Monitoring the Occupational Radiation Exposure of an Individual at Multiple Institutions

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Within a few years of its discovery, ionizing radiation demonstrated adverse effects on biologic systems. Since that time, great strides have been made in radiation protection, detection, and personnel monitoring. Monitoring of the occupational radiation dose to individuals is enforced by several regulatory agencies in the United States and is referenced in numerous sections of the *Code of Federal Regulations*. A literature review with an examination of regulatory guidelines and a radiation safety officer survey was conducted to evaluate how often radiation exposure is monitored when an individual receives occupational radiation doses at more than one facility. The length of time a radiation safety officer has overseen the radiation safety program at an institution can impact whether dosimetry reports are requested for individuals who 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.

Key Words: NRC; OSHA; occupational radiation exposure; RSO; radiation safety

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Occupational radiation exposure must be monitored, regulated, and accurately reported. Individuals exposed to radiation and radioactive materials are routinely monitored with different types of radiation dosimetry badges; these individuals include those working in radiology. Radiology employees may be exposed to radiation from machines, patients, and sealed and unsealed radioactive sources (*1*). When individuals working in radiology are employed by multiple institutions, it is important the individuals' 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 used in different facilities, this is a concern that will grow only more complex.

Occupational exposure can come from 2 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 requirements (*2*). The Occupational Safety and Health Administration (OSHA) is part of the U.S. Department of Labor and covers employees who work with radiation-producing machines. The primary goal of the Occupational Safety and Health Act of 1970 was to reduce workplace hazards and implement safety and health programs for both employers and their employees (*3*). The Occupational Safety and Health 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 called the Radiation Exposure Monitoring System. This database includes occupational radiation exposure 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 (*5*). The DOE provides available information about the ALARA (as low as reasonably achievable) 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 requirement may be a challenge for radiation workers who work at multiple institutions and receive radiation exposure in multiple ways; the individual worker can be exposed to machine-produced radiation, radionuclide-produced radiation, or both simultaneously. Because the personal dosimeters worn by individuals cannot differentiate between radiation produced by machines and radiation from radionuclides, issues arise with determining which governing body takes precedence regarding radiation exposure limits. The rules are not clear as to who should determine which facility or individual is responsible for monitoring the exposure from multiple locations; this lack of clarity brings an added challenge to the individual being monitored and the facilities. This article will examine U.S. government regulations on measuring an individual's occupational

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radiation exposure and will present findings from a survey of radiation safety officers (RSOs). The article will explore the challenges in recording an individual's 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 the DOE were reviewed. A literature review was done to determine whether a study of this type had been completed before, and no study was found. This review included the radiation aspects in the *Code of Federal Regulations,* the published information on the government websites, and the memorandum of agreements between the NRC and OSHA. This review also included individual radiation dose limits, which regulatory agency takes precedence over another when regulations overlap, and wording to determine the party responsible for keeping records of individual radiation exposure when individuals work at 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 on individual occupational dosimetry reports. The survey was sent and generated using Qualtrics XM software (Qualtrics). The radiation safety survey was sent to 300 RSOs and received 50 responses. The survey questions are listed in Table 1. The e-mail addresses of the RSOs were obtained by an active RSO via a listserv of U.S. Department of Veterans Affairs RSOs and academics across the country.

RESULTS

The literature review provided insight into the complexity of this issue. If radiation is not properly controlled, it can potentially be 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. Biologic effects on a person exposed to ionizing radiation are due to the ionization process, which 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 over 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, so as to prevent them from falling ill and 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 the wearer is receiving radiation exposure as part of 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 machine-produced radiation and radionuclide-produced radiation.

Radiation produced by machines is overseen by OSHA. Title 10 of the *Code of Federal Regulations,* part 20.1201, subpart C, addresses the occupational radiation dose limits: "the licensee shall control the occupational dose to individual adults" (*2*). Radiation from radionuclides is overseen by the NRC. OSHA and the NRC have the same annual whole-body limits for maximum recommended exposure to individuals but differ in specific radiation doses other than to the whole body. OSHA and the NRC use different periods to collect exposure limits; OSHA has quarterly limits, and the NRC has annual limits. Tables 2 and 3 show the dose limits for OSHA and the NRC, along with a comparison of annual dose for these agencies.

There are several ways that radiation to a worker or the public can be monitored. Title 10 of the *Code of Federal Regulations,* part 20.1502, addresses the conditions requiring individual monitoring of external and internal occupational dose. Workers are required to be monitored if the individual is likely to receive 10% of the maximum permissible radiation dose (Tables 2 and 3) (*12*). Minors, declared pregnant women, and individuals entering an area with high or very high radiation have specific and more restrictive requirements per these

TABLE 1
Radiation Safety Survey

Question	Answer
At what type of institution are you currently employed?	(A) Academic, (B) Community, (C) Government, (D) Other
Is institution you currently work at inside United States?	Yes or no
How long have you worked at this institution?	(A) <1 y, (B) 1–5 y, (C) 5–10 y, (D) >10 y with reference category set as D
Are you currently in charge of radiation safety program at your institution?	Yes or no
Do you request dosimetry reports for employees who work at multiple institutions?	Yes or no
Do you have any other comments or concerns regarding radiation exposure that you would like to share?	(Open for free text)
If you are open to discussing your institution-specific policies, please leave your contact information below.	(Open for free text)

TABLE 2
Dose Limits for OSHA and NRC (*2,8*)

Parameter	Radiation dose limit periods	
	OSHA, quarterly	NRC, annually
Deep dose equivalent	1.25 rem (0.0125 Sv)	5 rem (0.05 Sv)
Shallow dose equivalent	18.75 rem (0.1875 Sv), extremities; 7.5 rem (0.075 Sv), skin	50 rem (0.5 Sv)
Lens dose equivalent	1.25 rem (0.0125 Sv)	15 rem (0.15 Sv)

regulations (*12*). Pocket dosimeters, personal dosimeters, or film badges can be used to monitor radiation exposure (Figs. 1 and 2). Each personal dosimeter must be assigned to and worn by only one individual (*13*). Film badges must be replaced at periods not to exceed 1 mo, and other personal dosimeters evaluated by an accredited National Voluntary Laboratory Accreditation Program processor must be replaced at intervals of no more than 3 mo (*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, or on the party responsible for cumulating this information. The only statement found in the NRC regulations to mention this issue 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 how to reduce limits if an individual is unable to acquire data on the history (1.25 rem per quarter if history not available) (*2*).

The 50 responses to the survey represent a 17% response rate. 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 respondents (72%) answered yes and 10 (28%) answered no (Table 4). χ^2 tests, in the R Environment for Statistical Computing (version 2013; R Core Team), were used to determine whether those with different work experience or different work settings request dosimetry reports for individuals who work at different institutions (Tables 5 and 6). There was a statistically significant difference in dosimetry requests based on work experience ($\chi^2 = 11.041$, $P < 0.05$). Most notably, those with more than 10 y of experience were more likely than not to request the reports. On the other hand, no statistically significant differences in requesting dosimetry reports were found from those working at multiple institutions across different types of institutions ($\chi^2 = 3.3925$, $P > 0.05$).

DISCUSSION

Several regulatory agencies review radiation exposure to the worker. Regarding individuals working at multiple facilities, the regulations state that each dose should be adjusted when a radiation dose is received while the individual is 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. The literature review found that the NRC's annual exposure limit for radiation workers is a 5-rem (0.05 Sv) total dose equivalent. OSHA's occupational dose exposure limits for machine-based radiation doses is also 5 rem (0.05 Sv) per year, but with a limit of 1.25 rem (0.0125 Sv) per quarter. Radiation dosimeters are provided to an individual through that individual's employer. 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 whether the received radiation dose remains within a safe limit. These limits could be lower in states that regulate their radioactive materials, that is, agreement states. The monitoring of radiation exposure across multiple institutions will become more challenging with changes in radiology equipment (e.g., hybrid modalities such as SPECT/CT), new radioactive tracers, and theranostic agents. The monitoring and regulatory issues bring up several questions. Who oversees individual radiation exposure when an employee works at multiple facilities? Is the individual or the RSO or someone else responsible? If it is an RSO, it is the RSO at which institution? Are individuals responsible for requesting and monitoring their own personal radiation limits? Are the individuals required to report that they are employed at more than one institution? If the exposure of a radiation worker is outside the dose limits, to

TABLE 3
Comparison of Annual Dose for OSHA and NRC (*2,8*)

Parameter	OSHA	NRC
Deep dose equivalent	5 rem (0.05 Sv)	5 rem (0.05 Sv)
Shallow dose equivalent	75 rem (0.75 Sv), extremities; 30 rem (0.3 Sv), skin	50 rem (0.5 Sv)
Lens dose equivalent	5 rem (0.05 Sv)	15 rem (0.15 Sv)

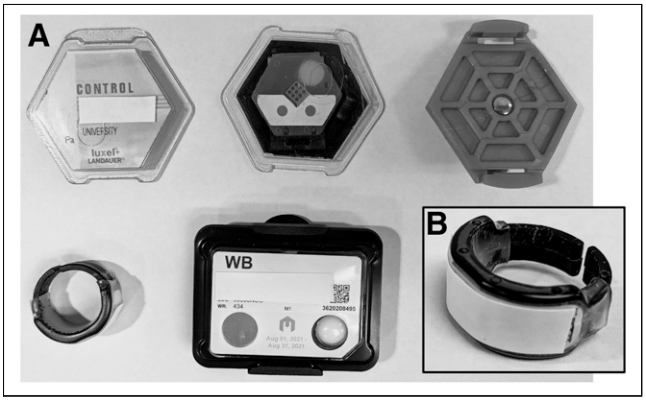

FIGURE 1. Radiation monitoring badges measure over time and do not provide real-time radiation exposure read-out. (A) Clockwise from top left: Luxel+ (Landauer) dosimeter badge that measures radiation exposure due to x-rays, γ-rays, and β-rays with optically stimulated luminescence (OSL) technology (*15*); inside of OSL badge; holder clip for Luxel+ OSL badge; film badge to measure and record radiation exposure due to x-rays, γ-rays, β-rays, and neutron radiation, which incorporates series of filters to determine quality of radiation; and a thermoluminescent extremity badge with a better view in B (*16*). (B) Thermoluminescent dosimetry extremity badge that measures exposure due to x-rays, β-radiation, and γ-radiation (*17*).

TABLE 4
Descriptive Statistics (Total $n = 36$)

Parameter	*n*	Percentage
RSO experience length		
1 y	3	8.3%
1–5 y	7	19.4%
5–10 y	10	27.8%
10 y	16	44.4%
RSO institution type		
Academic	19	52.8%
Government	5	13.9%
Community	11	30.6%
Other	1	2.8%

whom should this individual report this finding? Would these limits be quarterly or annual? Would ALARA be followed?

The survey sent to RSOs in the United States included basic questions to gather an understanding of the current practice at different institutions across the country. The concerns that RSO respondents listed in the survey included dosimeters 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 a lead apron versus over a lead apron. The proper positioning of the dosimeter on the body depends on the area in which the radiation worker is employed. The general practice is to wear a body dosimeter at the collar, chest, or waist level and to wear a ring dosimeter on the dominant hand when radionuclides are handled (*11*). Those who wear personal protective equipment, including lead aprons (frequently used in fluoroscopy), should wear their dosimeters at the collar level outside any personal protective equipment (*11*).

The survey found that most, but not all, RSOs at different types of institutions request dosimetry reports when employees work at multiple institutions. Of the respondent RSOs who request such reports, 68% (13/19) are from academic institutions, 82% (9/11) from community hospitals, and 80% (4/5) from government institutions. This study could be expanded to include more RSOs, more facilities, and a deeper knowledge of institutional policies. It would be beneficial to follow up with RSOs to see whether 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 regarding keeping track of badge readings for employees who work at more than one facility and use a different dosimeter at each. A future study could also consider answering some of the questions posed earlier in this "Discussion" section.

If answers cannot be obtained for these questions, a more specific guideline may need to be created. Workers who are exposed to radiation may benefit from having a central repository to which all companies must report. This repository could be like the DOE's Radiation Exposure Monitoring System database. This database could be government-controlled and regulated to follow NRC, OSHA, and DOE requirements. The occupational dose limits would be monitored depending

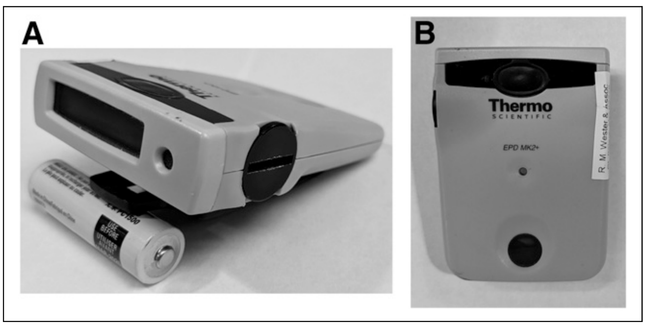

FIGURE 2. Digital electronic pocket dosimeters provide individual with immediate reading of exposure to x-rays and γ-rays (*16*). (A) Front of dosimeter (with AA battery), where real-time exposure can be viewed. (B) Top of dosimeter.

TABLE 5
Results of χ^2 Test and Descriptive Statistics for Dosimetry Request by Work Experience

Dosimetry request	Work experience (y)			
	<1	1–5	5–10	≥10
Yes	6 (86%)	6 (60%)	0 (0%)	14 (88%)
No	1 (14%)	4 (40%)	3 (100%)	2 (12%)

$\chi^2 = 11.041$ ($P < 0.05$); df = 3. Numbers in parentheses indicate column percentages.

TABLE 6

Results of χ^2 Test and Descriptive Statistics for Dosimetry Request by Institution Type

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

$\chi^2 = 3.3925$; df = 3. Numbers in parentheses indicate column percentages.

on the type of radiation to which the individual is exposed. If an individual works with machine-produced radiation and radioactive materials, the annual NRC radiation dose limits would take precedence. Agreement states with the NRC would have more stringent limits than the NRC, and the state limits would be followed. If a state wishes to establish programs to assume NRC regulatory authority, the NRC relinquishes to that state its 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 exposed only to machine-produced radiation, then OSHA's quarterly limits take precedence.

CONCLUSION

The *Code of Federal Regulations* and the radiation regulatory bodies in the United States want monitoring of cumulative radiation doses for an individual exposed to occupational radiation at more than one institution. The literature review of U.S. radiation-governing bodies found no clear guidelines for requiring and recording this cumulative occupational radiation dose when individuals are employed at more than one facility. The survey revealed that there are RSOs—especially those with more than 10 y of experience—requesting dosimetry records for their employees who work at multiple institutions; however, not all institutions are tracking these records. It is in the facility's and the individual's best interest to draw attention to an individual's combined exposure rate when employed at multiple facilities. The development of policies and regulations by institutions or regulatory bodies may need to be explored. These policies may need to address the different types of radiation and how it is produced, as well as capture the accumulation of radiation exposure at multiple institutions.

DISCLOSURE

No potential conflict of interest relevant to this article was reported.

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