activity where the majority of the activity is conducted at a distance of 3 feet or more. With the potential exception of very well-trained dogs that heel well, a typical dog will be walked with the dog at or near the extent of the leash. With a common minimum leash length of 3-4 feet, the length of an owner's arm, and taking consideration of the height difference between the dog's neck and leg joint, 3 feet is a reasonable minimum distance from a treated joint to a person's torso with greater distances more common. Figure 1 shows a large dog (107 lb) being walked by a small adult (4 ft 11 in tall). Scaling from the yardstick included in the photo, the distance from the dog's elbow to the center of the person's torso is approximately 5 ft.

Figure 1. Large dog being walked by small adult.

Westgarth's results indicate only 19 % of large dogs are walked 3 or more times per day and that the average walk duration is 16 minutes to one hour long, with smaller dogs less likely to be walked 3 or more times per day and younger dogs more likely to be walked longer. This is another activity where an osteoarthritic dog is much less likely to participate, leading to less and shorter walks for such a dog. Therefore, on-leash dog walking is assumed to be performed twice a day for no more than 30 minutes each time, or one hour per day as a reasonably conservative estimate.

Petting and the desire to be petted is the last of the "standing" activities. Petting is an activity that consists of hands-on contact with the dog. Additionally, the posture of the human is more likely to result in close contact with the dog, i.e., kneeling, sitting, bending over, etc. For this activity, an assumed distance of 1 foot is appropriate. The actual distance is likely to be longer given that the majority of petting is on the dog's torso or head and the geometry considerations with regard to dog joint proximity to the person's torso. However, 3 feet is likely not conservative. Figure 2 shows a typical posture for a person petting a dog.

Figure 2. Dog petting.

Figure 3 shows a worst-case scenario of a person sitting on the floor being affectionate with a dog. Even in this position, there is still a distance of more than a foot from the dog's elbow to the person's torso. More common would be a person standing or seated in a chair with a commensurately greater distance.

Figure 3. Dog petting.

While petting can be a frequent activity with dogs, each petting session typically does not last very long. Discussions with a focus group of dog owners indicated that a typical petting session would last 15-20 seconds and focus primarily on the dog's head. On a day with a lot of petting, there might be 8 to 10 such petting sessions, with fewer on other days, such as when at work or if the dog is outside often. This indicates petting commonly occupies up to 200 seconds, or 3.33 minutes per day. To be conservative, this is rounded to 5 minutes. Additionally, most petting, being petting on the head, would result in a human torso-dog joint distance of more than a foot, but less than 3 feet. While 2 feet is a reasonable estimate for the typical distance, it is conservatively assumed that the distance might be as little as 1 foot.

Sitting

The primary sitting interactions with a dog that are not already addressed above would be situations where a dog rests at its owner's feet or by the side of the owner's chair and dogs that sit in their owner's lap. For people that do not work from home, the opportunity for this behavior is limited to a couple hours in the evening each day. Stay-at-home parents are generally active and moving about during the day, making this estimate reasonable for them as well. An estimate of 3 hours per day would encompass the majority of the time after dinner and

before bedtime and would apply to either a dog resting by its owner's feet or sitting in its owner's lap. It is assumed that a given dog exhibits either one behavior or the other.

Due to the geometry considerations discussed in part above, a distance of 1 foot from a dog's leg joint to the human torso center of mass is appropriate for lap sitting. When in a person's lap, the dog's legs are separated from the person's torso by the dog's torso which also functions as a radiation shield since the dog's legs will be under it or stretched out away from the person's torso.

The maximally exposed part of the body for long duration close contact, as with lap-sitting, is not the center of the torso but rather the upper leg. NRC Regulatory Guide 8.40 Table 1 assigns each upper leg a weighting factor of 0.005 for external dose. Even for an anatomic region as small as the thigh, the dose rates are highly non-uniform when close to what is effectively a point source. The dose to the skin closest to the dog's elbow is not the dose to the anatomic region of the thigh. The average dose to the entire anatomic region of the upper leg is much lower. Given that the torso accounts for 88% of the total weighting factor, and a further 10% is on the head, use of the center of the torso is a reasonable means of estimating the average dose to an individual. Further calculations with regard to geometry are detailed below.

While the dog is resting at its owners feet or by the owner's chair, it will normally be lying down, either on its side or in a prone position. In either case, the dog's leg joints are effectively at floor height. In the case of a prone position, they are located underneath the dog, attenuating any radiation emitted towards the person. A standard chair seat has a height of 18 inches, limiting the lower extent of a person's torso to that height. The center of the torso would be some distance higher with an additional foot being conservative for the average adult (ICRP 2001). Coupled with the lateral offset of the dog (i.e., not under the chair), a distance of 3 feet from a dog's leg joints to the midpoint of a seated person's torso is a reasonable estimate. Figures 4 and 5 show typical positions.

Figure 4. Dog at feet.

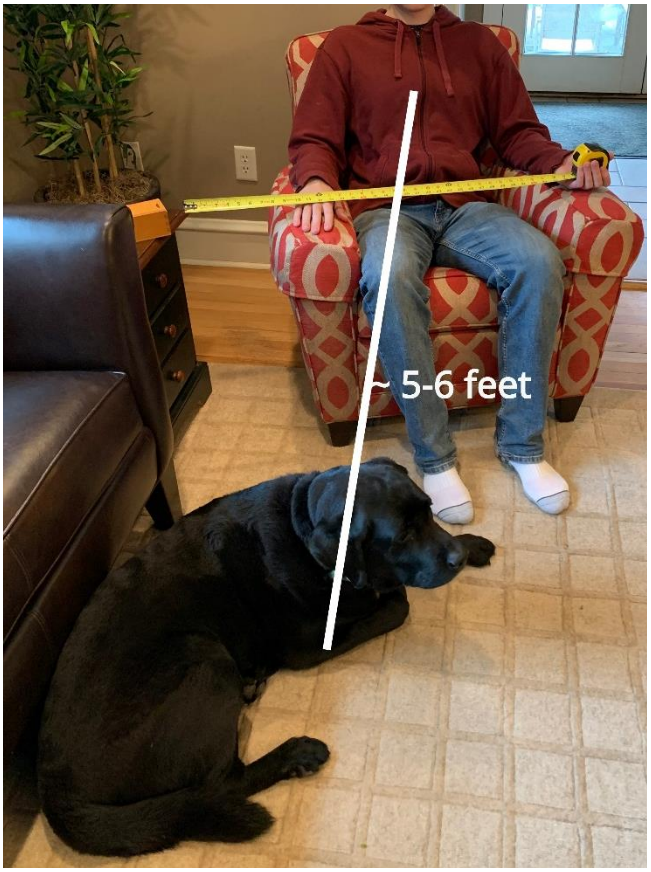

Figure 5. Dog near feet.

For those individuals that work from home or are otherwise relatively sedentary, such as the elderly, an additional 8 hours of time sitting with a dog at their feet or by the side of their chair may occur and is generically referring to as “officing.” This situation would only apply to those instances where the dog is close to them, i.e., at their feet or beside their chair; in many such instances, the dog is simply content to be in the room and may be some larger distance away, especially if a dog bed is present further removed from the person.

Co-Sleeping

Co-sleeping, defined as a dog that sleeps on its owner’s bed, is the single behavior with the greatest likelihood of contributing the most dose to a person due to the distance and length of time involved. For this reason, this behavior cannot be allowed, especially during the weeks immediately after treatment. As discussed above, a larger, older, osteoarthritic dog is highly unlikely to co-sleep not only because this behavior is not common among larger dogs, but also because an osteoarthritic dog for which other more common therapies have failed would not be capable of jumping up onto the owner’s bed unaided. Therefore, instructions that forbid this behavior are reinforcing existing behavior patterns rather than attempting to contradict natural tendencies. In the event that co-sleeping did occur, human and dog sleeping would

conservatively be about 8 hours per day based on Patel's (2017) observations of human and dog times in bed and sleep efficiencies.

Distances less than 1 foot
Some dogs are routinely carried by their owner as a therapy dog or a canine "security blanket." Common breeds for this are Chihuahua, Pomeranian, and Toy Poodles among others. All of these dogs weigh 3-7 lbs (AKC 2020a,b,c)and thus why they are light enough to routinely carry. The lower weight limit for a dog to be a candidate for Synovetin OA is 10 lbs. Therefore, this behavior is excluded from consideration.

Previous NRC evaluations of human-feline interactions focused on distances of 3 inches, 6 inches, 1 foot, and 3 feet (1 meter) and implicitly indicated that distances greater than 3 feet were not of importance, a conclusion with which we agree (NRC 2001). A distance of 3 inches was especially discussed with regard to lapcats. While a cat's thyroid may be near the torso, a dog's leg joint will be further away even when in a person's lap. This is especially true when considering the center of the torso rather than the closest portion of the torso as discussed in NRC 2003. For dogs, most of whom are substantially larger than the average cat, this distance is not applicable. Additionally, in most postures of lap-sitting, such as shown in Figure 6, the dog's body will serve as a shield for most of the human torso for radiation coming from the dog's legs or the dog would be in such a position that the average distance would be a foot or more, i.e. stretched out perpendicular to the human's legs or with the dog's legs pointed towards the human's knees.

Figure 6. Dog in lap.

There is an important anatomic distinction between radiation from a cat's thyroid and radiation from a dog's leg joint. Importantly, the distance from a person's torso to a dog's leg joint is not the same as the distance from any part of the person to any part of the dog. When we think of

the distance between a person and a dog, we commonly imagine the shortest distance involved, which would be the distance between the dog's head and the person's arm or hand. However, this is not appropriate for this evaluation. Even for a child or small adult, the distance from the human torso to the dog's leg joint can easily be a foot or more greater than the distance from the human's hand to the dog's head, especially when considering the center of mass of the human torso rather than the lower portion of the human's torso. Additive to this distance difference is the fact that the dog's leg joints are at the lower extent of the dog's torso, also increasing the distance to the human's torso. On top of these distance considerations is the fact that the closer a person is to a dog, the more the dog's torso functions as a radiation shield in that the radiation would be directed more vertically through the dog's torso to reach the person's torso, further reducing the net dose rate to the torso. Given these considerations, distances of 6 inches are not reasonable, and therefore radiation dose rates at 6 inches are not a consideration for lap-sitting.

The other scenario when a dog may be in close proximity to a human torso is the situation where the dog requires assistance such as in getting into and out of a vehicle, standing up on slick surfaces, or negotiating steps. Arthritic dogs are especially reluctant to jump up. For a large dog ($\geq$ 110 lbs.) receiving the maximum Synovetin OA amount in both elbows that needs assistance to be placed into a car, there are commonly used methods (an assist by pushing on the rump of a dog, two towels encircling the chest and in front of the hips or a cart with the dog on a blanket can be used to transfer the dog to the car, or a portable ramp). These solutions present minimal if any exposure for a caretaker due to the short duration of the assistance and allow some separation to remain between the dog's elbows and the person's torso. Unlike post-surgical dogs, jumping out of a car is not as difficult nor discouraged for an arthritic dog post Synovetin OA treatment. Some of these same arthritic dogs when arriving home jump out of a car due to their excitement of returning home.

The videos contained in Appendix B demonstrate the actions a person would need to take a transfer dogs of different sizes into a vehicle. As can be seen, the duration of each of these activities is very short, on the order of a few seconds of direct contact with the dog. The methods listed in the previous paragraph would tend to result in distances on the order of 1 foot while the closer distances shown in the videos are for a quite short duration. The length of time the smaller dog is held in the first video is for less than 10 seconds while the duration of contact assistance for the larger dog in the second video is also for less than 10 seconds. While the total duration of the "get dog into vehicle" activity may be substantially longer, the duration of actual contact is quite short. For calculation purposes, this is rounded up to 1 minute to account for multiple times the dog may need to be lifted in a single day during the duration of written instructions. In order to bound behaviors that may occur after expiration of the written instructions, a conservative estimate of no more than 5 minutes of contact per day is used.

<u>Occupancy Factors and Distances Summary</u>

Typical dog-human interactions are summarized in the table below. The preceding analysis shows that less than 6 minutes at 1 foot is common. However, the calculations and instructions here allow for up to 15 minutes per day at one foot. Among other things, that allows for small

periods of time at closer distances to help the dog into cars, up stairs, etc. for totals of 5 minutes per day on contact, 15 minutes per day at 1 foot, and 4 hours per day at 3 feet not including co-sleeping, lap sitting, or officing. Co-sleeping, lap sitting, and officing would result in 5 minutes per day on contact, 11 ¼ hours per day at 1 foot, and 9 hours per day at 3 feet as a worst-case scenario.

Typical Human-Dog Interactions

Interaction	**Distance**	**Time**
Carrying	contact	5 min/day
Feeding	1 ft	< 1 min/day
Petting	1 ft	5 min/day
Walking	3 ft	1 hr/day
Sitting[a]	3 ft	3 hr/day
Lap-sitting[a]	1 ft	3 hr/day
Co-sleeping	1 ft	8 hr/day
Officing	3 ft	8 hr/day

[a] A given dog exhibits one of these behaviors or the other, but not both since they are assumed to occur during the same time period.

In essence, dogs with osteoarthritis and thus a candidate for radiosynoviorthesis treatment, are self-selecting for dogs that do not spend prolonged time in close contact (touching) with their owner(s) because these candidates are older and larger dogs with painful joints which are sensitive to the touch and mobility limitations. Therefore, any written instructions issued limiting contact are reinforcing existing behavior patterns rather than attempting to contradict natural tendencies.

Of course, it is understood that in veterinary medicine the patient itself cannot understand any limitations noted in the release instructions. However, in this case, the most significant behaviors to limit (lap-sitting and co-sleeping) are precisely those behaviors that the severely arthritic dog cannot engage in unaided by the human caregiver. So long as the caregiver is willing and able to honor those limitations, the dog will not engage in them. And if the caregiver is unwilling or unable to honor those limitations then the dog will not be treated.

Calculation of Dose Rates

The above behavior evaluation categorized interactions are on contact, 1 ft, and 1 meter and establishes time for each type of interaction. In order to calculate an actual dose, the dose rates at each of these distances is needed. Wendt et al (2020) modeled the contact doses from a treated elbow. However, it is not reasonable to treat these dose rates as applicable to calculating a whole-body dose. They would be applicable to calculating extremity and skin dose for veterinary staff however extremity and skin dose is not relevant for members of the public. Skin is the only organ for which addressing dose to the maximally exposed portion is a regulatory issue and even for the skin the dose to a minimum of 100 cm^2 is evaluated. For all other organs, the average dose to the entire organ is used. Additionally, organ dose is not relevant for

evaluating dose to a member of the public. Therefore, only whole-body dose is considered in this evaluation.

As discussed above, the center of the human torso is treated as the dosimetric point of concern. For the distances of concern, this approximation requires refinement. At these distances, and especially for "contact" doses, NRC Regulatory Guide 8.40 is used to refine the calculations. NRC Regulatory Guide 8.40 divides the whole body into distinct portions for calculation of external dose and assigns each a compartment factor:

Regulatory Guide 8.40 compartment weighting factors

Compartment	**Weighting Factor**
Head & neck	0.10
Thorax, above the diaphragm	0.38
Abdomen, including the pelvis	0.50
Upper arms	0.005 ea.
Thighs	0.005 ea.

<u>Dose to Abdomen and Thorax</u>

MicroShield has been used to model the dose to the thorax and abdomen from a point source located on contact with the torso centered vertically, and at distances of 1 foot and 1 meter from the central surface of the torso. The torso is modeled as a right circular cylinder. Anatomic data from ICRP 89 (2001) and Tanner (1978) were used to construct the MicroShield model. ICRP 89 states that the trunk is equal to essentially half the human volume at all stages of development. This statement is extended to equate to approximately half the mass as well. NRC Regulatory Guide 8.40 divides the torso into two pieces, the thorax and abdomen. It is further assumed that each of these is approximately equal in length. ICRP 89 Table 2.9, Figure 4.5, and the un-numbered body height table on ICRP 89 page 63 are used to determine the overall trunk length and mass. Assuming a unit density, these values are used to determine the radius of the torso.[3] The salient values are provided in the table below. The values for males and females are the same for up to 15 years of age. The values for males are used for adults to provide an upper bound; the values for adult females would lie between those for the 15-year-old and the adult male.

MicroShield will not calculate the dose to a volume from a point source but it will calculate the dose to a point from a volume source. By super-positioning, these two geometries are the same. The photon emission data in MicroShield for Sn-117m with the emissions less than 15 keV excluded were used as the source. To normalize the results, the activity of the point source was chosen such that the dose rate at a point one meter from a point source was 0. 45 mrem/hr, equal to the maximum allowed dose rate for release of a dog. This activity was then evenly distributed within the volume of consideration for the MicroShield calculations.

3 A previous revision of this evaluation modeled the torso as an elliptic cylinder. In this revision, the torso is modeled as a right circular cylinder since MicroShield cannot model an elliptic cylinder.

ICRP 89 anatomic data

Age	Height, cm	Weight, kg	Torso length, %	Torso length, cm	Torso mass, kg	Radius, cm
1	76	10	40%	30	5	7.2
5	109	19	36%	39	9.5	8.8
10	138	32	33%	46	16	10.6
15	167	56	33%	55	28	12.7
Adult	176	73	33%	58	36.5	14.1

Wendt modeled the elbow as a 3 cm diameter cylinder with another 2 mm of skin. Therefore, the center of the elbow (modeled as a point source) is 1.7 cm away from the human skin when "on contact." This offset is used in the calculations.

In accordance with the discussion above, the thorax and abdomen are the same size and thus differ only by the compartment weighting factor assigned to each. The MicroShield model was set up to evaluate the dose to either compartment from a point source positioned "on contact," i.e., 1.7 cm away, and at distances of 1 foot and 1 meter horizontally from the perimeter of the vertical limit of the upright cylinder. Appendix D contains the MicroShield outputs for the adult. The models for the other ages are similar with adjustments for the different body sizes.

Dose to Head & Neck, Upper Arms, and Thighs

A treated dog's elbow can be treated as a point source if the distance from the elbow to the point of interest is large compared with the greatest dimension of the volume, the synovial sac in this case, containing the Synovetin OA. This allows scaling of the dose rate at one meter to other distances using the inverse square law. With distances as short as twice the longest dimension of the source, the error in using the inverse square law is approximately 2% for a sphere and effectively zero for a cylinder (Gollnick 2000 p. 136). As an annular space, the synovial sac can be treated as somewhere in-between these two geometries. Wendt modeled the elbow as a 3 cm diameter cylinder thus distances of 6 cm or greater can be modeled using the inverse square law with reasonable accuracy. This methodology is used to calculate the dose to the head and neck, upper arms, and upper legs and is a considerable conservatism compared to the method used for the thorax and abdomen.

For the head and neck, this anatomic region was conservatively modeled as a point located on the centerline at the upper extent of the torso. Similarly, the thighs were modeled as a point located on the centerline at the lower extent of the torso. The upper arms were modeled as points on the side of the cylinder representing the thorax at the vertical midpoint. No credit for shielding of these locations by the torso was taken.

Dose Calculation Results

The results of the modeling indicate the worst-case scenario is both dog elbows touching the torso directly above the torso center of mass. Using the maximum dose rate at release of 0.45

mrem/hr at 1 meter, the torso sizes based on the above table, and the 1.7 cm radius of the elbow (including the skin), the following dose rates using MicroShield were determined. To simplify the calculation, it is assumed all the activity is in one elbow. This dose rate includes the contribution from each anatomic region listed in Regulatory Guide 8.40. Any other position of the dog's elbow has a dose rate lower than when the dog's elbow is centered over the torso due to the increasing distance from an anatomic region (abdomen or thorax) which is a major contributor to the total dose.

MicroShield modeling results

	Dose rates, mrem/hr		
Age	**On Contact**	**1 ft**	**3 ft**
Adult	7.3	1.4	0.30
15	8.8	1.5	0.32
10	12.8	1.8	0.35
5	18.3	2.1	0.37
1	28.2	2.4	0.40

<u>Self-shielding</u>

The proposed release instructions are based upon the maximum exposure rate measured at a distance of 1 meter from the treated joint(s) of the dog. One meter is chosen because the veterinary technicians are accustomed to taking measurements at this distance as part of the receiving and shipping of radioactive materials. For the owners, distances are given in standard units, i.e., feet with distances of 1 and 3 feet for different activities since most people in the United States are more comfortable using standard units.

The maximum exposure rate will typically be measured either in the cranial or lateral direction with respect to the dog and at a height corresponding to the dog's treated joint(s). However, this height is quite low, corresponding to a human's knee height or less. The actual exposure rate experienced by a person will be modified by the height different between the dog's joint and the center of the person's torso and the interposition of the mass of the dog's torso, upper leg, and other bony and soft tissues. In general terms, there are 9 basic geometries that may be encountered thought of in terms of cardinal directions:

- Anterior, posterior, left lateral, and right lateral at treated joint height
- Anterior, posterior, left lateral, and right lateral at standing torso center height
- Dorsal (above)

The attached study in Appendix C measured the shielding effectiveness of the dog's torso for various size dogs and determined that a minimum average shielding effectiveness effect of 28% at 1 meter and 32% at 1 foot. These shielding effectiveness rates are used in this public dose evaluation. The adjusted dose rates are given in the table below.

Adjusted "effective" dose rates

	Dose rates, mrem/hr		
Age	**On Contact**	**1 ft**	**3 ft**
Adult	7.3	0.94	0.21
15	8.8	1.02	0.23
10	12.8	1.22	0.25
5	18.3	1.40	0.27
1	28.2	1.62	0.29

Dose to Members of the Public

When evaluating the dose to members of the public, the dog's owners are the most exposed group, especially with respect to the 100 mrem annual dose limit. The dose to other individuals such as friends, neighbors, and other people at a dog park are much lower simply due to the much shorter durations and longer distances of interactions with the dog. However, commercial grooming and boarding/kenneling are scenarios that merit consideration.

Board and Kenneling

Boarding and kenneling of a dog is an activity that has little close contact with a dog. It is important to keep in mind that commercial boarding and kenneling, including "doggy daycare," of a dog is not like an animal rescue operation, the SPCA, or a city/county animal shelter. It is a business staffed by employees and not staffed by volunteers. At an animal rescue operation, the SPCA, or a city/county animal shelter that might have volunteer staff, those entities are the dog's "owner" and none of them have the resources to fund this treatment and therefore interactions that occur at those facilities are not relevant.

At a commercial boarding facility, the dog spends the majority of its time isolated in a cage or dog run. During feeding, the kennel worker's proximity to the dog is not that close and the duration of the interaction is very limited. When let out to urinate/defecate or for playtime, it is leash led. The facility design is such that large dogs are kenneled at ground level and there is no reason for a kennel worker to have to lift the dog. Only small dogs might be in elevated cages. Other interaction with the dog is limited to when the dog is let out for exercise/playtime and one person is only loosely supervising 5 or more dogs. Close contact, such as prolonged petting and affection, is not done, in part because the operation is a business and the staff have many other tasks to perform, but also as a means of limiting the potential for infection spread between dogs. A given kennel worker is responsible for 30 or more dogs. Even if the worker had the inclination to spend time with an individual dog, to the dereliction of all the worker's other task, that would only allow no more than 16 minutes per dog per shift (day). Assuming as a worst case scenario that a kennel worker spent 30 minutes per day at one foot from a dog (petting distance), this would amount to a total dose of 9 mrem for the largest dogs released at the maximum release dose rate, 0.45 mrem/hr @ 1m. In reality, most interactions occur at greater distances and for less total time per day. The kennel should be supplied with a copy of the instructions to reinforce expectations and necessary behavior.

Commercial Grooming/Tactile Therapy

Commercial grooming and tactile therapy are activities that occurs at a distance of 1 foot. A 2-week delay in commercial grooming and factoring in the dog torso shielding factor results in a doserate of 0.94 mrem/hr at 1 foot, sufficient to meet the 2 mrem in any one hour criteria for even the largest dogs.

Dose from other licensed activities

Veterinary facilities have little dose to members of the public. Besides the dose a person receives from the treated dog, the only other source of dose would be the dose that a person receives while in the waiting room of the veterinary facility. The dose from this pathway is minimal within the length of time that a dog owner would be in the waiting room and thus is not quantitatively evaluated.

Unrestricted Dose to Owners

The maximum exposure rate at which a dog may be released is 0.45 mrem/hr. This criterion is based on ensuring that the maximum dose rate at a distance of 30 cm does not exceed 5 mrem/hr and thus does not create a radiation area. Based on this maximum expected exposure rate, these conservatively estimated contact times result in a dose of 27 mrem to an adult owner if the dog does not co-sleep with the owner, sit in its owner's lap, or lie at the feet of someone who offices at home, well below the 100 mrem in a year public dose limit. For a one-year-old child, the dose under the same scenario is 41 mrem, still well below the 100 mrem in a year public dose limit. If all three of those behaviors occur, the dose to an adult could be as high as 246 mrem for the largest dogs. The dose to a five-year-old under the same scenario is 359 mrem. The dose to a one-year-old is not calculated for this scenario because it is unreasonable to evaluate a dog of any size sleeping in a crib with a one-year-old while this behavior is credible with a five-year-old. For the same reason, a five-year-old is used for the extended close contact scenario. The doses resulting from smaller dogs would scale approximately linearly with dog weight due to the scaling of the administered activity with weight. The doses to 10- and 15-year-olds are not presented since they fall between the values given above.

The worst-case scenario for evaluating whether a person could receive 2 mrem in any one hour during the duration of the written instructions is a person that spends 1 minute on contact, 15 minutes at 1 foot and the remainder of the hour (44 minutes) at 3 feet. Under this scenario, the maximum dose would be 0.5 mrem for an adult and 1.1 mrem for a one-year-old. Two weeks after the procedure, the minimum duration for the written instructions, the worst-case scenario is 5 minutes on contact and 55 minutes at 1 foot. Under this scenario, the maximum dose would be 0.7 mrem for an adult and 1.9 mrem for a one-year-old.

It should be noted that for the common contact scenario, the maximum calculated dose is only 41 mrem to a one-year-old and even less to an adult, which would allow for multiple treatments

during a single year without exceeding the public dose limit. Regardless, this proposal is only seeking for one treatment per household in a one-year interval.

Restricting Dose to Owners

Dogs that do not lap sit, co-sleep, or office will be the most common behavior pattern among dogs with OA and treated by RSO for the reasons discussed above. It is expected that well over 90% of OA dogs will have this behavior pattern. In this situation, no written instructions are necessary to ensure compliance with the dose limit. Consequently, the use of written instruction provides a margin of dose reduction and is not the primary way of keeping the dose to members of the public below 100 mrem for the vast majority of cases. For the case where the dog offices, this one behavior needs to be limited.

As is currently the situation with release of cats treated with I-131, the most important behavior to avoid is co-sleeping with lap-sitting second. Preventing co-sleeping for up to 5 weeks or lap sitting for up to 2 weeks after treatment is sufficient to reduce the dose to less than 100 mrem in a year for the largest dogs. The necessary duration of such written instructions scales approximately linearly with exposure rate upon release and thus administered dose and dog size with no written instructions needed for the smallest dogs for the lap-sitting scenario which are also the dogs most likely to have this behavior. Therefore, the duration of the written instructions is inversely proportional to the behavior modification involved, i.e., the dogs most likely to lap sit (smallest dogs) are the ones for which this behavior must be avoided for the shortest period of time.

It is assumed that after expiration of the written instructions, the family will return to its prior behaviors with the dog since that is what they are used to doing. With regard to the dog, the relief provided by the injection is not instantaneous. The improvement is gradual over the course of several months and thus the dog's behavior can be expected to remain the same over the relevant time period. The instructions to the veterinarian in the procedure for use of Synovetin OA specify to emphasize this to the dog owners.

Death of the treated dog

In the event that the treated dog dies for any reason after treatment, the dog will contain residual radioactivity for a period of time. If the dog is buried, the dose to the public will be zero after burial and thus no restriction is needed. However, if the dog is to be cremated, there may be additional concerns and the carcass should be held for a period of time. In order to establish a reasonable time period to wait for cremation, the 10 CFR 30.71 exemption levels are used as a basis. Sn-117m is not listed in 10 CFR 30.71 and thus defaults to an exemption level of 0.1 µCi. However, Ba-140 and Cs-136 are listed gamma emitters with similar half-lives (12 and 13 days respectively) and that have exempt quantities of 10 µCi.

Therefore, 10 µCi is chosen as a reasonable maximum activity for cremation. The largest dog injected with the maximum activity in both elbows would decay below this level in 10 half-lives,

and 20 weeks. A total activity of 10 μCi is 0.5% of the whole body ingestion and inhalation ALIs and thus intake of the entire activity (an extreme overestimate) would result in a dose of only 25 mrem and thus emissions from the crematory are not a concern.

Proposed written instructions

Most dog behaviors and human-dog interactions do not need to be modified to successfully limit the dose to a member of the public to less than 100 mrem. This meshes well with the need to have instructions to which the owner can readily adapt and maintain. The objective is to minimize the behavior modification needed. For that reason, we have identified those possible dog behaviors that would most substantially impact the dose. Those are:

a) sleeping with a person,
b) sitting on the lap of a person for an extended period of time (”lapsitting”), and,
c) as a distant third, lying at the feet or beside someone that works from home or is sedentary (“officing”).

The veterinarian will conduct pre-screening prior to ordering treatment to identify up-front the dogs that engage in any of those behaviors or other behaviors resulting in similar contact distances and durations. The release instructions will be tailored specifically for dogs that do and do not normally engage in those behaviors. In that way, the minimal possible change in normal behavior for each dog is required. These instructions will be discussed with the owners and agreement reached that they can implement and abide by the instructions.

The proposed written instructions are patterned after those contained in NUREG-1556 Volume 7 Revision 1 Appendix D for I-131 treatment of cats but altered to address the specific characteristics of Sn-117m. Examples of activities that are conducted at distances of 1 foot or 3 feet are provided.

The fill-in-the-blanks on the release instructions will be completed based on the following table. For all situations, maximum allowed activity times of 1 minute, 15 minutes, and 4 hours are used for distances of <1 foot, 1 foot, and 3 feet respectively. Where present, parenthetical values are the calculated values; however, the instructions to the veterinarians would contain only the non-parenthetical values. The minimum instruction duration has been set to 2 weeks to provide a margin of dose reduction even where not strictly necessary. Note that the major behaviors being limited are co-sleeping and lap-sitting. The times provided in the table are the conservative values for time spent doing activities at those distances in the absence of instructions to limit contact with the dog and thus are not behavior modifications at all but simply reminders to the owners to limit contact. For dogs that exhibit multiple listed behaviors, the most conservative (longest) is selected. **The times are selected to result in a dose of less than 90 mrem to add a layer of conservatism and provide a margin of safety.**

Release Instructions Durations (weeks) and Allowed Times per person

Exposure Rate (mrem/h @ 1 m)[a]	**0.45**	**0.4**	**0.3**	**0.2**	**0.1**	**0.05**
Dogs that do not co-sleep, lap-sit, or office[b] Maximum 5 min @ <1 ft, 15 min @ 1 foot, 4 hours @ 3 feet						
Instruction Duration (weeks)	2 (0)	2 (0)	2 (0)	2 (0)	2 (0)	2 (0)
Extended Close Contact (Dogs that lap-sit[c]**)** Maximum 5 min @ <1 ft, 3 hr @ 1 foot, 4 hours @ 3 feet						
Instruction Duration (weeks)	2	2	2 (1)	2 (0)	2 (0)	2 (0)
Extended Intermediate Contact (Dogs that office[d]**)** Maximum 5 min @ <1 ft, 15 min @ 1 foot, 12 hours @ 3 feet						
Instruction Duration (weeks)	2 (0)	2 (0)	2 (0)	2 (0)	2 (0)	2 (0)
Prolonged Close & Intermediate Contact (Dogs that co-sleep[e]**)** (Maximum 5 min @ <1 ft, 11 hr @ 1 foot, 9 hours @ 3 feet)						
Instruction Duration (weeks)	5	5	4	2	2 (0)	2 (0)

[a] All measured exposure rates should be rounded up to the next higher value in the table.
[b] Most dogs will fall into this category. No instructions are necessary for this scenario; instructions are provided solely for additional margin of dose reduction.
[c] Lap-sitting is not allowed for the duration of the instructions.
[d] Officing is are not allowed for the duration of the instructions.
[e] Co-sleeping and lap-sitting are not allowed for the duration of the instructions.

The calculated dose to an owner who has the maximum allowed contact with their dog for the duration of the written instructions and also has the maximum anticipated contact afterwards is given in the table below.

Calculated maximum dose

Scenario	**Adult dose, mrem**	**Child dose, mrem**
Common	27	41
Extended Close	74	84
Extended Intermediate	56	82
Prolonged Close & Intermediate	76	85

Note that a release instruction duration of 2 weeks is sufficient to limit the dose below 100 mrem and prevent a person from exceeding 2 mrem in any one hour for all behavior scenarios except co-sleeping. As with cats, this is the single behavior that absolutely must be prevented in the weeks immediately after the treatment.

Restricting this population of dog from doing these activities will not be difficult due to the self-limiting pain already present. In addition, these dog breeds which typically weigh 50 lbs. or more, are not considered lap dogs due to the discomfort of having such a large amount of weight and bulk on a human lap. With regard to sharing a bed or couch, again, there is a size limitation that occurs in addition to the pain a dog with OA pain will experience. It should be remembered that dogs being treated with RSO are in pain and reluctant to jump and to be very active and that

this pain and reluctance will continue for the duration of the applicable period of instructions limiting contact.

A veterinarian treating a dog with pain and inflammation of OA has multiple treatment modalities available. Just like dealing with a client who cannot pill a cat, the practitioner determines the best treatment for the dog based on the client. Therefore, if a client cannot be separated from their painful dog to allow Sn-117m colloid to be used safely, another treatment will need to be instituted. However, if the same client returns with their dog which is refractive to the prescribed treatment then the CLIENT has to make the decision whether they can be separated from their painful dog long enough to be treated with Sn-117m colloid to successfully treat the painful OA condition. A signed statement to this effect is part of the documentation associated with the discharge guidance following Sn-117m treatment.

Reliance on written instructions

NUREG-1556, Volume 7, Revision 1 states that written instructions should provide a margin for dose reduction but should not be relied upon as the primary way of keeping the dose to members of the public below 100 mrem. Although seemingly clear and straightforward, the exact intent of this statement is nonetheless not completely clear. As demonstrated by NMED report 010664, some reliance upon release instructions, included those contained in NUREG-1556, Volume 7, Revision 1, is necessary to limit dose to members of the public to less than 100 mrem from I-131 therapy for cats. The statement in the NUREG is taken to mean that credit can be taken for the written instructions, but that the credit should be limited, i.e., the majority of the dose limitation should occur based upon other factors and that the written instructions are a secondary factor. This would be consistent with the approach taken in NCRP 148 (NCRP 2004) where there is no such restriction on the credit which may be taken for the written instructions. The NCRP approach is more emphatic in requiring particular components of the written instructions (cautioning against holding the animal, etc.).

Sn-117m therapy for dogs is similar in this regard as I-131 therapy for cats. The primary factors limiting dose to a member of the public are the natural behavior patterns for dogs in general and dogs with severe OA in particular. There are three potential behaviors which need to be controlled with dogs, co-sleeping, lap sitting, and officing, two of which happen to be the same behaviors which must most be limited with regard to cats and thus appear in the cat I-131 therapy instructions as the prohibitions against sleeping with the cat and minimizing the time in close contact.

Calculations

All calculations were performed using the following equation:

$$D = \frac{D_0}{\lambda} * \left[\left(1 - e^{-\lambda T_I}\right) * (D_3 * T_3 + D_1 * T_1 + D_c * T_c) + e^{-\lambda T_I} * (D_3 * T_{3inf} + D_1 * T_{1inf} + D_c * T_c)\right]$$

Where:
D = Total dose to a member of the public
λ = Sn-117m decay constant, 0.05097 d^{-1}
D_0 = Exposure rate at a distance of 1 meter at release, mrem/h
D_3 = Calculated initial dose rate at 1 meter adjusted to 3 feet and including the 0.72 shielding adjustment
D_1 = Calculated initial dose rate at 1 foot and including the 0.68 shielding adjustment
D_c = Calculated initial dose rate at <1 foot (on contact)
T_I = Duration of release instructions, days
T_3 = hours per day at 3 feet during duration of release instructions
T_{3inf} = hours per day at 3 feet after end of release instruction (default)
T_1 = hours per day at 1 foot during duration of release instructions
T_{1inf} = hours per day at 1 foot after end of release instruction (default)
T_c = hours per day at <1 foot (on contact) during duration of release instructions
T_c = hours per day at <1 foot (on contact) after end of release instruction (default)

The attached[4] spreadsheet in Appendix E contains the supporting calculations. The largest (110+ lb) dogs are expected to have a maximum exposure rate of approximately 0.4 mrem/hr at 1 meter. The expected exposure rate from smaller dogs will scale approximately linearly with size.

Conclusions

Treatment of OA in dogs with RSO is performed after the pain associated with OA has significantly impacted the dog's quality of life and other less expensive treatments have failed to provide satisfactory results. The majority of dogs treated with RSO are larger dogs with limited mobility. Even among healthy dogs, these dogs do not typically sleep in the bed with their owners or climb into their lap, and dogs with severe OA would be even less likely to do so. Conservative estimates of the amount of time, and associated distances, owners spend in routine activities with their dogs were performed based on behavior of normal dogs. In each instance, it can be expected that a dog with OA would spend the same or less time in each of those activities.

Calculations of the prospective dose to an owner based on these times and distances were performed which determined that for typical dogs (and vast majority of treated dogs) that do not sleep in its owner's bed or sit in its owner's lap, the dose from an RSO treatment with Synovetin OA would result in a dose of no more than 41 mrem to a child and 27 mrem to an adult from the

4 The spreadsheet is attached only to the electronic distribution of this report.

largest dogs and proportionately less for smaller dogs. For dogs that do sleep in its owner's bed, sit in its owner's lap, or lie by its owners chair most of the day, written instructions prohibiting these behaviors are necessary to ensure that the dose to the owner remains less than 100 mrem. In determining the necessary duration of the written instructions, the times are selected to result in a dose of less than 90 mrem to add a layer of conservatism and provide a margin of safety. These prohibitions for Sn-117m treatment of dogs are consistent with the prohibitions necessary to ensure treatment of cats with I-131 does not result in a dose to a member of the public of greater than 100 mrem. The behavior modification of the dogs is limited, most routine daily behavior are unmodified, and the time period for which modification is needed is limited, making compliance relatively straightforward and manageable.

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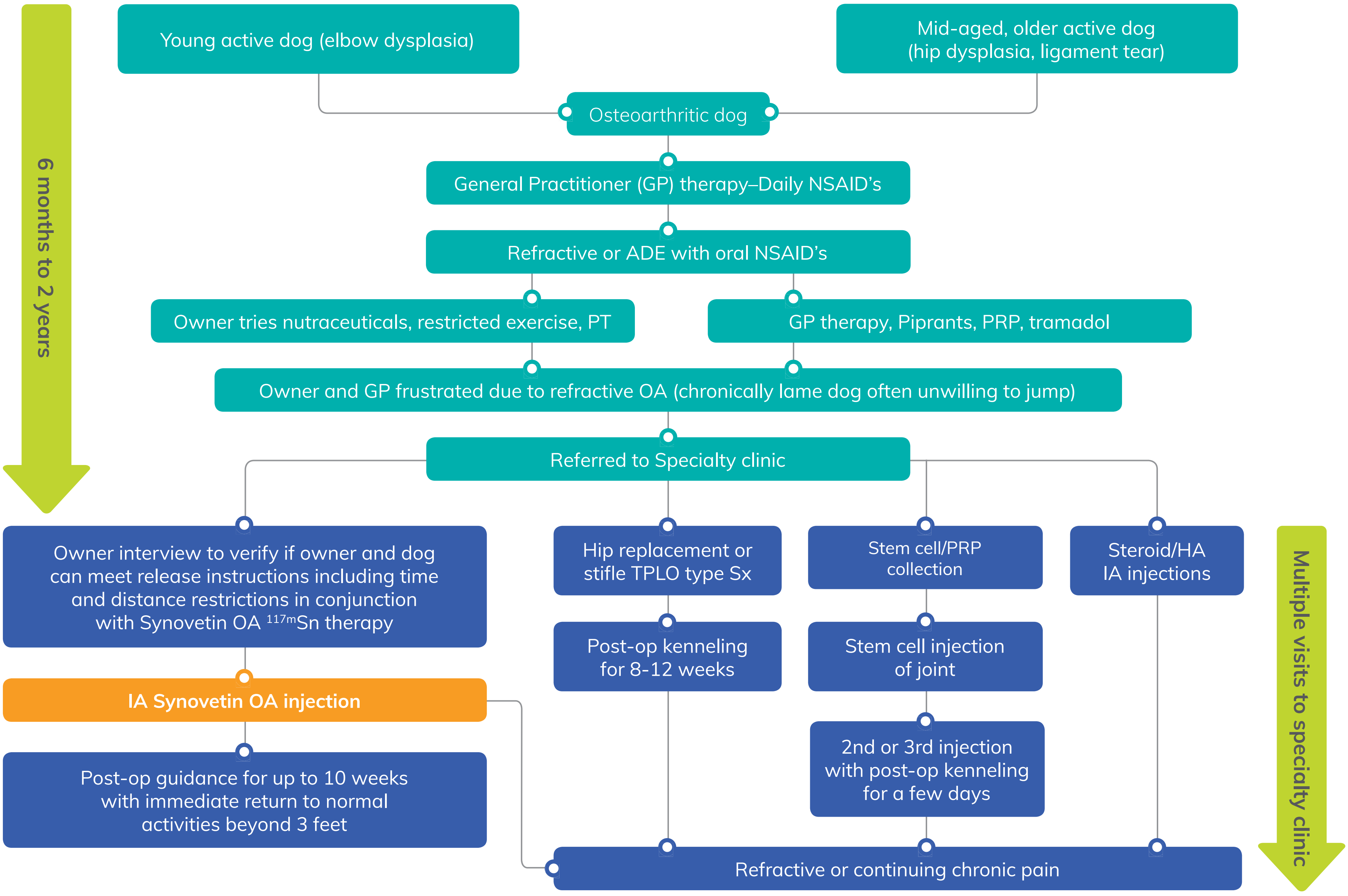
Appendix A
Radiosynoviorthesis Flow Chart

Decision Tree for Synovetin OA



Appendix B
Dog Interactions Video Clips
(electronic distribution only)

Appendix C
Canine Torso Shielding Evaluation

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Canine Torso Attenuation from Elbows Treated with Synovetin OA (Sn-117m)

Synovetin OA™ is used to treated dogs with osteoarthritic elbows by radiosynoviorthesis. Synovetin OA is a tin-117m colloid and the internal conversion and Auger electrons emitted by the tin-117m provide the therapeutic effect. Tin-117m also emits gamma rays, the highest energy of which is 158.56 keV. The external radiation field around a treated dog is of interest in order to limit the dose the owners/caretakers of the dog.

Canine anatomy is such that the dog's elbows are approximately at the same height as the lower extent of the dog's torso when in a standing position. In this position, the dog's torso attenuates the radiation being emitted towards the opposite side of the dog's body, above the dog, and towards the dog's posterior. In a seated position, this shielding effect is increased. This leads to a radiation field which is significantly non-isotropic. This study was conducted to establish the characteristics of this non-isotropic field.

A population of dogs of various sizes that could be injected with Synovetin OA was not available for various reasons. Therefore, in order to approximate the torso shielding effects from treated elbows, tin-117m sources were secured to the medial surface of the dog elbows and radiation field measurements were obtained. The tin-117m sources consisted of tin-iodide solutions absorbed on blotter paper and double-bagged in plastic Ziploc-type pouches for contamination control. The active area of the blotter paper was approximately 1 cm by 2 cm with total activities of 3.39 and 3.37 mCi each, about 10% more than the maximum prescribed activity per elbow. Figure 1 shows a dog with the sources taped to its elbows. Positioning of the sources in this manner is considered to be a good approximation for determining the radiation field at distances other than on contact.

10 dogs were selected for this study with sizes ranging from 11 pounds up to 85 lb. On each dog, up to 18 measurements were taken. Measurements were taken anterior, posterior, left lateral, and right lateral; at distances of 1 foot and 1 meter; and at the dog's elbow height and upwards at an angle of 45 degrees. This angle at a distance of 1 meter simulates the radiation field at the height of the torso of a person standing next to a dog. In addition, dorsal measurements were also taken at the 1 foot and 1 meter distances. The measurement locations are listed in table 1.

For all but the smallest dogs in the study, a distance of 1 foot anteriorly is under or within the dog's torso. Therefore, the 1 foot anterior measurements were taken at the dog's rump regardless of the distance from the rump to the elbow. The 1 foot dorsal measurement was taken on top of the dog's shoulders if this distance was 1 foot or more. The 1 foot upper anterior measurement was not made if it fell within the torso, in which case the doserate was assumed to be the same as for the 1 foot dorsal measurement (shown in red in table 2).

Table 1. Measurement locations

1 ft distance	1 meter distance
Anterior @ elbow height	Anterior @ elbow height
Left lateral @ elbow height	Left lateral @ elbow height
Right lateral @ elbow height	Right lateral @ elbow height
Posterior (on rump)	Posterior
Upper anterior	Upper anterior
Upper left lateral	Upper left lateral
Upper right lateral	Upper right lateral
Upper posterior	Upper posterior
Dorsal	Dorsal

Figure 1. Dog with sources secured to elbows.

Doserate measurements were made with a Ludlum 9DP ion chamber and with a Bicron µrem. However, the lack of precision in the analog scale on the Bicron was determined to not allow precise enough measurements to be made and therefore that data was rejected. A 1 meter fiberglass batten was used to ensure repeatability of 1 meter measurements and a fiberglass rod marked at 1 foot was likewise used for those measurements.

Table 2 provides the raw data from the measurements including the weight and breed of each dog used in the study. The average doserate at each distance was divided by the maximum doserate at that distance to determine an average effective shielding percentage provided by the dog's torso. A scatter plot of the results is presented in figure 2. Attachment A shows example doserate measurements.

Table 2. Survey Data, mR/hr (background doserate 0.003 mR/hr)

Weight (lb) / Breed	11 Dachsund	13 Dachsund	16 Terrier mix	26 Poodle mix	43 English bulldog	50 Border Collie	68 Pit bull/ Catahoula mix	74 Golden Retriever Mix	78 Chocolate Lab	85 Chocolate Lab
1m										
anterior	0.45	0.32	0.48	0.39	0.52	0.27	0.32	0.36	0.45	0.29
left lat	0.30	0.31	0.28	0.38	0.33	0.30	0.27	0.34	0.28	0.24
right lat	0.25	0.31	0.31	0.17	0.20	0.37	0.26	0.21	0.20	0.43
posterior	0.25	0.16	0.14	0.33	0.13	0.20	0.25	0.34	0.25	0.14
upper anterior	0.22	0.20	0.25	0.22	0.42	0.17	0.16	0.19	0.34	0.13
upper left lat	0.43	0.33	0.28	0.27	0.23	0.25	0.32	0.35	0.27	0.20
upper rt lat	0.30	0.41	0.28	0.28	0.17	0.40	0.31	0.17	0.29	0.30
upper posterior	0.32	0.26	0.16	0.29	0.15	0.28	0.08	0.09	0.07	0.08
dorsal	0.27	0.28	0.21	0.22	0.13	0.15	0.12	0.14	0.12	0.12
1 m max	0.447	0.407	0.477	0.387	0.517	0.397	0.317	0.357	0.447	0.427
1 m average	0.307	0.284	0.263	0.280	0.250	0.263	0.229	0.240	0.249	0.211
1 m Shielding reduction	31%	30%	45%	28%	52%	34%	28%	33%	44%	50%
1 ft										
anterior	1.6	1.36	2.8	2.6	2.3	0.94	1.3	2.1	2	1.5
left lat	0.8	1.8	1.3	2.1	1.5	1.3	1.6	1.5	1.3	1.1
right lat	1.4	2.16	1.6	1.5	0.95	2.1	1.2	1.05	0.84	2
posterior	2.1	0.5	0.5	0.43	0.3	0.45	0.15	0.26	0.35	0.16
upper anterior	0.8	1.4	1.8	1.6	1.5	0.84	1	1.1	1.5	1.2
upper left lat	2.3	1.6	1.4	1.6	1.6	1.2	1.4	1.9	1.3	0.84
upper rt lat	1.5	1.9	1.2	1.2	0.78	1.7	1	0.64	0.79	1.8
upper posterior	1.6	1.2	2.8	2.5	0.73	0.53	0.8	0.16	0.17	0.47
dorsal	1.6	0.85	2.8	2.5	0.73	0.53	0.8	0.16	0.17	0.47
1 ft max	2.297	2.157	2.797	2.597	2.297	2.097	1.597	2.097	1.997	1.997
1 ft average	1.519	1.416	1.797	1.778	1.151	1.063	1.025	0.983	0.933	1.057
1 ft Shielding reduction	34%	34%	36%	32%	50%	49%	36%	53%	53%	47%

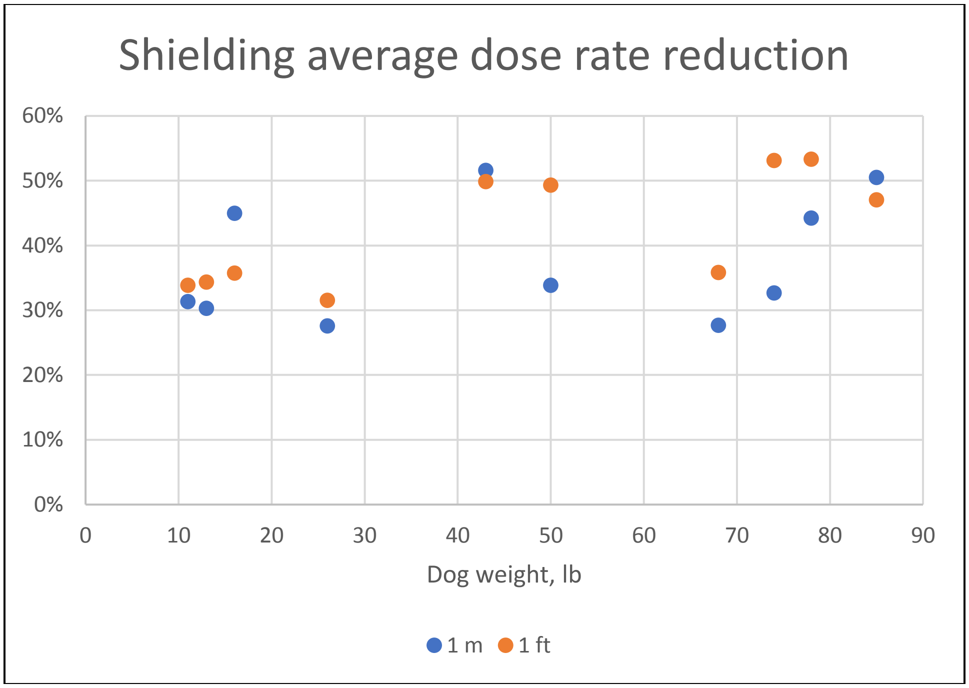


Figure 2.

The average 1 meter shielding effectiveness is a 37% reduction with a minimum reduction of 28%. The average 1 foot shielding effectiveness is a 42% reduction with a minimum reduction of 32%. The trendline for the percentage of effective shielding trends upward with increasing dog size although there is significant variability. This variability is attributed to the positioning of the tin-117m sources on the medial surface of the elbow rather than it being injected into the elbow which can result in streaming around the elbow for geometries other than anterior. However, for purposes of radiation safety, the results are still useful.

It is recommended that for the purposes of radiation safety, an average 1 foot shielding effectiveness of 32% and an average 1 meter shielding effectiveness of 28% be used.

Attachment A
Doserate measurement pictures

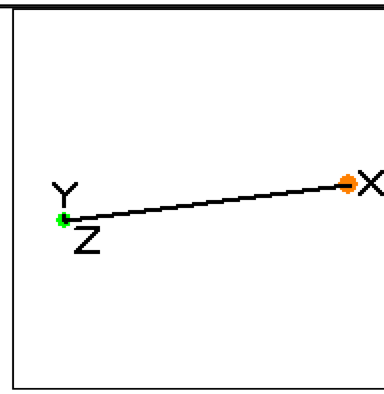
Appendix D
MicroShield Example Outputs

MicroShield 7.02
Foxfire Scientific (07-MSD-7.02-1309)

Date	By	Checked

Filename	Run Date	Run Time	Duration
1 m normalization.ms7	June 23, 2020	7:34:59 AM	00:00:00

Project Info	
Case Title	Bare source
Description	Bare Source
Geometry	1 - Point



Dose Points			
A	X	Y	Z
#1	100.0 cm (3 ft 3.4 in)	0.0 cm (0.0 in)	0.0 cm (0.0 in)

Shields			
Shield N	Dimension	Material	Density
Air Gap		Air	0.00122

Source Input: Grouping Method - Actual Photon Energies		
Nuclide	Ci	Bq
Sn-117m	3.0460e-003	1.1270e+008

Buildup: The material reference is Air Gap
Integration Parameters

Results					
Energy (MeV)	Activity (Photons/sec)	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.025	2.111e+07	3.985e+00	4.165e+00	6.837e-02	7.144e-02
0.0253	3.960e+07	7.552e+00	7.892e+00	1.260e-01	1.317e-01
0.0285	1.336e+07	2.902e+00	3.034e+00	3.354e-02	3.507e-02
0.156	2.378e+06	2.905e+00	2.977e+00	4.832e-03	4.951e-03
0.1586	9.737e+07	1.209e+02	1.239e+02	2.019e-01	2.068e-01
Totals	**1.738e+08**	**1.382e+02**	**1.419e+02**	**4.346e-01**	**4.500e-01**

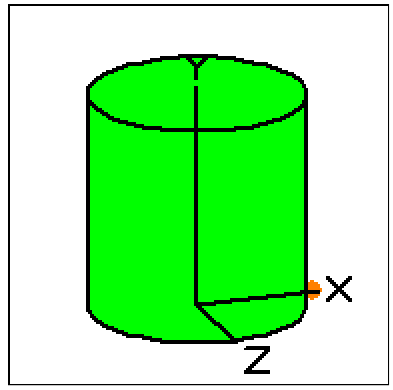
MicroShield 7.02
Foxfire Scientific (07-MSD-7.02-1309)

Date	By	Checked

Filename	Run Date	Run Time	Duration
adult torso center contact.ms7	June 23, 2020	6:17:07 PM	00:00:00

Project Info	
Case Title	
Description	
Geometry	7 - Cylinder Volume - Side Shields

Source Dimensions	
Height	29.0 cm (11.4 in)
Radius	14.1 cm (5.6 in)



Dose Points			
A	X	Y	Z
#1	15.8 cm (6.2 in)	0.0 cm (0.0 in)	0.0 cm (0.0 in)

Shields			
Shield N	Dimension	Material	Density
Source	1.81e+04 cm³	Tissue	1
Transition		Air	0.00122
Air Gap		Air	0.00122

Source Input: Grouping Method - Actual Photon Energies				
Nuclide	Ci	Bq	µCi/cm³	Bq/cm³
Sn-117m	3.0460e-003	1.1270e+008	1.6817e-001	6.2222e+003

Buildup: The material reference is Source Integration Parameters	
Radial	10
Circumferential	10
Y Direction (axial)	20

Results					
Energy (MeV)	Activity (Photons/sec)	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.025	2.111e+07	9.387e+00	1.500e+01	1.610e-01	2.573e-01
0.0253	3.960e+07	1.812e+01	2.923e+01	3.023e-01	4.876e-01
0.0285	1.336e+07	8.749e+00	1.623e+01	1.011e-01	1.876e-01
0.156	2.378e+06	2.475e+01	9.567e+01	4.117e-02	1.591e-01
0.1586	9.737e+07	1.034e+03	3.955e+03	1.727e+00	6.605e+00
Totals	**1.738e+08**	**1.095e+03**	**4.111e+03**	**2.333e+00**	**7.697e+00**

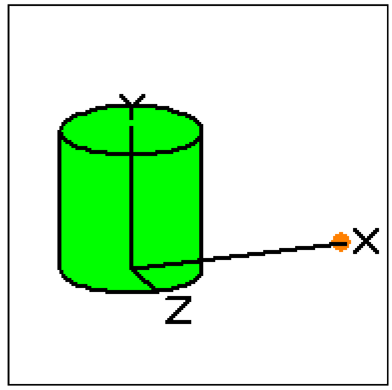
MicroShield 7.02
Foxfire Scientific (07-MSD-7.02-1309)

Date	By	Checked

Filename	Run Date	Run Time	Duration
adult torso center 1 ft.ms7	June 23, 2020	6:16:21 PM	00:00:00

Project Info	
Case Title	
Description	
Geometry	7 - Cylinder Volume - Side Shields

Source Dimensions	
Height	29.0 cm (11.4 in)
Radius	14.1 cm (5.6 in)



Dose Points			
A	X	Y	Z
#1	44.1 cm (1 ft 5.4 in)	0.0 cm (0.0 in)	0.0 cm (0.0 in)

Shields			
Shield N	Dimension	Material	Density
Source	1.81e+04 cm³	Tissue	1
Transition		Air	0.00122
Air Gap		Air	0.00122

Source Input: Grouping Method - Actual Photon Energies				
Nuclide	Ci	Bq	μCi/cm³	Bq/cm³
Sn-117m	3.0460e-003	1.1270e+008	1.6817e-001	6.2222e+003

Buildup: The material reference is Source Integration Parameters	
Radial	10
Circumferential	10
Y Direction (axial)	20

Results

Energy (MeV)	Activity (Photons/sec)	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.025	2.111e+07	1.803e+00	2.876e+00	3.093e-02	4.933e-02
0.0253	3.960e+07	3.479e+00	5.598e+00	5.804e-02	9.339e-02
0.0285	1.336e+07	1.670e+00	3.068e+00	1.930e-02	3.546e-02
0.156	2.378e+06	4.510e+00	1.620e+01	7.501e-03	2.695e-02
0.1586	9.737e+07	1.884e+02	6.699e+02	3.147e-01	1.119e+00
Totals	**1.738e+08**	**1.999e+02**	**6.976e+02**	**4.304e-01**	**1.324e+00**

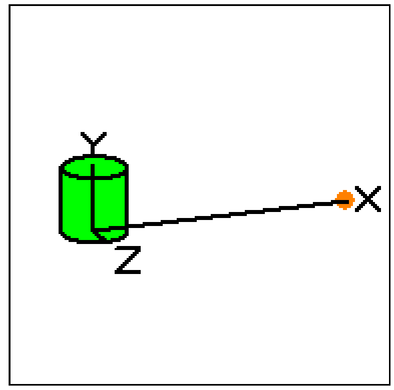
MicroShield 7.02
Foxfire Scientific (07-MSD-7.02-1309)

Date	By	Checked

Filename	Run Date	Run Time	Duration
adult torso center 1 m.ms7	June 23, 2020	6:14:58 PM	00:00:00

Project Info	
Case Title	
Description	
Geometry	7 - Cylinder Volume - Side Shields

Source Dimensions	
Height	29.0 cm (11.4 in)
Radius	14.1 cm (5.6 in)



Dose Points			
A	X	Y	Z
#1	114.1 cm (3 ft 8.9 in)	0.0 cm (0.0 in)	0.0 cm (0.0 in)

Shields			
Shield N	Dimension	Material	Density
Source	1.81e+04 cm³	Tissue	1
Transition		Air	0.00122
Air Gap		Air	0.00122

Source Input: Grouping Method - Actual Photon Energies				
Nuclide	Ci	Bq	μCi/cm³	Bq/cm³
Sn-117m	3.0460e-003	1.1270e+008	1.6817e-001	6.2222e+003

Buildup: The material reference is Source Integration Parameters	
Radial	10
Circumferential	10
Y Direction (axial)	20

Results					
Energy (MeV)	Activity (Photons/sec)	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.025	2.111e+07	2.664e-01	4.275e-01	4.570e-03	7.334e-03
0.0253	3.960e+07	5.142e-01	8.328e-01	8.578e-03	1.389e-02
0.0285	1.336e+07	2.483e-01	4.616e-01	2.869e-03	5.335e-03
0.156	2.378e+06	7.024e-01	2.617e+00	1.168e-03	4.353e-03
0.1586	9.737e+07	2.935e+01	1.082e+02	4.902e-02	1.807e-01
Totals	**1.738e+08**	**3.108e+01**	**1.125e+02**	**6.621e-02**	**2.116e-01**

Appendix E
Calculations Spreadsheet
(electronic distribution only)