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Test GammaPix™ Radiation Detection Software with Smartphones

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DISCLAIMER

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Introduction

GammaPix™ is a smartphone application available for both Android and iPhone operating systems that uses the smartphone camera sensor to detect and measure ionizing radiation fields. The software analyzes digital images produced by a smartphone camera to determine the local gamma-ray radiation environment. It compares a dark image (i.e., with the camera covered) to one with bright pixels caused by photons from a radiation source, which pass through a covered camera lens. Recently, a Rapid Response Test (RRT) was conducted at Brookhaven National Laboratory to test the effectiveness and accuracy of GammaPix™ in detecting radioactive materials on a range of smartphones. A series of experiments were carried out to evaluate the detection capability, measurement capability, and low and high detection limits of GammaPix™ and establish the working suitability of GammaPix™.

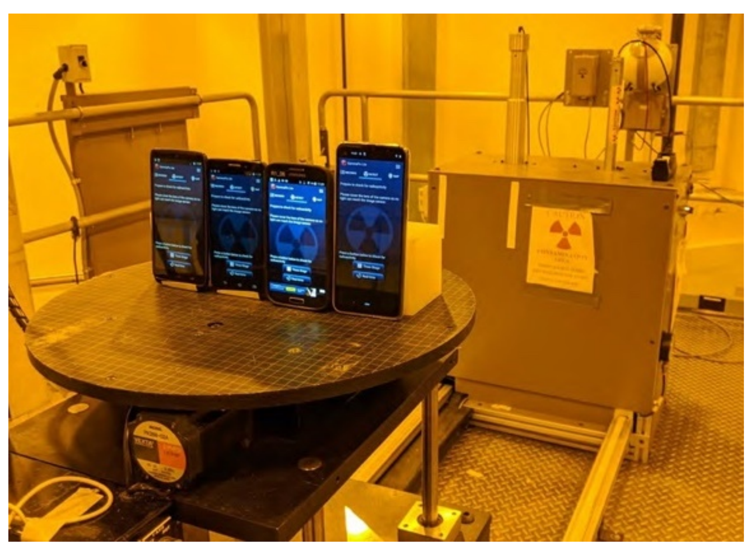
System Under Test (SUT) Selection

Ten smartphones were selected for this test as shown in the table below. The Samsung Galaxy S4 was the only SUT listed as an acceptable device on GammaPix™ website (http://gammapix.com/devices/). Given that the operating system for the phones listed constitutes a very low portion of current market share (less than 15%, see https://developer.android.com/about/dashboards), we decided to use primarily more modern phones in the test. Those phones would span the range in terms of megapixel sizes, to be able to capture any significant differences that may arise.

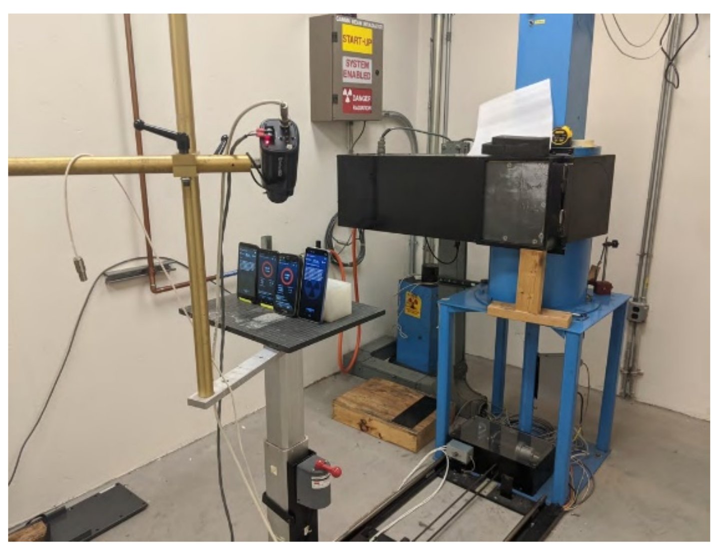
Phone Model (Camera Location)	Release Year	Camera Megapixels	GammaPix™ Version
Samsung Galaxy S4 (Front)	2013	2	Lite version
Apple iPhone 6S (Front)	2015	5	Full version
Samsung Galaxy S8 (Front)	2017	8	Lite version
Motorola Droid MAXX (Rear)	2013	10	Lite version
Samsung Galaxy S4 (Rear)*	2013	13	Lite version
Motorola Droid Turbo (Rear)	2014	21	Lite version
Samsung Galaxy A70 (Front)	2019	32	Lite version
Motorola One Vision (Rear)	2019	48	Lite version

* Device listed on the manufacturer's website

Experimental Setup



Low Scatter Irradiator

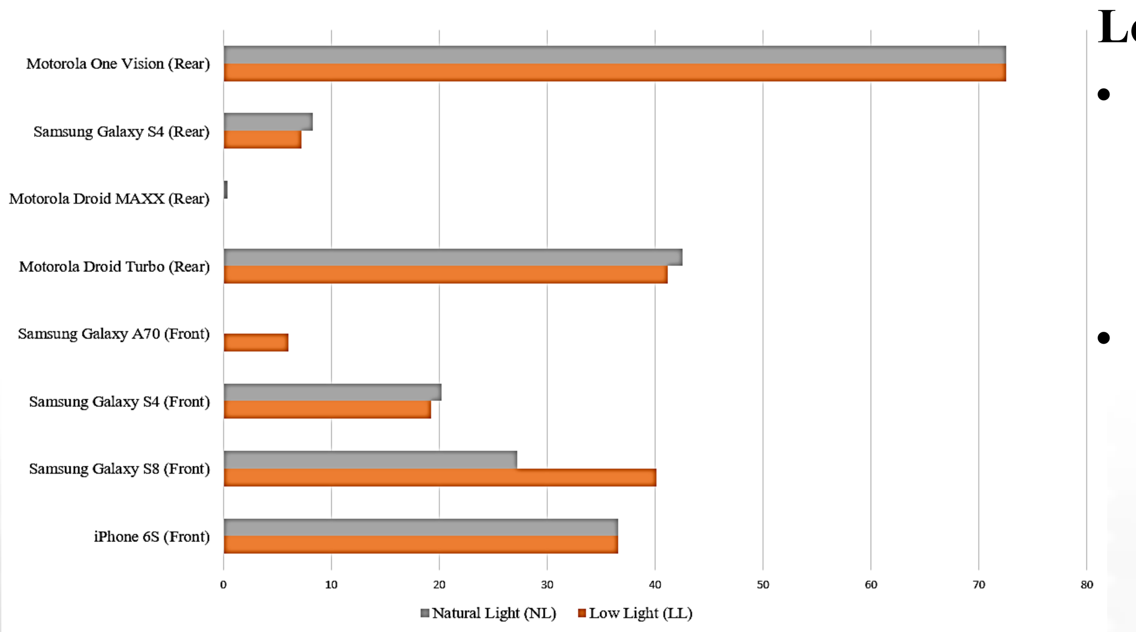


Gamma Beam Irradiator

Experiments

Experiments	Description
Low Light Measurement	To check if the phone cameras had been fully covered with aluminum foil and black tape, a requirement for GammaPix™ to function properly
Exposure Rate Measurement	To test the performance of GammaPix™ in radiation fields of intermediate energy gamma rays from ^{137}Cs. A range of dose rate sampling points from 1 mrem/hr to 100 rem/hr was measured.
High Energy Measurement	The same as the above exposure rate measurement, but with high-energy gamma rays from ^{60}Co. The purpose was to qualitatively study the change of the detection efficiency and accuracy along with the gamma-ray energy.
Over Range	This was a single point measurement to qualitatively test the response of GammaPix™ in a very high field, e.g., 1000 rad/hr.
Gamma in Presence of Neutrons	To determine whether GammaPix™ could detect and/or measure anomalies caused by neutron fields, and whether the presence of neutrons could affect the gamma rate measurements.

Test Results

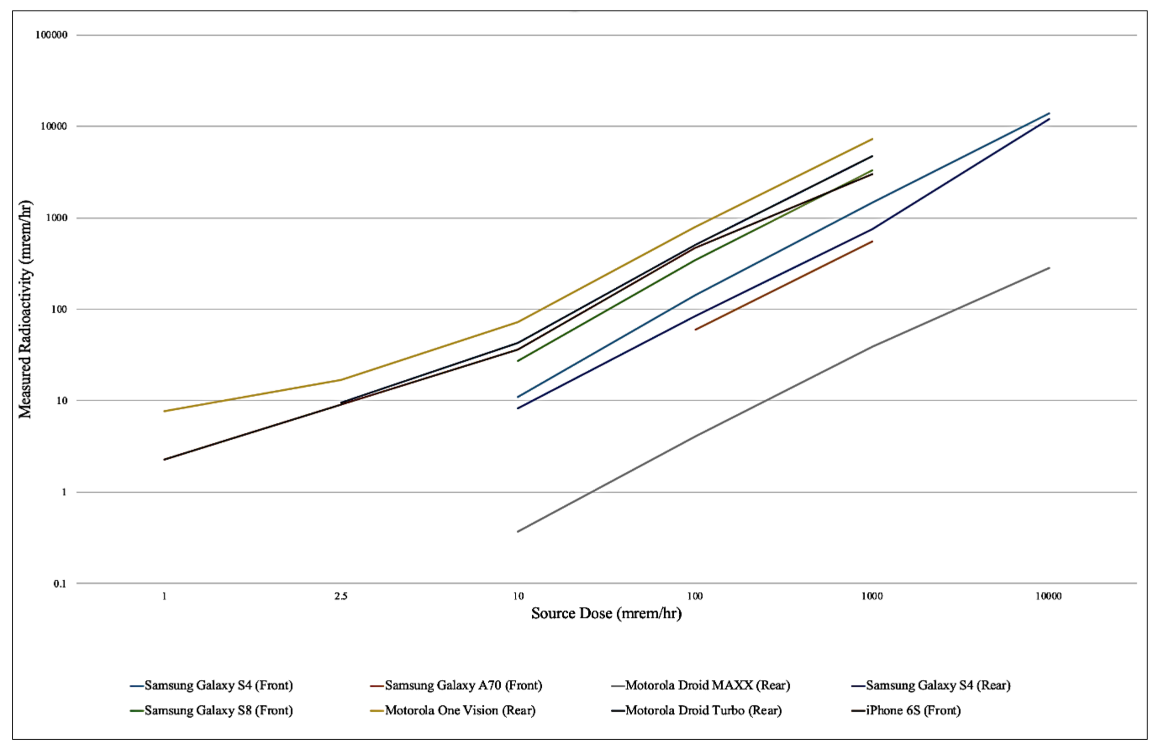


Low-light Measurements

- Most SUTs had comparable results in the two lighting conditions except the Samsung Galaxy S8 (Front).
- Note that Motorola Droid MAXX (Rear) gave Unclear in low light condition and Galaxy A70 (Front) gave All Clear in natural light condition, which were noted as zero.

Exposure Rate Measurements

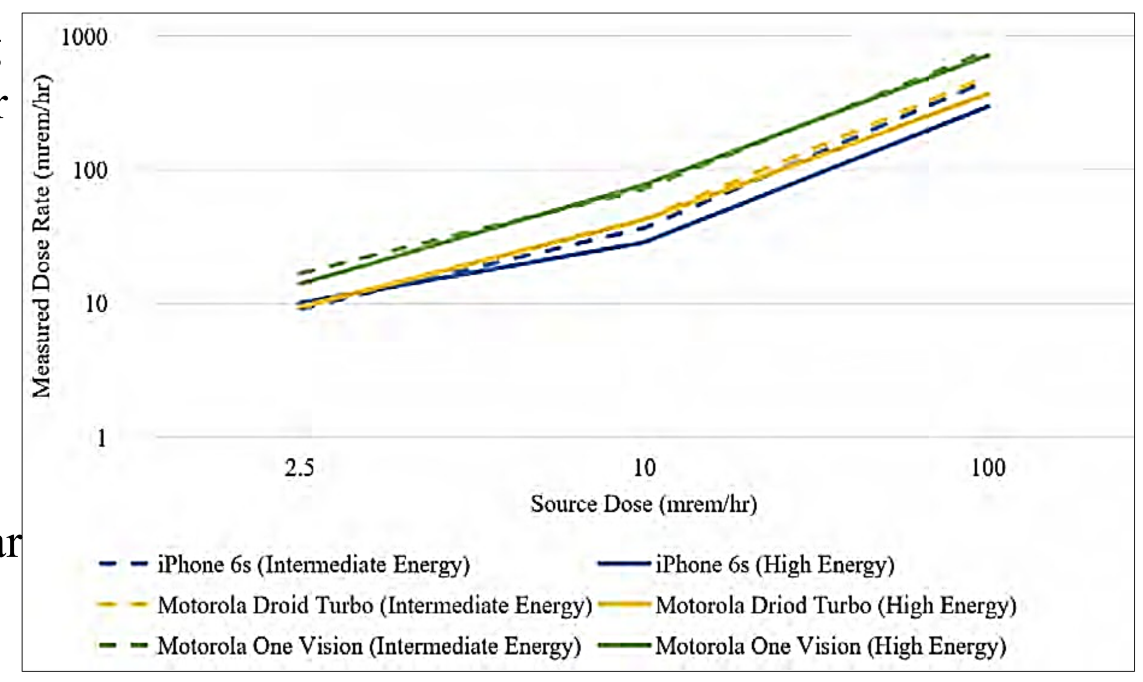
- None of the SUTs was particularly accurate, but the Samsung Galaxy S4 came closest with average absolute errors of 15% for the rear camera and 34% for the front camera.
- Most SUTs had good linearity allowing gain correction through single calibration.
- From a safety point of view, it would be better to use always-high phones.



- Most SUTs had a low detection threshold around 2.5-10 mrem/hr, and a high detection threshold of about 1 rem/hr.
- Two SUTs, the Apple iPhone 6S and the Motorola One Vision demonstrated wider detection ranges with the ability to get readings down at 1 mrem/hr.
- The Samsung Galaxy S4 had a range that managed to go up to 10 rem/hr for both cameras.

Exposure Rate Measurements

- Most SUTs didn't give a reading at 2.5 mrem/hr, indicating higher detection thresholds.
- Results of three low-threshold SUTs are shown on the right.
- The three SUTs can maintain similar gains at the lower dose range (2.5 - 10 mrem/hr).
- The three SUTs maintained linear factors like the ones in medium-energy response.



Over Range

- All the SUTs failed to give a reading in high fields with different report messages.

	Apple iPhone 6S (Front)	Samsung Galaxy S8 (Front)	Samsung Galaxy S4 (Front)	Samsung Galaxy A70 (Front)	Motorola Droid Turbo (Rear)	Motorola Droid MAXX (Rear)	Samsung Galaxy S4 (Rear)	Motorola One Vision (Rear)
Source Dose (1000 rem/hr)	ERROR	ERROR	ERROR	ERROR	ERROR	ERROR	ERROR	ERROR
Time to Fail (s)	30.0	LOOP	80.0	LOOP	180.0	180.0	LOOP	230.0
Error Message	Camera Anomaly	Camera Anomaly	Phone Camera Uncovered	Camera Anomaly	Camera Anomaly	Phone Camera Uncovered	Camera Anomaly	Camera Anomaly

Gamma Presence in Neutrons

- Phone cameras are insensitive to neutrons but may be vulnerable to neutron-induced radiation damages.
- Measured results (gains) are consistent with the gamma rate measurement above.

Source Dose (mrem/hr)	Apple iPhone 6S (Front)	Samsung Galaxy S8 (Front)	Samsung Galaxy S4 (Front)	Samsung Galaxy A70 (Front)	Motorola Droid Turbo (Rear)	Motorola Droid MAXX (Rear)	Samsung Galaxy S4 (Rear)	Motorola One Vision (Rear)
2.5	-	-	-	-	-	-	-	-
10.0	2.28	-	-	-	-	-	-	-
100.0	14.71	9.8	6.3	-	20.9	-	-	34.5

Conclusions

We tested GammaPix™ in NIST-tracible radiation fields with a wide range of smart phones. The test results highlighted the following findings:

- The detection limits varied with the SUTs but were assessed to be from 2.5 mrem/hr to approximately 1 rem/hr, indicating that GammaPix™ may not be suitable for some security-based applications, i.e. alert to low/transient levels of radiation in security and nonproliferation applications.
- The SUTs were generally inaccurate compared to the actual dose rate field. However, it should be noted that most models had linear response within the detection range. A simple calibration factor should yield a well-behaved response curve. Setting a manual calibration factor was not an available option in GammaPix™ so this could not be attempted in the test.
- The relatively slow response could put users in danger of overexposure in high dose rate fields.
- A calibration factor should be developed for each phone if a variety of models are going to be used.

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Test GammaPix™ Radiation Detection Software with Smartphones

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Abstract

GammaPix™ is a smartphone application that uses smartphone cameras to detect ionizing radiation. Brookhaven National Laboratory (BNL) evaluated the performance of the software in detecting radioactive materials. For this purpose, a series of tests were conducted at the Radiation Calibration Facility Annex at BNL. The experiments included dose measurements with three types of NIST-traceable calibration sources, ^{60}Co, ^{241}Am, and ^{137}Cs. The recorded results by GammaPix™ were compared with the values measured by calibrated dosimeters to determine the detection thresholds. Several selected models of iPhones and Android cell phones with different pixel sizes and resolution were tested. In this paper, we present the test procedures and discuss the test results.

1 Introduction

GammaPix™ is a smartphone application available for both Android and iPhone operating systems that uses the smartphone camera sensor to detect and measure ionizing radiation fields. The software analyzes digital images produced by a smartphone camera to determine the local gamma-ray radiation environment [1]. It compares a dark image (i.e., with the camera covered) to one with bright pixels caused by photons from a radiation source, which pass through a covered camera lens. This means that during operations, users would need to use electrical tape or other means to completely cover their phone cameras. Once covered, any additional light entering the camera can be considered ionizing radiation above background levels. It is important that the camera is covered during measurements so that GammaPix™ has an appropriate point of comparison and doesn't inadvertently calculate a high dose based on an uncovered camera.

Recently, a Rapid Response Test (RRT) was conducted at Brookhaven National Laboratory to test the effectiveness and accuracy of GammaPix™ in detecting radioactive materials on a range of smartphones. A series of experiments were carried out to evaluate the detection capability, measurement capability, and low and high detection limits of GammaPix™ and establish the working suitability of GammaPix™.

2 Test Methodology

2.1 System Under Test (SUT) Selection

In total, ten smartphones were tested. Table 1 below lists the model number of phones along with specification of the camera sensor location, pixel size and the version of the installed GammaPix™ app. The Lite Version of GammaPix™ was not available for iPhone, but still provided a quantifiable result via the full version. The full version has a longer initialization period and does not require a network connection for measurements. There were no other substantive differences found or stated between the Full and Lite versions.

The Samsung Galaxy S4 was the only SUT listed as an acceptable device on the manufacturer's website (http://gammapix.com/devices/), although that site appeared to not have been updated in quite a while based on the age of phones listed there. Given that the operating system for the phones listed constitutes a very low portion of current market share (less than 15%, see https://developer.android.com/about/dashboards), we decided to use primarily more modern phones in the test. Those phones would span the range in terms of megapixel sizes, to be able to capture any significant differences that may arise. The GammaPix™ app notes indicate that an initialization is required and that it will use the readings to provide a calibration for the phone. The Apple iPhone was added since there was an Apple version of GammaPix™ and we wanted to have that covered as well.

Table 1. List of tested phones

Phone Model (Camera Location)	Release Year	Camera Megapixels	GammaPix™ Version
Samsung Galaxy S4 (Front)	2013	2	Lite version
Apple iPhone 6S (Front)	2015	5	Full version
Samsung Galaxy S8 (Front)	2017	8	Lite version
Motorola Droid MAXX (Rear)	2013	10	Lite version
Samsung Galaxy S4 (Rear)*	2013	13	Lite version
Motorola Droid Turbo (Rear)	2014	21	Lite version
Samsung Galaxy A70 (Front)	2019	32	Lite version
Motorola One Vision (Rear)	2019	48	Lite version

* Device listed on the GammaPIX™ website

2.2 Experiments

The measurements were conducted in NIST-traceable fields in terms of exposure rate. Rates measured by the control equipment were used as reference values. Two irradiators were used for the experiments: the Low Scatter Irradiator for low-medium radiation fields and the Gamma Beam Irradiator for high radiation fields. In all the tests, the SUTs were setup in front of the irradiators with the camera of interest facing the source as shown in Figure 1. The table where SUTs were located was in line with the irradiator and adjusted automatically to positions for desired dose rates. The following measurements were carried out in order to fully assess the performance of GammaPix™ software:

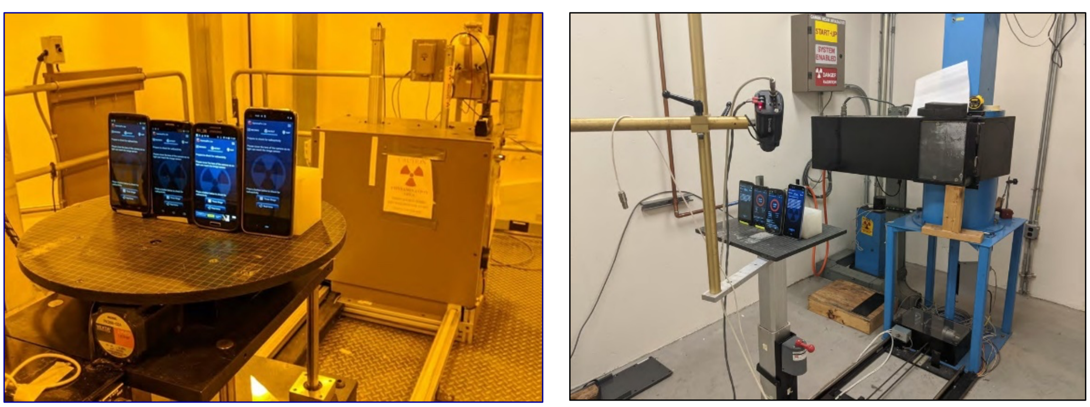

Figure 1. Experimental setup at the Low Scatter Irradiator (left) and the Gamma Beam Irradiator

- Low Light Measurement: This was a single-point dose rate measurement. Dose rate readings were recorded with the lighting in the test facility turned on and off. The purpose of this test was to check if the phone cameras had been fully covered with aluminum foil and black tape, a requirement for

GammaPix™ to function properly. If the taping is not done properly, the two readings with the lighting on and off would show a significant difference. This is a very important measurement, as one can get erroneous readings if GammaPix™ thinks there is too much light entering the camera.

- Exposure Rate Measurement: This tested the performance of GammaPix™ in radiation fields of intermediate energy gamma rays from ^{137}Cs. A range of dose rate sampling points from 1 mrem/hr to 100 rem/hr was measured. At each sampling point, the GammaPix™ readings or warning messages together with measurement times were recorded. Using the measurement results, the low and high detection threshold of GammaPix™ for a specific smartphone could be identified, and the accuracy and linearity of GammaPix™ response in the detection range could be calculated.
- High Energy Measurement: This was the same as the above exposure rate measurement, but with high-energy gamma rays from ^{60}Co. The purpose of this test was to qualitatively study the change of the detection efficiency and accuracy along with the gamma-ray energy.
- Over Range: This was a single point measurement to qualitatively test the response of GammaPix™ in a very high field, e.g., 1000 rad/hr.
- Gamma in Presence of Neutrons: This test determined whether GammaPix™ could detect and/or measure anomalies caused by neutron fields, and whether the presence of neutrons could affect the gamma rate measurements.

3 Experimental Results

This section describes the results of this RRT against the objectives of the project. Note that GammaPix™ reports results in mrad/hr, which for measurements of gamma radiation is equivalent to mrem/hr. The dose in rem equals the dose in rad multiplied by the quality factor (Q). For gamma radiation, the quality factor is taken as one, that is, rem equals rad.

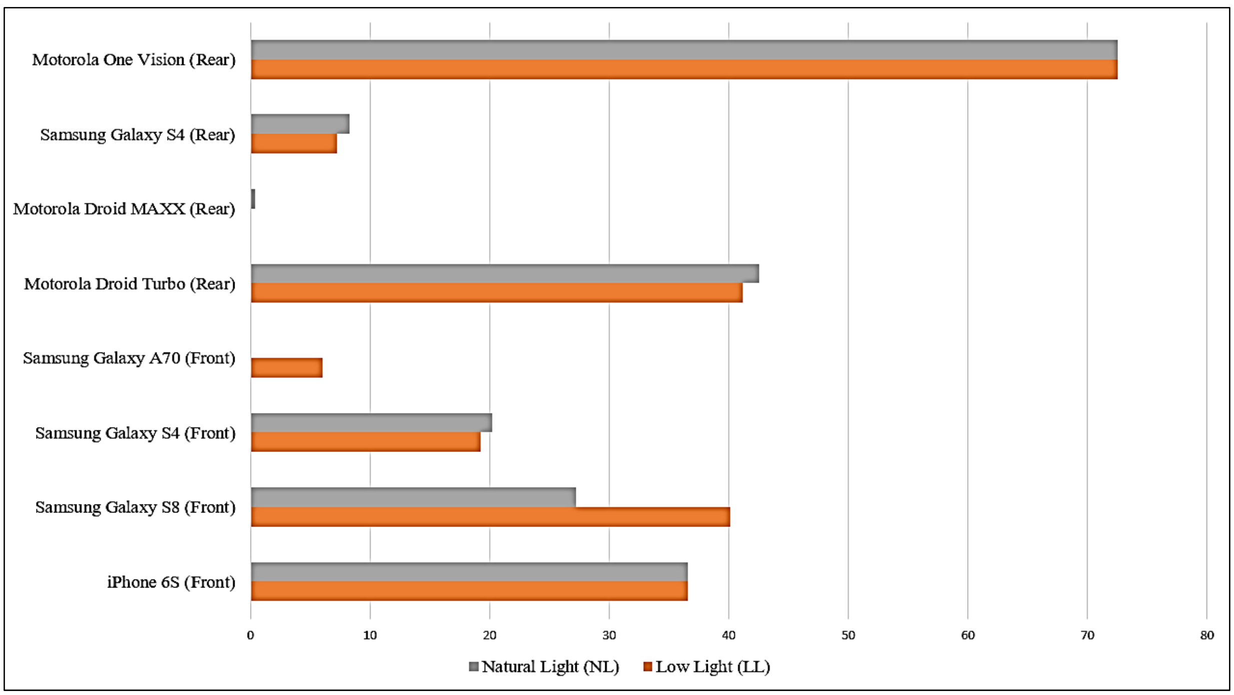

Figure 2. Comparison Between Low and Natural Light Responses (mrad/hr)

3.1 Low Light Measurement

Figure 2 shows the comparison of natural light and low light readings for all the SUTs. Note that Motorola

Droid MAXX (Rear) gave Unclear in low light condition and Galaxy A70 (Front) gave All Clear in natural light condition. It is difficult to interpret whether there is a significant difference for those two models given that we don't know the numerical dose rate thresholds for alarms. For visualization and comparison purposes, both results are treated as zero in the above figure. Most SUTs had comparable results in the two lighting conditions except the Samsung Galaxy S8 (Front). We were unable to correct the difference by adjusting the taping; it is possible that the glass front face of the S8 allows too much reflection of light.

3.2 Exposure Rate Measurement

The full results for the exposure rate measurements are laid out in Table 2. None of the SUTs was particularly accurate, but the Samsung Galaxy S4 came closest with average absolute errors of 15% for the rear camera and 34% for the front camera. The Samsung Galaxy A70 was the only other model that came close with 42% error over the small range that it acquired readings. All other SUTs had errors over 100%, although notably, some showed indications of good linearity, which can indicate an ability to correct with a simple calibration factor. Several phones underestimated the strength of the field to which they were exposed. The other phones always overestimated the field. From a safety point of view, in emergency situations when these phones are used as crude safety devices, it would be better to use always-high phones.

Table 2. Results of exposure rate measurement (mrem/hr)

Source Dose (mrem/hr)	Apple iPhone 6S (Front)	Samsung Galaxy S8 (Front)	Samsung Galaxy S4 (Front)	Samsung Galaxy A70 (Front)	Motorola Droid Turbo (Rear)	Motorola Droid MAXX (Rear)	Samsung Galaxy S4 (Rear)	Motorola One Vision (Rear)
1.0	2.3	-	-	-	-	-	-	7.6
2.5	9.1	-	-	-	9.4	-	-	16.9
10.0	36.6	27.2	20.2	-	42.6	0.4	8.3	72.5
100	470	344	141	60	503	4	84	783
1000	3000	3306	1482	559	4697	39	750	7250
10000	-	-	13908	-	-	285	12084	-

Figure 3 shows the measured dose rates of all the SUTs over the range of 1 mrem/hr to 1 rem/hr. Most SUTs had a low detection threshold around 2.5-10 mrem/hr, and a high detection threshold of about 1 rem/hr. Two SUTs, the Apple iPhone 6S and the Motorola One Vision demonstrated wider detection ranges with the ability to get readings down at 1 mrem/hr. The Samsung Galaxy S4 had a range that managed to go up to 10 rem/hr for both cameras. Within the primary detection range, all the SUTs had a linear response to gamma-ray radiation.

GammaPix™ has two operation modes: real-time measurement and three-stage measurement. The software description on the vendor's website doesn't give detailed information regarding the differences of these two modes. In actual experiments, it was observed that three-stage measurements were quicker than real-time measurements, lasting about two minutes each. The real-time mode appears to be essentially a series of the three-stage measurements, which vary depending on the measurement option setting. Figure 4 shows the comparison of real-time measurement and three-stage measurement at 100 mrem/hr for all the SUTs. The two measurement models showed comparable results. Given the shorter measurement time of the three-stage mode, it may have higher statistical error than real-time measurements. However, this was not the objective of this test and was not verified experimentally. Note that results for the MAXX were noted as both "All Clear" in GammaPix™ so there is no way to compare those responses.

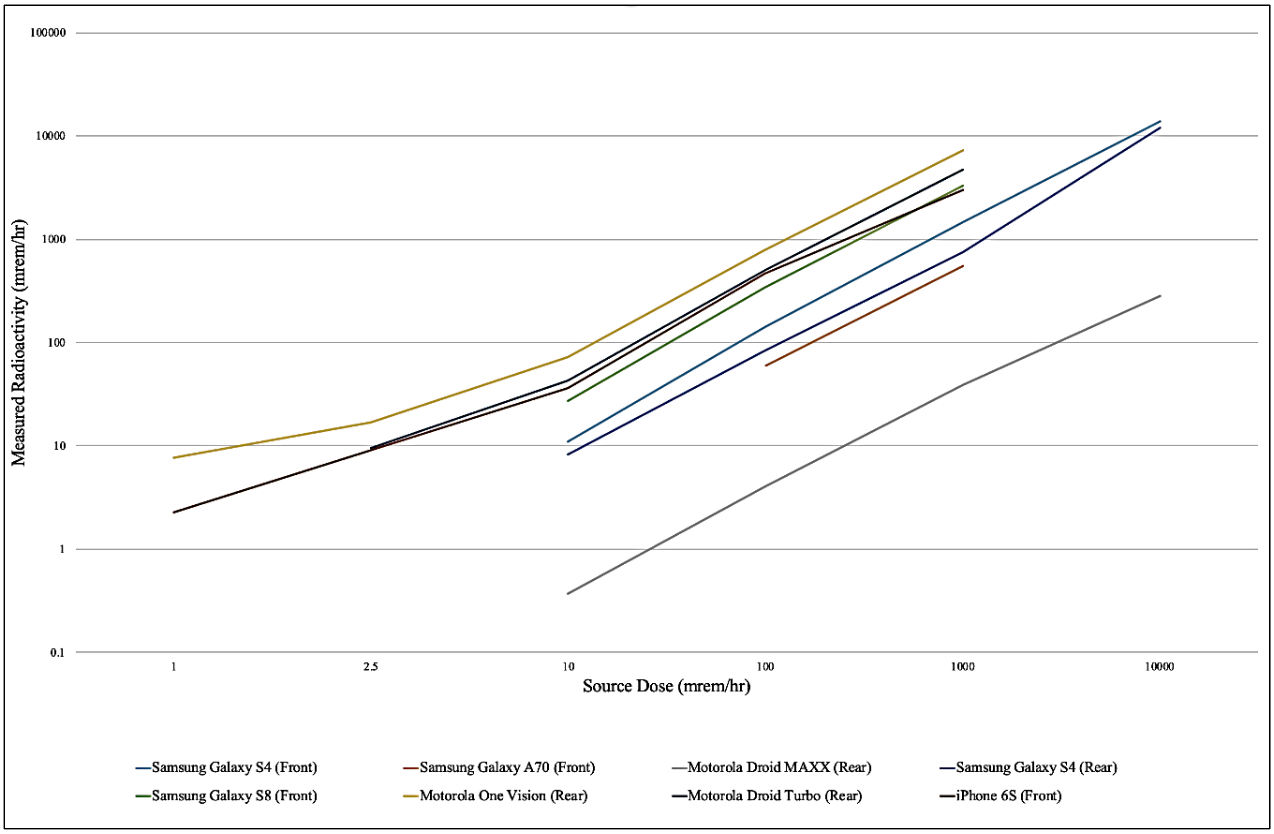

Figure 3. Results of Exposure Rate Measurement

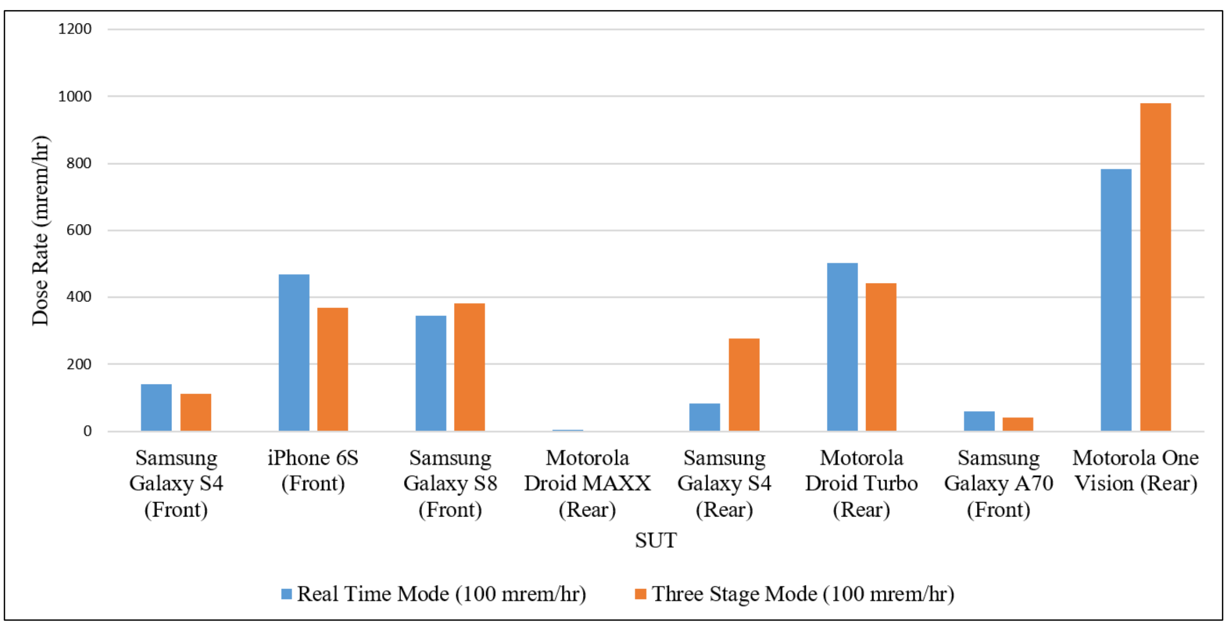

Figure 4. Comparison of Real-Time and Three-Stage Measurement Modes

3.3 High Energy Measurement

High energy measurement results with a ^{60}Co source at source dose rates of 2.5 mrem/hr, 10 mrem/hr and 100 mrem/hr are shown in Table 3. For comparison, the results of intermediate energy (^{137}Cs) are shown in Table 4. Most SUTs didn't give a reading at 2.5 mrem/hr, indicating higher detection thresholds. The following analysis is based on the measurements with three low-threshold SUTs, Apple iPhone 6S (Front), Motorola Droid Turbo (Rear) and One Vision (Rear). The three SUTs can maintain similar gains at the lower dose range (2.5 - 10 mrem/hr). At higher dose range (100 mrem/hr), the gains for high-energy gamma rays drop by 10-25%.

Table 3. High Energy Test Results

Source Dose (mrem/hr)	Apple iPhone 6S (Front)	Samsung Galaxy S8 (Front)	Samsung Galaxy S4 (Front)	Samsung Galaxy A70 (Front)	Motorola Droid Turbo (Rear)	Motorola Droid MAXX (Rear)	Samsung Galaxy S4 (Rear)	Motorola One Vision (Rear)
2.5	10.1	-	-	-	9.4	-	-	14.0
10.0	28.7	24.6	6.3	-	42.0	-	5.4	77.6
100.0	300.0	259.9	117.4	26.7	370.5	4.2	56.1	717.1

Table 4. Intermediate Energy Test

Source Dose (mrem/hr)	Apple iPhone 6S (Front)	Samsung Galaxy S8 (Front)	Samsung Galaxy S4 (Front)	Samsung Galaxy A70 (Front)	Motorola Droid Turbo (Rear)	Motorola Droid MAXX (Rear)	Samsung Galaxy S4 (Rear)	Motorola One Vision (Rear)
2.5	9.1	-	-	-	9.4	-	-	16.9
10.0	36.6	27.2	20.2	-	42.6	0.4	8.3	72.5
100.0	470.0	344.3	141.4	59.8	502.7	4.0	83.5	783.2

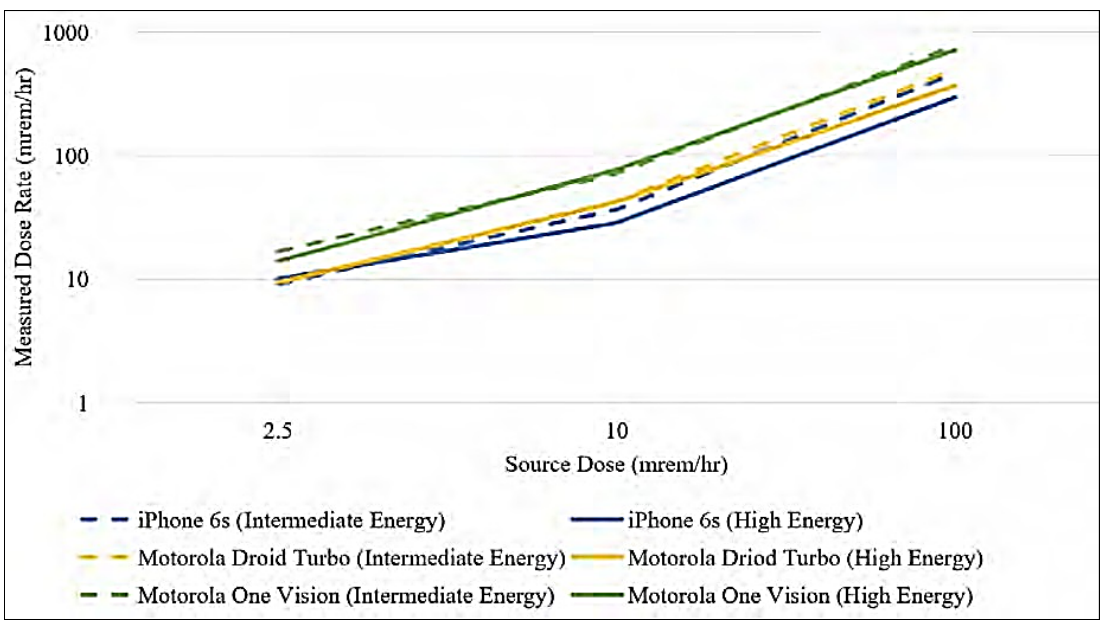

Figure 5. Comparison of High and Intermediate Energy Measured Dose Rate for iPhone 6s, Motorola Droid Turbo and One Vision

3.4 Over Range

Over range measurements were performed at 1000 rem/hr with a ^{137}Cs source. All the SUTs failed to give a reading as indicated in Table 5. Some SUTs gave warnings saying the dose rate may be too high, but GammaPix™ cannot tell whether the potential high readings are from a real radiation field or light leakage caused by taping issues. The rest of the SUTs stopped in the middle of the measurements because of unspecified errors without any high dose rate warning.

Table 5. Over Range Test

	Apple iPhone 6S (Front)	Samsung Galaxy S8 (Front)	Samsung Galaxy S4 (Front)	Samsung Galaxy A70 (Front)	Motorola Droid Turbo (Rear)	Motorola Droid MAXX (Rear)	Samsung Galaxy S4 (Rear)	Motorola One Vision (Rear)
Source Dose (1000 rem/hr)	ERROR	ERROR	ERROR	ERROR	ERROR	ERROR	ERROR	ERROR
Time to Fail (s)	30.0	LOOP	80.0	LOOP	180.0	180.0	LOOP	230.0
Error Message	Camera Anomaly	Camera Anomaly	Phone Camera Uncovered	Camera Anomaly	Camera Anomaly	Phone Camera Uncovered	Camera Anomaly	Camera Anomaly

3.5 Measurement Time

For all the SUTs, three-stage measurement is quicker than real-time measurement. However, the actual measurement time varies from one phone to another. For example, the measurement time of Samsung Galaxy S8 (Front) was 340 seconds in real-time mode, while that of Samsung Galaxy S4 was 730 seconds. There is not enough information currently to correlate the measurement time with any other parameters such as camera resolution or exposure rate. The processor speed may be one factor, but we cannot determine that definitively from this data set.

3.6 Gamma in Presence of Neutrons

The impact of neutrons on the gamma dose measurement was evaluated using a ^{252}Cf source. One would not expect any response from a purely neutron-based source from GammaPix™ since there would be no gamma rays entering the camera. With a ^{252}Cf source, there is a gamma component which would be detected. The results from the dose measurement by GammaPix™ are recorded in Table 6 below. The source dose rate listed in that table was neutron dose alone. The actual gamma-ray dose was monitored by an ionization chamber and was about 4% of the corresponding neutron dose, which is in general agreement with the GammaPix™ measurement results shown in Tables 2-4. Overall it was found that gamma measurements were generally able to be made in a neutron environment.

Table 6. Gamma Measurement in Neutron Field

Source Dose (mrem/hr)	Apple iPhone 6S (Front)	Samsung Galaxy S8 (Front)	Samsung Galaxy S4 (Front)	Samsung Galaxy A70 (Front)	Motorola Droid Turbo (Rear)	Motorola Droid MAXX (Rear)	Samsung Galaxy S4 (Rear)	Motorola One Vision (Rear)
2.5	-	-	-	-	-	-	-	-
10.0	2.28	-	-	-	-	-	-	-
100.0	14.71	9.8	6.3	-	20.9	-	-	34.5

4 Conclusions

We tested GammaPix™ in NIST-tracible radiation fields with a wide range of smart phones. The test results highlighted the following findings:

- The detection limits varied with the SUTs but were assessed to be from 2.5 mrem/hr to approximately 1 rem/hr, indicating that GammaPix™ may not be suitable for some security-based applications, especially as an alert to low/transient levels of radiation in security and nonproliferation applications.
- The SUTs were generally inaccurate compared to the actual dose rate field. However, it should be noted that most models had linear response within the detection range. A simple calibration factor could yield a well-behaved response curve, but the ability to set a manual calibration factor was not an available option in the tested version of GammaPix™.
- The relatively slow response could put users in danger of overexposure in high dose rate fields, a risk that is also identified by the National Council on Radiation Protection and Measurements in the 2018 report [2].
- A calibration factor should be developed for each phone if a variety of models are going to be used.

References

[1] G. A. Drukier, E. P. Rubenstein, P. R. Solomon, M. A. Wojtowicz, and M. A. Serio, "Low cost, pervasive detection of radiation threats," 2011 IEEE International Conference on Technologies for Homeland Security (HST), 2011.

[2] S. Perle, "NCRP Report No. 179, Guidance for Emergency Response Dosimetry," Health Physics, vol. 115, no. 4, pp. 507–508, 2018.