Investigation of charge buildup in cabled detectors in the Small Animal Radiation Research Platform (SARRP)

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Purpose: Preclinical radiation experiments using small animals are an integral part of understanding radiation effects in tissues. Reproducibility has proven difficult with radiation biology preclinical studies, and it is suggested that much of this is due to lack of viable dosimetry for small animal irradiators[1–3]. This work is part of a larger goal of improving dosimetry in the Small Animal Radiation Research Platform (SARRP), a low energy conformal irradiator with imaging and delivery capabilities similar to those of a clinical linear accelerator.

The purpose of this work was to investigate trends in ion chamber readings taken in the SARRP. Analysis of behavior of ion chambers with high dose has shown electret (quasi-permanent electric charge on a dielectric material) formation in the insulating materials of dosimeter cables. This effect can cause trending measurements during irradiation and high leakage current post-irradiation.

Methods: This study utilized the treatment beam of the SARRP, which is set at 220 kVp and 13 mA with 0.15 mm copper filtration. All measurements were taken with the detector placed at 35 cm SSD, where the open field size was approximately 13x13 cm^2. Initially, integrated charge readings of 30 seconds were taken over a period of 1 hour continuous radiation with an A10 parallel plate chamber. It was noticed that the reading changed with time of radiation.

Several different triaxial cables, electrometers, and ion chambers were used to attempt to understand the cause of the effect. To check for instabilities in the tube itself, measurements were taken with film and with two detectors in the field simultaneously. The film measurements showed a stable output over time, while the detector results are shown in figure 1. In Irradiation 1 the response continually decreases for the chamber 0.3% with an exposure of 30 minutes, whereas the diode increases the same amount with an exposure of 30 minutes.

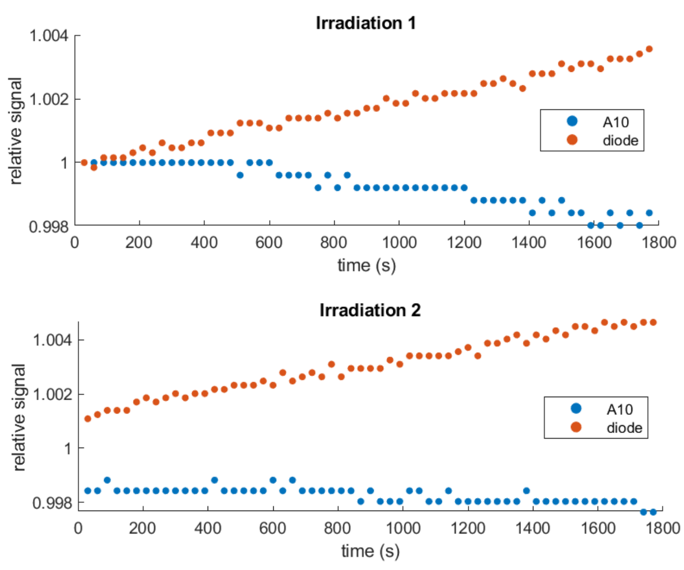

Figure 1: Results of 35-minute irradiations of an A10 and diode simultaneously with the beam off for 1.5 hours in between irradiations. The measurements for both detectors had a non-zero slope but trended in opposite directions. Additional measurements with a shorter beam off time in between irradiations had shown second irradiation initial measurements closer to the final measurement of the first irradiation, suggesting the trend was from a buildup of charge that decayed with time post-irradiation.

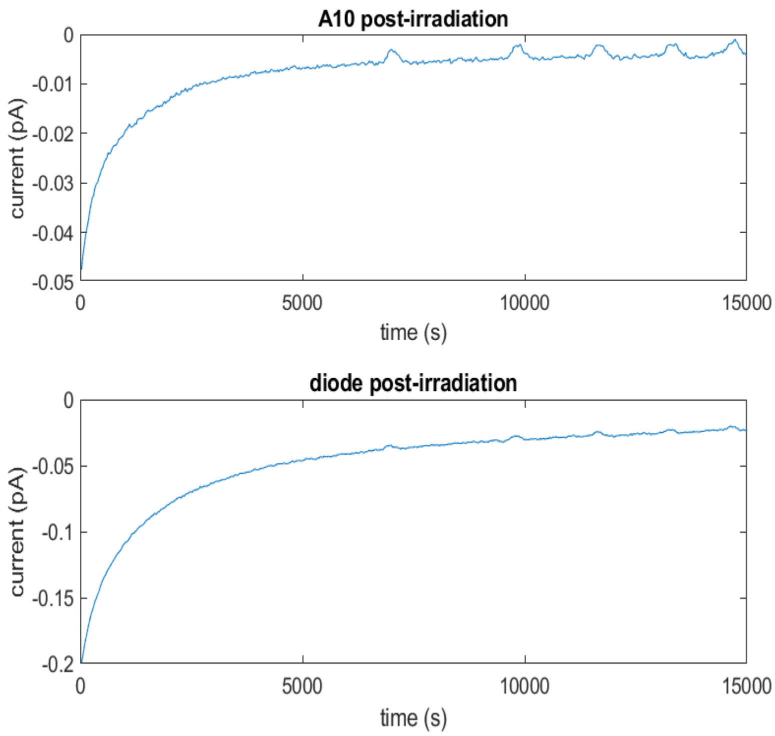

Figure 2: 30 second charge readings were taken post-irradiation for an A10 parallel plate chamber and diode. Readings are displayed as current in the figure. The retained charge due to electret formation was slow to decay and after about 2 hours the associated current synchronized with changes to the room temperature, resulting in the four spikes seen in the figure.

The effect of the cable in the field was investigated in several scenarios involving moving extra cable into or out of the field, shielding the cable, and collimating the field to be just larger than the sensitive volume of an ion chamber. All results agreed that the more insulating material was in the field, the steeper the slope of the measurements and the higher the current post-irradiation.

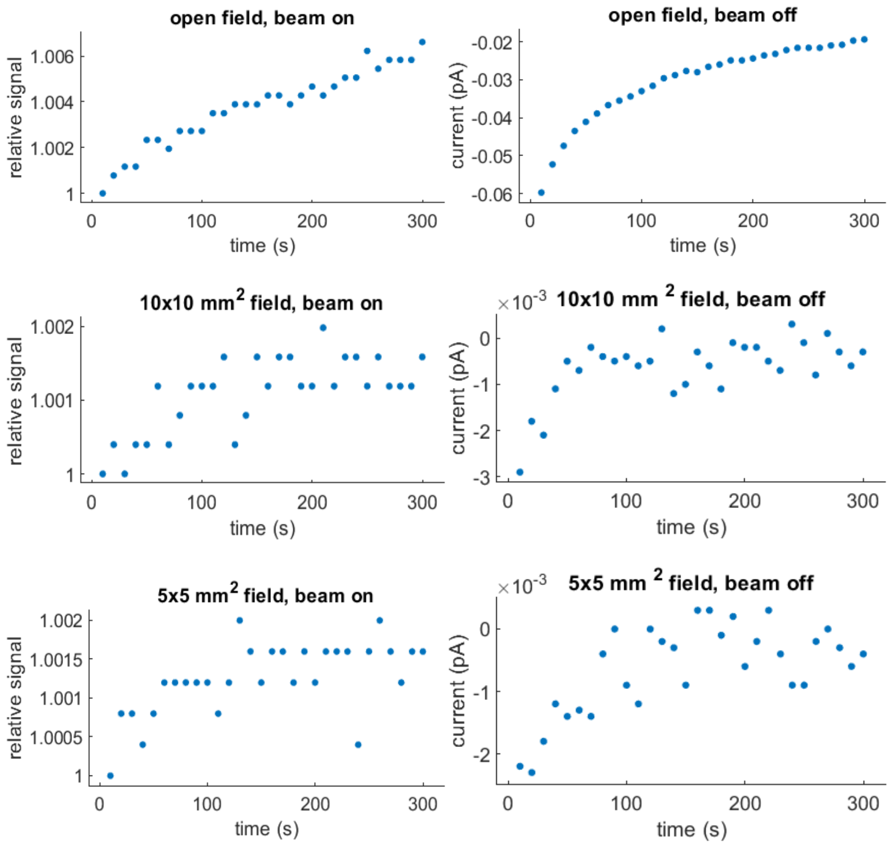

Figure 3: A26 in a 5x5 mm^2 field, just larger than the sensitive volume of the chamber. There is still a small trend with the collimated fields, but the effect is much less significant.

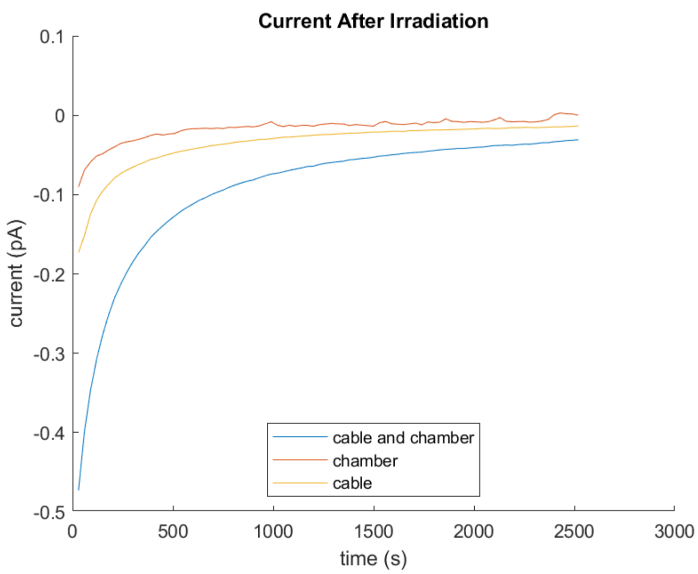

Figure 4: Post-irradiation 30- second charge readings using an A10 with just the chamber in the field, both the cable and the chamber in the field, and just the cable in the field with the chamber shielded and placed far from the field edges were taken and converted to current. The more cable was in the field, the more pronounced the current due to charge retention was.

The effect of bias on ionization chamber behavior was also examined, although the behavior of the diode had already suggested that external bias would not have an effect.

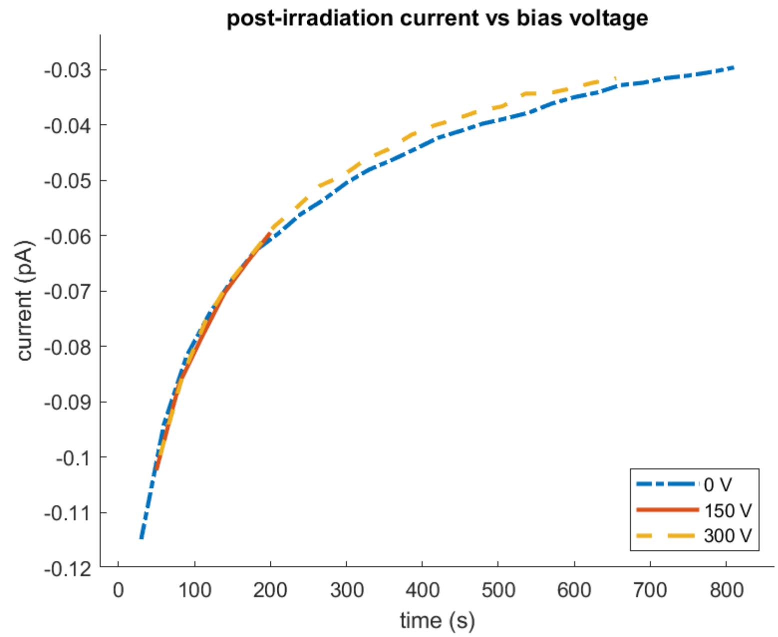

Figure 5: post-irradiation signal at different biases

Dose due to scatter was examined by taking film measurements along the length of the ion chamber cable outside the field in a normal open field irradiation setup. The first film was placed at the start of the cable 1 cm outside the edge of the field. Over a 30-minute irradiation, regions of the cable closest to the field edge received as much as 24 Gy for a total dose of 680 Gy over the course of this study.

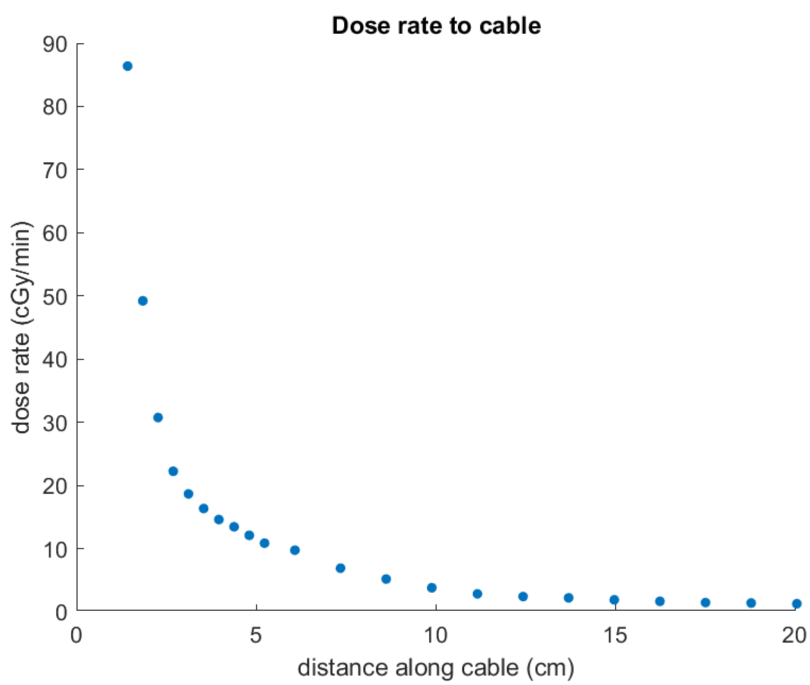

Figure 6: Out of field dose to the cable of an ion chamber. Dose rate about 1 cm outside the field is approximately 30% of the 3 Gy/min dose at isocenter.

The post-irradiation charge follows the temperature variation as shown in figure 2; the variation is about 3pC. These spikes continue for days after irradiation. These spikes were measured in a temperature-controlled environment and results can be seen in figure 7.

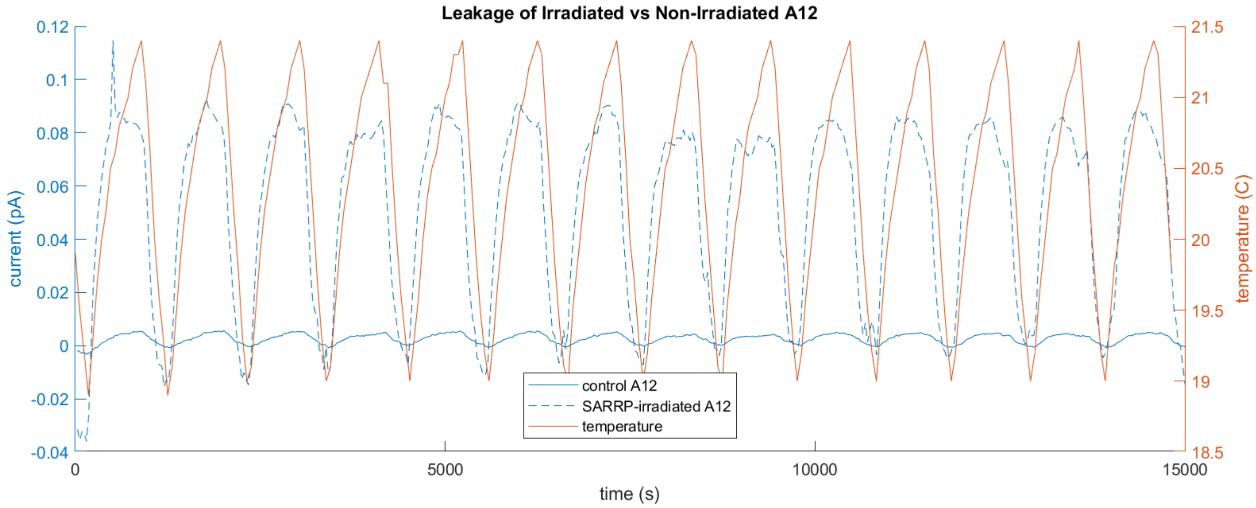

Figure 7: Charge readings for two A12 chambers with no radiation present– one chamber has been irradiated for 1 hour in the SARRP and one has not. Leakage was the same for both prior to irradiation of one in the SARRP. These spikes continue for many days and coincide with steep temperature gradients.

Results: The decay of the current post-irradiation was dependent on the amount of insulating material in the irradiation field and independent of bias voltage, which suggests a charge-trapping mechanism such as that found in solid-state-detectors, where electrons fill traps that will release over time, resulting in lingering current following irradiation. The effect was greatly reduced with collimation, caused by less cable irradiated but still was present. This suggests there could be significant out-of-field dose in the cabinet that is causing the charge buildup, which was verified by the measurement of high dose rate to the cable outside the field. The charge also has a very long half life at room temperature, causing high leakage current that oscillates with temperature changes for days following the irradiation. All of these behaviors align with previous studies on the formation of electrets in insulating materials as a result of low energy photons or electrons.[4–9]

Conclusions: This study investigated the abnormal response of detectors in the Small Animal Radiation Research Platform (SARRP). It was found that charge builds up on the insulating materials during irradiation, forming electrets that cause trending measurements and post-irradiation current with a long half-life. These effects can be reduced by collimating the field to be just larger than the chamber. The presence of insulators in the stem and ion chamber also enables some charge buildup even with the cable entirely shielded. The effects are minimal in short irradiations, where the out of field dose to the cable will be minimal. This electret formation can be reduced if the cables are shielded as thoroughly as possible. The time in the beam should be minimized to reduce the amount of charge stored.

Relevance to CIRMS: This work relates to the CIRMS mission since ion chambers are a common method of measuring dose, and care should be taken in not exposing cables to total high doses of low energy radiation more than necessary. The electret formation presented in this paper provides warning of high out of field dose to cables in the SARRP. The first author aims to become a clinical medical physicist working with ionization chambers to measure dose.

References:

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