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EPIDEMIOLOGICAL EVALUATION IN PUBLIC HEALTH APPLIED TO RADIOLOGICAL AND NUCLEAR EVENTS

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ABSTRACT

The urban environment comprises vital structures necessary for its functioning. This critical infrastructure includes sectors such as healthcare and transportation, essential for maintaining local stability. These elements are often valuable targets for asymmetric actions intended to cause disruption, leading to physical and psychological impacts on the population. Such an event could be triggered by activating a Radiological Dispersal Device (RDD). These devices can disperse radioactive substances into the atmosphere, resulting in individual exposure to radiation and environmental contamination. This study aimed to develop a model to conservatively estimate and assess the possible epidemiological consequences caused by the release of Cesium-137, with leukemia being identified as the primary outcome. Resilience was evaluated based on the local healthcare system's capacity to respond. For this purpose, analytical computational simulation (Gaussian model) was employed using the HotSpot Health Physics version 3.1.2 and RESRAD RDD programs to evaluate the modes and consequences of radioactive dispersion in the atmosphere. The modeling of atmospheric behavior was based on the atmospheric stability categories proposed by Pasquill. The relative risk assessment associated with leukemia development was based on the formulations in the BEIR V and VII reports. Subsequently, resilience modeling was developed in this work using a model that incorporated aspects of the urban infrastructure of Rio de Janeiro, particularly in the vicinity of the location selected for RDD activation. As a summary of the study's results, it is suggested that factors such as gender, age, location, and type of infrastructure are predominant in prognostic evaluations of such an event.

1. INTRODUCTION

Those seeking to destabilize a nation widely adopt deterrent elements. They aim to generate panic and demonstrate power against an opponent. One tool capable of causing such harmful effects is the Radiological Dispersal Device (RDD).

The RDD aims to spread radioactive material into the environment, targeting the local contamination of people, soil, and crops. Additionally, it causes significant instability in various areas, such as physical, economic, psychosocial, and public health aspects. What makes this mechanism particularly effective is the difficulty of detecting it, as it is de|| designed to be stealthy, at least until it is triggered [1].

Indeed, the immediate next step to mitigate the effects of the activation is to attempt to identify where the dispersion plume of the released material is heading to ensure the establishment of appropriate means for evacuation, sheltering, immediate relief, and possible decontamination. In light of this, determining the potential path of the released substance (in this case, the chosen source is Cesium-137) becomes an important issue to be analyzed.

In situations involving the release of an RDD, aside from the need for an action plan to reduce the damage and decontaminate people and materials, another issue warrants consideration in this work. In the event of a potential dispersion of radioactive materials, the healthcare system may not be adequately prepared to assist the victims of such an incident in terms of qualified personnel and appropriate equipment and infrastructure. This concern is significant, as there will be short-, medium-, and long-term repercussions, including the potential development of biological effects resulting from exposure to ionizing radiation, such as leukemia.

This study proposes a computational simulation to model the effects of Cesium-137 release from a Radiological Dispersal Device (RDD). The objective is to evaluate the potential health impacts on the exposed population, including the risk of developing leukemia, and to assess the resilience of the local healthcare system. .

2. METHODOLOGY

This study focuses on decision-making support during the initial phase of a radiological crisis, specifically in response to activating a Radiological Dispersal Device (RDD). The objective is to establish a deterrent scenario at the local level, with particular attention to the resilience of the healthcare system in this context, primarily considering the development of leukemia as a consequence of radiation exposure. The analysis scenario was designed conservatively, assuming the worst-case scenario. To this end, the methodology chosen for constructing this scenario was carefully analyzed, aiming to meet the specific requirements and demands of the proposal.

The location chosen for the scenario assessment was the city of Rio de Janeiro, more specifically, the northern zone, due to its particular context of population concentration and large hospitals. To obtain information about radiological aspects, the HotSpot program was used, which provided data such as dose and soil deposition rate.

It is essential to mention that the software was developed precisely to assist emergency response teams in mitigating the effects of radiological and nuclear events. In addition, the author created an equation to model the case's impacts on the public health system, using the estimates of excess relative risk present in the BEIR V and VII reports as one of the main parameters.

The importance of this group justifies the choice to analyze individuals under 30 as the primary emerging workforce responsible for driving the local economy in the coming decades.

2.1. Source Term

The element chosen for dispersion in the environment through simulation is Cesium-137 since its particular physical properties make it the best candidate. Cesium-137 is a radioactive element originating from the fission of uranium and can be used as a source of irradiators in multiple applications, such as in the food, blood, and tissue irradiation industry. It is characterized as a category I source, with high danger in case of material release [2]. Therefore, due to its intense use, it is a source with a greater possibility of being found, and the activity chosen for such a source is 440 TBq (approximately 1.2×10^4 Ci) [2].

Another point to be highlighted is the property of Cesium-137 to be pulverized since such crystals are soluble in water and are hygroscopic. They absorb moisture from the air, promoting adhesion to various surfaces, such as the skin of any individual who comes into contact with the dispersed material [3]. An additional trait for the preference of this element is its long half-life (about 30 years), which allows the sample to remain active for a significant time, emitting beta radiation, decaying into Barium-137 in a metastable state and, subsequently emitting gamma radiation (≈ 0.662 Mev) to stabilize the barium atom. Therefore, taking into account the entire decay process of Cesium-137, there is the emission of radiation whose energy reaches about 1.175 Mev, thus having a great capacity to cause damage to the human body [3].

2.2. Using HotSpot Health code

The HotSpot Health Physics code was developed as a tool for emergency response and planning professionals. It assists in assessing radioactive accidents, which for the present study is the dispersion of radioactive plumes in the environment [4]. The tool allows the user to insert data according to the operator's situation to get as close as possible to the actual event.

The release method chosen for Cesium-137 was the "general plume", that is, a release in the form of a plume without the use of explosives to activate the device (Fig. 1). This type of release can be carried out using a mechanical device, which Zimmerman (2001) [5] calls a "smoke bomb", characterizing a discreet release of radioactivity. According to [1], if this type of attack occurs, a city may take days or weeks to notice the contamination, considerably worsening the situation.

Fig. 1. Radioactive plume radioactive element release device.

The HotSpot Health code was applied to evaluate a conservative scenario focused on the so-called "early phase" (the first 100 hours or approximately 4 days) following contamination identification. The environment experiences the highest disorder and public panic levels. The mathematical model for plume propagation used by the software is based on the Gaussian (Fig. 2) hypothesis for particulate matter dispersion in the atmosphere [4]. Although Gaussian modeling generally does not provide an entirely realistic resolution, it safely meets the requirements for information on plume dispersion within the four-day evaluation period.

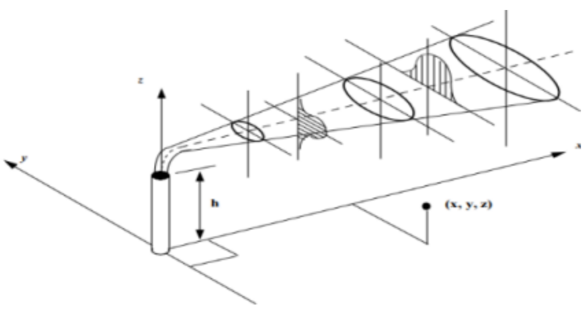

Fig. 2. Gaussian dispersion behavior [6].

According to the software's reference system, the wind direction adopted for plume propagation in the simulations was 240°. This was chosen because it is the predominant wind direction in the region selected for the RDD detonation, as indicated by the Global Wind website [7]. To clarify, the reference system used by the website considers 0° to be north, and the corresponding orientation on Global Wind relative to the HotSpot code is 60°.

A wind speed of 3 m/s, representing the city's average, was input into the software. This allowed for a comprehensive assessment of Pasquill-Gifford (PG) stability classes, ranging from A (very unstable) to F (very stable), with an emphasis on classes A and E due to their extreme conditions and, consequently, the most significant impacts on pollutant dispersion. Two release heights for the radioactive plume were analyzed: 10 and 100 meters. Additionally, the software provided standard parameters for the simulation, such as a receptor height of 1.5 m, representative of the height of organs most sensitive to radiation, and the definition of 16 assessment zones, covering a distance of 0.3 to 10 km. The analysis time for each sample was set at 10 minutes.

CNEN Norm NN 3.01 [8], through Regulatory Position 3.01/006:2011, establishes requirements for safety protocols and actions in radiological emergencies. The objective is to minimize public exposure to ionizing radiation, defining specific protective actions for each exposure level following Tab. 1.

Tab. 1. Generic radiation dose thresholds for protective actions [8].

Protective Action	**Level (mSv)**
Shelter	10
Evacuation	50
Stable iodine intake for prophylaxis	100

Based on the information in Table 1, the simulation considered the initial symptoms of Acute Radiation Syndrome (ARS) to define the dose levels in the plume. Thus, the following values were used: 700 mSv for the isodose contour closest to the triggering point, indicating a high-dose region and the potential development of ARS; 100 mSv for the median isodose contour, representing an intermediate dose; and 50 mSv for the outermost isodose contour, corresponding to a low-dose region.

2.3. BEIR V and BEIR VII Committees Conducting Epidemiological Studies to Estimate Excess Leukemia Risk

The BEIR V Committee [9] focused on the biological effects of low-LET (Linear Energy Transfer) ionizing radiation doses, specifically in the range of 0.1 to 4 Sv. The total effective dose (TEDE) used in these analyses was calculated using the HotSpot code. The BEIR VII Committee [10] conducted a comprehensive assessment of the biological effects, with a focus on cancer incidence, associated with low-dose ionizing radiation exposure (TEDE < 100 mSv). The equation used in both models to calculate excess relative risk for leukemia was applied to the data.

2.4. Health System Resilience Modeling and Analysis

The study proposed a model for assessing the resilience of the public health system by considering four key elements: road infrastructure for transporting victims, the number of hospitals affected by a radiological event, the estimated excess relative risk, and radiation dispersion. As the effects of high and low radiation doses differ significantly, the resilience measure was calculated using different equations. Equation 1 was used for high doses, and Equation 2 was used for low doses.

$$|Res| = \left|\frac{HA\ x\ FA}{TR\ x\ TF\ x\ ERR}\right| \quad (1)$$

$$|Res| = \left|\frac{HA\ x\ FA}{TR\ x\ TF\ x\ (1-ERR)}\right| \quad (2)$$

In this study, the FA and TR variables represent the number of routes favoring access to relief sites within a 1 km radius of hospitals and the total number of routes within this same radius. The HA variable indicates the number of hospitals affected by the dispersion, ERR represents the excess relative risk, and TF represents the transmission factor calculated using ordinary concrete with a density of 2.4 g/cm^3 as the attenuating material, considering hospital walls with a thickness of 15 cm.

Given this study's conservative approach, the worst-case dispersion scenario was considered, with release heights of 100 and 10 meters and a maximum extension limit of 10 km. The city's four largest hospitals were selected for evaluation as a health system.

3. RESULTS AND DISCUSSIONS

In this study, we define resilience as the health system's ability to cope with an unexpected surge in cases, especially those with long-term effects such as radiation-induced cancer, particularly leukemia. To calculate variables FA and TR, we analyzed the access routes that would be closed in an emergency, obtaining values of 25 and 51, respectively. The transmission factor (TF) was estimated to be 0.43, considering the radiation attenuation by the concrete hospital walls. Considering the conservative approach adopted in this study, we analyzed the worst-case scenario of the radioactive plume dispersion, which occurs in PG class A for the age group of 1 to 29 years, with a release height of 100 meters.

The analysis of the resulting data indicates that the health system's resilience does not vary significantly concerning the age of the affected individuals in this age group. This is due to the low effective dose (TEDE) in the analyzed conditions, which has a limited impact on the excess risk estimate and, consequently, on the resilience measure. Therefore, significant results were obtained after calculating resilience using equations 1 and 2, which can be graphically visualized in Fig. 4.

Maintaining the age range, the second scenario assessed resilience considering a release height of 10 meters and Pasquill-Gifford class E. The analysis demonstrates that individuals' age is a determining factor in the magnitude of the impact of radioactive dispersion, with this influence being more evident in regions with high dose rates, such as those presenting values of 840 mSv, 420 mSv, 230 mSv, 140 mSv, and 100 mSv, respectively, from the radioactive source.

It is essential to highlight that doses above 700 mSv can induce acute radiation syndrome. According to Fig. 4, in the interval above for one-year-old individuals, there is extremely low resilience, practically nonexistent at a TEDE of 890 mSv. When compared to 29-year-old individuals, individuals in the older age group have a higher resilience capacity. Another interesting point is that resilience behavior reverses for a dose of 100 mSv in the highlighted region, with higher values for one-year-old individuals.

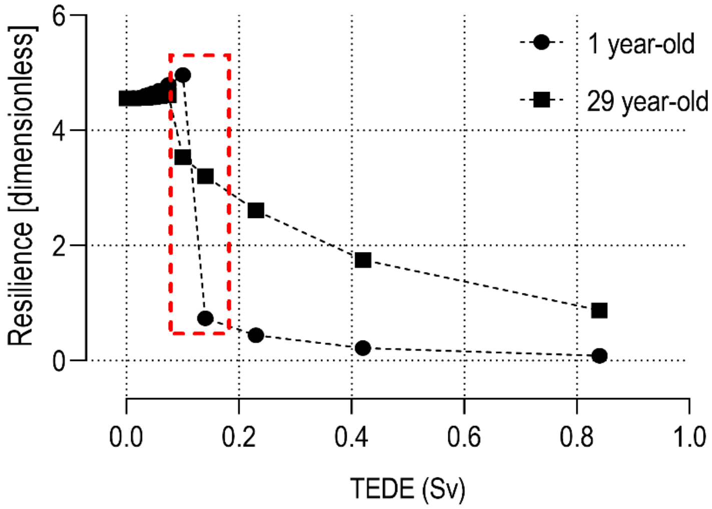

Fig. 4. Resilience behavior for age groups below 30 years old, with a release height of 10 meters and PG class E.

By analyzing the resilience data from both cases and applying the developed equation, we can infer that the closer to 0, the lower the resilience of the chosen location. Resiliency increases if the local critical infrastructure is improved by constructing more hospitals and their access routes. However, for the current chosen structure, it can be inferred that the closer the value of 5 is, the better the local resilience is.

4. CONCLUSION

The objective of this study was to develop a model for assessing resilience in individuals who may develop radiation-induced leukemia due to exposure to a Radiological Dispersal Device (RDD). Additionally, the study aimed to evaluate the public healthcare system's ability to support radiation accident victims. The findings highlighted a deficiency in the emergency response structure of the healthcare system, emphasizing the need for a more comprehensive hospital organization. The study identified the Marcílio Dias Naval Hospital as the most equipped facility for radiation accident victims. Establishing a specific emergency plan tailored to incidents discussed in the study was deemed essential for mitigating potential damage caused by an RDD. The research emphasized the critical impact of release heights and atmospheric stability classes on the resilience of the healthcare system during radiological events. It discovered that at lower release heights, such as 10 meters, younger individuals exhibited lower resilience than older individuals, underlining the significance of tailored support for this demographic during such incidents. Conversely, individuals across age groups showed better resilience at higher altitudes, such as 100 meters, and this can be further improved with appropriate mitigation measures.

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