Considerations in the Use of the RS 2000 X-ray Irradiator for Biological Research (Primarily Small Animal, tissue, and cells) and the fallacy of the High KV spectrum.

The performance goal for a small animal irradiation device is to provide a uniform dose throughout the animal so that negative effects of high concentrated dose (skin burn) or non-uniform dose (reduced biological effect) areas can be eliminated.

Unlike the monoenergetic source of an isotope (e.g. Cesium or Cobalt), an x-ray beam is comprised of a spectrum of energies defined in kVs (kilovolts). The kVp is the PEAK energy for a given x-ray spectrum. The spectrum for an x-ray beam is characterized by its kVp and target material (K edge) used to produce these photons. For example the K edge of tungsten (which most point-source x-ray tubes utilize) is about 58 kV. This is where the most photons are produced.

The geometric nature of the dose from a point source also affects dose rate. This geometric consideration cannot be mitigated by simple rotation. Rotation perpendicular to the source will reduce some of the heel effects of the cone shaped beam but not all. Either multiple sources or special property materials such as the patented **Rad Source Rad+** reflective chamber can alleviate this problem.

Regardlessofwhether the irradiation source is a gamma emitter or single point source x-ray tube, the dose will be reduced by $1/r^{2}$. (Where r^2 is a function of distance from the source). Therefore, there is a loss of dose from the point closest to the irradiation source (e.g., the back of the small animal) to the point furthest from the irradiation source (e.g. the belly of the small animal).

The requirement of the x-ray device is to take all of these variables, (multiple energies, variance in penetration of these energies at different levels, and distance from the point source) and still PROVIDE A UNIFORM DOSE IN THE SMALL ANIMAL.

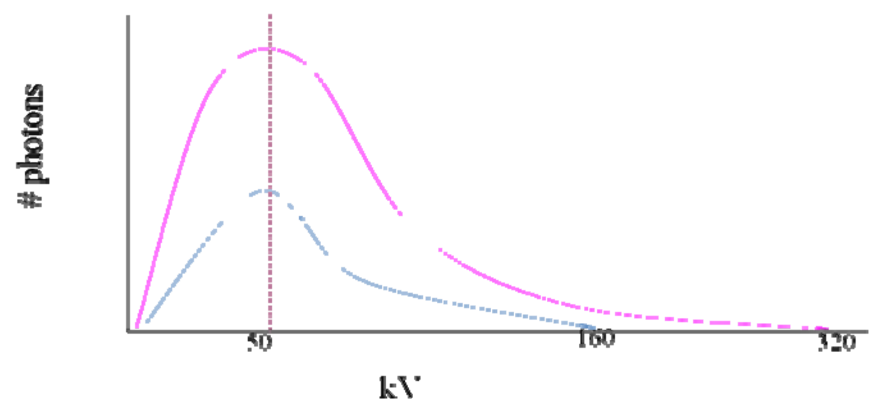
The first requirement is to modify the beam spectrum so that only the photons that have the penetration capability to get through a mouse are utilized.

It is therefore necessary to eliminate a high percentage of the photons that will not penetrate at least 1 cm of tissue (the skin burn issue) AND maintain a spectrum that has a majority of photons penetrating 2.5 cm of tissue.

(2.5 cm is an estimated maximum thickness of a mouse used for this discussion).

A beam spectrum that can be modified to meet these two criteria and still produce a viable dose rate will provide optimum dose distribution regardless of the lowest and the highest energy in the spectrum

X-ray Spectrum



To confidently use x-ray for small animal irradiation a spectrum must be shaped
To insure the lower energy portion of the spectrum remains above 45 kV. Any lower energies in the spectrum only create non-uniformity and in the worst case skin burn.

The proper method for modifying an x-ray spectrum is to place filters (thin sheets of high density materials) between the x-ray source and the mouse. <u>Filters have the effect of straining out low energy photons and lowering the energy of those remaining.</u> The energy reduction of the higher energy photons is not linear. **<u>The higher the energy, the less it is affected by filtering.</u>**

The phenomenon of skin burns in mice result from a build up of dose in the skin of the animal

<u>The objective is to generate a modified beam using filtration that results in photons of sufficient energies to insure no excess energy is deposited in the surface of the small animal and the maximum energy in the resulting spectrum at least penetrates the 2.5 cm of tissue.</u>

Actual dose distribution is inaccurately represented if the conversion from air to higher densities is inaccurate. The net result is the possibility of burning the mouse's skin while demonstrating acceptable ion chamber dose readings. However, if the dose is calculated correctly and the readings are accurate, <u>an x-ray energy spectrum modified to a minimum of 45 kV will not produce a skin burn any more than a cesium spectrum!</u>

<u>The way to mitigate this possibility is to insure the dose absorption for the first cm of tissue is comparable to the distribution for1, 1.5, 2 and 2.5 cm of depth</u>

The second comparative issue is penetration or total absorbed dose through the animal. Using the 2.5 cm depth as our standard, any photons passing completely through the 2.5 cm have imparted all the energy they can to the mouse (note: <u>any penetrating photons can cause scatter which is a condition where that photon passing through the subject matter hits the next object (floor of the chamber) and is reduced to lower energy photons that, in themselves, can bounce back toward the original subject matter (mouse) and result in accumulation of dose only to the surface - the very problem trying to mitigate</u>). <u>The higher energy of the emerging photon, the more likely the scatter.</u>

Performing the above tests results in determining the <u>minimum</u> penetrating kV for penetrating 2.5 cc of density 1 is <u>55 kV</u>.

To evaluate the dose uniformity of the RS2000 in a typical configuration for irradiating mice, the following method was used.

Uniformity and Low Energy Measurements for a Rad Source RS 2000

The following method was used.

Equipment: Rad Source RS2000

Rad+ Boron carbide chamber

Allentown Animal rearing cage

RadCal Ion Chamber

Rad Source polystyrene mouse phantom

ISP MD 55 Film

Risoscan Film Reader GEX Corp

Settings: 160 kV; 25mA; 20 minute exposure

Figure 1

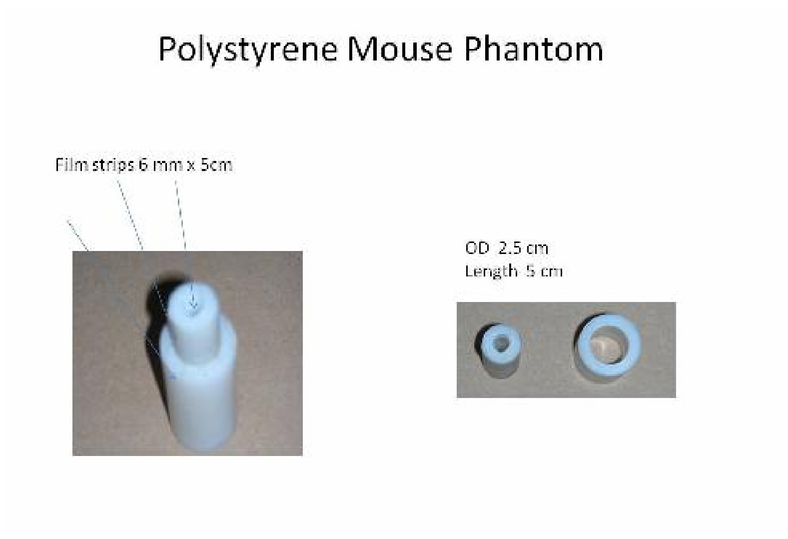
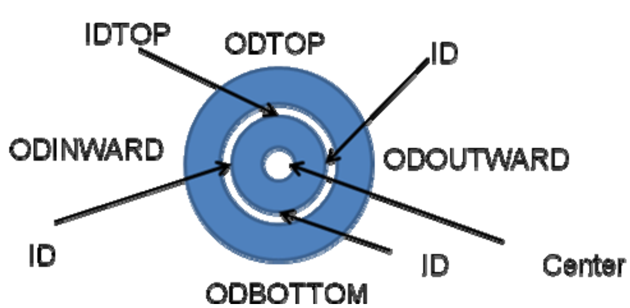


Figure 2

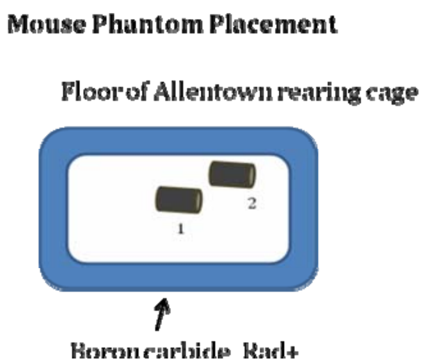


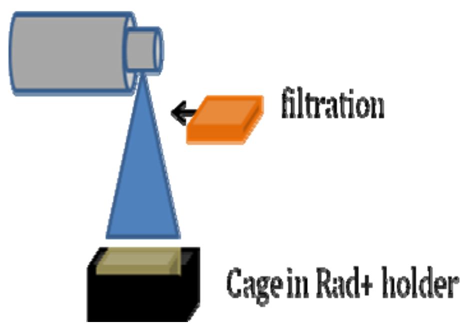
Phantom Construction

Methodology: A half value Layer was determined using the RadCal ion chamber, copper sheets and the RS 2000 with its standard .3 mm of Cu shielding. Machine power was at the recommended 160 kVp and 25 mA. The value was determined to be .62 mm of Cu.

Two Rad Source mouse phantoms (figure 1) were prepared with longitudinal strips of MD 55 film and placed in the RS 2000 (Figure 3) with .3 mm Cu filtration placed in the beam.(Figure 4)

Figure 3 Figure 4





The phantoms were irradiated for 20 minutes @160 kVp and 25 mA

First, vertical dose was measured.(Figure (6)

Figure 5 2” Vertical Measurement Ave.

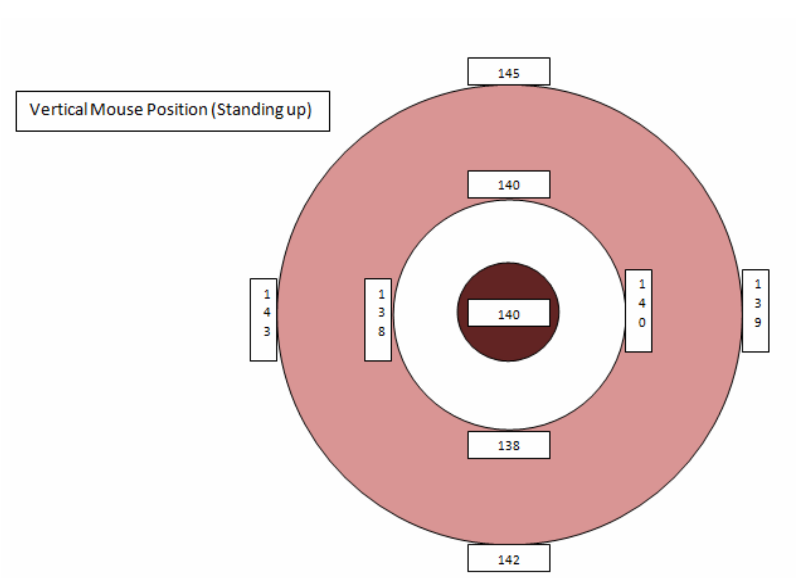
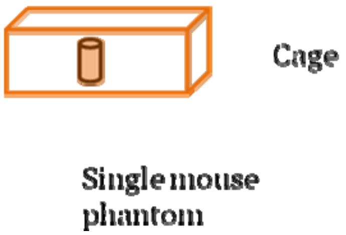
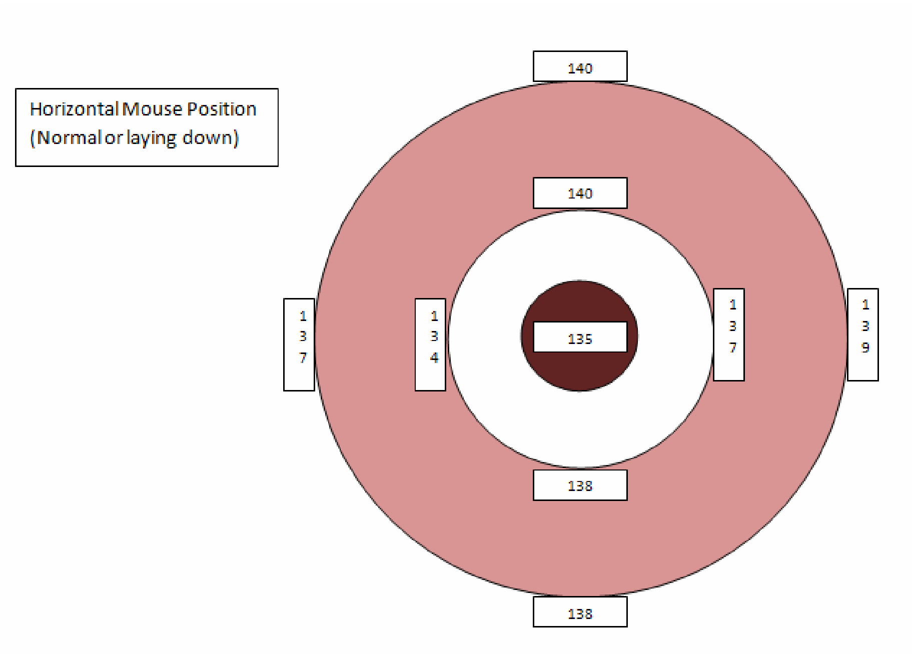


Figure 6





The optical density of the film strip was then plotted using the Risoscan software.

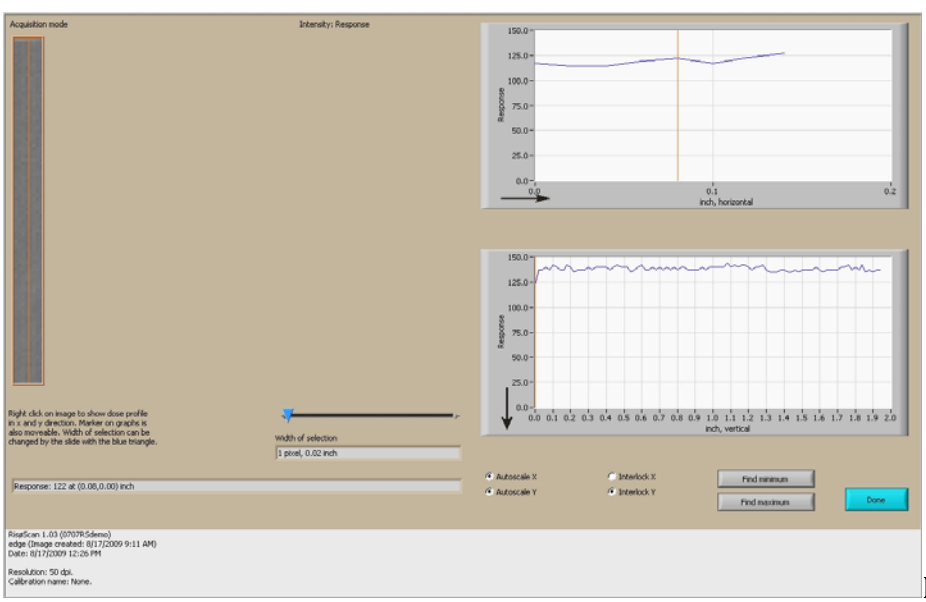


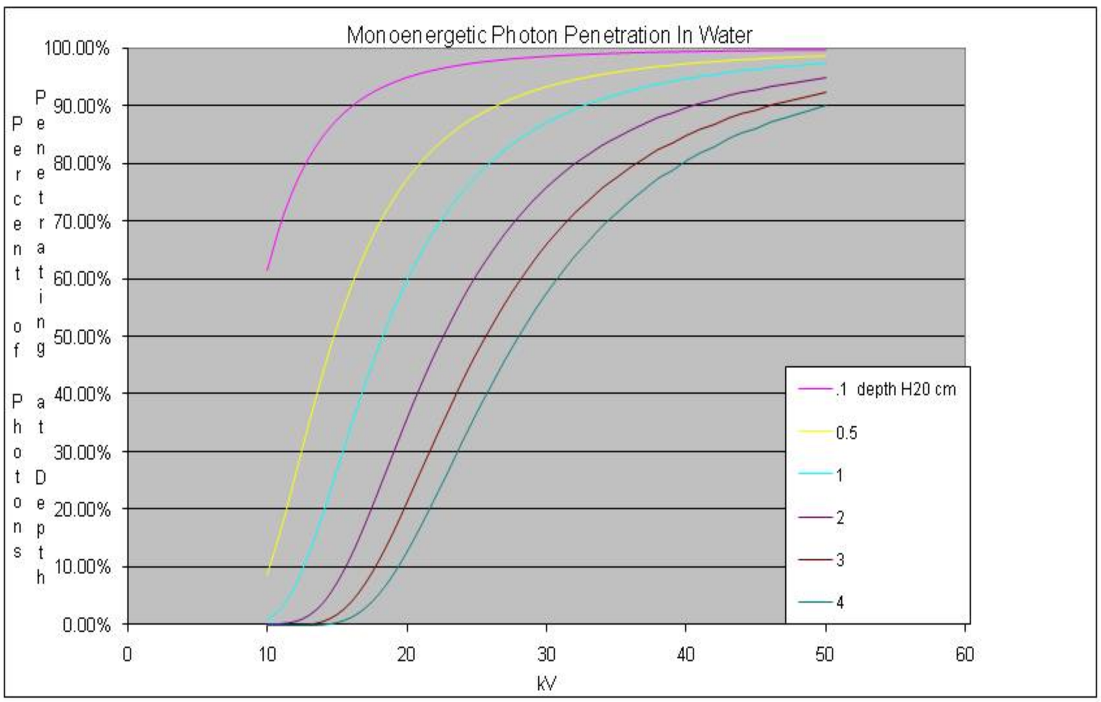
Figure 7

Sample output from Risoscan

The dose uniformity when evaluated both outside the mouse phantom and inside the phantom demonstrates a high degree of uniform irradiation. Odtop on position 1 demonstrates a 4% dose increase over the balance of the films. While we are investigating it as an anomaly, for this report it must be accepted as accurate.

As demonstrated by the phantom there is very little low energy in the spectrum. A monoenergetic beam was plotted using the Briggs & Lighthill Tables to determine monoenegetic photon penetration in water. The results indicate a high degree of penetration at 47 kV for 3 cm water. This allows some assumptions. A mouse irradiated with a spectrum of >47 kV to any maximum will eliminate any low energy effect. Exit energy of the photon is unimportant unless it is below the energy level of 100 eV. (the energy needed to complete ionization)

mono energetic photon penetration in H_2O (model)



RS2000 Spectrum

The spectrum of the RS 2000 represents a modified spectrum using .3 mm Cu filtration. Measurements were taken at kV levels from 30 kV to 45 kV at 5 kV intervals. A reference was measured at 160 kV to represent the full filtered spectrum.

RS 2000 % photons measured at given kV

Measured Results	Estimated photon loss (from table)
Total 1.36	
<30 kV .00075	<30 kV 32% absorbed through 3 cm water
<35 kV .0045	<35 kV 20%
<40 kV .012	<40 kV 17%
<45 kV .024	<45 kV 11%

Absorbed Photons *% / Total Photons
<30 kV .0024% absorbed through 3 cm water
<35 kV .006%
<40 kV .15%
<45 kV .19%

The amount of low energy in the spectrum as measured by this method shows a .19% component of energy < 45 kV. While it does not measure the distribution of the low energy the small amount below 30 kV therefore with a 10 Gy exposure .024 Gy is the level of interest and will have no effect.

Changes in kV and Practical Useable Dose:

Increases in kVp for a given power level produce complex irradiation results. The increase to 320 kVp does increase the total number of photons of all energies. At the k-edge or peak photon production energy 50+ kV the photon count increases the most.

This is irrespective of the peak kV.

The result is that the amount of filtration has to increase as compared to that at the 160 kVp example, to get the same uniformity of absorbed dose. If not, excessive low energy photons will affect the irradiation of the animal.

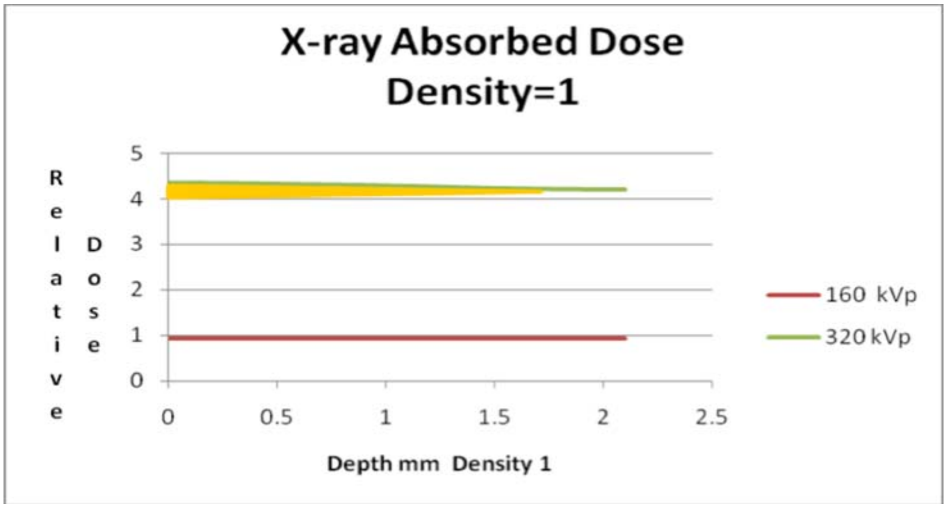
The overriding factors contributing to a successful outcome in ablating bone marrow in mice using a point source can be summed to four basic physical determinants:

First, the initial beam dose must be measured accurately between the filtration and the animal.

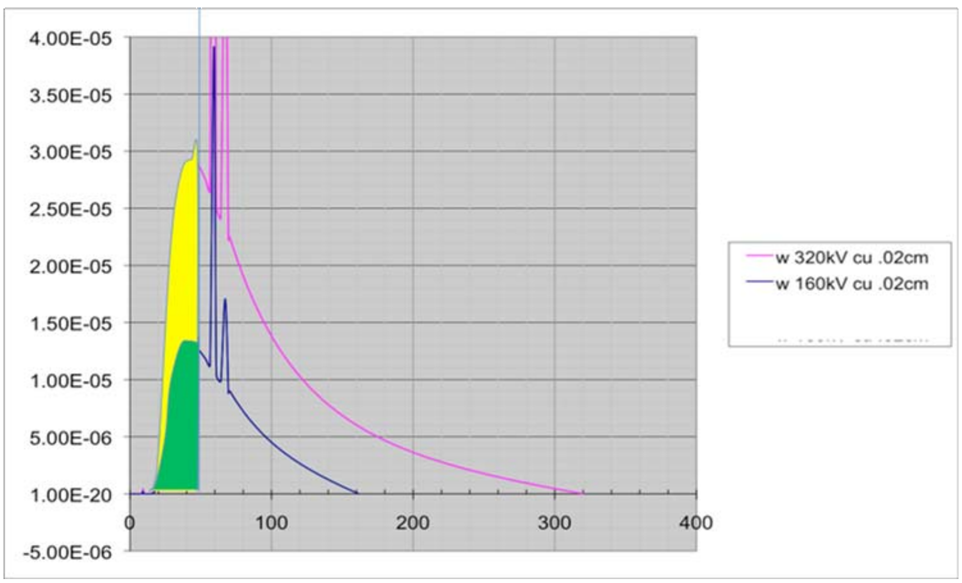
Second, filtration must result in a uniform deposition of energy through the animal.

Third, the geometric loss must be mitigated in some manner and

Fourth, the power (the kVp setting times the mA setting) must yield an acceptable dose rate after filtration.



= Photons deposited in non-linear fashion throughout the animal.



= Photons requiring filtration at 160kVp

= Photons requiring filtration at 320kVp