ORIGINAL RESEARCH

# Radiation Emergency Readiness Among US Medical Toxicologists: A Survey

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## ABSTRACT

**Introduction:** Large scale radiologic and nuclear disasters are rare; however, recent events such as the Fukushima Daiichi nuclear reactor emergency in Japan and current global political tensions have highlighted the need for health-care providers with expertise in managing radiation injuries. Medical Toxicologists have the ability to collaborate with other specialists in filling this critical role.

**Methods:** We conducted a cross-sectional survey to assess the attitudes, experiences, and knowledge of medical toxicologists through the assistance of the American College of Medical Toxicology.

**Results:** The survey was completed by 114 medical toxicologists during the enrollment period. Medical toxicologists who had a willingness to participate in radiologic or nuclear emergencies or who had taken care of patients contaminated with radioactive material were more likely to perform well on the knowledge assessment.

**Conclusion:** We identified that there is a group of medical toxicologists who have the willingness, experience, and knowledge to help manage patients in the event of a radiologic or nuclear emergency.

**Key Words:** American College of Medical Toxicology, medical toxicologists, preparedness, nuclear emergency, radiation emergency

The current risk of a radiation emergency has been highlighted by a recent national incident in Hawaii in which a nuclear weapon attack alerting system was accidently triggered as well as by increased international political tensions.[1-3] However, the rarity of large-scale radiation emergencies has resulted in a lack of familiarity and comfort by health-care providers and emergency responders with the assessment and management of radiation injuries.[4-6] Emergency physicians, traditionally on the frontline of treating casualties of any disaster, have been shown to lack sufficient knowledge and comfort in this area as well.[7,8] Similarly, Medical Reserve Corps volunteers and other health-care personnel who work in medical and diagnostic radiology, such as nuclear medicine technologists, lack adequate comfort and knowledge in radiation emergencies.[9]

The Radiation Emergency Assistance Center/Training Site (REAC/TS) is a world-renowned resource for providing emergency response, advice, and consultation, in addition to educating health-care providers since 1976. REAC/TS has partnered with medical toxicologists to jointly provide health-care education and consult on radiological injury cases. Through courses provided throughout the United States and the world, REAC/TS outreach efforts touch approximately 6000 health-care providers annually.[10] The joint efforts of the American College of Medical Toxicology (ACMT) and REAC/TS have focused on medical universities and international events, through funding from the Centers for Disease Control and Prevention (CDC), and has resulted in the training of approximately 2800 people. Unfortunately, the large gap left remaining for health-care providers, is not being fulfilled in the traditional health-care education system, ie, medical schools, postgraduate medical education, and advanced practitioner programs. There are efforts under way to expand these educational opportunities, but they are mainly aimed at online programs to accommodate physicians' and other health-care practitioners' limited schedules.[11,12]

Given that the risk of a radiation incident is at its highest point since the end of the Cold War,[3] there is an increased need for radiation subject matter experts who can provide important guidance to patients, health-care providers, public health professionals and leaders.[9,13] National specialty organizations such as the ACMT and the American Academy of Clinical Toxicology (AACT) have recognized the potential role that medical and clinical toxicologists can play in a radiation emergency and have engaged in a variety of training programs and activities since 2004.[14] This was underscored during the Fukushima Daiichi nuclear power plant emergency during which medical toxicologists played an important role through poison centers and Federal agencies.[15]



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TABLE 1

**Survey Questions Ascertaining Self-identification Comfort Level of Radiation Medicine**

| | |
|---|---|
| Question 1 | Am I willing to respond and participate in patient care during a radiation emergency? |
| Question 2 | Do I consider myself a top-tier medical provider resource (subject matter expert) in a radiation emergency? |
| Question 3 | Am I comfortable assessing and managing patients who have been exposed to ionizing radiation but are not contaminated with radioactive materials? |
| Question 4 | Am I comfortable assessing and managing patients who have been internally or externally contaminated with radioactive materials? |
| Question 5 | Am I comfortable assessing chronic and delayed effects of radiation in an outpatient clinic setting. This includes communicating cancer risks from ionizing radiation exposure (low and high dose)? |

## METHODS

This study consisted of a cross-sectional electronic survey of medical toxicologists. The primary investigator's Institutional Review Board approved this study. The goal of this study was to assess the level of comfort with, and knowledge of, United States medical toxicologists. The study also aimed to evaluate and assess their experience, comfort level, attitudes, and knowledge regarding radiation emergencies and injuries.

The first part of the survey assessed the respondent's past experiences, comfort level, and attitudes toward radiation emergencies (Table 1). The second part of the survey included a nonvalidated knowledge assessment that consisted of 10 multiple choice questions (Supplement 1) covering the following topics: triage and initial management, radiation physics, exposure dose determination, treatments, and delayed effects of radiation exposures including low and high doses.

The survey was developed by a recognized subject matter expert (SME) in the field of radiation emergencies and was distributed by the American College of Medical Toxicology (ACMT) to board-certified and board-eligible medical toxicologists. The SME is a physician, board-certified in both Emergency Medicine and Medical Toxicology, who has been involved in nuclear emergencies, such as the response to the Fukushima event, has participated in the development of a national response to nuclear or radiologic emergencies, and has trained numerous state and local actors in preparation of a nuclear or radiologic incident.

All responses and results were anonymous and were available to an ACMT staff member but were not accessible to the study investigators. ACMT staff compiled the results, ensured that they were free of identifying information, and provided the de-identified data to the investigators.

At the conclusion of the survey, the respondents were given the option to provide their email address if they desired to receive a free $5 gift card by means of email. This email address was not associated with the responses. No other compensation was provided, nor was compensation contingent on achieving a particular score.

### Statistical Analyses

Categorical and ordinal variables were described using percentages and 95% confidence intervals (95% CIs). Knowledge test results failed to meet the proportional odds assumption ($Ps < 0.05$), and subsequent multinomial regressions failed to estimate properly. The relationship between comfort-level and test performance was evaluated using binary logistic generalized estimating equations. Responses to individual items (ie, correct/incorrect) were nested within respondents. *P*-Values and 95% CIs were computed using a bias-corrected and accelerated bootstrapping procedure (5000 resamples).

## RESULTS

The cross-sectional survey was available for completion from 21 March until 08 April 2018 and was completed by 114 medical toxicologists, 68% ($n = 77$) of whom were male. Demographic characteristics and survey responses to experience and knowledge questions are presented in Table 2. There was an evenly distributed response rate of respondents in number of years of training and in years of practice in medical toxicology. Half of the respondents ($n = 57$) had received training in radiation emergencies during the previous 5 years. A quarter of the respondents had cared for a patient exposed to ionizing radiation, and approximately 13% had cared for patients contaminated with radioactive material.

The median score on the knowledge test was 60 with an interquartile range of 50–70. With respect to self-identified comfort with radiation medicine, 88.7% of respondents either agreed, or strongly agreed, with the statement that they are willing to respond and participate in patient care during a radiation emergency. Additionally, 46.8% agreed or strongly agreed, with self-identification as a top-tier subject matter expert in the field of radiation medicine. Sixty-eight percent of respondents either agreed or strongly agreed with feeling comfortable assessing and managing a patient exposed to ionizing radiation, and 56% believed the same for assessing and managing a patient contaminated with radioactive material. Forty-one percent believed they agreed or strongly agreed that they were comfortable assessing and managing the chronic or delayed effects of radiation exposure.

The association between survey responses and knowledge test scores are presented in Table 3. Years of practice, previous training in radiation, and experience caring for ionizing radiation exposed patients were not significantly associated with



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## TABLE 2

**Demographics of Survey Respondents and Survey and Knowledge Test Responses**

| Variable | % of Respondents | 95% CI |
|---|---|---|
| **Age (y)** | | |
| 30–35 | 13.2 | 6.95 - 19.36 |
| 36–45 | 37.7 | 28.82 - 46.62 |
| 46–60 | 32.5 | 23.86 - 41.05 |
| 61+ | 16.7 | 9.83 - 23.51 |
| **Gender** | | |
| Female | 31.6 | 23.05 - 40.11 |
| Male | 68.4 | 59.89 - 76.95 |
| **Have you received training in radiation emergencies during the past 5 years?** | | |
| No | 50 | 40.82 - 59.18 |
| Yes | 50 | 40.82 - 59.18 |
| **Have you ever cared for a patient exposed to ionizing radiation?** | | |
| No | 76.3 | 68.51 - 84.12 |
| Yes | 23.7 | 15.88 - 31.49 |
| **Have you ever cared for a patient who was externally contaminated with radioactive materials?** | | |
| No | 86.8 | 80.64 - 93.05 |
| Yes | 13.2 | 6.95 - 19.36 |
| **Years of practice** | | |
| < 5 years | 27.2 | 19.02 - 35.36 |
| ≥ 5 years, < 10 years | 17.5 | 10.56 - 24.53 |
| ≥ 10 years, < 20 years | 22.8 | 15.1 - 30.51 |
| ≥ 20 years | 32.5 | 23.86 - 41.05 |
| **I am willing to respond/participate** | | |
| Strongly disagree | 1.1 | 0 - 3.07 |
| Disagree | 2.2 | 0 - 5.04 |
| Neutral | 8.1 | 3.01 - 13.13 |
| Agree | 46.5 | 37.34 - 55.65 |
| Strongly agree | 42.2 | 33.11 - 51.28 |
| **I consider myself top-tier** | | |
| Strongly disagree | 9.0 | 3.7 - 14.37 |
| Disagree | 19.6 | 12.23 - 26.89 |
| Neutral | 24.6 | 16.66 - 32.46 |
| Agree | 36.9 | 28.05 - 45.81 |
| Strongly agree | 9.9 | 4.36 - 15.47 |
| **Comfortable assessing/managing ionizing radiation** | | |
| Strongly disagree | 2.8 | 0 - 5.93 |
| Disagree | 17.6 | 10.61 - 24.65 |
| Neutral | 10.8 | 5.03 - 16.55 |
| Agree | 49.2 | 40.02 - 58.41 |
| Strongly agree | 19.6 | 12.23 - 26.89 |
| **Comfortable assessing/managing contamination** | | |
| Strongly disagree | 2.7 | 0 - 5.76 |
| Disagree | 19.6 | 12.23 - 26.89 |
| Neutral | 21.9 | 14.33 - 29.53 |
| Agree | 44.9 | 35.75 - 54.07 |
| Strongly agree | 10.9 | 5.09 - 16.67 |
| **Comfortable assessing chronic/delayed effects of radiation** | | |
| Strongly disagree | 5.9 | 1.47 - 10.28 |
| Disagree | 27.2 | 19.02 - 35.36 |
| Neutral | 25.4 | 17.44 - 33.43 |
| Agree | 30.8 | 22.3 - 39.28 |
| Strongly agree | 10.7 | 4.98 - 16.43 |
| **Knowledge test results (% correct)** | | |
| 0 | 0 | 0 - 3.92 |
| 10 | 0 | 0 - 3.92 |
| 20 | 2.4 | 0 - 5.53 |
| 30 | 3.1 | 0 - 6.78 |
| 40 | 11.5 | 3.95 - 19.03 |
| 50 | 16.7 | 9.22 - 24.11 |
| 60 | 27.3 | 18.06 - 36.51 |
| 70 | 19.7 | 11.73 - 27.57 |
| 80 | 9.4 | 3.7 - 15.07 |
| 90 | 7.46 | 2.47 - 12.44 |
| 100 | 2.63 | 0 - 5.57 |

## TABLE 3

**Association Between Survey Responses and Knowledge Test Responses**

| Characteristic | OR | 95% CI | *P*-Value |
|---|---|---|---|
| Years of practice | 1.1 | 0.95 - 1.22 | 0.25 |
| Received training (yes/no) | 1.2 | 0.87 - 1.58 | 0.29 |
| Cared for a patient (exposed) (Yes/no) | 1.3 | 0.9 - 1.98 | 0.15 |
| Cared for a patient (contaminated) (Yes/no)* | 2.2 | 1.39 - 3.56 | <.001 |
| I am willing to respond/participate* | 1.3 | 1.06 - 1.59 | 0.01 |
| I consider myself top-tier* | 1.2 | 1.08 - 1.4 | 0.002 |
| Comfortable assessing/managing ionizing radiation* | 1.2 | 1.01 - 1.33 | 0.04 |
| Comfortable assessing/managing contamination* | 1.3 | 1.14 - 1.51 | <.001 |
| Comfortable assessing chronic/delayed effects of radiation* | 1.4 | 1.18 - 1.56 | <.001 |

* Indicates a statistically significant finding.

test scores. However, having received training in radiation medicine was highly correlated with respondents feeling that they were a top-tier subject matter expect (odds ratio [OR] = 3.4; 95% CI: 1.68–6.88; $P = 0.001$). Experience caring for contaminated patients, on the other hand, was associated with higher test scores. With respect to self-reported comfort and expertise, answers indicating higher comfort and expertise were associated with higher scores on the knowledge test.

Table 4 outlines the frequency of correct responses as a function of question and the correlation between individual test questions and the test total score. Question 10 and question 5 had the highest correlation with a high performance on the knowledge test. Question 10 asked about properties of uranium and was only answered correctly by 40% of the respondents. Question 5 asked about long-term risks related to low-dose iridium-192 exposure and was the third most correctly answered question in the knowledge test. Question 8,



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TABLE 4

**Knowledge Assessment Question Item-Total Correlation**

| Question Number | Knowledge Tested | % Correct | Item-Total Correlation |
|---|---|---|---|
| 1 | Triage and initial management | 57.5 | 0.38 |
| 2 | Radiation physics | 56.0 | 0.34 |
| 3 | Exposure dose determination | 78.6 | 0.15 |
| 4 | Triage and initial management | 50.4 | 0.34 |
| 5 | Delayed effects of radiation exposures | 73.2 | 0.46 |
| 6 | Treatments | 52.6 | 0.24 |
| 7 | Treatments | 64.9 | 0.40 |
| 8 | Treatments | 84.5 | 0.30 |
| 9 | Treatments | 55.5 | 0.38 |
| 10 | Radiation physics | 39.9 | 0.59 |

which asked about the antidote Prussian blue, was the question that most respondents answered correctly; however, it was poorly associated with an overall high score with an item-total correlation of only 0.30. This evaluation begins to lay a framework for a validated assessment of a clinician's radiation knowledge.

## DISCUSSION

The risk of a catastrophic radiological or nuclear incident has increased during the past two decades with the increased threat of terrorist groups using radioactive materials in a radiological dispersal device or in the detonation of an improvised nuclear device. Additionally, nations like North Korea and Iran have acquired, or are in the process of acquiring, nuclear weapons. In 2011, the Tohoku earthquake and tsunami caused a devastating disaster that was compounded by a large release of radioactive material from the Fukushima Daiichi nuclear power plant. All of these incidents have underscored the lack of capacity of the health care system and health care providers in providing appropriate medical assessment and care to the overwhelming number of victims that would require medical attention.

The identification of a group of subject matters experts in the field of radiation emergencies can partially mitigate the above stated problem by supporting other medical professionals by means of telemedicine or telephonic consultation and through just-in-time education. The Radiation Injury Treatment Network with its 83 medical centers has achieved significant progress since its creation in enhancing the national capacity to care for victims with the Acute Radiation Syndrome and associated bone marrow injuries from radiation exposure.[16] These centers follow rigorous standard operations procedures and participate in annual and periodic emergency preparedness activities with a plan to receive thousands of potential victims with bone marrow injuries after a catastrophic incident like a nuclear detonation. It is important to note that there are several type of radiation emergencies that are less likely to cause bone marrow injuries. In such scenarios, radiation exposures from external and internal contamination may be more prominent and require a different set of expertise than the one needed to care for the Acute Radiation Syndrome. Medical toxicologists can potentially complement medical oncologists at RITN center and augment their existing capabilities to respond to a broader range of radiation emergencies.[17]

The subspecialty of medical toxicology is recognized by the American Board of Medical Specialties that has thus far certified approximately 500 medical toxicologists who have completed 2 years of residency training at one the 30 plus programs in the United States. These residency programs follow the core content of medical toxicology which includes the following categories and parts that are directly relevant to the assessment and care of radiation injuries: Mutagenesis and Carcinogenesis (Category 1.5), Mechanisms of Reproductive and Developmental Toxicity (Category 1.6), Radiological Toxicants (Category 2.6), Assessment and Population Health (Category 5.0), Radiation Syndromes (Category 3.5), Radiation Exposure Management (Category 4.6), Assessment and Population Health (Part 5), and Analytical and Forensic Toxicology (Part 6).[18]

The study participants who completed a nonvalidated knowledge test had a median score of 60% and interquartile range of 50–70. Additionally, those who had higher scores were more likely to consider themselves subject matter experts and were more likely to have cared for a patient who was contaminated with radioactive materials. Overall, 45% of respondents reported "agree or strongly agree" when asked if they consider themselves a top-tier subject matter expert. Lastly, those with higher scores were more likely to be comfortable assessing patients with radiation exposure, contamination with radioactive materials and those with risk for delayed effects from radiation exposure.

The mainstream medical toxicology skill set includes several tools that would be relevant when evaluating or managing a patient exposed to ionizing radiation or contaminated with radioactive material. These include: telephonic consultation experience, formal roles in one of the Nation's 62 poison centers for many of the medical toxicologists, proper selection and use of personal protective equipment, decontamination, toxidrome recognition, bioassay interpretation, chelation therapies and risk assessment/communication (especially in low-level exposure situations).[18] As such, medical toxicologists are uniquely suited to participate in the National effort to meet our gaps in radiation emergency preparedness.

If we assume that these results are generalizable, then we could potentially conclude that there is a subgroup of medical



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toxicologists who would potentially be able to assist in the response of a catastrophic radiation emergency.

Our study results support the need for additional education for our medical toxicology workforce. In the present study, 50% of the respondents had received formal training in radiation medicine; however, this did not translate to improved test scores over those who had not recently received training. This is likely to be due to inherent limitations in our survey questions and the inability to further define or characterize the previous training courses that respondents have attended. Educational efforts can start at the medical toxicology residency training programs and through periodic symposia or webinars organized by the professional organizations in collaboration with other experts from the Radiation Emergency Assistance Center/Training Site, the Radiation Injury Treatment Network, the Health Physics Society, the National Council on Radiation Protection and Measurements, the Centers for Disease Control and Prevention and the Department of Health and Human Services. The amount of clinical practice since completing residency training, however, was not significantly associated with test scores despite the inclusion of radiation medicine in the medical toxicology core curriculum since 2004.[18] Due to the rarity of radiation emergencies, curricula should emphasize specific skills that would be most relevant for medical toxicologists such as the clinical assessment of various radiation-induced illnesses, interpretation of bioassays, use of medical countermeasures, and risk communication regarding delayed effects.

## LIMITATIONS

There were several limitations to this study. The sample size is relatively small despite the measures taken by the investigators (multiple reminder emails were sent out, and a gift card incentive was included in the invitation email). Additionally, our data are likely skewed by responder bias, but the goal of this study was not to determine the overall rate of medical toxicologists that are adept at nuclear and radiation medicine, but more to identify medical toxicologists who could potentially participate as subject matter experts in the response to a radiation incident

Another limitation is that the comfort level, attitude and history of receiving training in radiation medicine were self-reported and are subject to selection and recall bias. Also, while many medical toxicologists come from the primary specialty of emergency medicine, a large number of primary specialties are represented in ACMT. We did not collect data on the respondent's primary specialty, which may have an impact on their background knowledge of radiation medicine. Additionally, the knowledge test may not comprehensively cover the field of radiation medicine and has not been validated. Finally, the test content was created by a single person, the principle investigator, and, therefore, may be overly focused on idiosyncratic topics that fail to capture the full breadth of radiation medicine.

What is unclear, is whether or not those with previous experience scored higher as a result of taking care of contaminated patients, or whether they were sought out to care for such patients as a result of being previously recognized as experts. If the latter is true, it would be useful to evaluate how their training, and that of those who self-identified as experts, differed from that of their colleagues.

## CONCLUSION

Medical toxicologists are uniquely suited to contribute to filling a growing need for experts in the area of radiation emergency preparedness because they are one of the few medical specialists that receive formal training in radiation medicine and have a skill set that is relevant for response to radiation emergencies. Additionally, they are already connected to existing lines of communication with other radiation emergency preparedness partners through poison centers, and through Federal and State Public Health agencies. While our study suggests that, overall, the current training many medical toxicologists receive may need further evaluation and enhancement, it does suggest that certain subgroups, notably those who self-identify as experts and those who have previously cared for radiation patients, potentially possess the expertise required.

## DISCLAIMER

The view(s) expressed herein are those of the author(s) and do not reflect the official policy or position of the US Army Medical Department, the US Army Office of the Surgeon General, the Department of the Army, US Air Force Office of the Surgeon General, the Department of the Air Force, the Department of Defense, or the US Government.

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## Supplementary Material

To view supplementary material for this article, please visit https://doi.org/10.1017/dmp.2019.147



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