# Experimental Analysis of Wedge Factors for Neutron Therapy

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## ABSTRACT

Wedge Factor measurements were performed for the wedges that are used at the Neutron Therapy Facility for cancer neutron therapy. Wedge factors enable the calculation of the amount of beam that is necessary to deliver the required dose for treatments that use wedges. For the measurements an ionization chamber was positioned at different depths in a polyethylene phantom. The wedge factor dependence on the depth and collimator size was investigated. The procedure consists of measurements with and without wedges. The measured values were compared with the wedge factors calculated in 1983. After the analysis, recommendations and conclusions were made.

## INTRODUCTION

In 1976, the Neutron Therapy Facility (NTF) began providing neutron therapy for cancer treatments at Fermilab, [1-2]. A collimator system was developed to conduct the neutrons from the beryllium production target, where they are produced after the interaction of protons with the target, to the patient. Interchangeable concrete collimators with polyethylene beads as aggregate are used as part of the system. They have a total length of 78 cm and can be changed in order to obtain the desired field size [3].

When a patient is to be treated, it is necessary to shape the neutron beam in order to fit the contour of the patient and of the tumor. Sometimes wedge filters are used to compensate for the shape of the patient. These devices are positioned at the neutron beam output port and they are triangular in shape, Figure 1. They are made of Teflon and are used to produce the desired dose distribution [4]. The use of Teflon wedge filters has several advantages over other materials that could be used for this type of filters. Teflon has a short half-life (~20 min), which means that it does not remain radioactive for a long time. It is a very dense material and therefore makes it possible to construct more compact wedges. It traps the recoil protons that come from the interactions with the concrete collimator without adding a considerable amount of charged particles to the beam. Teflon also has favorable beam hardening properties [4].

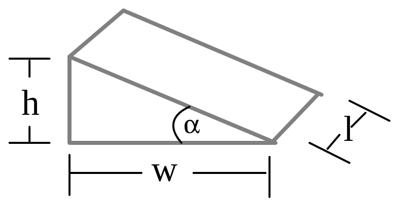


**Figure 1.** *Teflon Wedge Filter*

The wedges are characterized by a certain angle α, which tilts the isodose curves from their normal position and modifies the normal to the central axis. The isodose curves represent the distribution of dose that is to be received at a specific depth of the treatment area. It is possible to calculate the effects that the wedges can have on the tangent to the isodose curve at the central axis. If the tangent to the isodose curve needs to be rotated through an angle θ, the wedge should have an angle α such that the extra beam attenuation due to the thickness *a* of the wedge material compensates for the attenuation that would have occurred in the corresponding phantom thickness [4], Figure 2. For small angles of φ, for the neutron rays close to the central axis, the following expression relates the wedge physical angle to the isodose tilt angle:

$$\tan\alpha \propto \frac{R}{r}\tan\theta \ .$$

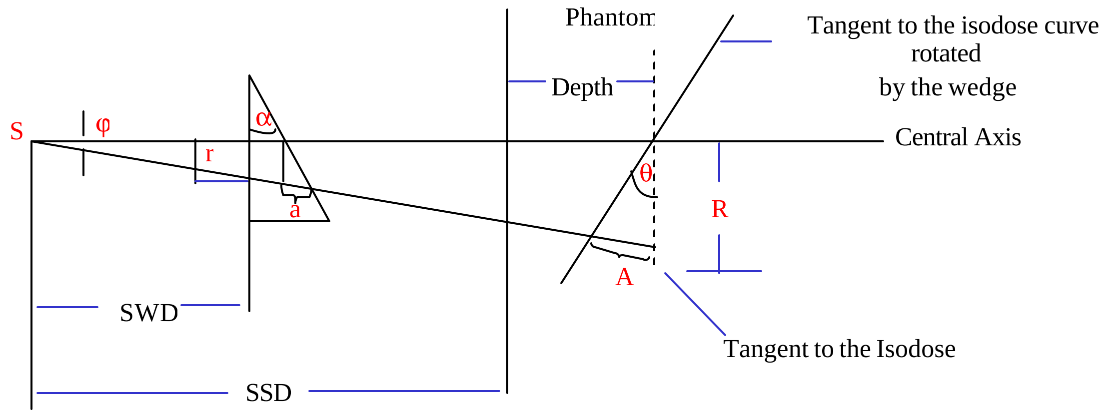


**Figure 2.** *Geometrical relationship between source, wedge, phantom and tangent to isodose curve at central axis; were S is the production source, R and r are distances measured from the central axis and are defined by an arbitrary ray from the source at an angle j from the central axis. SSD is the source to skin distance and SWD is source to wedge distance, [4].*

It is important to know how the dose changes when a wedge filter is present in order to provide the correct amount of beam necessary to give the patient the desired dose. This difference in dose, when wedges are used, is called the wedge factor. The wedge factor is a measurement of the amount of beam that is lost as it passes through the wedge. As part of this work, this factor was measured for different field sizes at different depths in a polyethylene phantom. The wedge factors obtained in this work will be compared with the factors that were calculated during the development of NTF's treatment planning system in 1983.

## METHODS AND MATERIALS

For measurements of the wedge factor four different wedges with the following properties were used.

| **Wedge** | **Isodose Tilt Angle** q **(º)** | **Height (cm)** | **Width (cm)** | **Length (cm)** | **Physical Wedge angle** a **(º)** |
|---|---|---|---|---|---|
| 1 | 45 | 5.3 | 8.9 | 17.2 | 31 |
| 2 | 45 | 8.9 | 15.0 | 17.5 | 31 |
| 3 | 60 | 10.2 | 10.2 | 10.2 | 45 |
| 4 | 60 | 15.2 | 15.2 | 15.2 | 45 |

**Table 1.** *Wedge properties excluding metal screw mounts*

The measurement phantom was a 40 cm x 40 cm x 40 cm cube of polyethylene and it was positioned approximately at 190 cm from the beryllium target. The cube has nine holes, each one separated by 4 cm. The holes provide different depths in increments of 4 cm. The addition of a 2 cm thick slab of polyethylene in front of the cube allowed the acquisition of data in 2 cm increments.

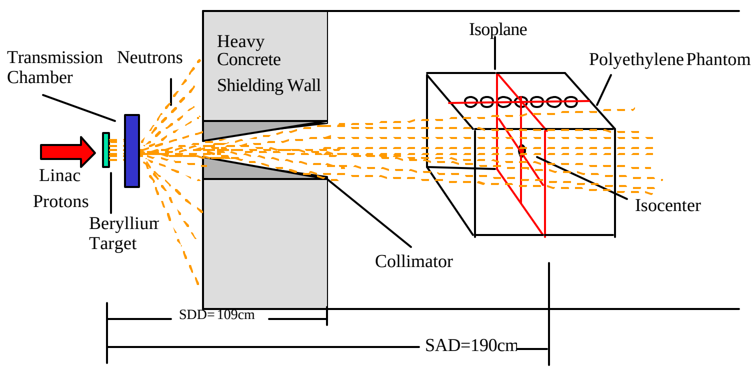


**Figure 3.** *Experimental Setup*

For the wedge factor measurements two ionization chambers were utilized. The first one is a Spokas Thimble Chamber, Model T2 with serial number 462 and with an active volume made of tissue equivalent plastic, Figure 4. This chamber was placed at each depth in the phantom to measure the dose that an actual patient would receive at that depth. The phantom was moved so the chamber was always at 190 cm from the beryllium target. The second ionization chamber is a transmission chamber located just downstream of the beryllium target. This chamber measures the amount of neutrons that are produced by the target just after protons hit it.

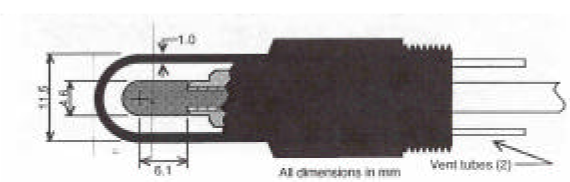


**Figure 4.** *Schematic diagram of the Spokas Thimble Chamber, Model T2.*

The wedge factor number calculation involves the measurements of the charge that is collected by the ionization chamber in the phantom normalized to the charge collected by the transmission chamber. To calculate the wedge factor, measurements were performed with and without wedges. The normalized charge was multiplied by a temperature, pressure correction factor: $TPCOR \equiv \frac{T + 273.15}{295.15} \times \frac{1013.25}{P}$, where T is the room temperature in ºC, and P is the pressure in millibars. The wedge factor is given by:

$$\text{Wedge Factor} = \frac{(\text{Normalized Charge x TPCOR})_{\text{wedge}}}{(\text{Normalized Charge x TPCOR})_{\text{no wedge}}}$$

The wedge factor was measured for different depths and different collimator sizes. The nominal collimator size is the area of beam that is projected at the plane normal to the beam axis at the isocenter. This plane is called the isoplane. The isocenter is the point on the beam axis at 190 cm from the target at the phantom, Figure 3. Not every wedge was used for each collimator, Table 2. Smaller wedges cannot be used with larger collimators, because they do not cover the beam aperture. Larger wedges are not normally used for small collimators because they absorb more of the beam and therefore the treatment takes a longer time.

| **Wedge** | **Collimators used (cm x cm)** |
|---|---|
| 1 | 3x3, 4x4, 6x6, 8x8, 10x10, 12x12, 14x14 |
| 2 | 10x10, 12x12, 14x14, 16x16, 18x18, 20x20, 24x24 |
| 3 | 3x3, 4x4, 6x6, 8x8, 10x10, 12x12, 14x14 |
| 4 | 10x10, 12x12, 14x14, 16x16, 18x18, 20x20, 24x24 |

**Table 2.** *Collimators used for each wedge*

## RESULTS AND DISCUSSION

The wedge factor was measured for each of the collimators presented in Table 2 and for depths ranging from 4 cm to 26 cm in the polyethylene phantom. As expected, the wedge factor is a function of the collimator size and the depth. It increases as depth and collimator size increase; while the dose reduction of the wedge diminishes, Figures 5-12. This relationship does not appear to be linear, and the wedge factors measured suggest a curvature as depth increases. After the measurements of the wedge factors were made, the results were compared with the calculations made in1983.

Our wedge factor measurements are close to the ones calculated for the 10 cm x 10 cm collimator at 10 cm deep, Figure 8. The deviation between the wedge factor values increase with increasing depth. Most deviations between them is in the range of 1%-3%. Three measurements have deviations larger than 3% for wedge 3. These measurements were performed at a depth of 26 cm in the phantom. The deviation for these points is, 4% for 3 cm x 3 cm collimator size, and 5% for 4 cm x 4 cm and 6 cm x 6 cm collimators, see Figures 5-7.

The discrepancies described above could be due to he fact that our measurements were performed in a polyethylene phantom where the ones made at 1983 were performed in a tissue equivalent material phantom. Certainly, these two materials have different absorption and scattering properties that can affect the amount of charge that is collected by the ionization chamber. It is possible that more beam was required for each measurement. If the measurements are performed for longer period, more charge will be collected and errors in the charge readings could be minimized.

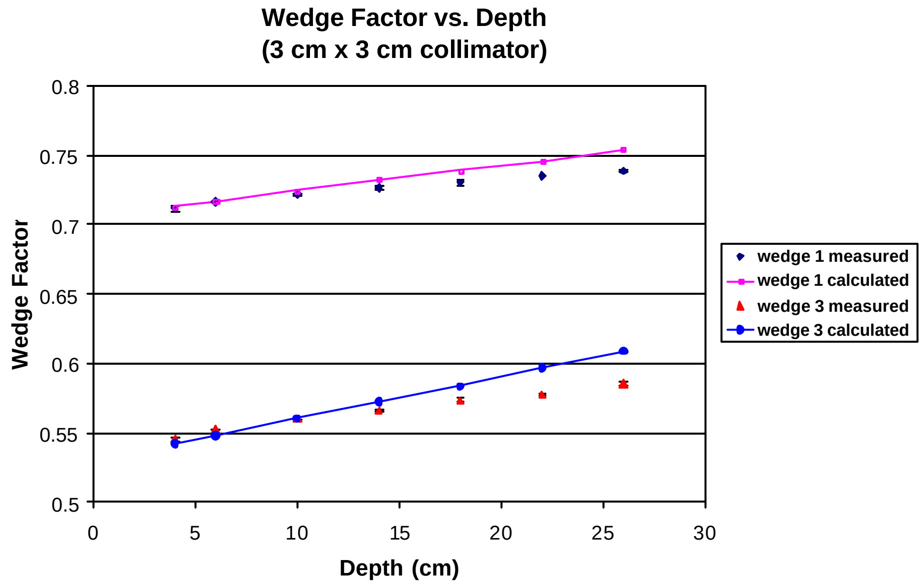


**Figure 5.** *Wedge Factor for 3cm x 3cm collimator as function of depth in the phantom.* The deviation between the wedge factors, the measured and the calculated, gets larger as depth increases, rising to 4% for wedge 3 at a depth of 26 cm in the phantom.

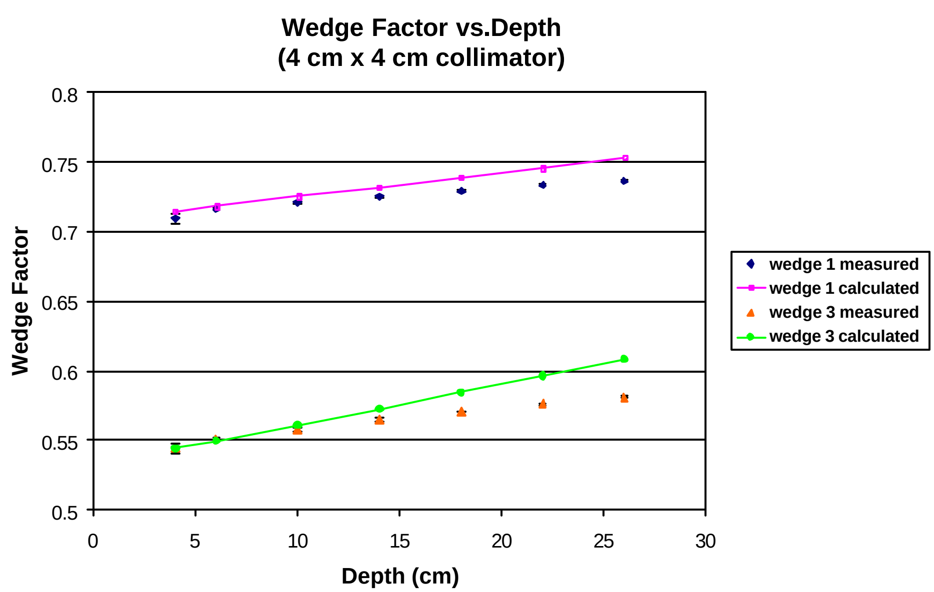


**Figure 6.** *Wedge Factor for 4 cm x 4 cm collimator as function of depth in phantom.* The deviation between the wedge factors measured and the calculated values gets larger as depth increases, rising to 5% for wedge 3 at a depth of 26 cm in the phantom.

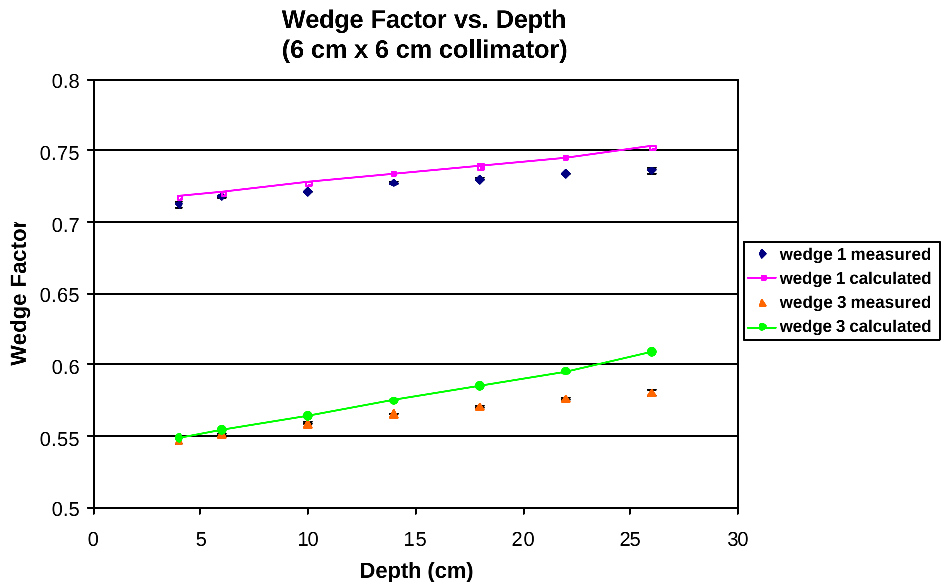


**Figure 7.** *Wedge Factor for 6 cm x 6 cm collimator as function of depth in the phantom.* The deviation between the wedge factors measured and the calculated values gets larger as depth increases, rising to 5% for wedge 3 at a depth of 26 cm in the phantom.

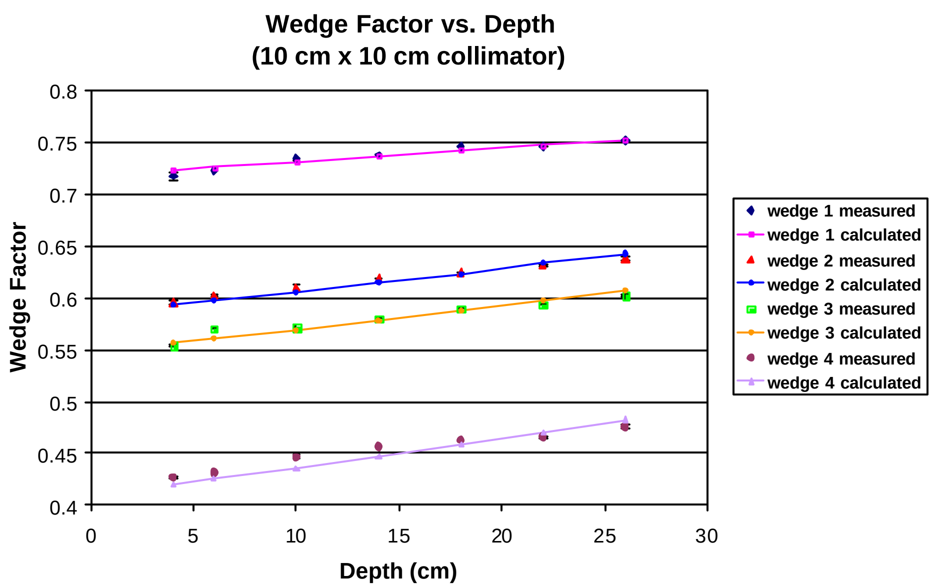


**Figure 8.** *Wedge Factor for 10 cm x 10 cm collimator as function of depth in phantom.* The wedge factors measured is consistent with wedge factors calculated for the wedges that were used. For wedge 1, 2 and 3 the deviation between the values is about 1% and for wedge 4 increases from 1% to 2%.

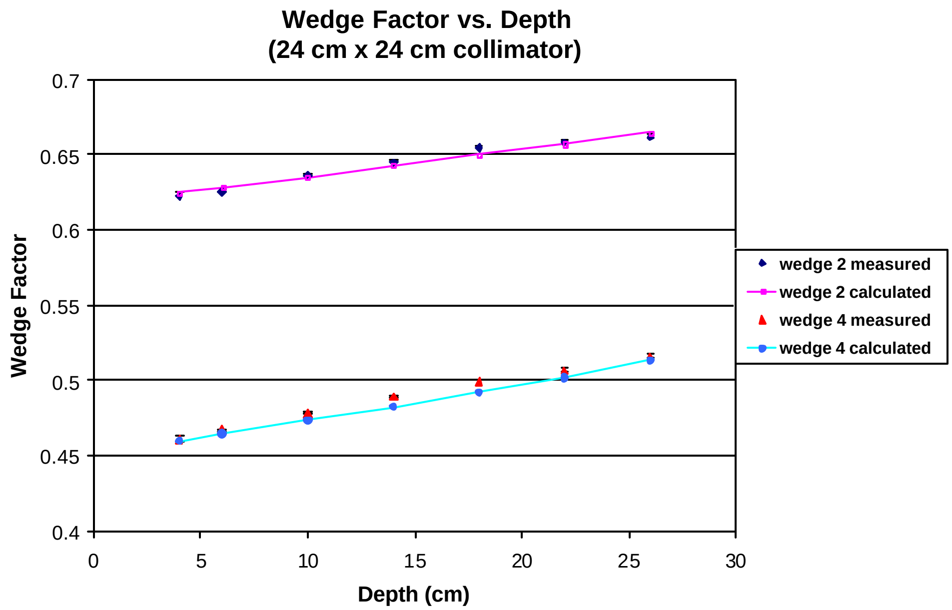


**Figure 9.** *Wedge Factor for 24 cm x 24 cm as function of depth in phantom*. The values of the wedge factors measured for this collimator are larger than the ones calculated as depth increases. The greatest deviation between the values is 1%.

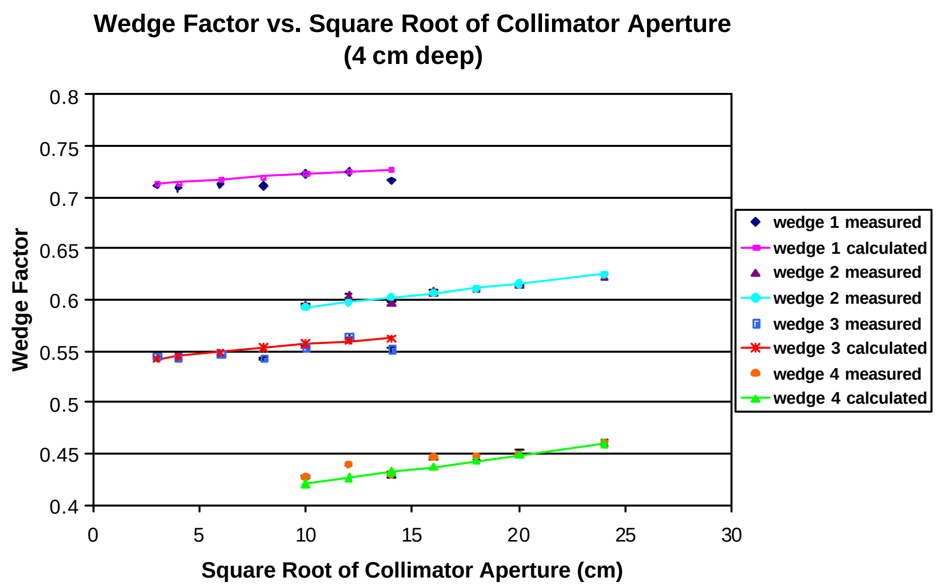


**Figure 10.** *Wedge Factor for measurements at 4 cm deep in the phantom*. The wedge factor is presented as a function of collimator size. The largest deviation between the values can be seen at wedge 4.

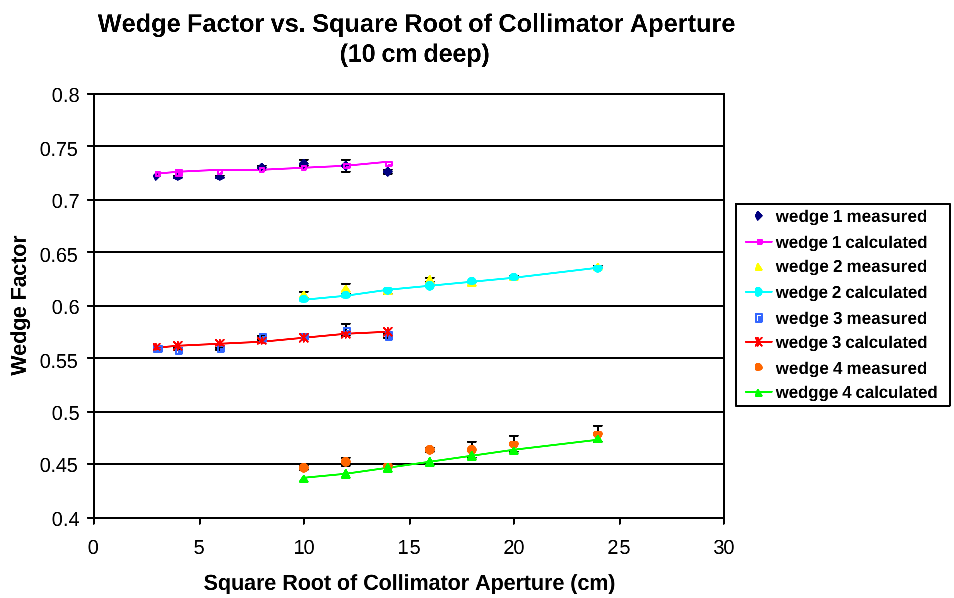


**Figure 11.** *Wedge Factor for measurements at 10 cm deep in the phantom.* At this depth both values are more consistent for 10 cm of square root of collimator aperture for the four wedges that were used. The highest deviation between the wedge factors was for wedge 4 for smaller collimators.

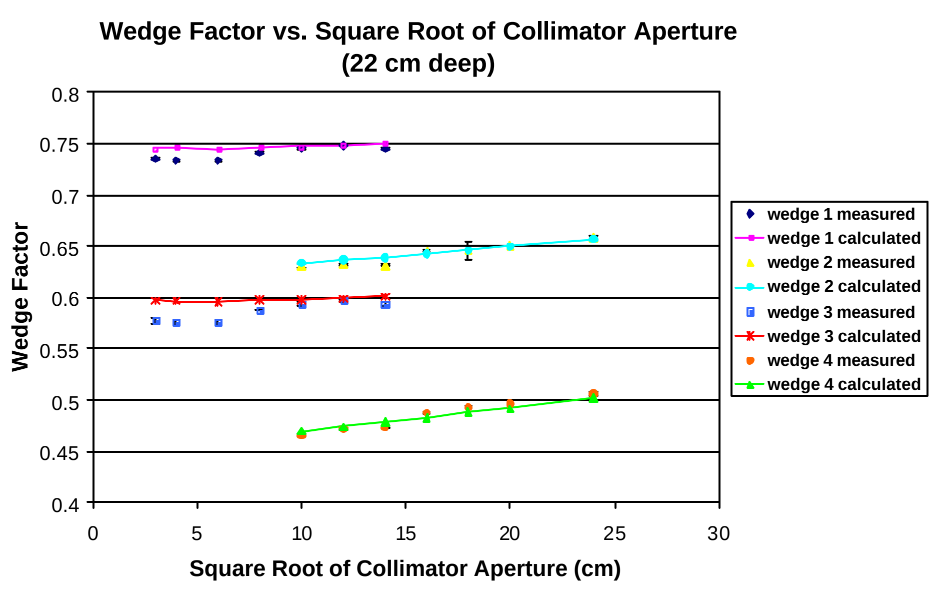


**Figure 12.** *Wedge Factor for measurements at 22 cm deep in the phantom.* For wedges 1 and 3 the deviation between the two wedge factors, measured and calculated, is larger for small collimators. On the other hand for wedges 2 and 4 the deviation is constant for all the collimators used.

## CONCLUSION AND RECOMMENDATIONS

A comparison of the wedge factors measured with those previously calculated, show a 1% to 3% difference for most measurements. At increased depth, the difference increases to 4%-5%. From the data is clear that the wedge factor depends on the collimator size and the depth in the phantom, but the wedge factor measured suggests a more complicated relationship with depth and collimator size than was originally used. Therefore it is recommended that new measurements be made. For the new measurements, a tissue equivalent phantom should be used to ensure more accurate data that can be compared with the 1983 data. It is also recommended that the measurements be performed with longer beam exposure time in order to increase the accuracy of the results. Finally an improved phantom positioning system should be developed to facilitate phantom setup after interruptions in data acquisition.

## REFERENCES

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