

Real-Time Dosimetry Badges

And the feasibility on their ability to reduce radiation exposure

An Interactive Qualifying Project Report

Submitted to the Faculty of the

WORCESTER POLYTECHNIC INSTITUTE

In partial fulfillment of the requirements for the

Degree of Bachelor of Science

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Date: May 6, 2014

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Abstract

The purpose of this project is to determine if the radiation absorbed dose to nurses, technicians and doctors are changed in active x-ray rooms that uses real-time radiation dose data displayed to them. The main idea is that if the information is available and visible, that it will help induce better safety behaviors. This is assessed using the recorded exposure data from the devices worn by the personnel in real day-to-day operations of the radiology department of a hospital.

About RaySafe

RaySafe is a company based in Sweden with the mission to improve quality assurance for diagnostic imaging. They sell products and services which aim to provide clear and accessible information on radiation exposure to people in hospitals. Their work focuses primarily on 2 elements: devices that are used to measure how much radiation an individual is receiving, and devices and software needed to aggregate and display effectively collected radiation dosimetry information in real-time.

The way they collect the radiation exposure data and quantify it is through a real-time dosimetry badge named i2. The i2 is a solid state detector for ionizing radiation. The badge detects ionizing radiation when a wave of radiation affects the voltage in a specialized type of circuit similar to a transistor. The badge data is relayed to a central computer where it is presented clearly on a large monitor mounted in the diagnostic imaging room where the person wearing it is working.

RaySafe and its customers see that the advantages of real-time dosimetry badges over current methods are significant and tangible. As the number of radiation intensive procedures continues to rise, so does the need to make sure that the technicians, nurses and doctors are appropriately monitored for their accumulated dosage of radiation. Staff radiation exposures are regulated under the federal code of regulations 10 CFR 20¹ which limits the amount of radiation that a worker can receive in the course of a year. To ensure compliance with 10 CFR 20, employers use passive dosimetry systems, such as Landauer's Optically Stimulated Dosimeter

¹ Referring to the Electronic Code of Federal Regulations, Title 10, Part 20. Available on the web from the U.S. Government Printing Office. http://www.ecfr.gov/cgi-bin/text-idx?tpl=/ecfrbrowse/Title10/10cfr20_main_02.tpl

(OSL). The OSL is worn by the worker for a period of time, usually a month. At the end of the month, the OSL is shipped back to Landauer who then measures the absorbed radiation dose received by the OSL during the time period. The advantage to having an external and accredited radiation dosimetry laboratory measure the OSL dose is that the readings are unbiased and independent. Unfortunately, the major limitation to this method is that if a person is unknowingly exposed to radiation, the person and the facilities radiation safety staff will not know about the exposure until almost two months after the exposure. To overcome this limitation, many companies offer personal electronic dosimeters that can provide information on radiation exposure. Unfortunately, these dosimeters, which are roughly the size of a pager, are difficult to use during a procedure.

What is radiation, who regulates it, and how is it measured?

Radiation is something that occurs all around us and is produced from a variety of sources. There are two main types of radiation, non-ionizing radiation and ionizing radiation. Non-ionizing radiation exists in the forms of light, radio waves, microwaves and radar. This kind of radiation is pervasive and generally harmless. It also generally does not contain the ability to change the atomic nature of various atoms. Ionizing radiation exists in the forms of x-rays, gamma rays, and particle bombardment. The effect that ionizing radiation has is that it can interact with atoms to bring them into an ionized state, that is, the energy transferred to an atom will be large enough to eject the electron from the atom which creates a free electron and an ion. The ion and the free electron have a net charge; they exhibit a different chemical behavior from the atom. More importantly they can cause damage to DNA, which could result in a biological effect.

The change in chemical behavior is why ionizing radiation concerns us more than non-ionizing radiation. This ionization can interfere with biological cells. There are essentially three outcomes when this happens. The first is that the ionizing radiation causes some part or portion of the cell to become damaged and that individual cell has the ability to eliminate or repair the damaged portion and continue to function normally. This is the most harmless outcome as everything remains essentially the same. The second is that the cell may become irreparably damaged by the ionizing radiation such that cell death is unavoidable. This is equally harmless as a human body has millions of cells dying and being replaced on a daily basis so a few more is not appreciable. The third is that the radiation will cause some change to the genetic structure within the cell where then normal functions produced by this genetic material are modified in

some way. This is the outcome that concerns people the most as this is how some cancers can be induced. As when the genetic material is altered it can end up so that it reproduces uncontrollably, resists the form and timing of natural cell death, etc.

An important fact to note about radiation is that it comes from both natural and man-made sources. All radiation, except for particle bombardment, is simply a massless energy wave in the electromagnetic spectrum. This spectrum goes from low energy to high energy waves and the difference between ionizing and non-ionizing is this energy difference. Higher energy radiation is the ionizing variety. As such, humans experience natural radiation from space sources as well as terrestrial sources. The cosmic usually being high energy gamma and x-rays and the terrestrial sources being from nuclear fission from dispersed natural sources, like uranium, which produces particles like alpha, beta, neutron etc.

Radiation poses a risk to human health once enough of it has been absorbed. The risk associated with radiation related health issues and radiation exposure is modeled as a linear relationship, which conservatively will provide an overestimate of the risks from low radiation exposures. Simply put, the more ionizing radiation one is exposed to, to higher their risk is. It is for this reason that one of the more important measurements of risk for a radiology worker in a hospital is how much radiation they have accumulated over their period of work. The government regulates how much one worker can accumulate safely on a yearly basis. If someone reaches the limit then they are no longer allowed to work in an area where they are at risk for exceeding this exposure limit. Presently, the assumption of a linear dose response predicts that the risk of obtaining a negative biological reaction, such as cancer, from exposure to 1 rem of radiation is estimated to be 0.05%. This risk is estimated rather than measured because this risk competes with the background average rate of cancer mortality per person, which is 21% to 23%.

Therefore, to actually measure a 0.05% increase in risk from 1 rem of radiation would require a population larger than the total number of people who have ever been exposed to 1 rem (or even those exposed to more than 1 rem).

There are different ways of measuring and classifying absorbed dose. The one used in this project is called deep dose equivalent or DDE for short. This is a representation of an absorbed dose normalized to absorption at 1 cm below the skin for the whole body. There are also other classifications of dose that pertain to the absorbed dose to the lens of the eye, lens dose equivalent or LDE and also the shallow dose equivalent or SDE which is a measure of radiation exposure to the skin or an extremity like an arm or leg.

The exposure that a person may receive is limited by the United States Nuclear Regulatory Commission (NRC) in *Title 10, Code of Federal Regulations Part 20* (10 CFR Part 20). The *Code of Federal Regulations* is the document that lays out the operational guidelines and procedures for government agencies. Title 10 is the division given to the Nuclear Regulatory Commission and Part 20 is the subsection that deals specifically with the standards for protection against radiation. This is where the units for equivalent dose are defined. The unit for dose equivalent used in this project is the rem, more specifically the milli-rem (mrem) or 1/1000th of 1 rem. The 10 CFR Part 20 lays out the mechanism by which they use to define the rem, but I will leave it simply as a system to normalize for the different natures of different kinds of radiation that one can be exposed to.

The limit that the 10 CFR Part 20 has set for the deep dose equivalent are 5,000 mrem per year. This is the regulation and is not a negotiable quantity. Operators of all workplaces that have anything nuclear in nature or have employees exposed to radiation must keep the yearly

accumulated DDE below this number. This obviously applies to hospitals and their active x-ray rooms.

This limit is reasonable as a cutoff for extreme safety cases; however, there is another policy that is very important, ALARA. This is an acronym for As Low As Reasonably Achievable. What this means is that if there is a process, procedure or method that can be used to reduce exposure to ionizing radiation, then it should be used. Because of the linear relationship between exposure and health risk it is important to always keep exposure down when possible. There are instances where a person will have to expose themselves to radiation because they need to for the success of their job. This can be the handling of radioactive material or standing next to an x-ray emitter to perform a medical task as well as many other situations.

An active x-ray room, also known as an active fluoroscopy room, is where medical professionals use a continuous source of x-rays to generate a real-time image of the patient and medical work being done inside the patient. This has many great applications as the uses for seeing into a patient while using a device inside of them are plentiful. A good example of this is if a patient needs a stent placed into one of their arteries near the heart to prevent it from collapsing, then it is advantageous to snake the placement device in from a location further down the body so that you can reduce risk. The risk in this situation is the loss of patient stability through extreme blood loss, which is easier to control in an extremity than in the torso.

The setup in an active fluoroscopy room is usually similar across all hospitals. There is a table or surface where the patient lays on and then there are a few types of setup variants from there. One where the x-ray emitter is placed under the table with the recorder, or camera, placed above the patient and table. Conversely there is the setup where the emitter is above the patient and the camera is below the table. There are also facilities now that have a swivel style device

that can rotate around the patient and table and provide a variety of possible camera angles for the medical team to use.

The device that has been used to measure radiation exposure consistently and accurately is called a dosimetry badge or dosimetry device. The most commonly used is the film badge dosimeter which is a simple and effective way of measuring exposure over time. It works by having a piece of x-ray film and a holder that the film is in until it is time to remove it, develop the film and record the level of exposure. This is generally done on a long time frame; usually one is worn for a month and then developed at the end to provide a monthly report of exposure. These passive badges are simple, durable and reliable. They are used nearly everywhere there is a radiation source. In addition to this passive dosimetry is an active dosimetry device. These have been used with some drawbacks. Such as they are larger than a film badge and they usually require a power source to operate the detector and any onboard electronics. There is also the issue that some varieties have difficulty detecting small amounts of radiation, or discerning the difference between x-rays emitted by the medical device in the room from the radiation that is constantly bombarding earth from cosmic and terrestrial natural sources.

This should be an adequate base for the presentation and discussion of the data to follow.

Methods

RaySafe has provided data from one of the sites that recently has implemented their i2 dosimetry package. The package includes the hardware and software which consists of their real-time dosimetry badges and the base station that receives, logs, and displays the data. The period that the data essentially covers is two different years of radiation readings. The first year is where the team in the active x-ray room wore only the standard passive badges underneath their protective gear and the second year is when they wore the passive badge and the active badge on the outside of their protective gear. The real-time badge is worn on the outside of the protective gear so that it has an unobstructed reading of how much radiation the wearer is receiving before any sort of protective shielding. This adds responsiveness to the data because the badge is essentially recording what kind of exposure the wearer would be receiving if they were in that location unshielded.

The information that will be focused on here is a comparison of the passive badges. The data from the real-time badges are significant in verifying that the real-time badge and the passive badge are detecting parallel levels of exposure. However, as a year to year comparison, the passive badges must be considered against each other independent of the real-time badges as there is only one year of data that has the real-time badge.

The time period that is most beneficial to look at is the year to date periods for January through August of 2012 and 2013. This is done because the most relevant way to look at the exposure is based on an accumulated dose perspective. This is chosen because it is the numerical way that safety regulations look at as well as how the exposure affects the safety of the person. Additionally the time period is limited to the first 8 months as this is all that was provided for the

year 2013. This is compared to the same months from the year previous because it is most likely to correlate to individual employees work habits. For example, an employee is likely to take similar amounts of time off of work in similar months year after year. It is also regulation that the passive dosimetry be reported on an accumulated exposure dose on a rolling year basis. So even if the regulatory period ends in a time that does not line up with the change of the calendar year then at least the data that is observed here is consistent in its relation to the end of the regulatory year.

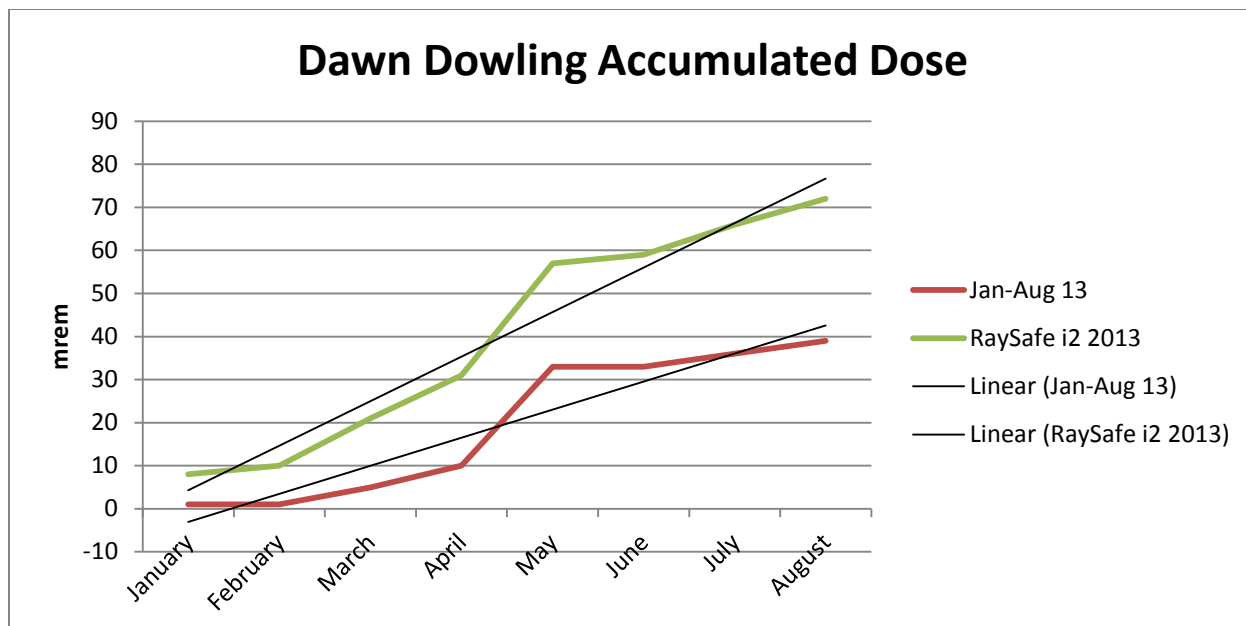
The data provided does come with some minor issues that must be accounted for or filtered out before the charts are presented and discussed. The first is that there is incomplete dosimetry data for some of the employees provided. These have been considered outside the usefulness of this project because without context or justification, they cannot be referenced against the rest of the group. The other inconsistencies that have to be eliminated are occurrences where an employee has non-zero data for one year and then zero for each month of the next year. This has likely occurred because the person no longer works in the radiology department or the like. Regardless of the reason for this kind of occurrence is not considered as it would unnecessarily skew the results.

That being said, this project will examine eight individuals working at Lawrence General Hospital in their active fluoroscopy room. They are a mix of radiologists, techs and nurses. For the purpose of this project they will be treated equally as all of which have had the necessary safety training and should be able to utilize it effectively.

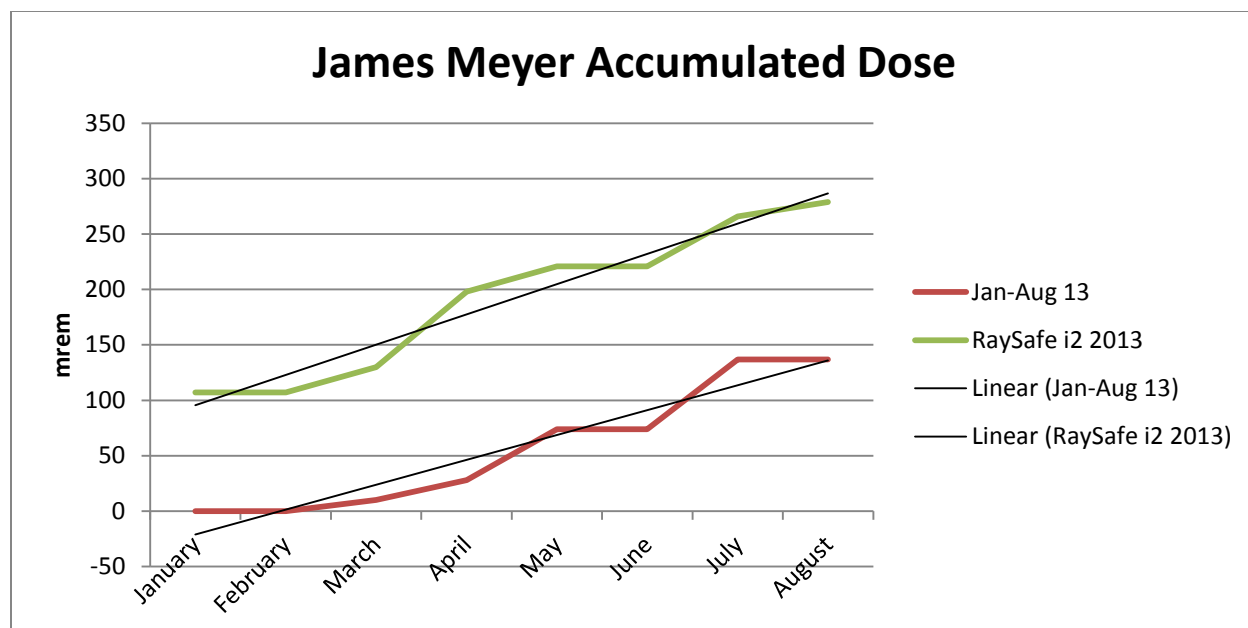
Results Part One

The first graphical data that needs to be presented is that the real-time badges are working as intended. This is not the most rigorous analysis, but there can be shown a relationship nonetheless. This is also the case because the physical technology of the real-time dosimetry badge is proprietary to RaySafe. Additionally it is not the aim of this project to prove that the badges work as intended; RaySafe has an interest in making sure this is true and has their team working with much more extensive tools and analysis to assure proper function.

The following two charts are of accumulated dose. One of the lines is the reading from the i2 RaySafe device while the other is the results from the passive dosimeter. The quantity difference between the two lines represents the fact that the i2 is worn outside of the protective clothing and that the passive badge is worn underneath the protective clothing. What is important to look for is parallel between slopes of the linear fit lines, and parallel between dose numbers on a month to month basis.



The chart here for Dawn Dowling meets both of the expected criteria fairly well. The month-to-month correlation is strong as for each month the slopes of the lines is very similar. The linear fit lines have slightly different slopes but they are within the bounds of reason. The difference mostly arises from the months of July and August having a divergent trend; otherwise the two lines are fairly identical in slope.



The chart for James Meyer clearly shows the correlation better than the one for Dawn Dowling. This is likely due to the fact that overall he has more total accumulated dose than Dawn on a total and month to month basis. This increase is probably due to more procedures performed or to being in a role where he is exposed to more of the radiation. This larger sample size has produced a more solid data set to go on. The month to month lines parallel very well; the slopes and gap between them does not change much over the period. The linear fit lines also are nearly parallel. Although they do diverge over time the difference is very small.

These two charts present what is expected of the real-time dosimetry badge. The badges are generally reading the same amount of radiation dosage as the passive badges, except at a shifted height on the y-axis. This is consistent with the idea that the real-time badge is unshielded from radiation and that the passive badge is protected by the radiation absorbing material worn by the employee.

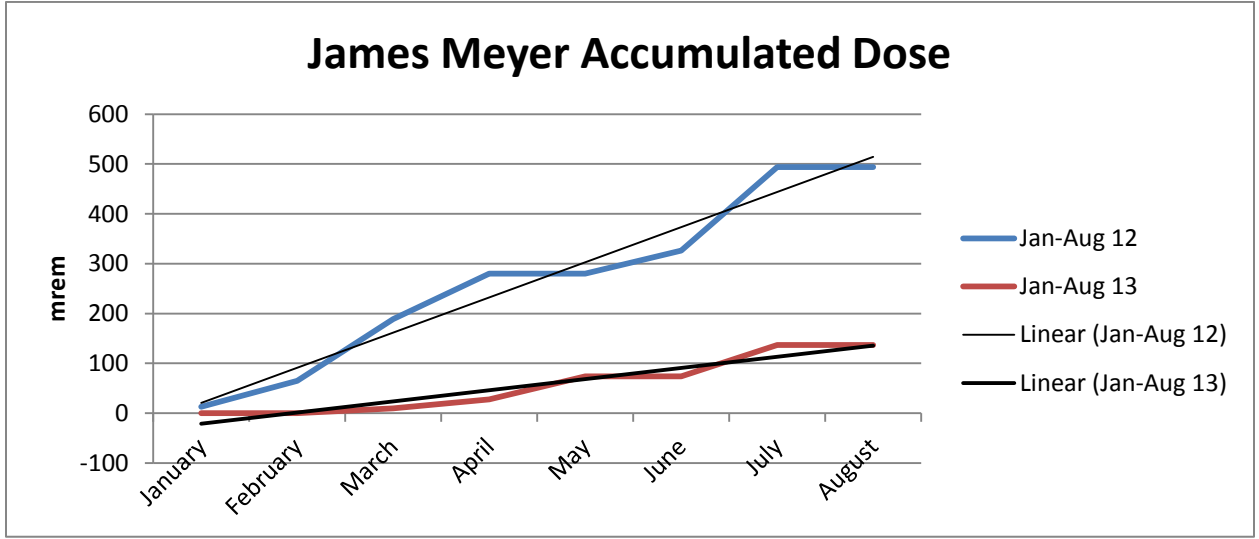
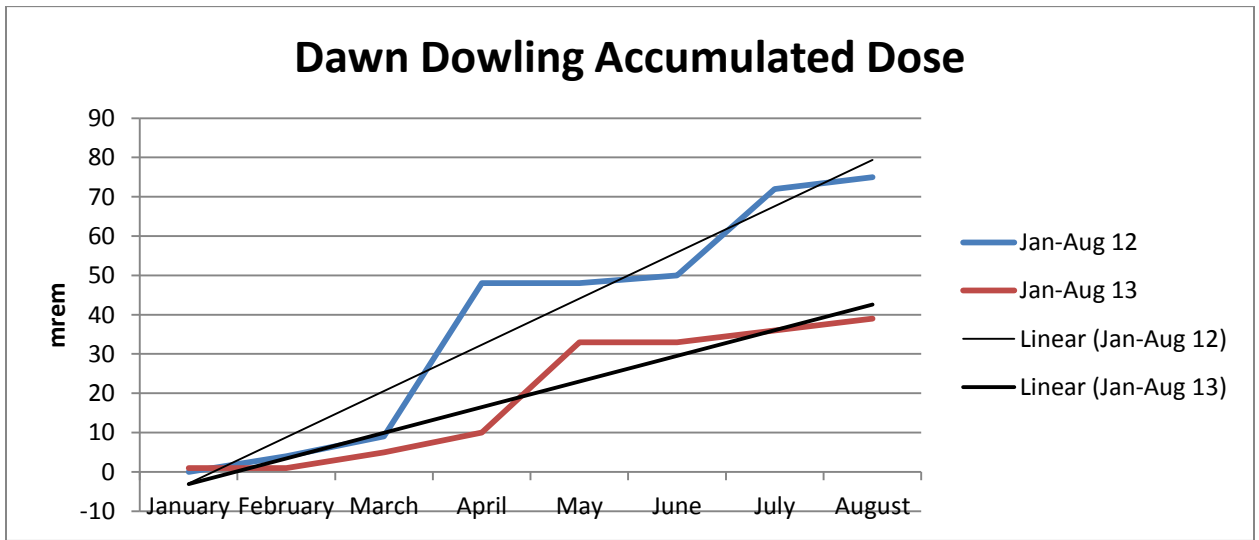
Results Part Two

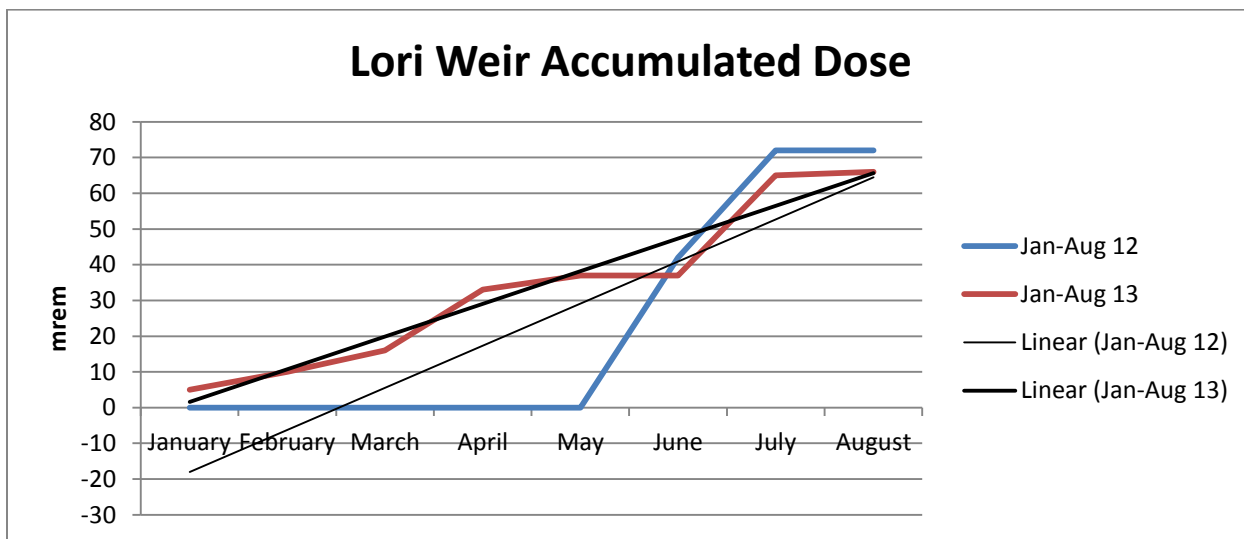
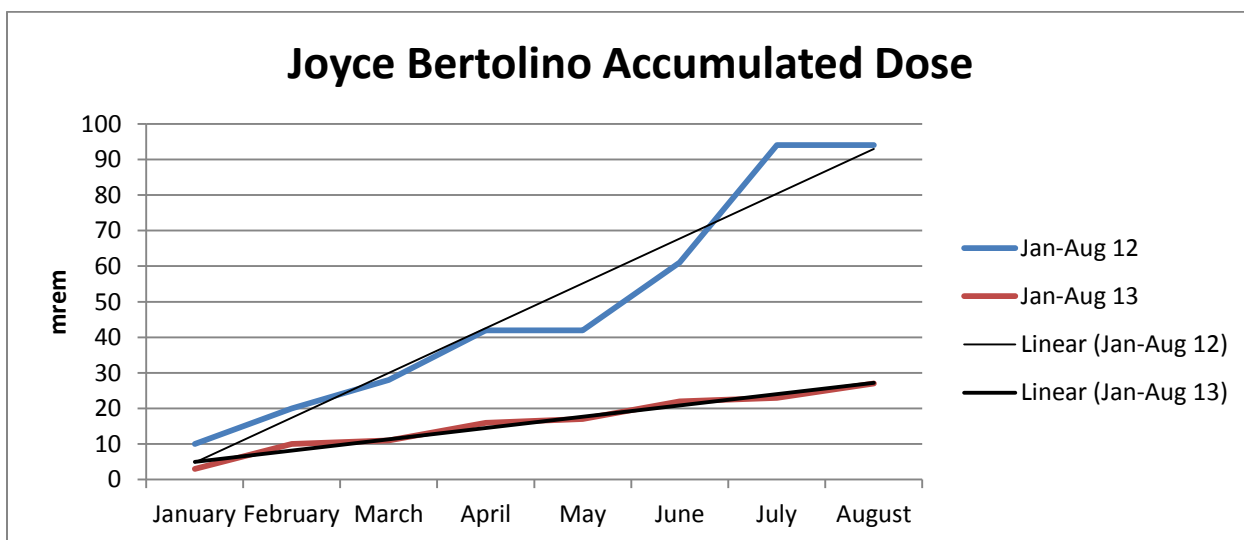
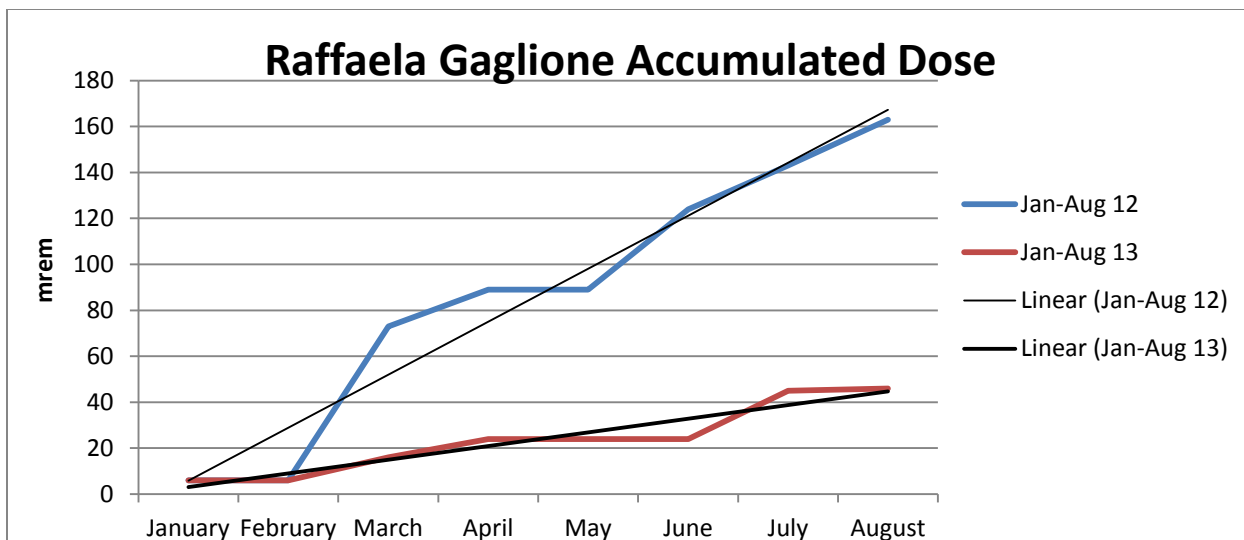
The next sets of charts that will be presented are the accumulated dose absorbed by the passive dosimeter graphed on an individual basis. This is where the effect of the real-time dosimetry badge can start to be quantified. Accumulated dose, as said before, is a quality metric to look at because it is the total radiation that has been absorbed over time by the passive badge and thus, the specific employee.

For the eight employees that I have presented here, there are 2 main groups that they can be divided into. They are simply group one, where there can be shown that there has been a measured decrease in the rate at which the employee receives radiation dosages. The second group is where there is not a decrease in the rate at which the employee receives radiation dosages. All five of the employees that are in group one show a significant decrease between the slope of their linear trendlines from the first eight months in 2012 compared with the first eight months in 2013. The second group contains two subcategories, one where the slope of the trendlines is roughly similar or ambiguous, and another where there is an increase in the slope of the trendlines from the year to year comparison.

What is notable about the division of the eight subjects into the two groups is that there is more than half of the sample, five employees, in the first group that shows improvement and the other three employees are split between the ambiguity subgroup, and the negative improvement subgroup. The first five charts are the first group and they are for Dawn Dowling, James Meyer, Raffaella Gaglione, Joyce Bertolino and Lori Weir. It is encouraging to see that five of eight individuals looked at have shown an improvement in the effort to reduce their accumulated dose.

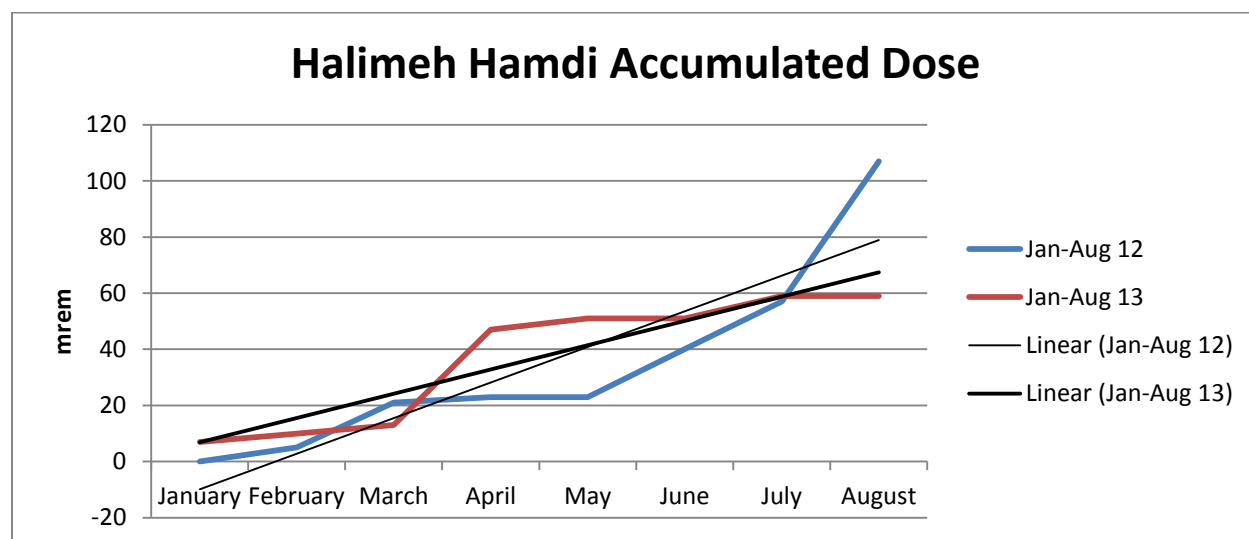
Four of the five in this group have clearly shown a reduction in the slope of their trendlines. This is positive evidence towards the aim of this project. The only one which is similar in slope is that of Lori Weir. However, if you consider that the first few months of registered dosage was zero then if you were to remove those specific data points that then the trendline would increase its slope accordingly. As this is for the year without the real-time dosimetry badge then that would cause the slope difference to increase in such a way that is an improvement.





The three of eight that exist in group two show little to no improvement or regression against the goal. The first two charts, for Halimeh Hamdi and Timothy Norton, show fairly similar lines for 2012 and 2013 as well as similar trendlines. From these charts these employees appear to not have received much benefit from the real-time dosimetry data. However it is still of important note that they both ended the period in 2013 below the accumulated dose for the same time period the year before; even though they are close in slope they still have a reduction in quantity, which is a desirable outcome.

The last chart to look at is the only one of the eight to have a significant increase in accumulated dose over the period is the last one. It is also worth noting here that the overall dosage received here is quite small. However this will be discussed more in the next section.



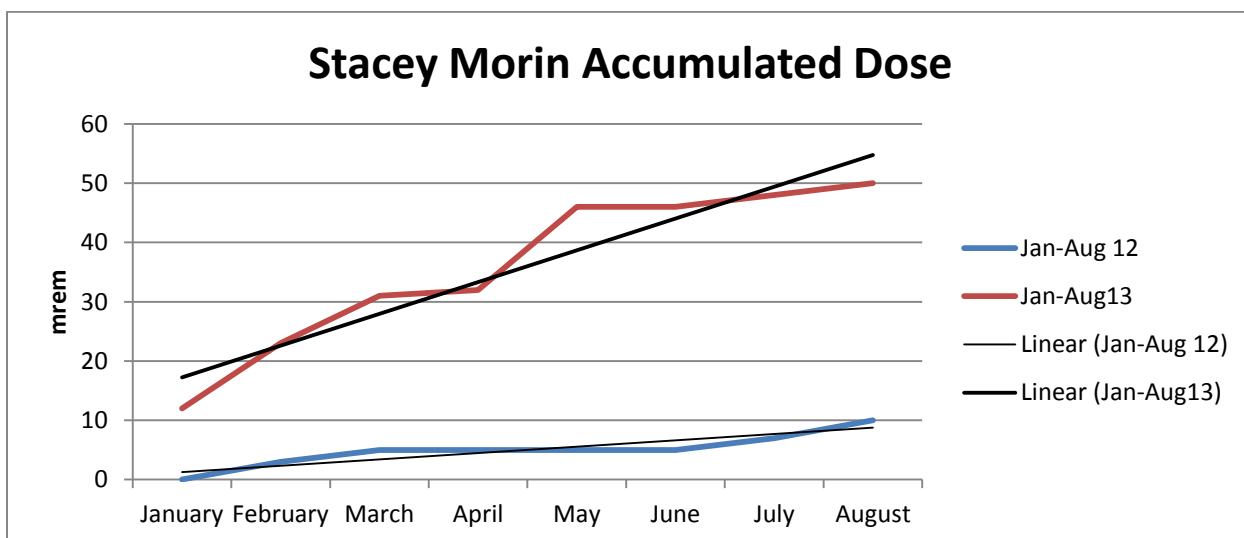
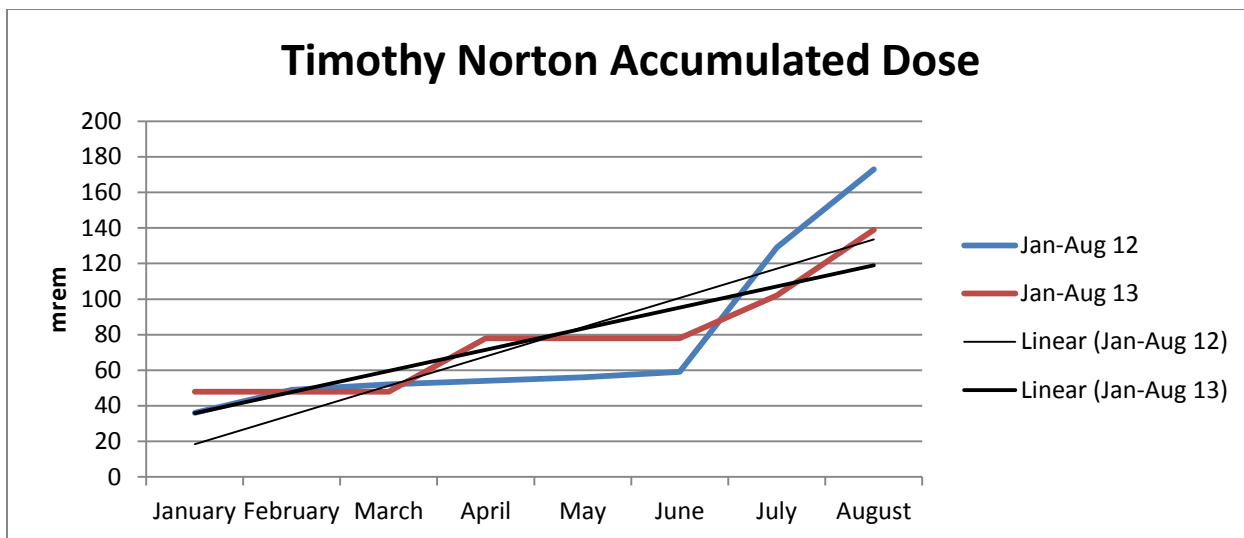
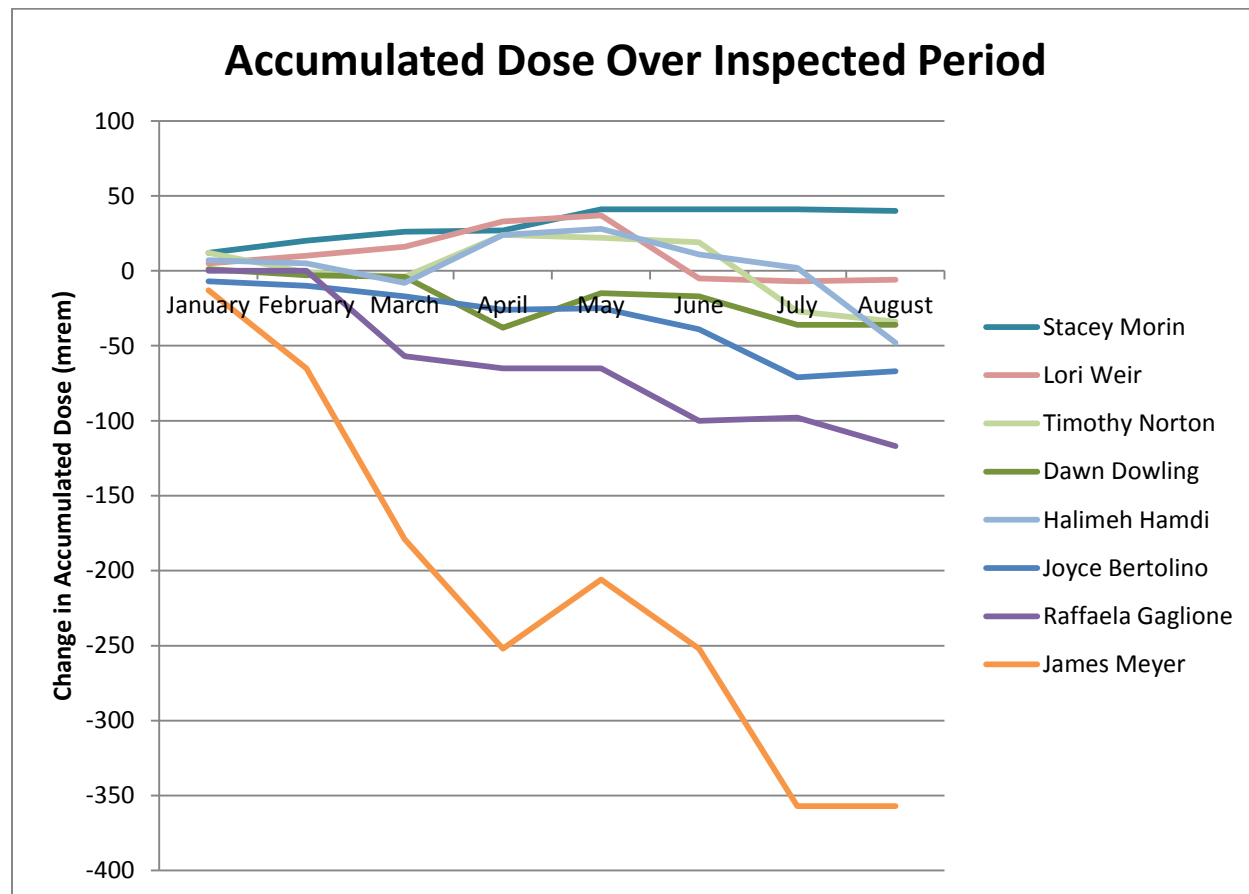


Table of Percent Change in Total mrems Accumulated			
Name	Accumulated 2012*	Accumulated 2013*	Percent Change
Stacey Morin	10	50	400%
Lori Weir	72	66	-8%
Timothy Norton	173	139	-20%
Dawn Dowling	75	39	-48%
Halimeh Hamdi	107	59	-45%
Joyce Bertolino	22	3	-86%
Raffaela Gaglione	163	46	-72%
James Meyer	494	137	-72%
*Consistent with the rest of the data in this report, the accumulation in a specific year is truncated to represent only the first 8 months of the year.			

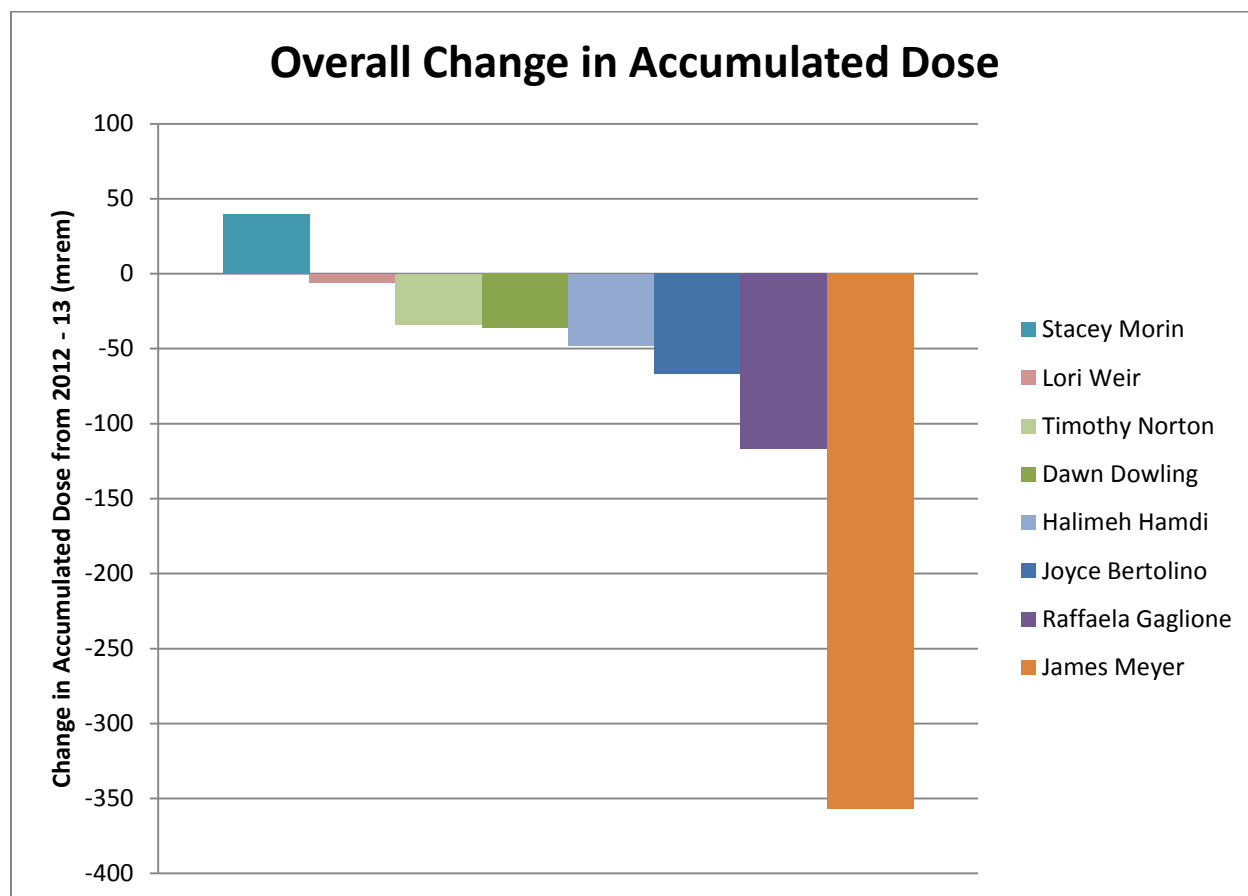
Results Part Three

The final set of charts will conclude the data presentation portion of the project. The first shows the by-month progress of how the absorbed dose received in the second year compares to the dosage received in the first year. Note that as the graphs before showed, that seven of the eight workers ended the first 8 months of the second year below where they were the previous year.



The next chart shows the final quantity difference between the two years for comparison. Like with the previous chart it is obvious that seven of the eight have had improvement. Three of

which have a reduction of 50 mrem or more, and James Meyer with the largest gain at over 350 mrem. This final graph shows that there has been a serious reduction in the radiation absorbed by about half of the workers, a few who are in a low improvement or no appreciable difference zone and only one who increased. And the only one who did increase did so by less than 50 mrem.



One factor that is present in any workplace safety discussion is the challenge of getting the new safety technology to be truly utilized by the people at risk. The real-time dosimetry device and data are not capable of enforcing a change in safety behavior. Yes, the data is present

and highly visible to the people in the fluoroscopy room, but it is still up to the individual to choose to react to that knowledge.

Conclusion

After reviewing all of the data there is a strong link between the use of real-time dosimetry data and a decrease in radiation exposure for these workers. It cannot be said conclusively that the real-time data present in the room for the workers to see is the cause of the reduction as there are several variables that need to be analyzed and considered before a true statistical analysis can be performed. The correlation is there nonetheless.

The result that two of the sample of eight showed a large reduction and that and additional four showed a small reduction is encouraging. There is potential that this is an extremely effective method for assisting radiation safety in active fluoroscopy rooms. It will require further research in the subject as this has been a very simplified overview. There are many things that need to be considered to be more statistically relevant. Such as detailed information about how many procedures are performed by each employee, what role they play in the room, the nature of their work safety history, how much time off they took from period to period. All of these small details play into the statistics and have been unavailable and out of the scope of this project. It was the aim here to explore the idea that real-time data presented to people in the room affects their safety habits. In that regard I think that it does. I think that it should be 'common-sense' that if someone is made aware of a safety error like standing too close to the emitter that they then would correct it on the spot. This is advantageous over merely having safety review sessions to reevaluate their knowledge of their safety protocols as well as the passive dosimetry data that covers one month at a time. The systems like the ones just mentioned are good, but there is room for improvement, and when the improvements can be made by simply alerting the employee to that they are risk at that very moment, then it seems

logical that they will correct their behaviors on the spot and put themselves out of excessive dosages of radiation. This also does not account for the issue of whether or not the specific employees in this data were receptive, indifferent or resistant to use the real-time data to their advantage. It can be assumed that most would take this kind of new technology to heart and apply it to their habits, but we all know that for some change is difficult and can be a challenge to achieve full cooperation in addition to full technical integration. This is brought up not to diffuse the strength of this assessment, but to acknowledge that there are several elements that play roles in how a safety doctrine works, if it works effectively, or if it is attended to by those it is meant to help protect.

Since the game of radiation risk is one of accumulation, eliminating or reducing the short spikes of high radiation more often will reduce the long term overall exposure. And less accumulated exposure means less risk. The product that RaySafe offers can be shown to be successful at this reduction effort. However, more testing and cross-referencing of employee data is required to produce a conclusive result.

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