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Monitoring Individual Occupational Radiation Exposure at Multiple Institutions

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Abstract

Within a few years of its' discovery, ionizing radiation demonstrated adverse effects on biological systems. Since that time great strides were made in both radiation protection, detection, and personnel monitoring. Monitoring occupational radiation dose to individuals is enforced by several regulatory agencies in the United States (U.S.) and is referenced in numerous sections of the Code of Federal Regulations (CFR). A literature review with an examination of regulatory guidelines and a Radiation Safety Officers (RSO) survey was conducted to evaluate how often radiation dose exposure is monitored when an individual receives occupational radiation dose at more than one facility. The length of time an RSO has overseen the radiation safety program at his/her institution can impact if dosimetry reports are requested for individuals that work at multiple places. Despite having safer equipment and occupational radiation exposure standards, there is no universal mechanism to track and record exposure for individuals working at more than one institution.

Introduction

Occupational radiation exposures must be monitored, regulated, and accurately reported. Individuals exposed to radiation and radioactive materials are routinely monitored with different types of radiation dosimetry badges which includes those working in radiology. Radiology employees may be exposed to radiation from machines, patients, sealed, and unsealed radioactive sources *(1)*. When individuals working in radiology are employed by multiple institutions, it is important the individual's cumulative radiation dose be monitored and accurately recorded at each facility. With the variety of imaging equipment, diagnostic nuclear tracers, therapeutic nuclear tracers, and theranostics being utilized in different facilities, this is a concern that will only grow more complex.

Occupational exposure can come from two different sources: radiation produced by machines and from radionuclides. The type, production, and use of the radioactive material changes which government-sponsored regulatory body in the United States is responsible for controlling and monitoring the radiation. The U.S. Nuclear Regulatory Commission (NRC) regulates commercial nuclear power plants and other uses of nuclear materials, such as in nuclear medicine, through licensing, inspection and enforcement of its requirement *(2)*. The Occupational Safety and Health Administration (OSHA) is part of the U.S. Department of Labor which covers radiation employees who work with radiation-producing machines. The primary goal of the Occupational Safety and Health (OSH) Act of 1970 is to reduce workplace hazards and implement safety and health programs for both employers and their employees *(3)*. The OSH Act covers most private sector employers and their workers as well as some public-sector employers and workers in the 50 states and certain territories and jurisdictions under federal authority *(4)*. The Department of Energy (DOE) Office of Environment, Health, Safety, and Security retains a database titled Radiation Exposure Monitoring System (REMS). REMS includes occupational radiation exposures at DOE facilities that provide an annual report that includes occupational radiation exposure for DOE workers and members of the public in radiation controlled areas. publicly controlled areas (*5*). The DOE provides available information in regards to the ALARA project descriptions, preparation of the annual data, and the cyber secure method to transmit these annual submittals (*6*).

The NRC states: "the licensee shall reduce the [radiation] dose that an individual may be allowed to receive in the current year by the amount of occupational dose received while employed by any other person (see § 20.2104(e))" *(2)*. This may be a challenge for radiation workers who work at multiple institutions and receive radiation exposure in multiple ways; the individual occupational worker can be exposed to machine-produced radiation, radionuclide-produced radiation, or both simultaneously. The personal dosimeters worn by individuals cannot differentiate between radiation produced by machines and radiation from radionuclides, so issues arise with determining which governing body takes precedence regarding radiation exposure limits. The rules are not clear as to who should keep track of which facility or individual is responsible for monitoring the exposures from multiple locations; this brings an added challenge to the individual being monitored and the facilities. This manuscript will examine the regulations from the U.S. government as it relates to measuring an individual's occupational radiation exposure and present findings from a survey to Radiation Safety Officers (RSO). It will explore the challenges in recording individual radiation exposure at different facilities with different machines and radioactive tracers.

Materials and Methods

The radiation regulations in the United States from OSHA, the NRC, and DOE were reviewed. A literature review was done to determine if a study of this type has been completed before and no known study exists. This review included the radiation aspects in the Code of Federal Regulations (CFR), the published information on the government websites, and the memorandum of agreements between NRC and OSHA. This review included individual radiation dose limits, the regulatory agency that takes precedence over the other when regulations overlap, and wording to determine the responsible party for keeping records of individual radiation exposure when individuals work in multiple institutions. In addition, an electronic survey was sent to RSOs at many types of public and private institutions including academic, community, and government facilities regarding radiation safety and each institution's protocol regarding individual occupational dosimetry reports. The survey was sent and generated using Qualtrics software (Copyright © 2019 Qualtrics). Qualtrics and all other Qualtrics product or service names are registered trademarks or trademarks of Qualtrics, Provo, UT, USA. https://www.qualtrics.com. The radiation safety survey was sent to 300 RSOs with 50 responses. The questions sent in the survey are listed in Table 1. The email addresses of the RSOs were obtained from an active RSO via a listserv of Veterans Affairs Radiation Safety Officers and Academics across the country.

Table 1

Radiation Safety Survey
Question: At what type of institution are you currently employed? Answers: (A) Academic, (B) Community, (C) Government, (D) Other
Question: Is the institution you currently work at inside the United States? Answers: Yes or No
(Length) Question: How long have you worked at this institution? Answers: (A) less than one year, (B) 1 - 5 years, (C) 5 - 10 years, (D) more than 10 years with reference category set as D
Question: Are you currently in charge of the radiation safety program at your institution? Answers: Yes or No
(Request) Question: Do you request dosimetry reports for employees who work at multiple institutions? Answers: Yes or No
Question: Do you have any other comments or concerns regarding radiation exposure that you would like to share? Answers were open for free text
Question: If you are open to discussing your institution-specific policies, please leave your contact information below. Answers were open for free text

Results

The literature review provided insight into the complexity of this issue. If radiation is not properly controlled, it can be potentially hazardous to the health of workers (*7*). Ionizing radiation sources may be found in a wide range of occupational settings, including health care facilities, research institutions, nuclear reactors, nuclear reactor support facilities, nuclear weapon production facilities, and other various manufacturing settings. Biological effects for a person exposed to ionizing radiation are due to the ionization process that destroys the capacity for cell reproduction or division or causes cell mutation (*8*). The effects of one type of radiation can be reproduced by any other type. A total given dose will cause more damage if received in a shorter time (*8*). A radiation dosimeter (often referred to as a radiation badge) does not provide protection but detects and measures the amount of radiation to which one has been exposed (*9*). These devices allow wearers to keep track of the radiation they are absorbing, to prevent them from falling ill, and to determine how hazardous a radioactive environment may be (*10*). These badges must be worn when working with X-ray equipment, radioactive patients, and radioactive materials. The dosimeters should not be worn while receiving radiation exposure as part of an individual's medical or dental care (*11*). The radiation dosimeter worn by an individual must be specific to that individual's occupational environment as each type of dosimeter will detect different types of radiation (*10*). Many individuals working with radiation in occupational settings are often exposed to both types of radiation: machine produced and radionuclide produced.

Radiation produced by machines is overseen by OSHA. Title 10 CFR Part 20.1201 subpart C addresses the occupational radiation dose limits which state "the licensee shall control the occupational dose to individual adults" (*2*). Radiation from radionuclides is overseen by the NRC. OSHA and NRC have the same yearly whole body limits for maximum recommended exposure to individuals but differ in specific radiation doses other than the whole body. OSHA and NRC use different periods to collect exposure limits; OSHA has quarterly limits and NRC has annual limits. See Table 2 and Table 3 for the dose limits for OSHA and the NRC along with the comparison of annual dose for these agencies.

Table 2

<table>
<tr><td colspan="3">Dose Limits for OSHA and NRC</td></tr>
<tr><td></td><td>OSHA</td><td>NRC</td></tr>
<tr><td>Radiation Dose Limit Time Periods</td><td>Quarterly</td><td>Annually</td></tr>
<tr><td>Deep Dose Equivalent (DDE)</td><td>1.25 rem (0.0125 Sv)</td><td>5 rem (0.05 Sv)</td></tr>
<tr><td rowspan="2">Shallow Dose Equivalent (SDE)</td><td>18.75 rem (0.1875 Sv) Extremities</td><td rowspan="2">50 rem (0.5 Sv)</td></tr>
<tr><td>7.5 rem (0.075 Sv) Skin</td></tr>
<tr><td>Lens Dose Equivalent (LED)</td><td>1.25 rem (0.0125 Sv)</td><td>15 rem (0.15 Sv)</td></tr>
</table>

(*2;8*)

Table 3

Comparison of Annual Dose for OSHA and NRC		
	OSHA	NRC
Deep Dose Equivalent (DDE)	5 rem (0.05 Sv)	5 rem (0.05 Sv)
Shallow Dose Equivalent (SDE)	75 rem (0.75 Sv) Extremities	50 rem (0.5 Sv)
	30 rem (0.3 Sv) Skin	
Lens Dose Equivalent (LED)	5 rem (0.05 Sv)	15 rem (0.15 Sv)

(*2;8*)

There are several ways radiation to an occupational worker or the public can be monitored. The NRC 10 CFR 20.1502 addresses the conditions requiring individual monitoring of external and internal occupational dose. Occupational workers are required to be monitored if the individual is likely to receive 10% of the maximum permissible radiation dose (*12*). These specific exposures for adults were listed previously in Tables 2 and 3. Minors, declared pregnant women, and individuals entering a high or very high radiation area have specific and more restrictive requirements per these regulations (*12*). Pocket dosimeters, personnel dosimeters, and/or film badges can be used to monitor radiation exposure. See figures 1 and 2. Each personnel dosimeter must be assigned to and worn only by one individual (*13*). Film badges must be replaced at periods not to exceed one month and other personnel dosimeters processed and evaluated by an accredited National Voluntary Laboratory Accreditation Program (NVLAP) processor must be replaced at periods not to exceed three months (*13*).

The radiation regulations in the United States from OSHA, the NRC, and the DOE are not specific on how radiation doses gathered from individuals working at multiple sites should be cumulated and not specific on the responsible party for cumulating this information. The only statement found in the NRC regulations to mention this fact is "the licensee shall reduce the [radiation] dose that an individual may be allowed to receive in the current year by the amount of occupational dose received while employed by any other person (see § 20.2104(e))" *(2)*. Section 20.2104 states the acceptable amounts and states how to reduce limits if an individual is unable to receive the history (1.25 REM/QTR if history not available) *(2)*.

From the survey to the 300 RSOs, 50 (17% response rate) responses were received. The survey gathered 36 responses to the question "do you request dosimetry reports for employees who work at multiple institutions?" Of the 36 responses to this question, 26 (72%) respondents answered 'Yes' and 10 (28%) answered "No'. See Table 4 for the descriptive statistics for this data. Chi-Squared tests, in the R Environment for Statistical Computing (R Core Team, 2013), were used to determine whether those with different experience or different work settings request dosimetry reports for individuals who work at different institutions. The results of the Chi-Squared tests are included below in Tables 5 and 6. There is a statistically significant difference in dosimetry requests based on work experience (X^2 = 11.041, $p < .05$). Most notably, those with more than 10 years of experience are more likely than not to request the reports. On the other hand, no statistically significant differences were found in requesting dosimetry reports from those working at multiple institutions were found across different types of institutions (X^2 = 3.3925, $p > .05$).

Table 4

Descriptive Statistics		
RSO experience length	N = 36	Percentage
Less than one year	3	8.3%
1 to 5 years	7	19.4%
5 to 10 years	10	27.8%
More than ten years	16	44.4%
RSO Institution Type	N = 36	
Academic	19	52.8%
Government	5	13.9%
Community	11	30.6%
Other	1	2.8%

Table 5

Results of Chi-square Test and Descriptive Statistics for Dosimetry Request by Work Experience

Work Experience (in Years)					
Dosimetry Request		< 1	1-5	5-10	10+
Yes		6 (86%)	6 (60%)	0 (0%)	14 (88%)
No		1 (14%)	4 (40%)	3 (100%)	2 (12%)

Note. χ^2 = 11.041*, df = 3. Numbers in parentheses indicate column percentages.

*p < .05

Table 6

Results of Chi-square Test and Descriptive Statistics for Dosimetry Request by Institution Type

		Institution Type			
Dosimetry Request		Academic	Community	Government	Other
Yes		13 (68%)	9 (82%)	4 (80%)	0 (0%)
No		6 (32%)	2 (18%)	1 (20%)	2 (100%)

Note. χ^2 = 3.3925, df = 3. Numbers in parentheses indicate column percentages.

Discussion

Several regulatory agencies review radiation exposure to the occupational worker. Regarding individuals working at multiple facilities, the regulations state each dose should be adjusted when the occupational radiation dose is received while employed at another facility. The regulations do not elaborate on the party responsible for keeping track of the radiation doses for individuals working at multiple institutions. This literature review found the NRC's annual exposure limits for radiation workers is 5 rem (0.05 Sv) total dose equivalent per year. OSHA's occupational dose exposure limits for machine-based radiation dose is also 5 rem (0.05 Sv) per year, but these have limits of 1.25 (0.0125 Sv) rem per quarter. Radiation dosimeters are provided for an individual through his or her place of employment. When an individual is employed at more than one facility, the individual usually has a radiation dosimeter for each location.

A total of all radiation exposure a person has encountered is necessary to determine if the received radiation dose remains within a safe limit. These limits could be lower in states who regulate their radioactive materials, i.e. agreement states. The monitoring of radiation exposures across multiple institutions will become more challenging with changes in radiology equipment (i.e. hybrid modality like SPECT/CT), new radioactive tracers, and theranostic agents. The monitoring and regulatory issues bring up several of the following questions. Who oversees individual occupational radiation exposure when an employee works at multiple facilities? Is the individual or the RSO or someone else responsible? If it is an RSO, which institution? Is the individual responsible for requesting and monitoring his or her own personal radiation limits? Is the individual required to report if (s)he is employed at more than one institution? If the occupational exposure of a radiation worker is outside of dose limits, who should this individual report this finding? Would this be quarterly or yearly limits? Would ALARA be followed?

The survey sent to RSOs in the United States included basic questions to gather an understanding of the current practice being done in different institutions across the United States. The concerns listed in the survey by RSO respondents included the following: dosimeters are not being worn properly, dosimeters not being worn at all, dosimeters left in areas where additional exposure may occur when not being worn, and dosimeters placed under lead apron versus over lead apron. The proper area on the body to wear dosimeters depends on which area the radiation worker is employed. The general practice includes body dosimeters that should be worn at collar level, chest level, or waist level, and ring dosimeters that should be worn on the dominant hand when handling radionuclides (*11*). Those that wear personal protective equipment including lead aprons (many times in Fluoroscopy), should wear their dosimeters on the collar level outside any personal protective equipment (*11*).

This study found through the survey that most RSOs at different types of institutions are requesting dosimetry reports when employees work at multiple institutions; however, this number is not 100%. Of respondent RSOs that request dosimetry reports for employees who work at multiple institutions, this study found that 68% (13/19) are from academic institutions, 82% (9/11) from community hospitals and 80% (4/5) are from government institutions. This study could be expanded to include more RSOs, more facilities, and deeper knowledge of institutional policies. It would be beneficial to follow up with RSOs to see if facilities are using policies or procedures for tracking radiation exposure at multiple institutions. The goal would be to expand the survey to more RSOs and receive feedback on their institutions' policies for keeping track of employee badge readings when working for more than one facility with different dosimeters. A future study could also consider answering some of the questions posed earlier in this discussion section.

If these questions do not have answers, a more specific guideline may need to be created. It may be beneficial to workers who are exposed to occupational radiation doses to have a central repository in which all companies must report. This repository could be like the DOE's REMS database. This database could be government-controlled and regulated to follow the NRC, OSHA, and DOE requirements. The occupational dose limits would be monitored depending on the type(s) of radiation the individual is exposed to. If an individual works with machine-produced radiation and radioactive materials, the yearly NRC radiation dose limits would take precedence. If this is an Agreement State with the NRC, then these states would have more stringent limits than NRC and the state limits would be followed. The NRC aids states expressing interest in establishing programs to assume NRC regulatory authority by providing a legal basis which the NRC relinquishes to the portions of the state of its regulatory authority to license and regulate byproduct materials (radioisotopes); source materials (uranium and thorium); and certain quantities of special nuclear materials (*14*). If an individual is only exposed to machine-produced radiation, then OSHA's quarterly limits should take precedence.

Conclusion

The CFR and the radiation regulatory bodies in the U.S. want cumulative radiation doses to be monitored for an individual receiving occupational radiation doses from more than one institution. After reviewing the U.S. radiation governing bodies, the literature review found no clear guidelines for requiring and recording this cumulative occupational radiation dose when individuals are employed at more than one facility. The survey generated and analyzed in this study revealed that there are Radiation Safety Officers requesting dosimetry records for their employees who work in multiple institutions especially for those RSOs with more than 10 years of experience; however, not all institutions are tracking these. It is in the facility's and the individual's best interests to draw attention to an individual's combined exposure rates when employed at multiple facilities. The development of policies and regulations by institutions and/or regulatory bodies may need to be explored. These policies may need to address the different types of radiation, how the radiation is produced, and capture the accumulation of radiation exposure at multiple institutions.

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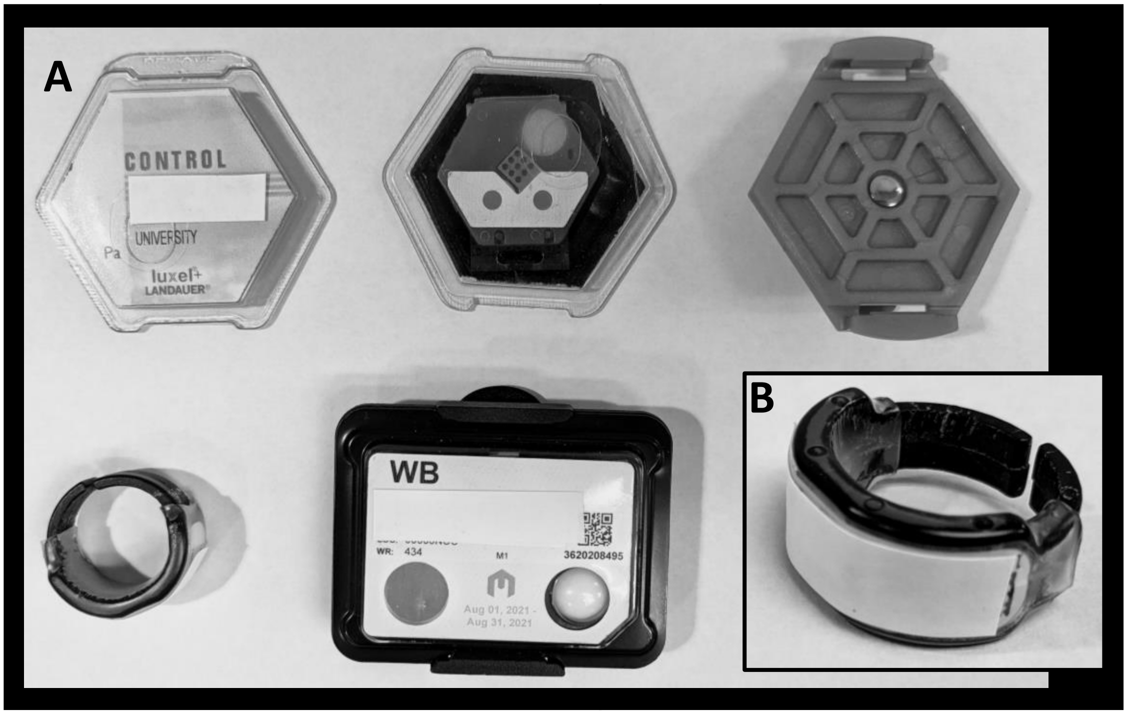

Figure 1

(A) Images clockwise from top left. Radiation monitoring badges measure over time and do not provide a real-time radiation exposure read-out. Image A is a Luxel+ dosimeter badge that measures radiation exposure due to X-ray, gamma, and beta radiation with optically stimulated luminescence (OSL) technology (*15*). The middle top image shows the inside of the OSL badge. The right top image is the holder clip for the Luxel+ OSL badge. The bottom middle image is the film badge which is used to measure and record radiation exposure due to gamma rays, X-rays, beta particles, and neutron radiation sources which incorporates a series of filters to determine the quality of the radiation (*16*).

(B) Image B is a Thermoluminescent Dosimetry (TLD) extremity badge that measures exposure due to x-rays, beta, and gamma radiation (*17*).

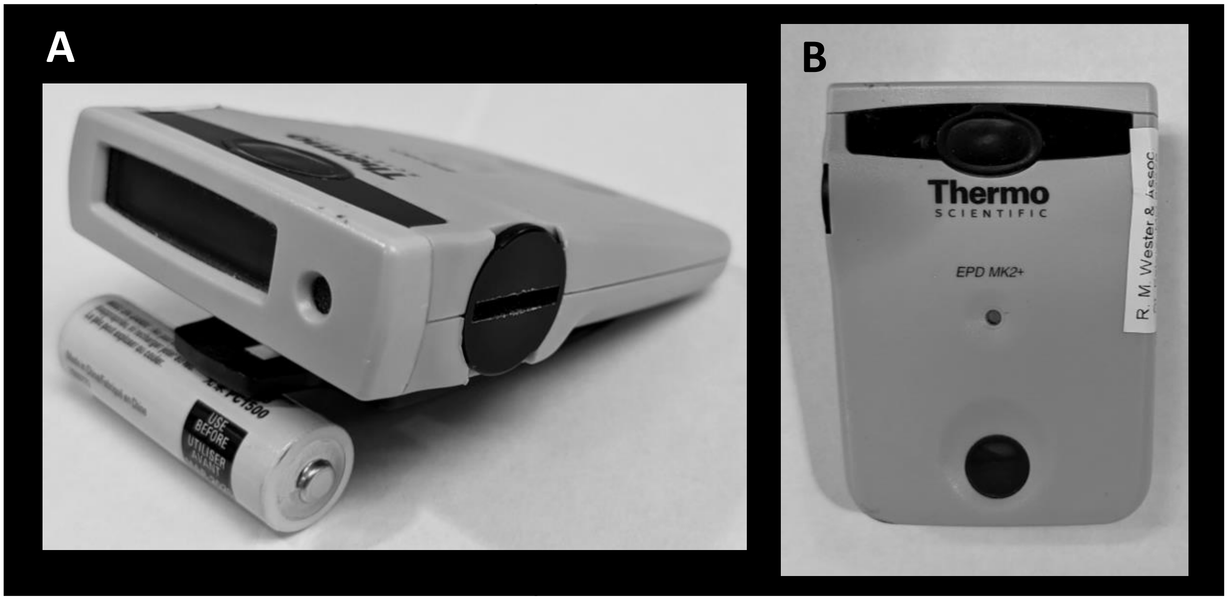

Figure 2

Pocket dosimeters are used to provide the individual wearer with an immediate reading of his or her exposure to x-rays and gamma rays (*16*). (A) is shown with a AA battery. This view shows the front of the digital electronic pocket dosimeter where the real time exposure can be viewed. (B) This view shows the top of the dosimeter.