Predicting Nuclear Medicine and PET/CT Technologists' Exposure and Establishing Benchmarks for Safe Practice

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Helping Administrators determine the appropriate staff needed to keep technologist below their ALARA 1 Limit

About Me

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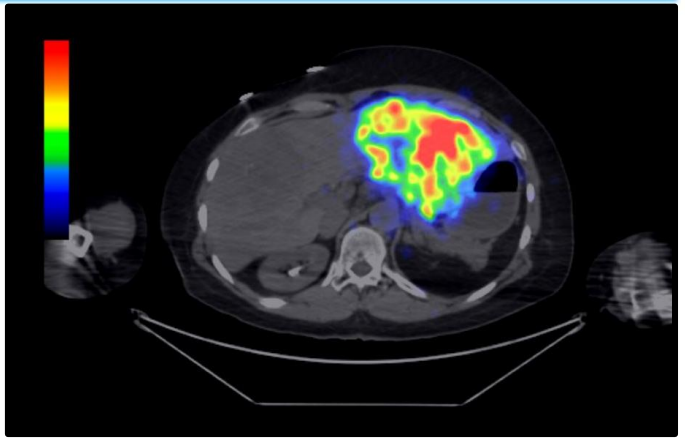
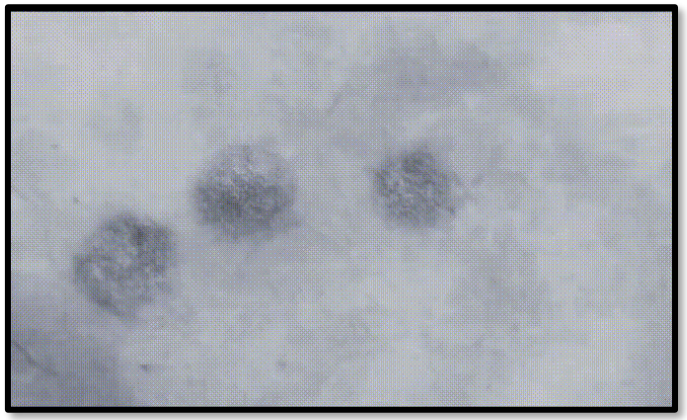
Overview

- Medical Imaging
- Issues in Medical Imaging
  - What problem can I solve?
  - How can I help?
  - What is the solution?
- Data Collection and Evaluation
  - Materials and Methods
  - Results
  - Conclusion
  - Discussion
- Open Discussion

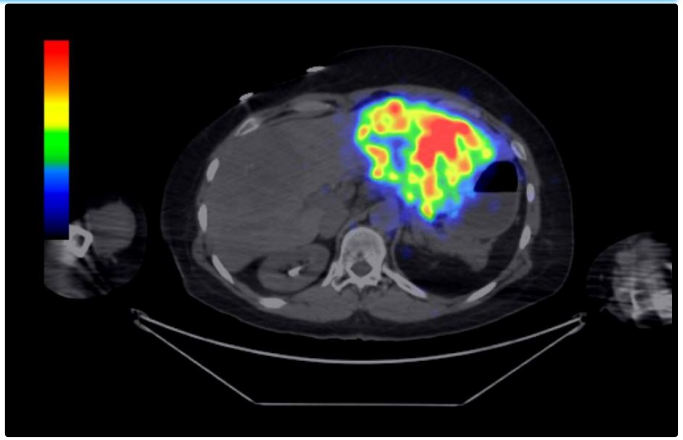


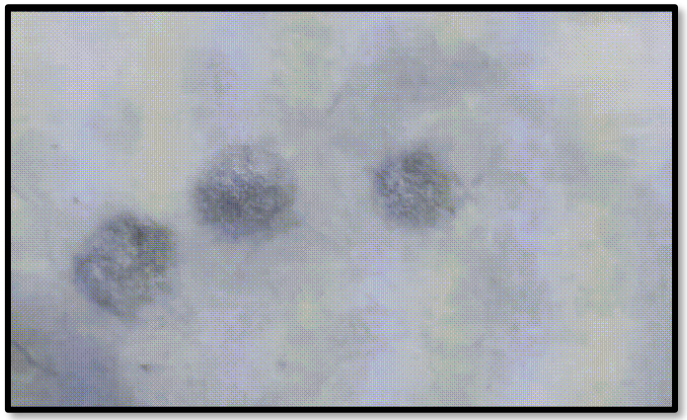


Medical Imaging

Imaging Modalities

- Computed Tomography
- Fluoroscopy
- Magnetic Resonance
- Nuclear Medicine
- PET/CT
- X-Ray





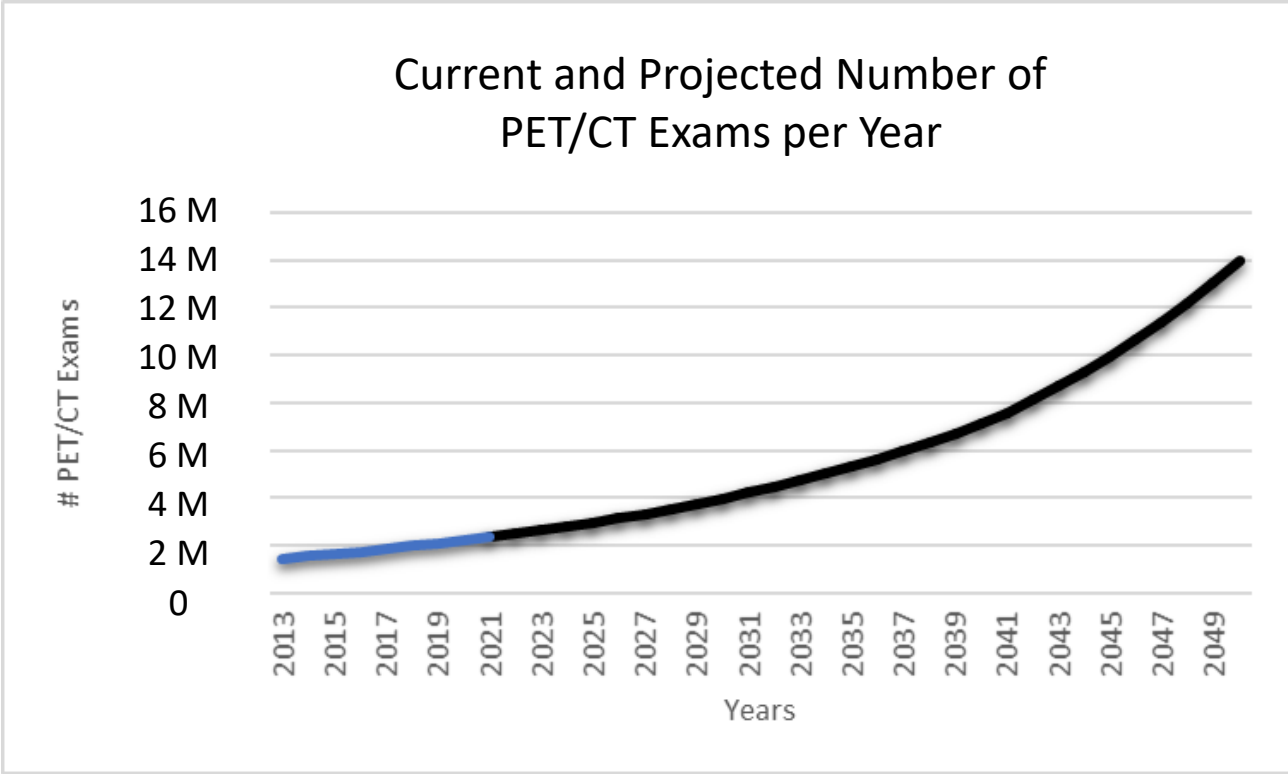
Medical Imaging

- High Exposure Modalities
  - PET/CT Technologist
    - Average Annual Exposure ***300 mRem***
  - Fluoroscopy Technologist
    - Average Annual Exposure 155 mRem
  - Nuclear Medicine
    - Average Annual Exposure 100 mRem
- Low Exposure Modalities
  - X-Ray Technologist
    - Average Annual Exposure 25 mRem (12x less)
  - CT Technologist
    - Average Annual Exposure 12 mRem (25x less)
  - MRI Technologist
    - Average Annual Exposure 8 mRem (38x less)

Exposure data from CARTI overview for 2020.

Issues in Medical Imaging

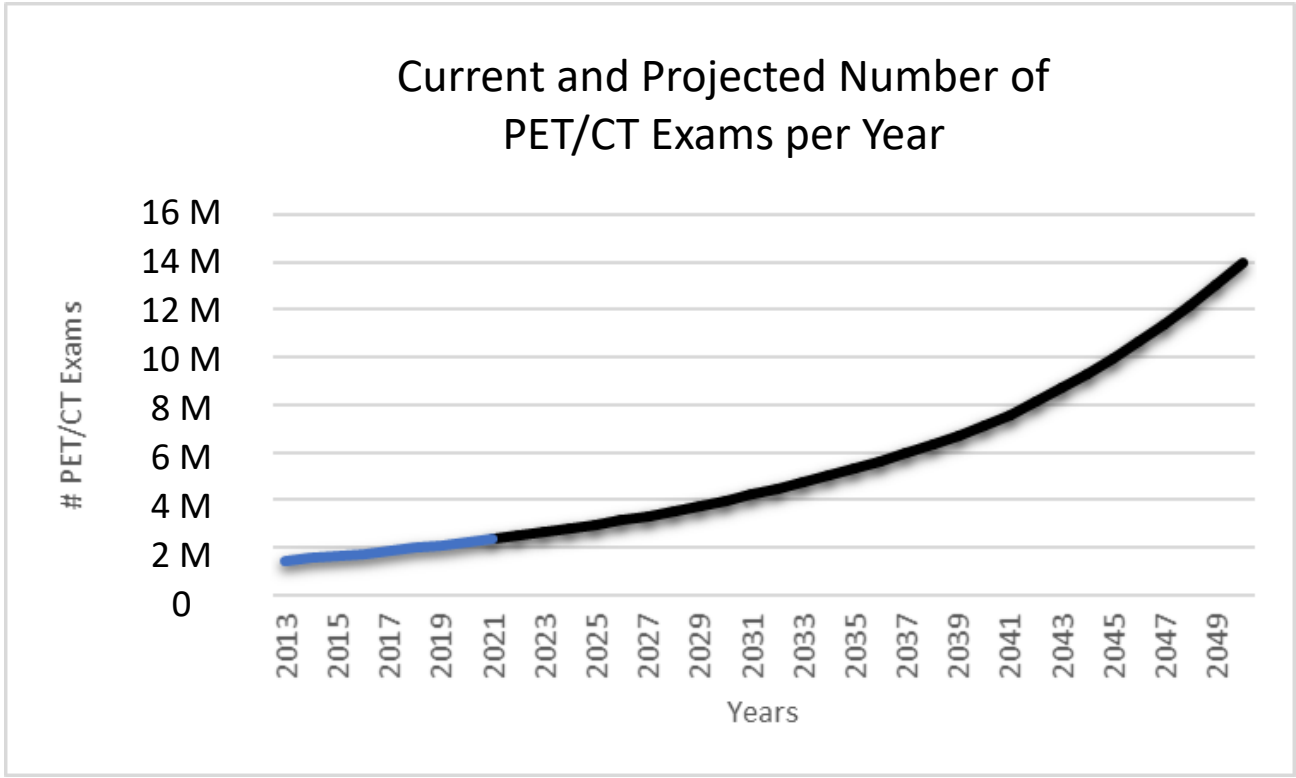
- PET/CT Technologist has the highest radiation exposure in Radiology
- PET/CT is a rapidly growing field
- Total number of PET/CT scan has increased > 6% every year since 2013*
- How will this Exponential growth affect technologist exposure?



*Young, L. (2019, August 6). *PET/CT drives PET scan volume to New Heights*. IMV Medical Information Division. Retrieved January 3, 2022, from https://imvinfo.com/pet-ct-drives-pet-scan-volume-new-heights/

Issues in Medical Imaging

- What Problem can I solve?
  - I can help PET/CT Technologist radiation exposure stay within a safe limit.
- How can I help?
  - Develop a formula to predict a technologist exposure with a given patient workload.
- What is the solution?
  - Collect, evaluate, and interpret the technologist exposure data.
  - Develop a formula to predict PET Technologist Exposure
  - Publish the data to allow technologist to benefit



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Issues in Medical Imaging

ALARA

- "As Low As Reasonably Achievable"
- Although there is no documented evidence linking any health effect with exposures less than 10,000 mrem (100 mSv) delivered at a high dose rate, it is assumed that any radiation exposure may carry some risk.*
- Annual Limit is half of the dose seen to produce effects
- Action Limits:
  - Level I
    - Receive 2.5% of the annual limit in one quarter
  - Level II
    - Receive 7.5% of the annual limit in one quarter

Quarterly ALARA Action Limits

Dosimeter Location	ALARA I Limits		ALARA II Limits	
	mSv	mRem	mSv	mRem
Whole Body	1.25	125	3.75	375
Lens of the Eye	3.75	375	11.25	1125
Extremities	12.5	1250	37.5	3750
Fetal*			5.0	500

**Embryo/Fetus limit took over the entire pregnancy*

*Alara program - WKU - Western Kentucky University. (n.d.). Retrieved January 4, 2022, from https://www.wku.edu/ehs/radiation/module-4_alara_program.pdf

Data Collection and Evaluation

- How to Start
  1. Collect technologist total body and extremity exposures for every quarter from 2017-2021.
     - 251 Deep Dose Exposures (DDE) and 251 extremity exposures were recorded
     - Totaling 502 data points
  2. Document the total General Nuclear Medicine and PET/CT exams completed per technologist.
     - 48,974 patient's exams were used in this data set
     - There was a total of 23 Nuclear Medicine and PET/CT technologist
       - 5 Males
       - 18 Females
       - 35 years old average age
       - 0 technologist has been diagnosed with cancer or radiation related disease

Data Collection and Evaluation

3. Determine the Ratio between PET/CT & Nuclear Medicine exams
   - All technologists are issued badges monthly and routinely rotate between the departments.
   - The quarterly totals are an uneven mix of exposure rate.

4. Developing a weighting fraction for the PET/CT & Nuclear Medicine Exposures
   - My guest was about a 1:5 ratio (NM:PET)
     - Verified with a simple test
       - There was a couple of time between 2017-2021 where a technologist was in a department for an entire monthly.
       - Divide the exposure by the number of patients dose gave an average exposure per patient.
       - Compare the ratio between Nuclear Medicine : PET/CT

Data Collection and Evaluation

5. After the sample evaluation
   - 1:5 was **WRONG**
   - It was determined that 1: 3.5
   - Then it was noticed that the major energies were 140:511 keV
   - This was the same ratio between the two energy levels (1: 3.65)
   - So, 21.5% and 78.5% was the ratio difference, or PET/CT exams deposited 37.7% faster.
   - Looking back, it made since that the energy was deposited in the exact energy ratio as the major isotopes used at this facility ~97.6% of the total exams used the below isotopes.
     - ^{99m}Tc = 140 keV
     - ^{18}F = 511 keV

Data Collection and Evaluation

Methods and Materials

- Retrospectively – Occupational radiation exposure data was evaluated from 2017-2021
- Radiation Exposure was recorded through Landauer
  - Landauer Luxel – Body Dosimeter
    - Optically Stimulated Luminescence (OSL)
  - Landauer Saturn – Ring Dosimeter
    - Thermoluminescent Dosimeter (TLD)

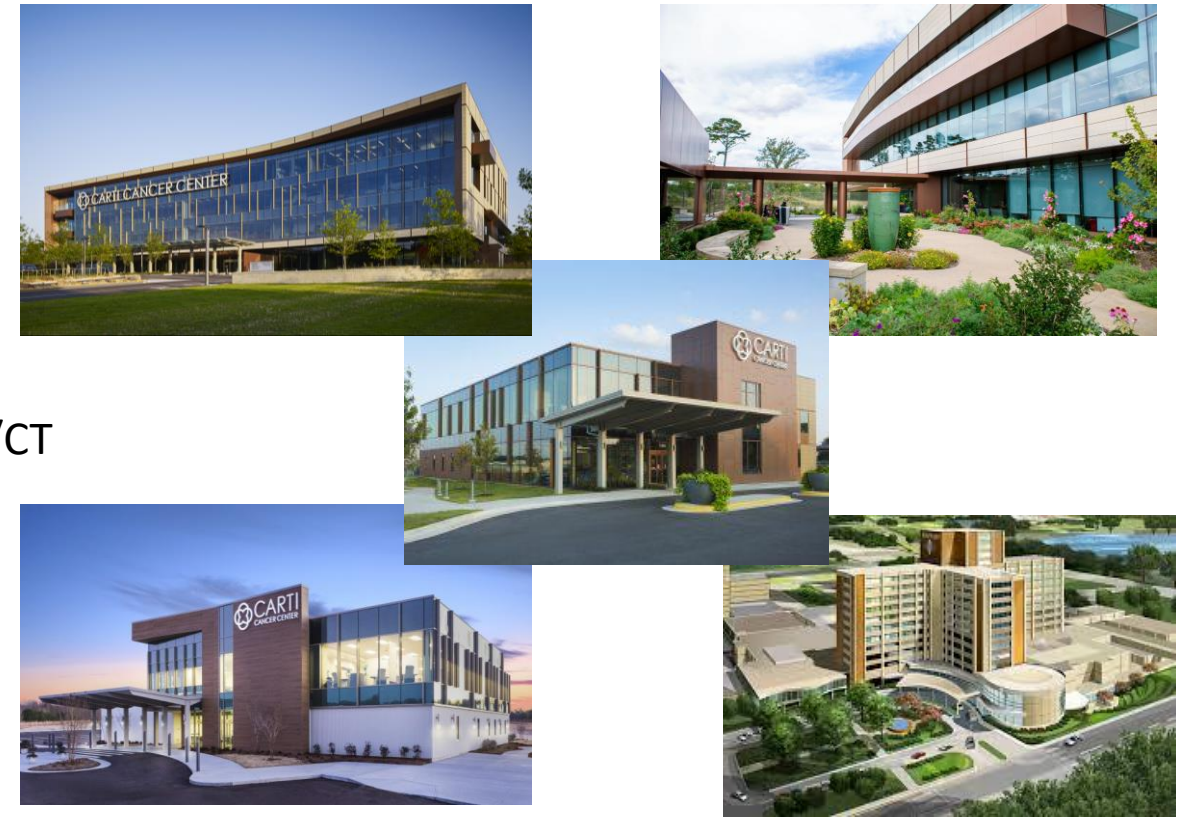
LANDAUER®

Images from Landauer.com

Data Collection and Evaluation

Methods and Materials

- Nuclear and PET/CT Department Locations
  - CARTI Cancer Center, Little Rock – PET/CT
  - CARTI Cancer Center, Little Rock– Nuclear Medicine
  - CARTI Outpatient at Baptist Hospital, Little Rock – PET/CT
  - CARTI Cancer Center, Pine Bluff – PET/CT
  - CARTI Cancer Center, North Little Rock – PET/CT



www.carti.com/locations/

Data Collection and Evaluation

Methods and Materials

- Equipment used:
  - GE Discovery MI PET/CT (x2)
  - Philips Gemini TF 64 PET/CT
  - Philips Gemini TF 16 PET/CT
  - Philips Brightview Gamma Cameras (x2)

https://meditegic.com/philips-medical-imaging-parts/
https://www.mediram.net/product-category/philips/pet-ct-philips/gemini-tf-64-spare-parts
ge.com/news/press-releases/going-beyond-analog-ge-healthcare-launches-digital-next-generation-molecular-imaging

Data Collection and Evaluation

Methods and Materials

- Most Procedures use a standard prescribed activity
  - This optimizes imaging quality while keeping the dose low for the patient
  - The standard dose remains while multiple technologist perform the same procedure
  - Only a few procedures use a weight base or personized treatment plans
    - Ra^{223} Xofigo - Palliative Bone Pain Treatment
    - Y^{90} SIR-Spheres - Primary/ metastatic Liver Treatment

TABLE 2.
Routine Exams and Standard Prescribing Activity

Procedure	Prescribed Dose (mCi)	Dose Range (mCi)
Axumin ^{18}F	10	8-12
Dotatate ^{68}Ga	5.4	4.86-5.4
FDG ^{18}F	15	8-20
Gastric Emptying ^{99m}Tc	2	± 10%
Hepatobiliary ^{99m}Tc	7	± 10%
MDP ^{99m}Tc	25	± 10%
MUGA ^{99m}Tc	30	± 10%
Parathyroid ^{99m}Tc	25	± 10%
Pylarify ^{18}F	10	8-12

Data Collection and Evaluation

Methods and Materials

- 23 nuclear medicine technologist radiation exposure data was evaluated
  - Over 5 years from 2017-2021
  - Two different category of exams
    - PET/CT : using a 511 keV annihilation photon pair
    - General : using primarily 140 keV gamma photon
- Each technologist's exposure was weighted by the number of exams completed in each category.

Image taken from CARTI's Facebook page

Data Collection and Evaluation

Methods and Materials

- Using the energy ratio's
  - 511 keV – 78.5%
  - 140 keV – 21.5%
- Here are the derived formulas to estimated exposure per number of patients completed.
- Again, this data was taken over 5 years, 23 technologist and over 48,974 patients.

Weighted Body Exposure per Nuclear Procedure

$$Nm^{b}_{exp} = \frac{Nm_p}{T_P}(0.215)\left(H^{b}_{exp}\right)$$

Weighted Extremity Exposure per Nuclear Procedure

$$Nm^{e}_{exp} = \frac{Nm_p}{T_P}(0.215)\left(H^{e}_{exp}\right)$$

Weighted Body Exposure per PET/CT Procedure

$$PET^{b}_{exp} = \frac{PET_p}{T_P}(0.785)\left(H^{b}_{exp}\right)$$

Weighted Extremity Exposure per PET/CT Procedure

$$PET^{e}_{exp} = \frac{PET_p}{T_P}(0.785)\left(H^{e}_{exp}\right)$$

Data Collection and Evaluation

Methods and Materials

- Determining the maximum number of exams to remain below ALARA I and ALARA II

"Limit"

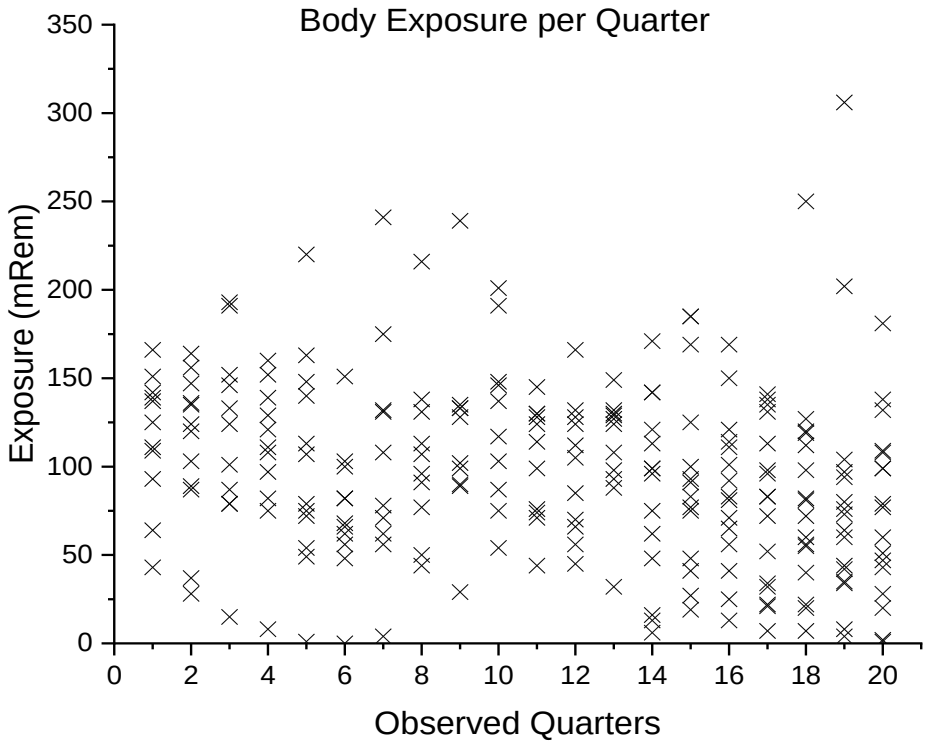
- Body:
  - ALARA I: 125 mRem
  - ALARA II: 375 mRem
- Extremity:
  - ALARA I: 1,250 mRem
  - ALARA II: 3,750 mRem

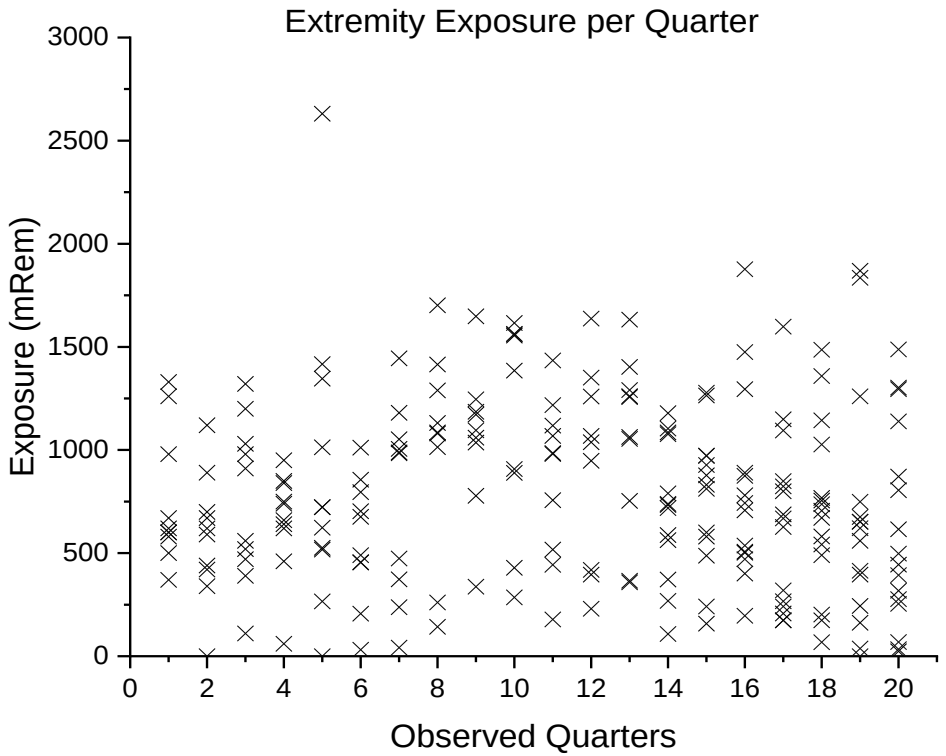
Exams per given limit

$$\frac{Avg_{exp}}{Limit} \div 3 = {}^{Exams}/_{Month}$$

Data Collection and Evaluation

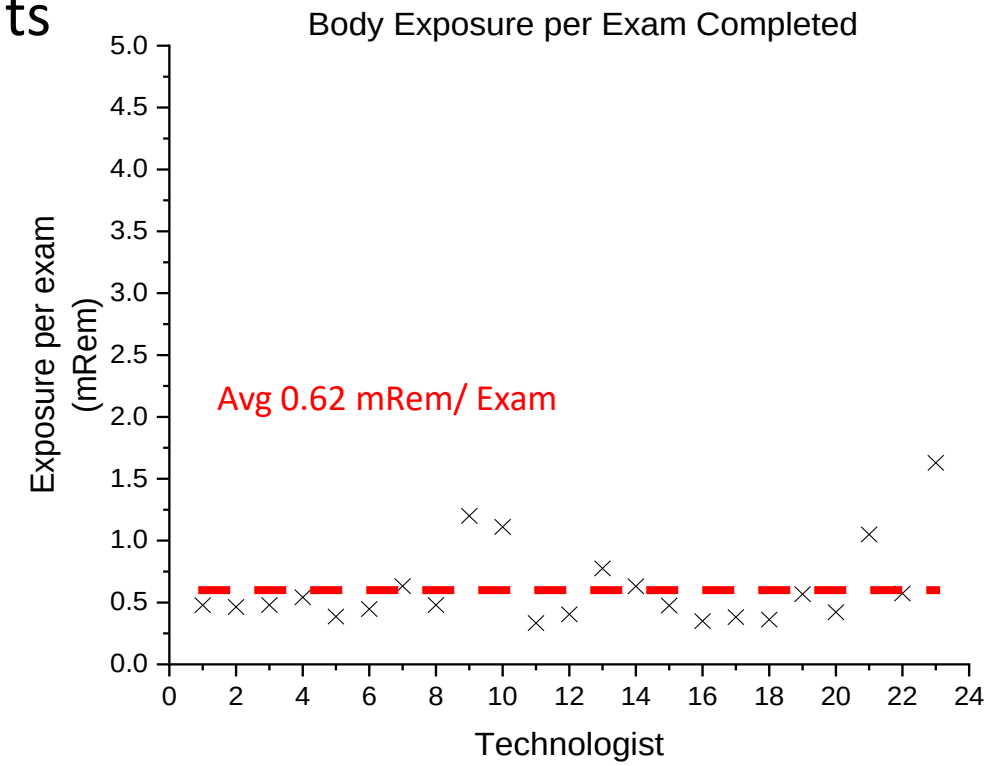
Results

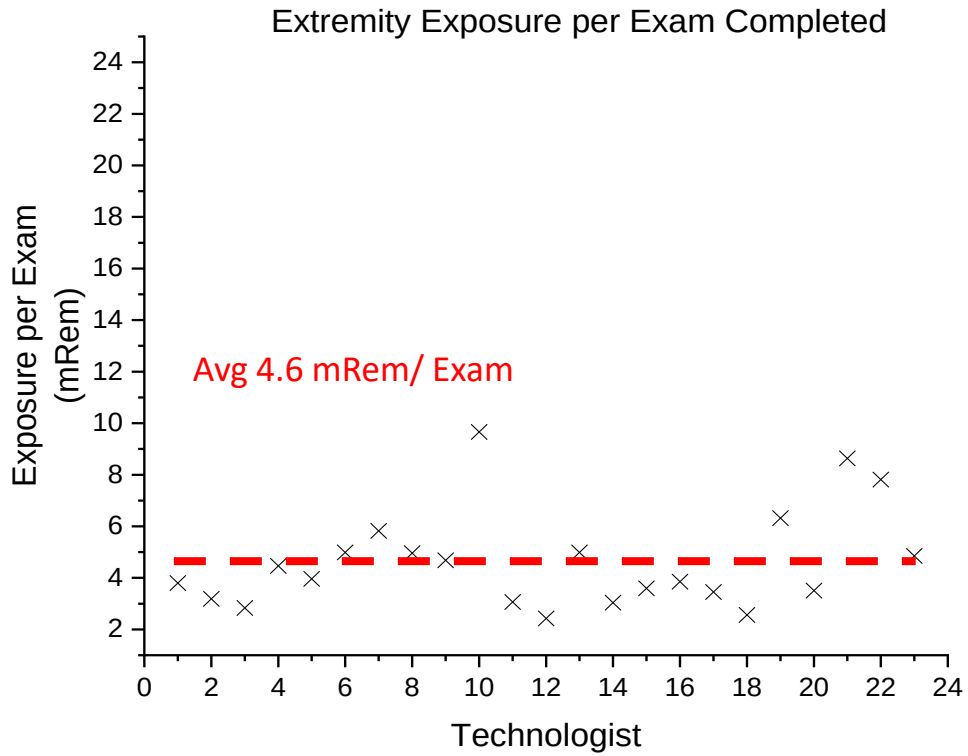




Data Collection and Evaluation

Results

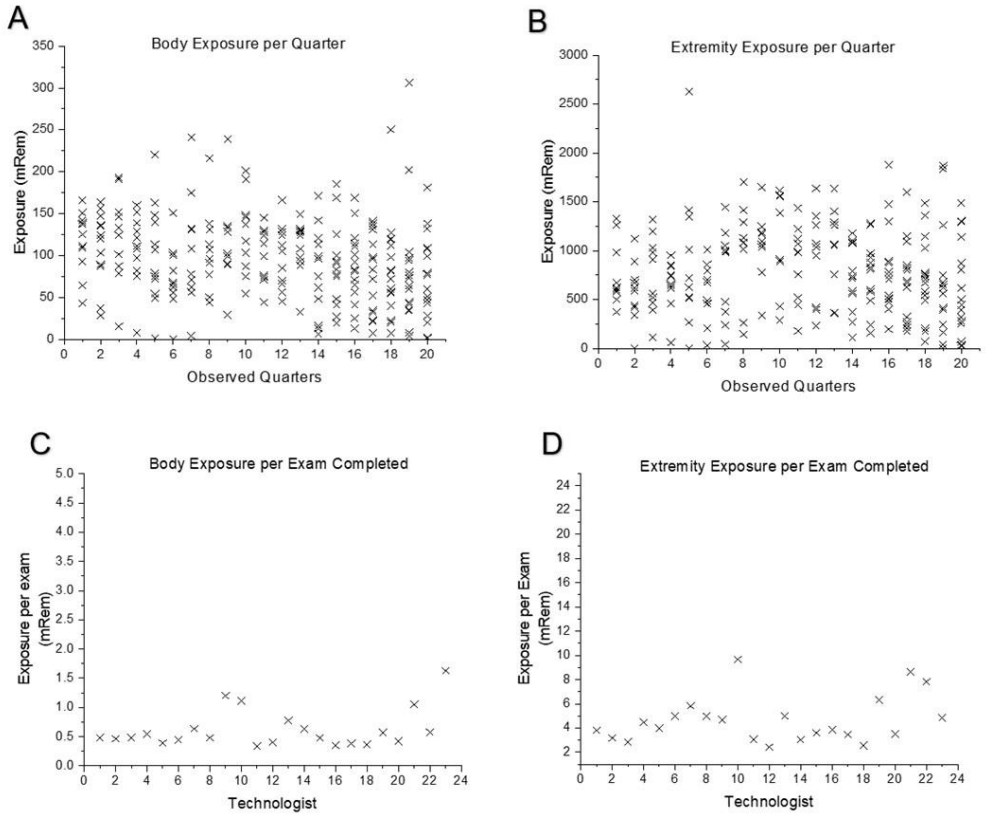




Data Collection and Evaluation

Results

- Graph A shows the whole-body exposure readings for all twenty-three Nuclear Medicine technologists from 2017 to 2021.
- Graph B shows the extremity exposure over the same time frame similar to graph A.
- Graph C shows the average body exposures per exam completed.
- Graph D shows the average extremity exposures per exam completed.



Data Collection and Evaluation

Results

- Overall Exposure:
  - Body was 0.62 mRem ±0.32 per exam completed.
  - Extremity was 4.63 mRem ± 1.88 per exam completed.
- PET/CT Exposure:
  - Body was 1.14 mRem ±0.35 per PET/CT exam completed
  - Extremity was 8.95 mRem ± 2.33 per PET/CT exam completed
- Nuclear Medicine
  - Body was 0.11 mRem ± 0.06 per Nuclear exam completed
  - Extremity was 0.92 mRem ± 0.73 per nuclear exam completed

https://carticancer.sharepoint.com/sites/Imaging/Shared Documents/General/Imaging Team Meeting Agenda 05.20.20.doc?web=1

Data Collection and Evaluation

Results

- After determining the weighted average of both PET/CT and general Nuclear Medicine exam for the body and extremity an equation can be derived to calculate the predicted technologist exposure with a given number of exams.

Total Estimated Body Exposure

$$H_{exp}^{\gamma b} = (1.140x) + (0.113y)$$

Total Estimated Extremity Exposure

$$\mathrm{H}_{exp}^{\gamma \mathrm{e}} = (8.951x) + (0.917y)$$

Data Collection and Evaluation

Results

Total Estimated Body Exposure

$$H_{exp}^{\gamma b} = (1.140x) + (0.113y)$$

Total Estimated Extremity Exposure

$$\mathrm{H}_{exp}^{\gamma e} = (8.951x) + (0.917y)$$

Total Technologists Needed per Body Exposure

$$T^{\gamma b} = \frac{\left(H_{exp}^{\gamma b}\right)}{ALARA\ I\ Limit}$$

Total Technologists Needed per Extremity Exposure

$$T^{\gamma e} = \frac{\left(H_{exp}^{\gamma e}\right)}{ALARA\ I\ Limit}$$

Where:

$H_{exp}^{\gamma b}$ = Estimated Body Exposure per Quarter

$\mathrm{H}_{exp}^{\gamma e}$ = Estimated Extremity Exposure per Quarter

$T^{\gamma b}$ = Total Technologists Needed per Body Exposure

$T^{\gamma e}$ = Total Technologists Needed per Extremity Exposure

x = Number of PET/CT Exams per Quarter

y = Number of Nuclear Exams per Quarter

Data Collection and Evaluation

Results

Example:

Whole-Body Exposure

$$H_{exp}^{\gamma b} = (1.140x) + (0.113y)$$

$$H_{exp}^{\gamma b} = (1.140(\mathbf{744})) + (0.113(\mathbf{1045}))$$

$$H_{exp}^{\gamma b} = 966.24 \text{ mRem}$$

$$T^{\gamma b} = 966.24 \,/\, (125^{\text{ ALARA I Body}})$$

$$T^{\gamma b} = 7.7 \text{ or } \underline{8 \text{ Technologists}}$$

Extremity Exposure

$$\mathrm{H}_{exp}^{\gamma e} = (8.951x) + (0.917y)$$

$$\mathrm{H}_{exp}^{\gamma e} = (8.951(\mathbf{744})) + (0.917(\mathbf{1045}))$$

$$\mathrm{H}_{exp}^{\gamma e} = 7617.81 \text{ mRem}$$

$$T^{\gamma e} = 7{,}617.81 / (1{,}250^{\text{ ALARA I Extremity}})$$

$$T^{\gamma e} = 6.1 \text{ or } \underline{7 \text{ Technologists}}$$

Where:

$H_{exp}^{\gamma b}$ = Estimated Body Exposure per Quarter

$\mathrm{H}_{exp}^{\gamma e}$ = Estimated Extremity Exposure per Quarter

$T^{\gamma b}$ = Total Technologists Needed per Body Exposure

$T^{\gamma e}$ = Total Technologists Needed per Extremity Exposure

x = Number of PET/CT Exams per Quarter

y = Number of Nuclear Exams per Quarter

Data Collection and Evaluation

Conclusion

- The average body exposure was 101 mRem per quarter with and extremity exposure of 841 mRem per quarter
- The combined overall average body exposure was 0.616 mRem and a combined average extremity exposure per exam was 4.63 mRem for exam
- Maximum number of PET/CT exams per month to remain below ALARA I was 36.56 exams.
- Maximum number of PET/CT exams per month to remain below ALARA II was 109.69 exams.
- Maximum number of nuclear exams per month remain below ALARA I was 368.73 exams.
- Maximum number of nuclear exams per month to remain below ALARA II was 1,106.19 exams.

Data Collection and Evaluation

Conclusion

- Establishing Benchmarks for Safe Practice
- Technologist can use this model to determine if their exposure is above/ below the average per exam completed.
- Allow administrators to evaluate Technologist exposure per exam completed.

Table 3.

Exposure Benchmarks for Safe Practice per Patient (mRem)

	Average	Minimum	Maximum	Standard Deviation
Average overall body exposure	0.62	0.33	1.63	0.32
Average overall extremity exposure	4.63	2.43	9.66	1.88
PET body exposure per patient	1.14	0.57	2.01	0.35
PET extremity exposure per patient	8.95	4.82	12.82	2.33
NM body exposure per patient	0.11	0.03	0.28	0.06
NM extremity exposure per patient	0.92	0.21	3.74	0.73

Data Collection and Evaluation

Conclusion

- Formula Verification between the Predicted and Actual Exposure Value
  - 8 random technologist were blindly selected to evaluate the accuracy of the exposure predicted equation derived in this research.
  - The overall accuracy of the 8 technologist and 16 samples was determined by predicting the technologist exposure within ± 20.8 mRem for the whole body and ± 208 mRem for the extremity.
  - Sixteen of the sixteen exposures were within the predicted value giving an overall accuracy of 100% with the acceptable range of $1/6^{th}$ of the ALARA I limit. (± 20.8 mRem/ ± 208 mRem)
  - With an acceptable range of $1/10^{th}$ ALARA I limit resulted in the formula accurately predicting technologist exposure was 81.3% (± 12.5 mRem/ 125 mRem)

Data Collection and Evaluation

Conclusion

Formula Validation Between the Predicted and Actual Exposure Value

Tech ID	# PET Patients	# NM Patients	Predicted WB Exp. (mRem)	Predicted Ext. Exp. (mRem)	Actual WB Exp. (mRem)	Actual Ext. Exp. (mRem)	WB Difference	Ext. Difference
1	21	62	31	245	33	216	-2	29
2	13	26	18	140	34	223	-16	-83
3	36	0	41	322	41	195	0	127
4	22	10	26	206	19	181	7	25
5	12	7	14	114	27	66	-13	48
6	33	39	42	331	52	275	-10	56
7	42	0	48	376	42	227	6	149
8	21	60	31	243	28	404	3	-161

Data Collection and Evaluation

Discussion

- This study was taken using data from an outpatient imaging department specializing in oncology. Neurological, endocrinological, and gastrological exams were performed less frequently.
- Also, the technologist dosing workflow allows every technologist to dose and scan approximately the same number of patients.
- They did **not** have a dedicated technologist running the hot lab or have multiple technologists handling the dose before administration.
- Additional data needs to be collected comparing the results from this study to other common department scenarios.
    - A PET/CT Cardiology Clinic
    - Academic Nuclear Department using a wide range of energies to see how this 140/511 keV scheme holds up to different circumstances
    - Finally, a more extensive data set would better affirm or evaluate the accuracy of our study.

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Open Discussion

Questions?

Please leave a comment if you have questions!

Thank you