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# Global Disparities in the Preparedness for Radiation Emergencies

Umesh C Sharma, MD, PhD[1], Saraswati Pokharel, MD, PhD[2]

[1] Cardio-Oncology Research Group, Department of Medicine, Division of Cardiology, Jacob's School of Medicine and Biomedical Sciences, Buffalo, NY, USA

[2] Ionizing Radiation and Coronary Microvascular Disease Research Group, Department of Pathology and Laboratory Medicine, Division of Thoracic Pathology and Oncology, Roswell Park Comprehensive Cancer Center, Buffalo, NY, USA

**Address for Correspondence**

Saraswati Pokharel, MD, PhD

Associate Professor of Oncology

Ionizing Radiation and Coronary Microvascular Disease Research Group

Roswell Park Comprehensive Cancer Center, Buffalo, NY, USA

Elm and Carlton, Buffalo, New York 14203

**Phone**: 716.845.4959

**E-mail**: saraswati.pokharel@roswellpark.org

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## Abstract

**Objectives**: Radiation emergencies are rare but can have minor confined effects to catastrophic consequences across the large geographical territories. Geographical disparities in the preparedness for radiation emergencies can negatively impact public-safety and delay protective actions. We examined such disparities using the global and regional radiation preparedness data from the revised annual International Health Regulations (IHR) datasets.

**Settings**: We used IHR State Party Annual Reporting (SPAR) tool and its associated health indicators developed to mitigate public health-risk from radiation emergencies. Using the most recent (2019) SPAR database developed for radiation emergencies, along with 12 other cross-sector indicators, we examined the disparities among World Health Organization (WHO) state and region-wide capacity scores for operational preparedness.

**Results**: Based on the analysis of the 2019 annual reporting datasets from 171 countries, radiation emergency was one of the top 3 global challenges with an average global preparedness capacity of 55%. Radiation emergency preparedness capacity scores showed highest dispersion score amongst all 13 capacities suggesting higher disparities for preparedness across the globe. Only 38% of the countries had advanced functional capacity with ≥80% operational readiness, with 28% countries having low to very-low operational readiness. No geographical regions had ≥80% operational readiness for radiation emergencies, with 4/6 geographical regions showing limited capacity or effectiveness.

**Conclusion**: We found major global disparities for the operational preparedness against radiation emergencies. Collaborative approaches involving the public health officials and policymakers at the regional and state levels are needed to develop additional guidance to adapt emergency preparedness plans for radiation incidents.


**Keywords:** Radiation, Emergency Preparedness, Disparities, WHO

**Strenghths and Limitations**

- There are limited data examining the global disparities in the preparedness against radiation emergencies.
- Analysis of International Health Regulations (IHR) datasets shows radiation emergency as one of the top 3 global challenges.
- Major discrepancies in operational readiness also existed across different geographical regions.
- This study highlights the need for further research to identify most appropriate approaches to addressing the disparities accounted for radiation emergency planning.

## Introduction

Recent reports on the status of country preparedness capacity prepared in coordination with the Global Preparedness Monitoring Board (GPMB), the World Health Organization (WHO) has highlighted that a threat to public health anywhere in the world is now a threat to public health everywhere in the world[1,2]. Although we cannot predict the origin, nature or severity of next global health emergency, radiation emergencies constitute a major threat to human wellbeing[3,4]. The extent of injuries from high-dose radiation exposure can be acute, subacute or late, manifesting several decades after the incident event[5,6]. The late effects of radiation exposure from Hiroshima and Nagasaki disasters are still being realized[5].

Radiation exposure can be latent and subtle, and early recognition of its adverse effects can be challenging[7,8]. Once detected, complete reversal of radiation-induced injuries is not possible and treatment remains supportive or palliative[9]. Such latent properties of ionizing radiation pose major public health hazard. More importantly, a large scale radiation exposure may expand beyond the geographic boundaries putting a large human population at risk[10]. Early detection and reporting of such risks and implementing plans and policies for the mitigation of adverse effects will require a multidisciplinary approach involving the public health officials, health care providers and emergency preparedness team[11-13].

In 2005, International Health Regulations (IHR) developed State Party Self-Assessment reporting tools to allow World Health Organization (WHO) Secretariat to compile a report for the statistics of health capacities of individual countries[1,14,15]. This annual voluntary reporting tool has 13 **capacities**, with specific **indicators** associated with these capacities. Each indicator is graded in five **levels of performance**, for which discreet **action elements or attributes** are defined. States are

encouraged to respond to all the indicators so that an accurate view of the national capacities can be determined[1,14,16].

Of the 13 various capacities included in the IHR state party self-assessment annual reporting tool, radiation emergencies (radiological emergencies and nuclear accidents) constitute potentially catastrophic disasters with large scale of biological consequences. The guidelines for the preparedness and response for radiation emergencies have been reported previously by International Atomic Energy Agency (IAEA)[17]. However, there are no clear data comparing radiation emergency preparedness capacities in relation to other cross-sector emergency preparedness indices. Since radiation exposure can be widespread, there needs to be multinational and strategic co-ordination to confine risk and mitigate the harmful effects.

To this end, we have analyzed the individual and combined IHR indicators for radiation emergencies, as well as other cross-sector indicators including national health emergency framework, finances, legislation, surveillance, human resources, coordination of efforts, health service provision and risk communications. We have also studied the global and regional disparities in IHR indicators that influence the capacities and resources utilized to address radiation emergencies.

## Methods

The Electronic State Parties Self-Assessment Annual Reporting Tool (e-SPAR) is publicly accessible web-based data reporting platform, under the WHO IHR Monitoring and Evaluation Framework. The SPAR tool has 13 capacities and number of indicators that are graded into 5 levels of performance. The states are instructed to select one of the five levels for their implementation status for each indicator. Irrespective of the status of elements in the higher level(s), the lowest level is considered valid if two or more levels were selected. In the event of no selection, the final score for the capacity indicator was calculated as zero[14,15].

The ***primary goal*** of this analysis was to study radiation emergencies (C13) and each of the indicators related to the state capacities and resources (C13.1). The selected SPAR indicators and corresponding levels (1 to 5) are provided in the **Supplemental Table 1**.

The ***secondary goal*** was to further examine the cross-sector preparedness for infrastructure, legislation, and coordination. We first analyzed IHR-SPAR Indicators from 2019 in relation to the capacities to be prepared for radiation emergencies. Additionally, 24 IHR-SPAR indicators amongst the 13 capacities (**Supplemental Table 2)** were used for the analytical approaches comparing the capacity scores for radiation emergency preparedness in relation to the overall public health risk score across the globe as well as six unique geographic regions.

### Combined indices for global and regional capacity scores included in this analysis

We analyzed the overall capacity indices for the preparedness of radiation emergencies and its relationship with other 12 trans-sector capacities using a mathematic model similar to the one previously reported by Kandel et al[18]. For this analysis, we included 24 indicators that were all determined to be relevant to assess the operational capacity for radiation emergency preparedness. We aggregated the key

indicators and calculated arithmetic average to develop an ordinal scale of levels 0-5 or a percentage scale of 0% to 100% (0 as 0%, 1 as 20%, 2 as 40%, 3 as 60%, 4 as 80% and 5 as 100%) on the basis of overall scores. Since many countries did not submit part or all of the data, complete datasets were available for analysis from a total of 171 countries. The combined indices used in our analysis are comparable to the overall capacity levels used to assess health capacity algorithm developed by IHR-SPAR.

**Statistical analysis for the calculation of global and regional variations (disparities) in the capacities for the preparedness**

To study the global and regional variations on radiation emergency preparedness, we calculated the dispersion of the health capacity indices using standard deviations and interquartile ranges. Unlike conventional total range analysis approaches, interquartile range (IQR) has a breakdown point of 25% and thus is often preferred for such analyses. To study the global and regional relationship between radiation readiness and other reported capacities, we performed a correlation analysis across the different datasets.

For the statistical analyses, categorical and continuous variables were reported as percentage and mean ± standard deviation (SD), respectively where appropriate. All 13 capacities and 24 SPAR indicators are graded into 5 levels of performance and presented as percentages when appropriate. A p-value of < 0.05 was considered statistically significant for all statistical analyses. Statistical analyses were performed using Microsoft excel (16.47.1, 21032301).

**Patient involvement**

Patients were not involved in this study.

## Results

We used composite determinants of all capacities and individual IHR capacity metrics to assess global public health security. In particular, we first analyzed the most IHR-SPAR indicators in relation to the capacities for operational readiness to respond to radiation emergencies. We then examined how the preparedness against radiation emergency relates to 12 other reported capacities and their corresponding indicators. The IHR monitoring and evaluation framework categorized countries in to 5 levels across these indices, in which level 1 represented lowest level of the national capacity and level 5 as the highest[15,19] (**Supplemental Table 1).** In addition, we comparatively analyzed the data at the six WHO geographic regional levels. A total score of the 24 IHR-SPAR Indicators were used amongst the 13 capacities (**Supplemental Table 2**).

**Comparative analysis of the global and regional capacities for radiation emergency preparedness**

The analysis of the 2019 annual reporting data from 171 countries showed that the radiation emergency preparedness was one of the top 3 global challenges with an average global score per capacity of 55%. When the preparedness levels were closely examined, 28% of the countries scored none to very-low on the operational capacity (level 0 or 1). Similarly, 34% of the 171 countries had the capacity scores ranging between level 2-3, and only 38% had the advanced level of preparedness with the capacity scores ranging between level 4-5 **(Table 1)**.

At the regional level, 51% of the countries had very-low and 6% had no capacity in the WHO African (**AFRO)** region. Only 4% of the countries in this region had advanced capacity (level 4 or 5). In the WHO Region for the Americas **(AMRO)**, 24% of the 29 countries had very-low or no capacity for radiation emergency preparedness, whereas 41% had the higher-level preparedness (level 4 and 5). In WHO Eastern Mediterranean Region **(EMRO)**, 19 countries were included for analyses, of which 11%

had no capacity, 21% had very-low capacity and 47% had the capacity levels of 4 to 5. The WHO European Region **(EURO)** countries were relatively better-prepared for the radiation emergencies with 33% of the countries falling into the capacity levels of 2 to 3, and 67% with the capacity scores of 4 to 5. In contrast, in the WHO South-East Asia Region **(SEARO)**, 36% of all the countries reported no or very-low levels of radiation emergency preparedness capacity, and only 18% had the advanced level capacity. In the WHO Western Pacific Region **(WPRO)**, data from 14 countries were examined, which showed the capacity levels of very-low to low in 28% of the countries and advanced level of operational readiness in 43% of the countries. Radiation emergency preparedness capacity scores showed highest dispersion score among all 13 capacities suggesting higher disparities across the globe.

**Interrelationship between overall and individual core capacities and its relationship with the preparedness for radiation emergencies**

The major global challenges were points of entry (56% overall score per capacity), radiation emergencies (55% overall score per capacity) and chemical events (53% overall score per capacity). Relationship between radiation emergency preparedness capacity and other reported capacities at global and regional levels are summarized in **Table 2**. Analyses of the global data from 171 countries showed that capacity to respond to radiation emergency strongly correlated with capacity for chemical events with a correlation coefficient (ρ) of 0.70. Other closely associated indicators included legislation and financing (ρ=0.68), national health emergency framework (ρ=0.63), IHR coordination and national IHR focal point functions (ρ=0.68), and health service provision (ρ= 0.66). The lowest correlation was noted with the risk communication and point of entry (ρ= 0.45 each).

The analyses of the regional data, however, showed variable interrelationship within specific geographic regions. In the **AFRO** region, data from all 47 countries were included. Overall, a 32% score per capacity was reported for the radiation emergency readiness. The other health capacity indicators from AFRO region showed similar capacity scores including a 32% score for chemical events. Again, capacity to respond to radiation emergency strongly correlated with chemical events preparedness (ρ=0.70), which was followed by legislation and financing (ρ=0.61).

In the **AMRO**, data from 29 countries were analyzed and six were excluded due to incomplete reporting. The relationship between capacity for radiation emergency vs., legislation and financing were the strongest among all capacities (ρ=0.52), which was followed by point of entry (ρ=0.50) and human resource (ρ=0.48). The relationship with IHR coordination and National IHR focal point functions was found to be relatively weak (ρ=0.13).

In the **EMRO**, data from 19 countries were included for analyses. Strong correlation was noted between radiation emergency preparedness and legislation and financing, and chemical events (all ρ ≥0.6).

In the **EURO**, radiation emergency preparedness showed an unexpected but strong relationship with point of entry (ρ= 0.77) and health service provision (ρ=0.61).

Data from all 11 countries were included for analysis for the **SEARO**. SEARO region demonstrated trends that were either similar to the overall global data, or to EURO and AMRO regions. For example, the SEARO radiation emergency preparedness was strongly related to the chemical events (ρ=0.85), and IHR coordination and national IHR focal point functions (ρ> 0.66), which are similar to global capacity indicators. On the other hand, a strong relationship between the capacity for radiation emergency and the capacities for human resources (ρ=0.85) and point of entry (ρ=0.79) shared identical patterns as in the EURO and AMRO regions.

In the **WPRO**, radiation emergency preparedness capacity showed the strongest relationship with chemical events and health service provision (ρ=0.89 each). Additionally, a strong correlation was noted between the capabilities for radiation emergency and legislation and financing, IHR coordination and IHR focal point functions, human resource, national health emergency framework, health service provision, and point of entry (ρ>0.7 each). Of the 27 countries reporting data from this region, complete data were available only from 14 countries, which were further analyzed. The summary of all data in relation to the highly correlated individual capacity scores have been presented in **Table 2**.

**Global and regional disparities in overall and radiation emergency preparedness capacities**

A large dispersion indicates that the capacity indices spread far from the average capacity for operational readiness, which requires inter-state multisectoral coordination mechanisms. Our data analysis showed striking disparities in radiation emergency preparedness capacities when compared with the overall capacities. We found that radiation emergency capacity was widely dispersed as compared to the overall IHR capacity scores at the global level (**Figure 1).** The interquartile range (IQR) for overall capacity score was 49 to 81, and IQR for radiation emergency preparedness score ranged between 20 to 80. The lowest reported overall capacity was 17, but the lowest reported capacity score for the radiation emergency preparedness was 0, indicating absolute unpreparedness. In the **AFRO region**, the overall capacity IQR was calculated at 34 to 53 with the median score of 44. In contrast, the IQR for radiation emergency preparedness was at 20 to 40 with the median score of 32. Unfortunately, the lowest overall and radiation emergency capacity scores were at 17 and 0, respectively. In the **AMRO,** IQR for overall capacity was at 58 to 83 with a median score of 71. The lowest reported capacity was 48 with a highest score of 99. For radiation emergency preparedness, the IQR was at 30 to 80 with a median score of 59. However, the data demonstrated a wide dispersion and ranged from 0 to 100.

In the **EMRO**, the overall capacity score ranged from 32 to 96 with an IQR between 49 to 80, while the capacity for radiation emergency preparedness ranged between 0 to 100 with an IQR of 20 to 80.

The data from the **EURO** showed a stronger capacity score for radiation emergency preparedness compared to other geographic regions. The IQR for the overall capacity was between 65 to 86 with a range between 35 to 99. For radiation emergency preparedness, the IQR was between 60 to 100 with the lowest reported value of 40 and the median capacity of 77. Examination of data from the **SEARO** followed similar trends as the global capacity scores. The IQR for the overall capacity was between 51 to 73 with a range of 34 to 85. For radiation emergency preparedness capacity, the data ranged from 0 to 100 with and IQR of 20 to 60. In the **WPRO**, the IQR for overall capacity was between 52 to 92, while that for radiation emergency preparedness was at 20 to 80 with the lowest reported value of 0.

## Discussion

This study analyzes 2019 radiation emergency preparedness data from 171 countries. Most striking findings are that only two third of the countries are operationally prepared to counteract the catastrophic effects of radiation emergencies. In addition, major discrepancies exist between the individual countries within each geographical region. More importantly, several countries reported a non-uniform level of preparedness for individual health capacities, which implies operational challenges for collaborative action in such emergencies. Compared to average overall national capacity score, global preparedness for radiation emergencies showed lower operational capacity and higher levels of dispersion across the globe.

Our data analysis from 171 countries showed that radiation emergency preparedness was one of the top 3 global challenges. It was noted that 28% of the countries had low to non-existing capacity for radiation emergency. EURO appeared better prepared than the rest of the geographic regions followed by EMRO and AMRO regions indicating a major regional variation. Radiation emergencies are not confined by geographical limits and can be widespread across these boundaries. WHO IHR database is a validated platform developed by experts and can provide  objective scoring capacities to mitigate radiation hazard in ways that are commensurate with and restricted to public health risks[20]. Our analyses showed that almost 1/3$^{rd}$ of the countries across the globe had either non-existent or underdeveloped preparedness levels. Importantly, disproportionate variations in the operational capacities among different countries indicate that there can be delays in coordinated management process including emergency procedures at site, safe evacuations and shelter.

Innovative health capacity scores developed for global radiation emergencies are crucial to recognize the overall radiation risk preparedness. Such risk scoring approach also helps to coordinate

with parties across other sectors and capacities [2,14]. Our data show that the capacity for radiation preparedness is closely related to other health indicator capacities. For example, our global data analysis showed that capacity to respond to radiation emergency strongly correlated with capacity for chemical events and legislation and financing. Overall, having an objective risk assessment approach sets up standards and obligations for the state parties to develop and maintain essential core capacities to act against such emergencies of international concern[19]. This stated, one limitation of our study is that the radiation emergency preparedness data are self-reported by individual countries and are not independently verified. However, prior publications have reported that SPAR data strongly correlate with other externally evaluated data such as the Joint External Evaluation results[18,21].

This analysis also highlights striking global discrepancies that exist for the mitigation of radiation emergencies. Compared to overall capacity score, the radiation emergency preparedness score varied widely across the globe with lowest reported capacity score of zero, which shows absolute unpreparedness. With the exception of EURO, this variation persisted at the regional level with the capacity score ranging from non-existent to advanced level preparedness. As radiation disasters are not limited by geographical borders, such variation in cross-country preparedness levels can put larger population at risk. A large-scale emergency across the wide geographic boundaries requires a synchronous response, and inadequate and skewed responses from individual parties can destabilize the entire operation. In this context, we should also learn our lessons from novel coronavirus (2019-nCoV) pandemic that challenged our capacities for case detection, surveillance, and preparedness and response, both at national and international levels[18,22]. Emergency preparedness against radiation challenges are no exceptions to the urgent actions recommended by Global Preparedness Monitoring Board (GPMB), which recommends states commit to preparedness by implementing their obligations by dedicating resources for emergency preparedness[1,2,23]. A rapidly evolving radiation emergency, whether accidental

or deliberate, requires robust preparedness, with means to share medical countermeasures across the countries[11,24,25].

Side by side comparison of radiation emergency capacity with the overall IHR capacity scores showed that radiation emergency capacity was widely dispersed as compared to the overall IHR capacity scores at the global level. According to U.S. Department of Health and Human Services, a radiological or nuclear incident can be through contamination of food or water with radioactive material, placement of radiation sources in public places, or other severe measures including detonation, high-level nuclear waste and improvised devices[10]. Although the IHR capacity scores developed for radiation emergencies are expected to represent the operational readiness, it is crucial to interpret these data in line with the cross-sector preparedness for infrastructure, legislation, and coordination (C1)[18,24]. For such coordinated efforts, government bodies, ministries and agencies need to collaborate and involve other sectors including environment, transport, points of entry, travel, radiation safety, disaster management, emergency services (C2)[26]. This is highlighted by our data showing strong interrelationship between the capacity for radiation emergency and other capacities including chemical events, legislation and financing, and health service provision at the global and regional levels.

Additional capacities including well-trained and multisector workforce (C7), and a robust national health emergency framework (C8) and health service provision (C9) facilitate timely response and aid surge capacity for scaling up large national events[27]. For a concerted approach across the geographical boundaries, a coordinated public health surveillance between points of entry (C11) and national health surveillance system is recommended[28]. The radiation emergencies from technological incidents, natural disasters deliberate events and contaminated foods and products, utilize the similar resources for detection and alert system as in the management capacity outlined for chemical events

(C12)[29]. In addition to public health preparedness capacities, the health care providers, who are amongst the first responses against such emergencies, should have specific guidelines, recommendations and training[17]. IHR indicators (C13) are inclusive to embrace most of these needs[20].

In summary, we have found major discrepancies in the preparedness for radiation emergencies across the globe. Failure to recognize the degree of emergency preparedness influences its capacity to recover. Protecting all communities to the highest extent possible should be the overall goal of the radiation emergency preparedness[30]. Recent global COVID-19 pandemic displayed the disconnect between the incident and timely response[22]. Many countries that have lower level of preparedness rank at the bottom of leading health and economy indicators. Beyond health care capacities, our study also highlights the need for further research to identify most appropriate approaches to addressing the disparities accounted for radiation disaster planning.

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**Author Contribution Statement**

UCS was responsible for the conceptualization, manuscript writing and data analysis. SP was responsible for conceptualization, data review, manuscript editing and overall supervision.

**Data Sharing Statement**

The original datasets used for analysis can be obtained from the corresponding author.

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**Table 1. Summary of radiation emergency preparedness capacity at global and regional levels**

| | *No Capacity* | *Level 1 Capacity* | *Level 2 and 3 Capacity* | *Level 4 and 5 Capacity* | *Number of reporting Countries* |
|---|---|---|---|---|---|
| All Data (Global) | 5 | 23 | 34 | 38 | 171 |
| AFRO | 6 | 51 | 38 | 4 | 47 |
| AMRO | 3 | 21 | 34 | 41 | 29 |
| EMRO | 11 | 21 | 21 | 47 | 19 |
| EURO | 0 | 0 | 33 | 67 | 51 |
| SEARO | 9 | 27 | 45 | 18 | 11 |
| WPRO | 5 | 23 | 34 | 38 | 14 |

**Data presented in column 2, 3, 4 and 5 represent the percentage of the countries at different capacity scores.** AFRO, WHO African Region; AMRO, WHO Region for the Americas; EMRO, WHO Eastern Mediterranean Region; EURO, WHO European Region; SEARO, WHO South-East Asia Region; WPRO, WHO Western Pacific Region.

**Table 2. Relationship between radiation emergency preparedness capacity and other reported capacities at global and regional levels**

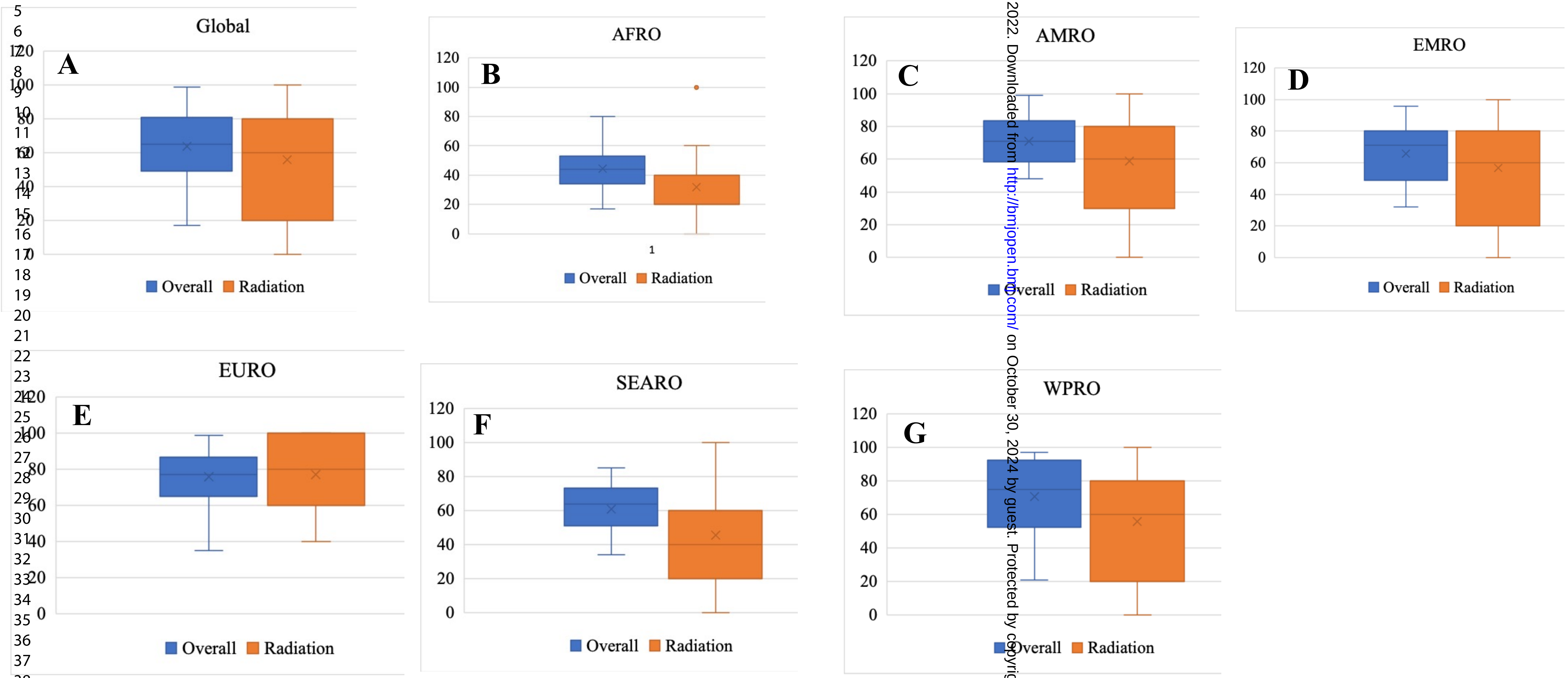
| | ***Legislation and Financing*** | ***IHR Coordination and NIHR Focal Point Functions*** | ***Human Resource*** | ***National Health Emergency Framework*** | ***Health Service Provision*** | ***Points of Entry*** | ***Chemical Events*** |
|---|---|---|---|---|---|---|---|
| All Data (Global) | 0.68 | 0.59 | 0.53 | 0.63 | 0.66 | 0.45 | 0.70 |
| AFRO | 0.61 | 0.43 | 0.36 | 0.49 | 0.43 | 0.36 | 0.70 |
| AMRO | 0.52 | 0.13 | 0.48 | 0.42 | 0.36 | 0.49 | 0.34 |
| EMRO | 0.62 | 0.57 | 0.33 | 0.43 | 0.48 | 0.41 | 0.60 |
| EURO | 0.29 | 0.47 | 0.22 | 0.47 | 0.61 | 0.07 | 0.49 |
| SEARO | 0.74 | 0.66 | 0.85 | 0.66 | 0.22 | 0.79 | 0.85 |
| WPRO | 0.79 | 0.73 | 0.76 | 0.76 | 0.89 | 0.81 | 0.89 |

**Data presented represent correlation coefficients. IHR, International Health Regulations.** AFRO, WHO African Region; AMRO, WHO Region for the Americas; EMRO, WHO Eastern Mediterranean Region; EURO, WHO European Region; SEARO, WHO South-East Asia Region; WPRO, WHO Western Pacific Region.

## Figure Legend

**Figure 1**. Box and whisker plots comparing overall vs., radiation emergency preparedness data dispersion across the globe. A, represents global data; B, shows the data from WHO African Region (AFRO); C, demonstrates the data from WHO Region for the Americas (AMRO); D, depicts the data from WHO Eastern Mediterranean Region (EMRO); E. shows WHO European Region data; F, depicts the data from WHO South-East Asia Region (SEARO) and G, represents the data from WHO Western Pacific Region (WPRO).

# Figure 1


A
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Radiation

**Supplemental Table 1.** IHR-SPAR Indicators for Radiation Emergencies (***Source: References 17,21)***

| **Level** | **C13.1 Capacity and resources** |
|---|---|
| Level 1 | Surveillance mechanisms and resources for radiation emergencies are under development |
| Level 2 | Radiation sources have been inventoried and radiation risk mapping has been conducted and documented |
| Level 3 | Access to specialized health care for radiation injuries is in place AND access to laboratory testing capacity for monitoring, identification and assessment of radiation exposure is in place |
| Level 4 | Access to technical expertise for managing radiation emergencies, including guidelines, protocols and regularly trained experts, is in place AND access to stockpile to support radiation emergency preparedness and response is in place |
| Level 5 | Radiation emergency arrangements are formally evaluated and tested on a regular basis, and improvements are made accordingly |

IHR, International Health Regulations (IHR) dataset, SPAR, State Party Annual Reporting

**Supplemental Table 2.** Selection criteria for each of the health capacity indicators (***Source: References 17,21)***

**C1 Legislation and Financing (3 indicators)**

C1.1 Legislation, laws, regulations, policy, administrative requirements or other government instruments to implement the IHR

C1.2 Financing for the implementation of IHR capacities response

C1.3 Financing mechanism and funds for timely response to public health emergencies

**Rationale**: Research, licensing, marketing authorization and procurement procedures for radioactive substances.

**C2 IHR coordination and national IHR focal point functions (2 indicators)**

C2.1 National IHR Focal Point functions under IHR

C2.2 Multisectoral IHR coordination mechanisms

**Rationale**: Collaboration and coordination among government bodies, ministries and agencies. These sectors can also include environment, transport, points of entry, travel, radiation safety, disaster management, emergency services, etc.

**C3 Zoonotic events and the human-animal interface (1 indicator)**

C3.1. Collaborative effort on activities to address zoonoses

**Rationale for exclusion**: Fundamental health care framework established to battle emerging zoonotic diseases is directly relevant to the management of radiation emergencies.

**C4 Food safety (1 indicator)**

C4.1 Multisectoral collaboration mechanism for food safety events

**Rationale**: Problems involving food contamination and food safety needs similar protocols for detection, investigation and response as in radiation emergencies.

**C5 Laboratory (3 indicators)**

C5.1. Specimen referral and transport system

C5.2 Implementation of a laboratory biosafety and biosecurity regime

C5.3 Access to laboratory testing capacity44 for priority diseases45

**Rationale**: The biosafety and biosecurity guidelines and regulations can ensure personnel and public safety by minimizing the risk of accidental radiation exposure.

**C6 Surveillance (2 indicators)**

C6.1 Early warning function: indicator-and event-based surveillance

C6.2 Mechanism for event management (verification, risk assessment, analysis investigation)

**Rationale**: A sensitive surveillance system can aid timely risk assessment, notification and response, including contact tracing.

**C7 Human resources (1 indicator)**

C7.1 Human resources for the implementation of IHR capacities

**Rationale**: Availability of a multisectoral and trained workforce capacity essential for the timely management of the radiation emergencies.

**C8 National health emergency framework (3 indicators)**

C8.1 Planning for emergency preparedness and response mechanism

C8.2 Management of health emergency response operations

C8.3 Emergency resource mobilization

**Rationale for inclusion**: Having a robust emergency preparedness and response team can deliver timely response to radiation emergencies.

**C9 Health service provision (3 indicators)**

C9.1 Case management capacity for IHR relevant hazards chemical and radiation decontamination

C9.2 Capacity for infection prevention and control and chemical and radiation decontamination

C9.3: Access to essential health services

**Rationale for inclusion**: Strong health care system at primary, secondary and tertiary levels, and availability of an existing emergency health care provision helps urgent response to radiation emergencies.

**C10 Risk communication (1 indicator)**

C10.1 Capacity for emergency risk communications

**Rationale**: A real-time exchange of information, advice and opinion can facilitate prevention, reporting and response by enabling health care providers and public to make informed decisions.

**C11 Points of entry (2 indicators)**

C11.1 Core capacity requirements at all times for designated airports, ports and ground crossings

C11.2 Effective public health response at points of entry

**Rationale**: Implementing point of entry capacity with an all-hazard and multisectoral approach is an integral part of surveillance and response system.

**C12 Chemical events (1 indicator)**

C12.1 Resources for detection and alert

**Rationale**: Chemical events resulting from technological incidents or contaminated foods can be of similar origin, nature or consequences to radiation emergencies.

**C13 Radiation emergencies (refer to Supplemental Table 1 for the levels of preparedness)**

BMJ Open

# Global Disparities in the Preparedness for Radiation Emergencies: Analyses of Datasets from International Health Regulations Annual Reports



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# Global Disparities in the Preparedness for Radiation Emergencies: Analyses of Datasets from International Health Regulations Annual Reports

Umesh C Sharma, MD, PhD[1], Kristopher Attwood, PhD[2], Saraswati Pokharel, MD, PhD[3]

[1] Cardio-Oncology Research Group, Department of Medicine, Division of Cardiology, Jacob's School of Medicine and Biomedical Sciences, Buffalo, NY, USA

[2] Department of Biostatistics and Bioinformatics, Roswell Park Comprehensive Cancer Center, Buffalo, NY, USA

[3] Ionizing Radiation and Coronary Microvascular Disease Research Group, Department of Pathology and Laboratory Medicine, Division of Thoracic Pathology and Oncology, Roswell Park Comprehensive Cancer Center, Buffalo, NY, USA

**Address for Correspondence**

Saraswati Pokharel, MD, PhD

Associate Professor of Oncology

Ionizing Radiation and Coronary Microvascular Disease Research Group

Roswell Park Comprehensive Cancer Center, Buffalo, NY, USA

Elm and Carlton, Buffalo, New York 14203

**Phone**: 716.845.4959

**E-mail**: saraswati.pokharel@roswellpark.org

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**Competeing Interests**: There are no competing interests for any author

## Abstract

**Objectives**: Radiation emergencies are rare but can have minor confined effects to catastrophic consequences across the large geographical territories. Geographical disparities in the preparedness for radiation emergencies can negatively impact public-safety and delay protective actions. We examined such disparities using the global and regional radiation preparedness data from the revised annual International Health Regulations (IHR) datasets.

**Settings**: We used IHR State Party Annual Reporting (SPAR) tool and its associated health indicators developed to mitigate public health-risk from radiation emergencies. Using the most recent (2019) SPAR database developed for radiation emergencies, along with 12 other cross-sector indicators, we examined the disparities among World Health Organization (WHO) state and region-wide capacity scores for operational preparedness.

**Results**: Based on the analysis of the 2019 annual reporting datasets from 171 countries, radiation emergency was one of the top 3 global challenges with an average global preparedness capacity of 55%. Radiation emergency preparedness capacity scores showed highest dispersion score amongst all 13 capacities suggesting higher disparities for preparedness across the globe. Only 38% of the countries had advanced functional capacity with ≥80% operational readiness, with 28% countries having low to very-low operational readiness. No geographical regions had ≥80% operational readiness for radiation emergencies, with 4/6 geographical regions showing limited capacity or effectiveness.

**Conclusion**: We found major global disparities for the operational preparedness against radiation emergencies. Collaborative approaches involving the public health officials and policymakers at the regional and state levels are needed to develop additional guidance to adapt emergency preparedness plans for radiation incidents.

**Keywords:** Radiation, Emergency Preparedness, Disparities, WHO

**Strenghths and Limitations**

- There are limited data examining the global disparities in the preparedness against radiation emergencies.
- Analysis of International Health Regulations (IHR) datasets shows radiation emergency as one of the top 3 global challenges.
- Major discrepancies in operational readiness also existed across different geographical regions.
- This study highlights the need for further research to identify most appropriate approaches to addressing the disparities accounted for radiation emergency planning.

## Introduction

Recent reports on the status of country preparedness capacity prepared in coordination with the Global Preparedness Monitoring Board (GPMB), the World Health Organization (WHO) has highlighted that a threat to public health anywhere in the world is now a threat to public health everywhere in the world[1,2]. Although we cannot predict the origin, nature or severity of next global health emergency, radiation emergencies constitute a major threat to human wellbeing[3,4]. The extent of injuries from high-dose radiation exposure can be acute, subacute or late, manifesting several decades after the incident event[5,6]. The late effects of radiation exposure from Hiroshima and Nagasaki disasters are still being realized[5].

Radiation exposure can be latent and subtle, and early recognition of its adverse effects can be challenging[7,8]. Once detected, complete reversal of radiation-induced injuries is not possible and treatment remains supportive or palliative[9]. Such latent properties of ionizing radiation pose major public health hazard. More importantly, a large scale radiation exposure may expand beyond the geographic boundaries putting a large human population at risk[10]. Early detection and reporting of such risks and implementing plans and policies for the mitigation of adverse effects will require a multidisciplinary approach involving the public health officials, health care providers and emergency preparedness team[11-13].

In 2005, International Health Regulations (IHR) developed State Party Self-Assessment reporting tools to allow World Health Organization (WHO) Secretariat to compile a report for the statistics of health capacities of individual countries[1,14,15]. This annual voluntary reporting tool has 13 **capacities**, with specific **indicators** associated with these capacities. Each indicator is graded in five **levels of performance**, for which discreet **action elements or attributes** are defined. States are

encouraged to respond to all the indicators so that an accurate view of the national capacities can be determined[1,14,16].

Of the 13 various capacities included in the IHR state party self-assessment annual reporting tool, radiation emergencies (radiological emergencies and nuclear accidents) constitute potentially catastrophic disasters with large scale of biological consequences. The guidelines for the preparedness and response for radiation emergencies have been reported previously by International Atomic Energy Agency (IAEA)[17]. However, there are no clear data comparing radiation emergency preparedness capacities in relation to other cross-sector emergency preparedness indices. Since radiation exposure can be widespread, there needs to be multinational and strategic co-ordination to confine risk and mitigate the harmful effects.

To this end, we have analyzed the individual and combined IHR indicators for radiation emergencies, as well as other cross-sector indicators including national health emergency framework, finances, legislation, surveillance, human resources, coordination of efforts, health service provision and risk communications. We have also studied the global and regional disparities in IHR indicators that influence the capacities and resources utilized to address radiation emergencies.

## Methods

The Electronic State Parties Self-Assessment Annual Reporting Tool (e-SPAR) is publicly accessible web-based data reporting platform, under the WHO IHR Monitoring and Evaluation Framework. The SPAR tool has 13 capacities and number of indicators that are graded into 5 levels of performance. The states are instructed to select one of the five levels for their implementation status for each indicator. Irrespective of the status of elements in the higher level(s), the lowest level is considered valid if two or more levels were selected. In the event of no selection, the final score for the capacity indicator was calculated as zero[14,15].

The ***primary goal*** of this analysis was to study radiation emergencies (C13) and each of the indicators related to the state capacities and resources (C13.1). The selected SPAR indicators and corresponding levels (1 to 5) are provided in the **Supplemental Table 1**.

The ***secondary goal*** was to further examine the cross-sector preparedness for infrastructure, legislation, and coordination. We first analyzed IHR-SPAR Indicators from 2019 in relation to the capacities to be prepared for radiation emergencies. Additionally, 24 IHR-SPAR indicators amongst the 13 capacities (**Supplemental Table 2)** were used for the analytical approaches comparing the capacity scores for radiation emergency preparedness in relation to the overall public health risk score across the globe as well as six unique geographic regions.

### Combined indices for global and regional capacity scores included in this analysis

We analyzed the overall capacity indices for the preparedness of radiation emergencies and its relationship with other 12 trans-sector capacities using a mathematic model similar to the one previously reported by Kandel et al[18]. For this analysis, we included 24 indicators that were all determined to be relevant to assess the operational capacity for radiation emergency preparedness. We aggregated the key

indicators and calculated arithmetic average to develop an ordinal scale of levels 0-5 or a percentage scale of 0% to 100% (0 as 0%, 1 as 20%, 2 as 40%, 3 as 60%, 4 as 80% and 5 as 100%) on the basis of overall scores. Since many countries did not submit part or all of the data, complete datasets were available for analysis from a total of 171 countries. The combined indices used in our analysis are comparable to the overall capacity levels used to assess health capacity algorithm developed by IHR-SPAR.

**Statistical analysis for the calculation of global and regional variations (disparities) in the capacities for the preparedness**

To study the global and regional variations on radiation emergency preparedness, we calculated the dispersion of the health capacity indices using standard deviations and interquartile ranges. Unlike conventional total range analysis approaches, interquartile range (IQR) has a breakdown point of 25% and thus is often preferred for such analyses. To study the global and regional relationship between radiation readiness and other reported capacities, we used the Pearson correlation coefficient with 95% confidence intervals obtained using Fisher's z-transformation.

For the statistical analyses, categorical and continuous variables were reported as percentage and mean ± standard deviation (SD), respectively where appropriate. All 13 capacities and 24 SPAR indicators are graded into 5 levels of performance and presented as percentages when appropriate. The overall capacity and radiation emergency preparedness scores were compared using the two-sided paired t-test (with Normality assessed using the Anderson Darling test). The scores were compared between regions using a one-way ANOPVA model with Tukey adjusted pirwise comaprisons. A p-value of $< 0.05$ was considered statistically significant for all statistical analyses. Statistical analyses were performed using Microsoft excel (16.47.1, 21032301) and SAS v9.4 (Cary, NC).

### Patient involvement

Patients were not involved in this study.

### Results

We used composite determinants of all capacities and individual IHR capacity metrics to assess global public health security. In particular, we first analyzed the most IHR-SPAR indicators in relation to the capacities for operational readiness to respond to radiation emergencies. We then examined how the preparedness against radiation emergency relates to 12 other reported capacities and their corresponding indicators. The IHR monitoring and evaluation framework categorized countries in to 5 levels across these indices, in which level 1 represented lowest level of the national capacity and level 5 as the highest[15,19] (**Supplemental Table 1).** In addition, we comparatively analyzed the data at the six WHO geographic regional levels. A total score of the 24 IHR-SPAR Indicators were used amongst the 13 capacities (**Supplemental Table 2**).

### Comparative analysis of the global and regional capacities for radiation emergency preparedness

The analysis of the 2019 annual reporting data from 171 countries showed that the radiation emergency preparedness was one of the top 3 global challenges with an average global score per capacity of 55%. When the preparedness levels were closely examined, 28% of the countries scored none to very-low on the operational capacity (level 0 or 1). Similarly, 34% of the 171 countries had the capacity scores ranging between level 2-3, and only 38% had the advanced level of preparedness with the capacity scores ranging between level 4-5 **(Table 1)**.

**Table 1. Summary of radiation emergency preparedness capacity at global and regional levels**

| | *No Capacity* | *Level 1 Capacity* | *Level 2 and 3 Capacity* | *Level 4 and 5 Capacity* | *Number of reporting Countries* |
|---|---|---|---|---|---|
| All Data (Global) | 5 | 23 | 34 | 38 | 171 |
| AFRO | 6 | 51 | 38 | 4 | 47 |
| AMRO | 3 | 21 | 34 | 41 | 29 |
| EMRO | 11 | 21 | 21 | 47 | 19 |
| EURO | 0 | 0 | 33 | 67 | 51 |
| SEARO | 9 | 27 | 45 | 18 | 11 |
| WPRO | 5 | 23 | 34 | 38 | 14 |

**Data presented in column 2, 3, 4 and 5 represent the percentage of the countries at different capacity scores.** *AFRO, WHO African Region; AMRO, WHO Region for the Americas; EMRO, WHO Eastern Mediterranean Region; EURO, WHO European Region; SEARO, WHO South-East Asia Region; WPRO, WHO Western Pacific Region.*

At the regional level, 51% of the countries had very-low and 6% had no capacity in the WHO African (**AFRO**) region. Only 4% of the countries in this region had advanced capacity (level 4 or 5). In the WHO Region for the Americas **(AMRO)**, 24% of the 29 countries had very-low or no capacity for radiation emergency preparedness, whereas 41% had the higher-level preparedness (level 4 and 5). In WHO Eastern Mediterranean Region **(EMRO)**, 19 countries were included for analyses, of which 11% had no capacity, 21% had very-low capacity and 47% had the capacity levels of 4 to 5. The WHO European Region **(EURO)** countries were relatively better-prepared for the radiation emergencies with 33% of the countries falling into the capacity levels of 2 to 3, and 67% with the capacity scores of 4 to 5. In contrast, in the WHO South-East Asia Region **(SEARO)**, 36% of all the countries reported no or very-low levels of radiation emergency preparedness capacity, and only 18% had the advanced level capacity. In the WHO Western Pacific Region **(WPRO)**, data from 14 countries were examined, which showed the capacity levels of very-low to low in 28% of the countries and advanced level of operational readiness in 43% of the countries. Radiation emergency preparedness capacity scores showed highest dispersion score among all 13 capacities suggesting higher disparities across the globe.

**Interrelationship between overall and individual core capacities and its relationship with the preparedness for radiation emergencies**

The major global challenges were points of entry (56% overall score per capacity), radiation emergencies (55% overall score per capacity) and chemical events (53% overall score per capacity). Relationship between radiation emergency preparedness capacity and other reported capacities at global and regional levels are summarized in **Table 2**.

**Table 2. Relationship between radiation emergency preparedness capacity and other reported capacities at global and regional levels**

| | ***Legislation and Financing*** | ***IHR Coordination and NIHR Focal Point Functions*** | ***Human Resource*** | ***National Health Emergency Framework*** | ***Health Service Provision*** | ***Points of Entry*** | ***Chemical Events*** |
|---|---|---|---|---|---|---|---|
| All Data (Global) | 0.68 (0.59, 0.75) | 0.59 (0.49, 0.68) | 0.53 (0.41, 0.63) | 0.63 (0.53, 0.71) | 0.66 (0.56, 0.73) | 0.45 (0.32, 0.56) | 0.70 (0.61, 0.77) |
| AFRO | 0.61 (0.39, 0.76) | 0.43 (0.17, 0.64) | 0.36 (0.08, 0.59) | 0.49 (0.23, 0.68) | 0.43 (0.16, 0.64) | 0.36 (0.09, 0.59) | 0.70 (0.51, 0.82) |
| AMRO | 0.52 (0.18, 0.74) | 0.13 (-0.25, 0.48) | 0.48 (0.14, 0.72) | 0.42 (0.06, 0.68) | 0.36 (-0.01, 0.64) | 0.49 (0.15, 0.73) | 0.34 (-0.03, 0.63) |
| EMRO | 0.62 (0.23, 0.84) | 0.57 (0.15, 0.81) | 0.33 (-0.15, 0.68) | 0.43 (-0.04, 0.74) | 0.48 (0.02, 0.76) | 0.41 (-0.06, 0.73) | 0.60 (0.20, 0.83) |
| EURO | 0.29 (0.02, 0.53) | 0.47 (0.24, 0.67) | 0.22 (-0.07, 0.46) | 0.47 (0.18, 0.63) | 0.61 (0.33, 0.72) | 0.07 (-0.26, 0.29) | 0.49 (0.23, 0.67) |
| SEARO | 0.74 (0.23, 0.92) | 0.66 (0.08, 0.90) | 0.85 (0.48, 0.96) | 0.66 (0.08, 0.90) | 0.22 (-0.44, 0.72) | 0.79 (0.33, 0.94) | 0.85 (0.50, 0.96) |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| WPRO | 0.79<br>(0.44, 0.93) | 0.73<br>(0.31, 0.90) | 0.76<br>(0.38, 0.92) | 0.76<br>(0.38, 0.92) | 0.89<br>(0.69, 0.97) | 0.81<br>(0.49, 0.94) | 0.89<br>(0.67, 0.96) |

**Data presented represent correlation coefficients.** *Confidence intervals for the Pearson correlation coefficients were obtained using Fisher's z transformation. Pearson correlation coefficient (95% Confidence Interval) IHR, International Health Regulations. AFRO, WHO African Region; AMRO, WHO Region for the Americas; EMRO, WHO Eastern Mediterranean Region; EURO, WHO European Region; SEARO, WHO South-East Asia Region; WPRO, WHO Western Pacific Region.*

Analyses of the global data from 171 countries showed that capacity to respond to radiation emergency strongly correlated with capacity for chemical events with a correlation coefficient (ρ) of 0.70 (confidence interval, CI 0.61, 0.77). Other closely associated indicators included legislation and financing (ρ=0.68; CI 0.59, 0.75)), national health emergency framework (ρ=0.63; CI 0.53, 0.71), health service provision (ρ= 0.66, CI 0.56, 0.73), and IHR coordination and national IHR focal point functions (ρ=0.59; CI 0.49, 0.68). The lowest correlation was noted with the risk communication and point of entry (ρ= 0.45 each).

The analyses of the regional data, however, showed variable interrelationship within specific geographic regions. In the **AFRO** region, data from all 47 countries were included. Overall, a 32% score per capacity was reported for the radiation emergency readiness. The other health capacity indicators from AFRO region showed similar capacity scores including a 32% score for chemical events. Again, capacity to respond to radiation emergency strongly correlated with chemical events preparedness (ρ=0.70, CI 0.51, 0.82), which was followed by legislation and financing (ρ=0.61, CI 0.59, 0.76).

In the **AMRO**, data from 29 countries were analyzed and six were excluded due to incomplete reporting. The relationship between capacity for radiation emergency vs., legislation and financing were the strongest among all capacities (ρ=0.52, CI 18, 0.74), which was followed by point of entry (ρ=0.49, CI 0.15, 0.73) and human resource (ρ=0.48, CI 0.14, 0.72). The relationship with IHR coordination and National IHR focal point functions was found to be relatively weak (ρ=0.13, CI 0.25, 0.48).

In the **EMRO**, data from 19 countries were included for analyses. Strong correlation was noted between radiation emergency preparedness and legislation and financing, and chemical events (all ρ ≥0.6).

In the **EURO**, radiation emergency preparedness showed a strong relation with health service provision (ρ= 0. 61, CI 0.33, 0.72).

Data from all 11 countries were included for analysis for the **SEARO**. SEARO region demonstrated trends that were either similar to the overall global data, or to EURO and AMRO regions. For example, the SEARO radiation emergency preparedness was strongly related to the chemical events (ρ=0.85, CI 0.50, 0.96), and IHR coordination and national IHR focal point functions (ρ> 0.66), which are similar to global capacity indicators. On the other hand, a strong relationship between the capacity for radiation emergency and the capacities for human resources (ρ=0.85, CI 0.48, 0.96) and point of entry (ρ=0.79, CI 0.33, 0.94) shared identical patterns as in the EURO and AMRO regions.

In the **WPRO**, radiation emergency preparedness capacity showed the strongest relationship with chemical events and health service provision (ρ=0.89 each). Additionally, a strong correlation was noted between the capabilities for radiation emergency and legislation and financing, IHR coordination and IHR focal point functions, human resource, national health emergency framework, health service provision, and point of entry (ρ>0.7 each). Of the 27 countries reporting data from this region, complete data were available only from 14 countries, which were further analyzed. The summary of all data in relation to the highly correlated individual capacity scores have been presented in **Table 2**.

**Global and regional disparities in overall and radiation emergency preparedness capacities**

A large dispersion indicates that the capacity indices spread far from the average capacity for operational readiness, which requires inter-state multisectoral coordination mechanisms. Our data analysis showed striking disparities in radiation emergency preparedness capacities when compared with the overall capacities. We found that radiation emergency capacity was widely dispersed as compared to the overall IHR capacity scores at the global level (**Figure 1).** The interquartile range (IQR) for overall capacity score was 49 to 81, and IQR for radiation emergency preparedness score ranged between 20 to 80. The lowest reported overall capacity was 17, but the lowest reported capacity score for the radiation emergency preparedness was 0 ($p<0.001$), indicating absolute unpreparedness. In the **AFRO region**, the overall capacity IQR was calculated at 34 to 53 with the median score of 44. In contrast, the IQR for radiation emergency preparedness was at 20 to 40 with the median score of 32 ($p<0.001$). Unfortunately, the lowest overall and radiation emergency capacity scores were at 17 and 0, respectively. In the **AMRO,** IQR for overall capacity was at 58 to 83 with a median score of 71. The lowest reported capacity was 48 with a highest score of 99. For radiation emergency preparedness, the IQR was at 30 to 80 with a median score of 59 ($p= 0.009$). However, the data demonstrated a wide dispersion and ranged from 0 to 100.

In the **EMRO**, the overall capacity score ranged from 32 to 96 with an IQR between 49 to 80, while the capacity for radiation emergency preparedness ranged between 0 to 100 with an IQR of 20 to 80 .

The data from the **EURO** showed a stronger capacity score for radiation emergency preparedness compared to other geographic regions. The IQR for the overall capacity was between 65 to 86 with a range between 35 to 99. For radiation emergency preparedness, the IQR was between 60 to 100 with the lowest reported value of 40 and the median capacity of 77 ($p=0.31$). Examination of data from the **SEARO** followed similar trends as the global capacity scores. The IQR for the overall capacity was between 51 to 73 with a range of 34 to 85. For radiation emergency preparedness capacity, the data ranged from 0 to 100 with and IQR of 20 to 60. This difference, however, was not statistically significant (p=0.39), likely due to a high standard deviation. In the **WPRO**, the IQR for overall capacity was between 52 to 92, while that for radiation emergency preparedness was at 20 to 80 with the lowest reported value of 0 (p=0.002).

## Discussion

This study analyzes 2019 radiation emergency preparedness data from 171 countries. Most striking findings are that only two third of the countries are operationally prepared to counteract the catastrophic effects of radiation emergencies. In addition, major discrepancies exist between the individual countries within each geographical region. More importantly, several countries reported a non-uniform level of preparedness for individual health capacities, which implies operational challenges for collaborative action in such emergencies. Compared to average overall national capacity score, global preparedness for radiation emergencies showed lower operational capacity and higher levels of dispersion across the globe.

Our data analysis from 171 countries showed that radiation emergency preparedness was one of the top 3 global challenges. It was noted that 28% of the countries had low to non-existing capacity for radiation emergency. EURO appeared better prepared than the rest of the geographic regions followed by EMRO and AMRO regions indicating a major regional variation. Radiation emergencies are not confined by geographical limits and can be widespread across these boundaries. WHO IHR database is a validated platform developed by experts and can provide objective scoring capacities to mitigate radiation hazard in ways that are commensurate with and restricted to public health risks[20]. Our analyses showed that almost 1/3rd of the countries across the globe had either non-existent or underdeveloped preparedness levels. Importantly, disproportionate variations in the operational capacities among different countries indicate that there can be delays in coordinated management process including emergency procedures at site, safe evacuations and shelter.

Innovative health capacity scores developed for global radiation emergencies are crucial to recognize the overall radiation risk preparedness. Such risk scoring approach also helps to coordinate

with parties across other sectors and capacities [2,14]. Our data show that the capacity for radiation preparedness is closely related to other health indicator capacities. For example, our global data analysis showed that capacity to respond to radiation emergency strongly correlated with capacity for chemical events and legislation and financing. Overall, having an objective risk assessment approach sets up standards and obligations for the state parties to develop and maintain essential core capacities to act against such emergencies of international concern[19]. This stated, one limitation of our study is that the radiation emergency preparedness data are self-reported by individual countries and are not independently verified. However, prior publications have reported that SPAR data strongly correlate with other externally evaluated data such as the Joint External Evaluation results[18,21].

This analysis also highlights striking global discrepancies that exist for the mitigation of radiation emergencies. Compared to overall capacity score, the radiation emergency preparedness score varied widely across the globe with lowest reported capacity score of zero, which shows absolute unpreparedness. With the exception of EURO, this variation persisted at the regional level with the capacity score ranging from non-existent to advanced level preparedness. As radiation disasters are not limited by geographical borders, such variation in cross-country preparedness levels can put larger population at risk. A large-scale emergency across the wide geographic boundaries requires a synchronous response, and inadequate and skewed responses from individual parties can destabilize the entire operation. In this context, we should also learn our lessons from novel coronavirus (2019-nCoV) pandemic that challenged our capacities for case detection, surveillance, and preparedness and response, both at national and international levels[18,22]. Emergency preparedness against radiation challenges are no exceptions to the urgent actions recommended by Global Preparedness Monitoring Board (GPMB), which recommends states commit to preparedness by implementing their obligations by dedicating resources for emergency preparedness[1,2,23]. A rapidly evolving radiation emergency, whether accidental

or deliberate, requires robust preparedness, with means to share medical countermeasures across the countries[11,24,25].

Side by side comparison of radiation emergency capacity with the overall IHR capacity scores showed that radiation emergency capacity was widely dispersed as compared to the overall IHR capacity scores at the global level. According to U.S. Department of Health and Human Services, a radiological or nuclear incident can be through contamination of food or water with radioactive material, placement of radiation sources in public places, or other severe measures including detonation, high-level nuclear waste and improvised devices[10]. Although the IHR capacity scores developed for radiation emergencies are expected to represent the operational readiness, it is crucial to interpret these data in line with the cross-sector preparedness for infrastructure, legislation, and coordination (C1)[18,24]. For such coordinated efforts, government bodies, ministries and agencies need to collaborate and involve other sectors including environment, transport, points of entry, travel, radiation safety, disaster management, emergency services (C2)[26]. This is highlighted by our data showing strong interrelationship between the capacity for radiation emergency and other capacities including chemical events, legislation and financing, and health service provision at the global and regional levels.

Additional capacities including well-trained and multisector workforce (C7), and a robust national health emergency framework (C8) and health service provision (C9) facilitate timely response and aid surge capacity for scaling up large national events[27]. For a concerted approach across the geographical boundaries, a coordinated public health surveillance between points of entry (C11) and national health surveillance system is recommended[28]. The radiation emergencies from technological incidents, natural disasters deliberate events and contaminated foods and products, utilize the similar resources for detection and alert system as in the management capacity outlined for chemical events

(C12)[29]. In addition to public health preparedness capacities, the health care providers, who are amongst the first responses against such emergencies, should have specific guidelines, recommendations and training[17]. IHR indicators (C13) are inclusive to embrace most of these needs[20].

Radiation emergency capacity of a country and the region as a whole is affected by several factors, including the existence of institutional framework, adherence to the policy and protocols, prevention and control measures, population density etc. When the radiation emergency occurs as a result of a major events such as nuclear accidents or conflicts involving the nuclear weapons, the capacity to mitigate the harm is directly related to the population density and the resources available. Analysis of the other risk variables associated with managing the radiation emergencies would benefit from understanding the existing country capacities, vulnerabilities due to socioeconomic conditions, and lack of health infrastructures. The information and data from these assessments should be analysed to build the readiness and response plans for preventing and controlling health emergencies including radiation emergencies[18].

As reported by Keeshmiri and colleagues[30], identification of the risk and systematic preparation is the best way to mitigate impact of public health risk. Effective health-care delivery systems and, the hospital readiness in particular, represent a major foundation for reducing the impact of the crisis such as radiation emergencies. Additionally, several intra-and intersectoral communication, coordination and preparedness is required at the national level for managing the radiation incidents to prevent inconsistent response following the incidence. Just like controlling COVID-19 pandemic, an integrated and multidisciplinary approach toward local and regional management of casualties in the event of a radiation emergency is needed. This involves several pillars, including skilled staff, the hospital’s physical space, equipment, coordination, structure, organization, processes, guidelines, and information systems in intra- and intersectoral multidisciplinary arrangements. Coordination among the various hospital departments and with different nonhealth-care organizations is a fundamental principle in times of crisis. Regular maneuvers and continuous training of the numerous occupational groups involved in the response team are the key factors in maintaining the readiness and appropriate response of health-care systems to radiation emergencies[31].

In summary, we have found major discrepancies in the preparedness for radiation emergencies across the globe. Failure to recognize the degree of emergency preparedness influences its capacity to recover. Protecting all communities to the highest extent possible should be the overall goal of the radiation emergency preparedness[32]. Currently, resources related to radiation play active roles in our daily lives. In certain countries or region, its utility could be of limited scope such as those used for medical diagnostic or therapeutic purposes (X-ray and gamma-knife radiation) while other countries could be more leliant in nuclear energy such as nuclear power plants, and the weapons of defense. Due to their importance and widespread presence, there needs to be a realization of dangers related to radiation accidents and the greater need for preparation to respond in the event of such accidents. Recent global COVID-19 pandemic displayed the disconnect between the incident and timely response[22]. Many countries that have lower level of preparedness rank at the bottom of leading health and economy indicators. However, disasters such as Chernobyl, Fukushima, and similar cases have shown that lack of attention to the necessary safety considerations can have irreparable risks for the human community, which are of varying intensity and scope. Beyond health care capacities, our study also highlights the need for further research to identify most appropriate approaches to addressing the disparities accounted for radiation disaster planning.

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UCS was responsible for the conceptualization, manuscript writing and data analysis. KA provided expert help with the statistical analyses. SP was responsible for conceptualization, data review, manuscript editing and overall supervision.

**Data Sharing Statement**

All data relevant to the study are included in the article or uploaded as supplementary information. Data are available upon request.

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**Figure Legend**

**Figure 1**. Box and whisker plots comparing overall vs., radiation emergency preparedness data dispersion across the globe. A, represents global data; B, shows the data from WHO African Region (AFRO); C, demonstrates the data from WHO Region for the Americas (AMRO); D, depicts the data from WHO Eastern Mediterranean Region (EMRO); E. shows WHO European Region data; F, depicts the data from WHO South-East Asia Region (SEARO) and G, represents the data from WHO Western Pacific Region (WPRO). The overall capacity and radiation emergency preparedness scores were compared in the overall sample and by region using a two-sided paired t-test (normality was assessed using the Anderson Darling test). There were significant differences globally, as well as in the AFRO, AMRO, and WPRO regions.

**Figure 1**

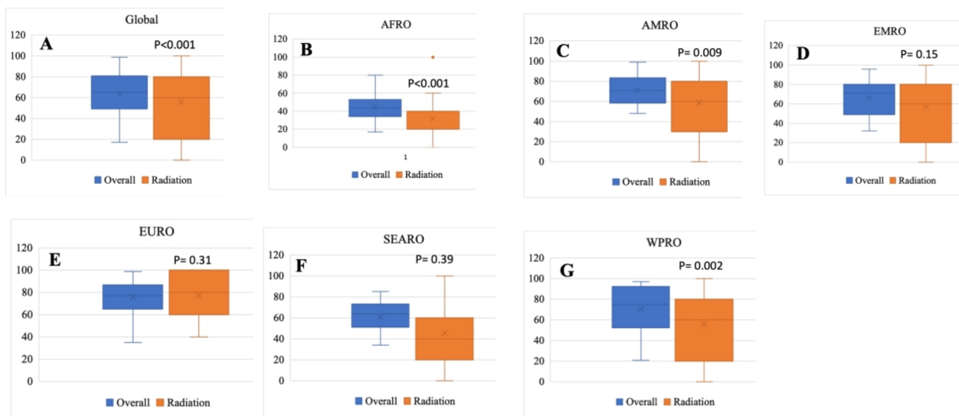


Figure 1

337x189mm (173 x 173 DPI)

**Supplemental Table 1.** IHR-SPAR Indicators for Radiation Emergencies (***Source: References 17,21)***

| **Level** | **C13.1 Capacity and resources** |
|---|---|
| Level 1 | Surveillance mechanisms and resources for radiation emergencies are under development |
| Level 2 | Radiation sources have been inventoried and radiation risk mapping has been conducted and documented |
| Level 3 | Access to specialized health care for radiation injuries is in place AND access to laboratory testing capacity for monitoring, identification and assessment of radiation exposure is in place |
| Level 4 | Access to technical expertise for managing radiation emergencies, including guidelines, protocols and regularly trained experts, is in place AND access to stockpile to support radiation emergency preparedness and response is in place |
| Level 5 | Radiation emergency arrangements are formally evaluated and tested on a regular basis, and improvements are made accordingly |

**Supplemental Table 2.** Selection criteria for each of the health capacity indicators (***Source: References 17,21)***

**C1 Legislation and Financing (3 indicators)**

C1.1 Legislation, laws, regulations, policy, administrative requirements or other government instruments to implement the IHR

C1.2 Financing for the implementation of IHR capacities response

C1.3 Financing mechanism and funds for timely response to public health emergencies

**Rationale**: Research, licensing, marketing authorization and procurement procedures for radioactive substances.

**C2 IHR coordination and national IHR focal point functions (2 indicators)**

C2.1 National IHR Focal Point functions under IHR

C2.2 Multisectoral IHR coordination mechanisms

**Rationale**: Collaboration and coordination among government bodies, ministries and agencies. These sectors can also include environment, transport, points of entry, travel, radiation safety, disaster management, emergency services, etc.

**C3 Zoonotic events and the human-animal interface (1 indicator)**

C3.1. Collaborative effort on activities to address zoonoses

**Rationale for exclusion**: Fundamental health care framework established to battle emerging zoonotic diseases is directly relevant to the management of radiation emergencies.

**C4 Food safety (1 indicator)**

C4.1 Multisectoral collaboration mechanism for food safety events

**Rationale**: Problems involving food contamination and food safety needs similar protocols for detection, investigation and response as in radiation emergencies.

**C5 Laboratory (3 indicators)**

C5.1. Specimen referral and transport system

C5.2 Implementation of a laboratory biosafety and biosecurity regime

C5.3 Access to laboratory testing capacity44 for priority diseases45

**Rationale**: The biosafety and biosecurity guidelines and regulations can ensure personnel and public safety by minimizing the risk of accidental radiation exposure.

**C6 Surveillance (2 indicators)**

C6.1 Early warning function: indicator-and event-based surveillance

C6.2 Mechanism for event management (verification, risk assessment, analysis investigation)

**Rationale**: A sensitive surveillance system can aid timely risk assessment, notification and response, including contact tracing.

**C7 Human resources (1 indicator)**

C7.1 Human resources for the implementation of IHR capacities

**Rationale**: Availability of a multisectoral and trained workforce capacity essential for the timely management of the radiation emergencies.

**C8 National health emergency framework (3 indicators)**

C8.1 Planning for emergency preparedness and response mechanism

C8.2 Management of health emergency response operations

C8.3 Emergency resource mobilization

**Rationale for inclusion**: Having a robust emergency preparedness and response team can deliver timely response to radiation emergencies.

**C9 Health service provision (3 indicators)**

C9.1 Case management capacity for IHR relevant hazards chemical and radiation decontamination

C9.2 Capacity for infection prevention and control and chemical and radiation decontamination

C9.3: Access to essential health services

**Rationale for inclusion**: Strong health care system at primary, secondary and tertiary levels, and availability of an existing emergency health care provision helps urgent response to radiation emergencies.

**C10 Risk communication (1 indicator)**

C10.1 Capacity for emergency risk communications

**Rationale**: A real-time exchange of information, advice and opinion can facilitate prevention, reporting and response by enabling health care providers and public to make informed decisions.

**C11 Points of entry (2 indicators)**

C11.1 Core capacity requirements at all times for designated airports, ports and ground crossings

C11.2 Effective public health response at points of entry

**Rationale**: Implementing point of entry capacity with an all-hazard and multisectoral approach is an integral part of surveillance and response system.

**C12 Chemical events (1 indicator)**

C12.1 Resources for detection and alert

**Rationale**: Chemical events resulting from technological incidents or contaminated foods can be of similar origin, nature or consequences to radiation emergencies.

**C13 Radiation emergencies (refer to Supplemental Table 1 for the levels of preparedness)**

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# Quantitative Analysis of International Health Regulations Annual Reports to Identify Global Disparities in the Preparedness for Radiation Emergencies

Umesh C Sharma, MD, PhD[1], Kristopher Attwood, PhD[2], Saraswati Pokharel, MD, PhD[3]

[1] Cardio-Oncology Research Group, Department of Medicine, Division of Cardiology, Jacob's School of Medicine and Biomedical Sciences, Buffalo, NY, USA

[2] Department of Biostatistics and Bioinformatics, Roswell Park Comprehensive Cancer Center, Buffalo, NY, USA

[3] Ionizing Radiation and Coronary Microvascular Disease Research Group, Department of Pathology and Laboratory Medicine, Division of Thoracic Pathology and Oncology, Roswell Park Comprehensive Cancer Center, Buffalo, NY, USA

**Address for Correspondence**

Saraswati Pokharel, MD, PhD

Associate Professor of Oncology

Ionizing Radiation and Coronary Microvascular Disease Research Group

Roswell Park Comprehensive Cancer Center, Buffalo, NY, USA

Elm and Carlton, Buffalo, New York 14203

**Phone**: 716.845.4959

**E-mail**: saraswati.pokharel@roswellpark.org



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**Abstract**

**Objectives**: Radiation emergencies are rare but can have minor confined effects to catastrophic consequences across the large geographical territories. Geographical disparities in the preparedness for radiation emergencies can negatively impact public-safety and delay protective actions. We examined such disparities using the global and regional radiation preparedness data from the revised annual International Health Regulations (IHR) datasets.

**Settings**: We used IHR State Party Annual Reporting (SPAR) tool and its associated health indicators developed to mitigate public health-risk from radiation emergencies. Using the most recent (2019) SPAR database developed for radiation emergencies, along with 12 other cross-sector indicators, we examined the disparities among World Health Organization (WHO) state and region-wide capacity scores for operational preparedness.

**Results**: Based on the analysis of the 2019 annual reporting datasets from 171 countries, radiation emergency was one of the top 3 global challenges with an average global preparedness capacity of 55%. Radiation emergency preparedness capacity scores showed highest dispersion score amongst all 13 capacities suggesting higher disparities for preparedness across the globe. Only 38% of the countries had advanced functional capacity with ≥80% operational readiness, with 28% countries having low to very-low operational readiness. No geographical regions had ≥80% operational readiness for radiation emergencies, with 4/6 geographical regions showing limited capacity or effectiveness. Global data from 171 countries showed that the capacity to respond to radiation emergencies correlated with the capacity for chemical events with a correlation coefficient ($\rho$) of 0.70 (confidence interval, CI 0.61, 0.77).

**Conclusion**: We found major global disparities for the operational preparedness against radiation emergencies.  Collaborative approaches involving the public health officials and policymakers at the regional and state levels are needed to develop additional guidance to adapt emergency preparedness plans for radiation incidents.

**Keywords:** Radiation, Emergency Preparedness, Disparities, WHO

**Strengths and Limitations**

- There are limited data examining the global disparities in the preparedness against radiation emergencies.
- Failure to recognize the degree of emergency preparedness influences its capacity to recover.
- Major discrepancies in operational readiness for cross-sector preparedness for infrastructure, legislation, and coordination also existed globally and across different geographical regions.
- This study highlights the need for further research to identify most appropriate approaches to addressing the disparities accounted for radiation emergency planning.

## Introduction

Recent reports on the status of country preparedness capacity prepared in coordination with the Global Preparedness Monitoring Board (GPMB), the World Health Organization (WHO) has highlighted that a threat to public health anywhere in the world is now a threat to public health everywhere in the world[1,2]. Although we cannot predict the origin, nature or severity of next global health emergency, radiation emergencies constitute a major threat to human wellbeing[3,4]. The extent of injuries from high-dose radiation exposure can be acute, subacute or late, manifesting several decades after the incident event[5,6]. The late effects of radiation exposure from Hiroshima and Nagasaki disasters are still being realized[5].

Radiation exposure can be latent and subtle, and early recognition of its adverse effects can be challenging[7,8]. Once detected, complete reversal of radiation-induced injuries is not possible and treatment remains supportive or palliative[9]. Such latent properties of ionizing radiation pose major public health hazard. More importantly, a large scale radiation exposure may expand beyond the geographic boundaries putting a large human population at risk[10]. Early detection and reporting of such risks and implementing plans and policies for the mitigation of adverse effects will require a multidisciplinary approach involving the public health officials, health care providers and emergency preparedness team[11-13].

In 2005, International Health Regulations (IHR) developed State Party Self-Assessment reporting tools to allow World Health Organization (WHO) Secretariat to compile a report for the statistics of health capacities of individual countries[1,14,15]. This annual voluntary reporting tool has 13 **capacities**, with specific **indicators** associated with these capacities. Each indicator is graded in five **levels of performance**, for which discreet **action elements or attributes** are defined. States are

encouraged to respond to all the indicators so that an accurate view of the national capacities can be determined[1,14,16].

Of the 13 various capacities included in the IHR state party self-assessment annual reporting tool, radiation emergencies (radiological emergencies and nuclear accidents) constitute potentially catastrophic disasters with large scale of biological consequences. The guidelines for the preparedness and response for radiation emergencies have been reported previously by International Atomic Energy Agency (IAEA)[17]. However, there are no clear data comparing radiation emergency preparedness capacities in relation to other cross-sector emergency preparedness indices. Since radiation exposure can be widespread, there needs to be multinational and strategic co-ordination to confine risk and mitigate the harmful effects.

To this end, we have analyzed the individual and combined IHR indicators for radiation emergencies, as well as other cross-sector indicators including national health emergency framework, finances, legislation, surveillance, human resources, coordination of efforts, health service provision and risk communications. We have also studied the global and regional disparities in IHR indicators that influence the capacities and resources utilized to address radiation emergencies.

## Methods

The Electronic State Parties Self-Assessment Annual Reporting Tool (e-SPAR) is publicly accessible web-based data reporting platform, under the WHO IHR Monitoring and Evaluation Framework. The SPAR tool has 13 capacities and number of indicators that are graded into 5 levels of performance. The states are instructed to select one of the five levels for their implementation status for each indicator. Irrespective of the status of elements in the higher level(s), the lowest level is considered valid if two or more levels were selected. In the event of no selection, the final score for the capacity indicator was calculated as zero[14,15].

The ***primary goal*** of this analysis was to study radiation emergencies (C13) and each of the indicators related to the state capacities and resources (C13.1). The selected SPAR indicators and corresponding levels (1 to 5) are provided in the **Supplemental Table 1**.

The ***secondary goal*** was to further examine the cross-sector preparedness for infrastructure, legislation, and coordination. We first analyzed IHR-SPAR Indicators from 2019 in relation to the capacities to be prepared for radiation emergencies. Additionally, 24 IHR-SPAR indicators amongst the 13 capacities (**Supplemental Table 2)** were used for the analytical approaches comparing the capacity scores for radiation emergency preparedness in relation to the overall public health risk score across the globe as well as six unique geographic regions.

### Combined indices for global and regional capacity scores included in this analysis

We analyzed the overall capacity indices for the preparedness of radiation emergencies and its relationship with other 12 trans-sector capacities using a mathematic model similar to the one previously reported by Kandel et al[18]. For this analysis, we included 24 indicators that were all determined to be relevant to assess the operational capacity for radiation emergency preparedness. We aggregated the key

indicators and calculated arithmetic average to develop an ordinal scale of levels 0-5 or a percentage scale of 0% to 100% (0 as 0%, 1 as 20%, 2 as 40%, 3 as 60%, 4 as 80% and 5 as 100%) on the basis of overall scores. Since many countries did not submit part or all of the data, complete datasets were available for analysis from a total of 171 countries. The combined indices used in our analysis are comparable to the overall capacity levels used to assess health capacity algorithm developed by IHR-SPAR.

**Statistical analysis for the calculation of global and regional variations (disparities) in the capacities for the preparedness**

To study the global and regional variations on radiation emergency preparedness, we calculated the dispersion of the health capacity indices using standard deviations and interquartile ranges. Unlike conventional total range analysis approaches, interquartile range (IQR) has a breakdown point of 25% and thus is often preferred for such analyses. To study the global and regional relationship between radiation readiness and other reported capacities, we used the Pearson correlation coefficient with 95% confidence intervals obtained using Fisher's z-transformation.

For the statistical analyses, categorical and continuous variables were reported as percentage and mean ± standard deviation (SD), respectively where appropriate. All 13 capacities and 24 SPAR indicators are graded into 5 levels of performance and presented as percentages when appropriate. The overall capacity and radiation emergency preparedness scores were compared using the two-sided paired t-test (with Normality assessed using the Anderson Darling test). The scores were compared between regions using a one-way ANOPVA model with Tukey adjusted pirwise comaprisons. A p-value of $< 0.05$ was considered statistically significant for all statistical analyses. Statistical analyses were performed using Microsoft excel (16.47.1, 21032301) and SAS v9.4 (Cary, NC).

**Patient involvement**

Patients were not involved in this study.

**Results**

We used composite determinants of all capacities and individual IHR capacity metrics to assess global public health security. In particular, we first analyzed the most IHR-SPAR indicators in relation to the capacities for operational readiness to respond to radiation emergencies. We then examined how the preparedness against radiation emergency relates to 12 other reported capacities and their corresponding indicators. The IHR monitoring and evaluation framework categorized countries in to 5 levels across these indices, in which level 1 represented lowest level of the national capacity and level 5 as the highest[15,19] (**Supplemental Table 1).** In addition, we comparatively analyzed the data at the six WHO geographic regional levels. A total score of the 24 IHR-SPAR Indicators were used amongst the 13 capacities (**Supplemental Table 2**).

**Comparative analysis of the global and regional capacities for radiation emergency preparedness**

The analysis of the 2019 annual reporting data from 171 countries showed that the radiation emergency preparedness was one of the top 3 global challenges with an average global score per capacity of 55%. When the preparedness levels were closely examined, 28% of the countries scored none to very-low on the operational capacity (level 0 or 1). Similarly, 34% of the 171 countries had the capacity scores ranging between level 2-3, and only 38% had the advanced level of preparedness with the capacity scores ranging between level 4-5 **(Table 1)**.

**Table 1. Summary of radiation emergency preparedness capacity at global and regional levels**

| | ***No Capacity*** | ***Level 1 Capacity*** | ***Level 2 and 3 Capacity*** | ***Level 4 and 5 Capacity*** | ***Number of reporting Countries*** |
|---|---|---|---|---|---|
| All Data (Global) | 5 | 23 | 34 | 38 | 171 |
| AFRO | 6 | 51 | 38 | 4 | 47 |
| AMRO | 3 | 21 | 34 | 41 | 29 |
| EMRO | 11 | 21 | 21 | 47 | 19 |
| EURO | 0 | 0 | 33 | 67 | 51 |
| SEARO | 9 | 27 | 45 | 18 | 11 |
| WPRO | 5 | 23 | 34 | 38 | 14 |

**Data presented in column 2, 3, 4 and 5 represent the percentage of the countries at different capacity scores.** *AFRO, WHO African Region; AMRO, WHO Region for the Americas; EMRO, WHO Eastern Mediterranean Region; EURO, WHO European Region; SEARO, WHO South-East Asia Region; WPRO, WHO Western Pacific Region.*

At the regional level, 51% of the countries had very-low and 6% had no capacity in the WHO African (**AFRO**) region. Only 4% of the countries in this region had advanced capacity (level 4 or 5). In the WHO Region for the Americas **(AMRO)**, 24% of the 29 countries had very-low or no capacity for radiation emergency preparedness, whereas 41% had the higher-level preparedness (level 4 and 5). In WHO Eastern Mediterranean Region **(EMRO)**, 19 countries were included for analyses, of which 11% had no capacity, 21% had very-low capacity and 47% had the capacity levels of 4 to 5. The WHO European Region **(EURO)** countries were relatively better-prepared for the radiation emergencies with 33% of the countries falling into the capacity levels of 2 to 3, and 67% with the capacity scores of 4 to 5. In contrast, in the WHO South-East Asia Region **(SEARO)**, 36% of all the countries reported no or very-low levels of radiation emergency preparedness capacity, and only 18% had the advanced level capacity. In the WHO Western Pacific Region **(WPRO)**, data from 14 countries were examined, which showed the capacity levels of very-low to low in 28% of the countries and advanced level of operational readiness in 43% of the countries. Radiation emergency preparedness capacity scores showed highest dispersion score among all 13 capacities suggesting higher disparities across the globe.

**Interrelationship between overall and individual core capacities and its relationship with the preparedness for radiation emergencies**

The major global challenges were points of entry (56% overall score per capacity), radiation emergencies (55% overall score per capacity) and chemical events (53% overall score per capacity). Relationship between radiation emergency preparedness capacity and other reported capacities at global and regional levels are summarized in **Table 2**.

**Table 2. Relationship between radiation emergency preparedness capacity and other reported capacities at global and regional levels**

| | ***Legislation and Financing*** | ***IHR Coordination and NIHR Focal Point Functions*** | ***Human Resource*** | ***National Health Emergency Framework*** | ***Health Service Provision*** | ***Points of Entry*** | ***Chemical Events*** |
|---|---|---|---|---|---|---|---|
| All Data (Global) | 0.68 (0.59, 0.75) | 0.59 (0.49, 0.68) | 0.53 (0.41, 0.63) | 0.63 (0.53, 0.71) | 0.66 (0.56, 0.73) | 0.45 (0.32, 0.56) | 0.70 (0.61, 0.77) |
| AFRO | 0.61 (0.39, 0.76) | 0.43 (0.17, 0.64) | 0.36 (0.08, 0.59) | 0.49 (0.23, 0.68) | 0.43 (0.16, 0.64) | 0.36 (0.09, 0.59) | 0.70 (0.51, 0.82) |
| AMRO | 0.52 (0.18, 0.74) | 0.13 (-0.25, 0.48) | 0.48 (0.14, 0.72) | 0.42 (0.06, 0.68) | 0.36 (-0.01, 0.64) | 0.49 (0.15, 0.73) | 0.34 (-0.03, 0.63) |
| EMRO | 0.62 (0.23, 0.84) | 0.57 (0.15, 0.81) | 0.33 (-0.15, 0.68) | 0.43 (-0.04, 0.74) | 0.48 (0.02, 0.76) | 0.41 (-0.06, 0.73) | 0.60 (0.20, 0.83) |
| EURO | 0.29 (0.02, 0.53) | 0.47 (0.24, 0.67) | 0.22 (-0.07, 0.46) | 0.47 (0.18, 0.63) | 0.61 (0.33, 0.72) | 0.07 (-0.26, 0.29) | 0.49 (0.23, 0.67) |
| SEARO | 0.74 (0.23, 0.92) | 0.66 (0.08, 0.90) | 0.85 (0.48, 0.96) | 0.66 (0.08, 0.90) | 0.22 (-0.44, 0.72) | 0.79 (0.33, 0.94) | 0.85 (0.50, 0.96) |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| WPRO | 0.79<br>(0.44, 0.93) | 0.73<br>(0.31, 0.90) | 0.76<br>(0.38, 0.92) | 0.76<br>(0.38, 0.92) | 0.89<br>(0.69, 0.97) | 0.81<br>(0.49, 0.94) | 0.89<br>(0.67, 0.96) |

**Data presented represent correlation coefficients.** *Confidence intervals for the Pearson correlation coefficients were obtained using Fisher's z transformation. Pearson correlation coefficient (95% Confidence Interval) IHR, International Health Regulations. AFRO, WHO African Region; AMRO, WHO Region for the Americas; EMRO, WHO Eastern Mediterranean Region; EURO, WHO European Region; SEARO, WHO South-East Asia Region; WPRO, WHO Western Pacific Region.*

Analyses of the global data from 171 countries showed that capacity to respond to radiation emergency strongly correlated with capacity for chemical events with a correlation coefficient (ρ) of 0.70 (confidence interval, CI 0.61, 0.77). Other closely associated indicators included legislation and financing (ρ=0.68; CI 0.59, 0.75), national health emergency framework (ρ=0.63; CI 0.53, 0.71), health service provision (ρ= 0.66, CI 0.56, 0.73), and IHR coordination and national IHR focal point functions (ρ=0.59; CI 0.49, 0.68). The lowest correlation was noted with the risk communication and point of entry (ρ= 0.45 each).

The analyses of the regional data, however, showed variable interrelationship within specific geographic regions. In the **AFRO** region, data from all 47 countries were included. Overall, a 32% score per capacity was reported for the radiation emergency readiness. The other health capacity indicators from AFRO region showed similar capacity scores including a 32% score for chemical events. Again, capacity to respond to radiation emergency strongly correlated with chemical events preparedness (ρ=0.70, CI 0.51, 0.82), which was followed by legislation and financing (ρ=0.61, CI 0.59, 0.76).

In the **AMRO**, data from 29 countries were analyzed and six were excluded due to incomplete reporting. The relationship between capacity for radiation emergency vs., legislation and financing were the strongest among all capacities (ρ=0.52, CI 18, 0.74), which was followed by point of entry (ρ=0.49, CI 0.15, 0.73) and human resource (ρ=0.48, CI 0.14, 0.72). The relationship with IHR coordination and National IHR focal point functions was found to be relatively weak (ρ=0.13, CI 0.25, 0.48).

In the **EMRO**, data from 19 countries were included for analyses. Strong correlation was noted between radiation emergency preparedness and legislation and financing, and chemical events (all ρ ≥0.6).

In the **EURO**, radiation emergency preparedness showed a strong relation with health service provision (ρ= 0. 61, CI 0.33, 0.72).

Data from all 11 countries were included for analysis for the **SEARO**. SEARO region demonstrated trends that were either similar to the overall global data, or to EURO and AMRO regions. For example, the SEARO radiation emergency preparedness was strongly related to the chemical events (ρ=0.85, CI 0.50, 0.96), and IHR coordination and national IHR focal point functions (ρ> 0.66), which are similar to global capacity indicators. On the other hand, a strong relationship between the capacity for radiation emergency and the capacities for human resources (ρ=0.85, CI 0.48, 0.96) and point of entry (ρ=0.79, CI 0.33, 0.94) shared identical patterns as in the EURO and AMRO regions.

In the **WPRO**, radiation emergency preparedness capacity showed the strongest relationship with chemical events and health service provision (ρ=0.89 each). Additionally, a strong correlation was noted between the capabilities for radiation emergency and legislation and financing, IHR coordination and IHR focal point functions, human resource, national health emergency framework, health service provision, and point of entry (ρ>0.7 each). Of the 27 countries reporting data from this region, complete data were available only from 14 countries, which were further analyzed. The summary of all data in relation to the highly correlated individual capacity scores have been presented in **Table 2**.

**Global and regional disparities in overall and radiation emergency preparedness capacities**

A large dispersion indicates that the capacity indices spread far from the average capacity for operational readiness, which requires inter-state multisectoral coordination mechanisms. Our data analysis showed striking disparities in radiation emergency preparedness capacities when compared with the overall capacities. We found that radiation emergency capacity was widely dispersed as compared to the overall IHR capacity scores at the global level (**Figure 1).** The interquartile range (IQR) for overall capacity score was 49 to 81, and IQR for radiation emergency preparedness score ranged between 20 to 80. The lowest reported overall capacity was 17, but the lowest reported capacity score for the radiation emergency preparedness was 0 ($p<0.001$), indicating absolute unpreparedness. In the **AFRO region**, the overall capacity IQR was calculated at 34 to 53 with the median score of 44. In contrast, the IQR for radiation emergency preparedness was at 20 to 40 with the median score of 32 ($p<0.001$). Unfortunately, the lowest overall and radiation emergency capacity scores were at 17 and 0, respectively. In the **AMRO,** IQR for overall capacity was at 58 to 83 with a median score of 71. The lowest reported capacity was 48 with a highest score of 99. For radiation emergency preparedness, the IQR was at 30 to 80 with a median score of 59 ($p= 0.009$). However, the data demonstrated a wide dispersion and ranged from 0 to 100.

In the **EMRO**, the overall capacity score ranged from 32 to 96 with an IQR between 49 to 80, while the capacity for radiation emergency preparedness ranged between 0 to 100 with an IQR of 20 to 80 .

The data from the **EURO** showed a stronger capacity score for radiation emergency preparedness compared to other geographic regions. The IQR for the overall capacity was between 65 to 86 with a range between 35 to 99. For radiation emergency preparedness, the IQR was between 60 to 100 with the lowest reported value of 40 and the median capacity of 77 ($p=0.31$). Examination of data from the **SEARO** followed similar trends as the global capacity scores. The IQR for the overall capacity was between 51 to 73 with a range of 34 to 85. For radiation emergency preparedness capacity, the data ranged from 0 to 100 with and IQR of 20 to 60. This difference, however, was not statistically significant (p=0.39), likely due to a high standard deviation. In the **WPRO**, the IQR for overall capacity was between 52 to 92, while that for radiation emergency preparedness was at 20 to 80 with the lowest reported value of 0 (p=0.002).

## Discussion

This study analyzes 2019 radiation emergency preparedness data from 171 countries. Most striking findings are that only two third of the countries are operationally prepared to counteract the catastrophic effects of radiation emergencies. In addition, major discrepancies exist between the individual countries within each geographical region. More importantly, several countries reported a non-uniform level of preparedness for individual health capacities, which implies operational challenges for collaborative action in such emergencies. Compared to average overall national capacity score, global preparedness for radiation emergencies showed lower operational capacity and higher levels of dispersion across the globe.

Our data analysis from 171 countries showed that radiation emergency preparedness was one of the top 3 global challenges. It was noted that 28% of the countries had low to non-existing capacity for radiation emergency. EURO appeared better prepared than the rest of the geographic regions followed by EMRO and AMRO regions indicating a major regional variation. Radiation emergencies are not confined by geographical limits and can be widespread across these boundaries. WHO IHR database is a validated platform developed by experts and can provide objective scoring capacities to mitigate radiation hazard in ways that are commensurate with and restricted to public health risks[20]. Our analyses showed that almost 1/3$^{rd}$ of the countries across the globe had either non-existent or underdeveloped preparedness levels. Importantly, disproportionate variations in the operational capacities among different countries indicate that there can be delays in coordinated management process including emergency procedures at site, safe evacuations and shelter.

Innovative health capacity scores developed for global radiation emergencies are crucial to recognize the overall radiation risk preparedness. Such risk scoring approach also helps to coordinate

with parties across other sectors and capacities [2,14]. Our data show that the capacity for radiation preparedness is closely related to other health indicator capacities. For example, our global data analysis showed that capacity to respond to radiation emergency strongly correlated with capacity for chemical events and legislation and financing. Overall, having an objective risk assessment approach sets up standards and obligations for the state parties to develop and maintain essential core capacities to act against such emergencies of international concern[19]. This stated, one limitation of our study is that the radiation emergency preparedness data are self-reported by individual countries and are not independently verified. However, prior publications have reported that SPAR data strongly correlate with other externally evaluated data such as the Joint External Evaluation results[18,21].

This analysis also highlights striking global discrepancies that exist for the mitigation of radiation emergencies. Compared to overall capacity score, the radiation emergency preparedness score varied widely across the globe with lowest reported capacity score of zero, which shows absolute unpreparedness. With the exception of EURO, this variation persisted at the regional level with the capacity score ranging from non-existent to advanced level preparedness. As radiation disasters are not limited by geographical borders, such variation in cross-country preparedness levels can put larger population at risk. A large-scale emergency across the wide geographic boundaries requires a synchronous response, and inadequate and skewed responses from individual parties can destabilize the entire operation. In this context, we should also learn our lessons from novel coronavirus (2019-nCoV) pandemic that challenged our capacities for case detection, surveillance, and preparedness and response, both at national and international levels[18,22]. Emergency preparedness against radiation challenges are no exceptions to the urgent actions recommended by Global Preparedness Monitoring Board (GPMB), which recommends states commit to preparedness by implementing their obligations by dedicating resources for emergency preparedness[1,2,23]. A rapidly evolving radiation emergency, whether accidental

or deliberate, requires robust preparedness, with means to share medical countermeasures across the countries[11,24,25].

Side by side comparison of radiation emergency capacity with the overall IHR capacity scores showed that radiation emergency capacity was widely dispersed as compared to the overall IHR capacity scores at the global level. According to U.S. Department of Health and Human Services, a radiological or nuclear incident can be through contamination of food or water with radioactive material, placement of radiation sources in public places, or other severe measures including detonation, high-level nuclear waste and improvised devices[10]. Although the IHR capacity scores developed for radiation emergencies are expected to represent the operational readiness, it is crucial to interpret these data in line with the cross-sector preparedness for infrastructure, legislation, and coordination (C1)[18,24]. For such coordinated efforts, government bodies, ministries and agencies need to collaborate and involve other sectors including environment, transport, points of entry, travel, radiation safety, disaster management, emergency services (C2)[26]. This is highlighted by our data showing strong interrelationship between the capacity for radiation emergency and other capacities including chemical events, legislation and financing, and health service provision at the global and regional levels.

Additional capacities including well-trained and multisector workforce (C7), and a robust national health emergency framework (C8) and health service provision (C9) facilitate timely response and aid surge capacity for scaling up large national events[27]. For a concerted approach across the geographical boundaries, a coordinated public health surveillance between points of entry (C11) and national health surveillance system is recommended[28]. The radiation emergencies from technological incidents, natural disasters deliberate events and contaminated foods and products, utilize the similar resources for detection and alert system as in the management capacity outlined for chemical events

(C12)[29]. In addition to public health preparedness capacities, the health care providers, who are amongst the first responses against such emergencies, should have specific guidelines, recommendations and training[17]. IHR indicators (C13) are inclusive to embrace most of these needs[20].

Radiation emergency capacity of a country and the region as a whole is affected by several factors, including the existence of institutional framework, adherence to the policy and protocols, prevention and control measures, population density etc. When the radiation emergency occurs as a result of a major events such as nuclear accidents or conflicts involving the nuclear weapons, the capacity to mitigate the harm is directly related to the population density and the resources available. Analysis of the other risk variables associated with managing the radiation emergencies would benefit from understanding the existing country capacities, vulnerabilities due to socioeconomic conditions, and lack of health infrastructures. The information and data from these assessments should be analysed to build the readiness and response plans for preventing and controlling health emergencies including radiation emergencies[18].

As reported by Keeshmiri and colleagues[30], identification of the risk and systematic preparation is the best way to mitigate impact of public health risk. Effective health-care delivery systems and, the hospital readiness in particular, represent a major foundation for reducing the impact of the crisis such as radiation emergencies. Additionally, several intra-and intersectoral communication, coordination and preparedness is required at the national level for managing the radiation incidents to prevent inconsistent response following the incidence. Just like controlling COVID-19 pandemic, an integrated and multidisciplinary approach toward local and regional management of casualties in the event of a radiation emergency is needed. This involves several pillars, including skilled staff, the hospital's physical space, equipment, coordination, structure, organization, processes, guidelines, and information systems in intra- and intersectoral multidisciplinary arrangements. Coordination among the various hospital departments and with different nonhealth-care organizations is a fundamental principle in times of crisis. Regular maneuvers and continuous training of the numerous occupational groups involved in the response team are the key factors in maintaining the readiness and appropriate response of health-care systems to radiation emergencies[31].

In summary, we have found major discrepancies in the preparedness for radiation emergencies across the globe. Failure to recognize the degree of emergency preparedness influences its capacity to recover. Protecting all communities to the highest extent possible should be the overall goal of the radiation emergency preparedness[32]. Currently, resources related to radiation play active roles in our daily lives. In certain countries or region, its utility could be of limited scope such as those used for medical diagnostic or therapeutic purposes (X-ray and gamma-knife radiation) while other countries could be more leliant in nuclear energy such as nuclear power plants, and the weapons of defense. Due to their importance and widespread presence, there needs to be a realization of dangers related to radiation accidents and the greater need for preparation to respond in the event of such accidents. Recent global COVID-19 pandemic displayed the disconnect between the incident and timely response[22]. Many countries that have lower level of preparedness rank at the bottom of leading health and economy indicators. However, disasters such as Chernobyl, Fukushima, and similar cases have shown that lack of attention to the necessary safety considerations can have irreparable risks for the human community, which are of varying intensity and scope. Beyond health care capacities, our study also highlights the need for further research to identify most appropriate approaches to addressing the disparities accounted for radiation disaster planning.

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## Figure Legend

**Figure 1**. Box and whisker plots comparing overall vs., radiation emergency preparedness data dispersion across the globe. A, represents global data; B, shows the data from WHO African Region (AFRO); C, demonstrates the data from WHO Region for the Americas (AMRO); D, depicts the data from WHO Eastern Mediterranean Region (EMRO); E. shows WHO European Region data; F, depicts the data from WHO South-East Asia Region (SEARO) and G, represents the data from WHO Western Pacific Region (WPRO). The overall capacity and radiation emergency preparedness scores were compared in the overall sample and by region using a two-sided paired t-test (normality was assessed using the Anderson Darling test). There were significant differences globally, as well as in the AFRO, AMRO, and WPRO regions.

**Figure 1**

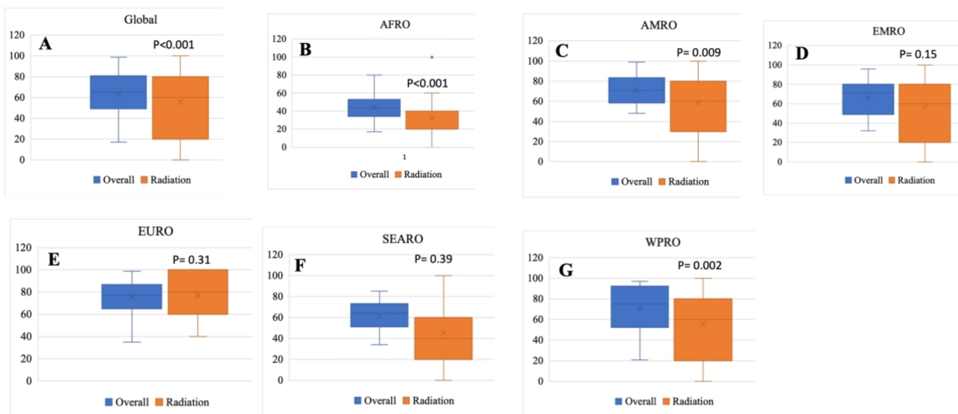


Figure 1

337x189mm (173 x 173 DPI)

**Supplemental Table 1.** IHR-SPAR Indicators for Radiation Emergencies (***Source: References 17,21)***

| **Level** | **C13.1 Capacity and resources** |
|---|---|
| Level 1 | Surveillance mechanisms and resources for radiation emergencies are under development |
| Level 2 | Radiation sources have been inventoried and radiation risk mapping has been conducted and documented |
| Level 3 | Access to specialized health care for radiation injuries is in place AND access to laboratory testing capacity for monitoring, identification and assessment of radiation exposure is in place |
| Level 4 | Access to technical expertise for managing radiation emergencies, including guidelines, protocols and regularly trained experts, is in place AND access to stockpile to support radiation emergency preparedness and response is in place |
| Level 5 | Radiation emergency arrangements are formally evaluated and tested on a regular basis, and improvements are made accordingly |

**Supplemental Table 2.** Selection criteria for each of the health capacity indicators (***Source: References 17,21)***

**C1 Legislation and Financing (3 indicators)**

C1.1 Legislation, laws, regulations, policy, administrative requirements or other government instruments to implement the IHR

C1.2 Financing for the implementation of IHR capacities response

C1.3 Financing mechanism and funds for timely response to public health emergencies

**Rationale**: Research, licensing, marketing authorization and procurement procedures for radioactive substances.

**C2 IHR coordination and national IHR focal point functions (2 indicators)**

C2.1 National IHR Focal Point functions under IHR

C2.2 Multisectoral IHR coordination mechanisms

**Rationale**: Collaboration and coordination among government bodies, ministries and agencies. These sectors can also include environment, transport, points of entry, travel, radiation safety, disaster management, emergency services, etc.

**C3 Zoonotic events and the human-animal interface (1 indicator)**

C3.1. Collaborative effort on activities to address zoonoses

**Rationale for exclusion**: Fundamental health care framework established to battle emerging zoonotic diseases is directly relevant to the management of radiation emergencies.

**C4 Food safety (1 indicator)**

C4.1 Multisectoral collaboration mechanism for food safety events

**Rationale**: Problems involving food contamination and food safety needs similar protocols for detection, investigation and response as in radiation emergencies.

**C5 Laboratory (3 indicators)**

C5.1. Specimen referral and transport system

C5.2 Implementation of a laboratory biosafety and biosecurity regime

C5.3 Access to laboratory testing capacity44 for priority diseases45

**Rationale**: The biosafety and biosecurity guidelines and regulations can ensure personnel and public safety by minimizing the risk of accidental radiation exposure.

**C6 Surveillance (2 indicators)**

C6.1 Early warning function: indicator-and event-based surveillance

C6.2 Mechanism for event management (verification, risk assessment, analysis investigation)

**Rationale**: A sensitive surveillance system can aid timely risk assessment, notification and response, including contact tracing.

**C7 Human resources (1 indicator)**

C7.1 Human resources for the implementation of IHR capacities

**Rationale**: Availability of a multisectoral and trained workforce capacity essential for the timely management of the radiation emergencies.

**C8 National health emergency framework (3 indicators)**

C8.1 Planning for emergency preparedness and response mechanism

C8.2 Management of health emergency response operations

C8.3 Emergency resource mobilization

**Rationale for inclusion**: Having a robust emergency preparedness and response team can deliver timely response to radiation emergencies.

**C9 Health service provision (3 indicators)**

C9.1 Case management capacity for IHR relevant hazards chemical and radiation decontamination

C9.2 Capacity for infection prevention and control and chemical and radiation decontamination

C9.3: Access to essential health services

**Rationale for inclusion**: Strong health care system at primary, secondary and tertiary levels, and availability of an existing emergency health care provision helps urgent response to radiation emergencies.

**C10 Risk communication (1 indicator)**

C10.1 Capacity for emergency risk communications

**Rationale**: A real-time exchange of information, advice and opinion can facilitate prevention, reporting and response by enabling health care providers and public to make informed decisions.

**C11 Points of entry (2 indicators)**

C11.1 Core capacity requirements at all times for designated airports, ports and ground crossings

C11.2 Effective public health response at points of entry

**Rationale**: Implementing point of entry capacity with an all-hazard and multisectoral approach is an integral part of surveillance and response system.

**C12 Chemical events (1 indicator)**

C12.1 Resources for detection and alert

**Rationale**: Chemical events resulting from technological incidents or contaminated foods can be of similar origin, nature or consequences to radiation emergencies.

**C13 Radiation emergencies (refer to Supplemental Table 1 for the levels of preparedness)**