Id.: CR26

ELEMENTAL COMPOSITION OF HEALTHCARE WASTE FOR DEVELOPING SIMULATOR OBJECTS IN RADIATION STERILIZATION

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Key words: Simulator Object; Healthcare Waste Composition; Industrial Irradiation

ABSTRACT

The primary goal was to determine the proportion of chemical elements present in Health Care Waste (HCW) to develop phantoms for dosimetry use in sterilization processes. Certain HCW (Healthcare Waste) must undergo treatment either at the generating unit or before final disposal in landfills to reduce or eliminate their pathogenic characteristics, which are harmful to humans and the environment. An emerging method for inactivating pathogens in HCW is the use of ionizing radiation emitted by industrial particle accelerators. Dosimetry processes involved in the irradiation of HCW, such as beam characterization and calibration, require the development of phantom objects that simulate the item to be irradiated. Based on the products found in segregated HCW and the Technical Dossiers provided to ANVISA, which mandate reporting the chemical substances present in health products, the chemical composition, and proportions of the elements in HCW were determined for the development of Simulator Objects for sterilization processes using ionizing radiation. The main chemical elements in HCW were identified as carbon (52.53%) weight percentage, oxygen (25.35%), chlorine (9.85%), hydrogen (6.77%), and sodium (1.39%). Other elements were found in individual proportions of less than 1.00% and collectively account for only 1.39% of the total mass weight.

1. INTRODUCTION

Industrial radiation processes using high-power electron accelerators (6 MeV or 10 MeV) with dose rate of the order of dozens of KGy/s are attractive due to their high energy yields, resulting in competitive costs per unit compared to conventional chemical processes. According to CLELAND *et al.* [1], additionally, energy usage in electrons or photons beam processing is lower than in typical thermal treatments, avoiding the need for strict temperature or humidity control and allowing immediate use of irradiated materials.

The application of this technology in sterilizing Healthcare Waste (HCW) requires demonstrations of technical and economic feasibility. The viability of HCW treatment by radiation is assessed by its effectiveness in pathogen inactivation in packaged waste, directly related to the homogeneity and value of the absorbed dose in the packages, according to HANSEN *et al.* [2]. A practical approach to demonstrating effectiveness is computational simulation of radiation transport by particle using Monte Carlo Methods by softwares like MCNP, PHITS, ERGS in HCW packages, evaluating fluency and spatial dose distribution compared to levels necessary for pathogenic inactivation.

Package characterization is essential for HCW sterilization; however, determining HCW composition is challenging due to varying demands for medical products in each hospital sector and specific economic conditions. According FERREIRA [3] caracterizing healthcare waste (HCW) is a complex task that involves inherent risks during the process of opening and segregating the packaging, as it entails handling infectious material. To overcome this challenge, characterization analyses select hospitals with similar sectors and procedures, conducting segregation and quantitative/statistical analyses to achieve comparable characterization.

The objective of this research is to conduct an analysis of the chemical composition of components present in HCW, aiming to determine the standard composition of segregated HCW in groups and subgroups, as well as non-segregated waste, to reflect the reality found in hospital and from this, determine the chemical composition of simulator objects for dosimetric processes simulation using Monte Carlo Method involving HCW.

2. METHODOLOGY

2.1 SEGREGATION OF HCW

The Segregation of RSS was based on the Resolution of the Brazilian Collegiate Board of the National Health Surveillance Agency, RDC nº 306 [4], which was later replaced by RDC nº 222 [5], with the classification being maintained. HCW was classified into Group A and its subgroups A1 and A4, B, D, and E; this classification was based on data collected of ADUAN *et al*. [6] from six hospitals in Vitória/ES, Brazil, through analysis of the content of open containment containers. As per this same source, it was observed that none of the hospitals segregated Group A HCW into all its subgroups (A1, A2, A3, A4, and A5), a trend that continues nationwide.

HCW was identified as belonging to Group A – infectious, across various groups and subgroups. Following the literature, approximately 57 % of HCW was categorized in Group D – general, 41 % in Group A – biological risk, 1.5 % in Group B – chemical risk, and 0.05% in Group E – sharps. Group A comprised entirely of HCW from subgroups A1 and A4, as waste types A2, A3, and A5 are easily distinguishable and have well-defined legislation and protocols, typically not mixed with subgroups A1 and A4. The proportion of Group E waste in the mixture was considered very small and therefore not relevant for characterization purposes.

2.2 STOICHIOMETRIC CHEMICAL ANALYSIS

The methodology employed to determine the stoichiometric chemical elements of Healthcare Waste (HCW) was based on RDC No. 751 [7], which mandates that every medical product manufacturer must provide a Technical Dossier supplied to ANVISA [8]. Among various technical product information, this dossier must describe its chemical composition, indicating characteristics, purpose, mode of use, content, special precautions, potential risks, production process, and additional necessary information.

The chemical composition of segregated products was assessed using the HCW segregation data conducted and through the mandatory Technical Dossier. The relative proportion of each material present in the waste was determined using segregation into groups A (A1 and A4), B, and D.

2.3 DETERMINING CHEMICAL COMPOSITION OF HCW

The proportion of each element in a chemical substance is given by the ratio between the mass number of the element and the proportion of that element in the substance. In a product where one of the components is given by the formula $X_nY_mZ_p$... Where X, Y, Z... are the chemical elements in the formula, the subscripts n, m, p... are the quantity of each chemical element in the formula. According JOHN *et al.*. [9], the proportion δ of a certain element X, Y, Z... in the formula (1) is given by:

$$\delta = \alpha/\beta \qquad (1)$$

Where $\alpha=(n.A_X;m.A_Y\ldots)$; $\beta=(n.A_X+m.A_Y+pA_Z+\cdots)$ and A corresponds to the mass number of a given element. To determine the proportion of the other elements in the formula, simply replace the numerator with the product of the number of atoms of the element in the formula by the mass number of that element.

One way to identify the composition of HCW is to segregate or separate the HCW individually opening the HCW bags collected in hospitals and through this identification, verify the chemical composition of these products in the mandatory Technical Dossier of ANVISA. ADUAN *et al*.[6] made this segregation in about 180 HCW bags and identified the standard composition of the materials contained.

Based on the identification made by ADUAN *et al*.[6] was determined through the proportion of these products and chemical composition found in the Technical Dossier and using Eq. (1), not only the proportion of each group/subgroup of residues in the HCW containment bag Tab (1), but the proportion of each chemical element in groups and subgroups, Tab (2).

3. RESULTS

The proportion of each HCW group and subgroup in the non-segregated HCW is shown in Tab.1.

Tab.1 : Individual proportion of group and subgroup in the total HCW mixture.

HCW Group/Subgroup	Proportion of group/subgroup in the Total HCW mixture (A1+A4+B+D)
Group A1	5,96 %
Group A4	35,27 %
Group B	1,61 %
Group D	57,16 %
Total HCW mixture (A1+A4+B+D)	100,00 %

Source : ADUAN *et al* (2014).

From the information collected from ADUAN *et al*.[6], using the chemical composition of the segregated products mandatorily informed in ANVISA's Technical Dossier , we were able to determine the stoichiometric chemical proportion of the elements of subgroup of HCW is presented in Tab.2 for A1, A4, B and D, in addition to the proportion of these elements in the unsegregated mixture due to that group or subgroup.

Tab.2 : Stoichiometric chemical proportion of the elements of subgroups

Subgroup	Chemical Element	Elementar Ratio in HCW of group/subgroup	Proportion in HCW mixture (A1+A4+B+D)
A1	Carbon – C	51,5 %	3,069 %
	Oxygen – O	34,2 %	2,038 %
	Chlorine – Cl	4,3 %	0,256 %
	Hydrogen – H	4,0 %	0,238 %
	Silicon – Si	2,6 %	0,155 %
	Boron – B	0,3 %	0,018 %
	Sodium – Na	0,2 %	0,012 %
	Aluminium – Al	0,1 %	0,006 %
	Total Characterized A1	97,0 %	5,781 %
	Global uncertainty A1*	2,5 %	3,0 %
A4	Carbon – C	70,05 %	24,707 %
	Oxygen – O	16,82 %	5,932 %
	Hydrogen – H	8,57 %	3,023 %
	Chlorine – Cl	2,41 %	0,850 %
	Iron – Fe	0,12 %	0,042 %
	Fluor – F	0,11 %	0,039 %
	Calcium – Ca	0,07 %	0,025 %
	Potassium – K	0,05 %	0,018 %
	Cromo – Cr	0,03 %	0,011 %
	Total characterized A4	98,23 %	34,646 %
	Global uncertainty A4*	2,0 %	3,0 %
B	Carbon – C	17,40 %	0,280 %
	Oxygen – O	9,06 %	0,146 %
	Hydrogen – H	2,41 %	0,039 %
	Total characterized B	28,87 %	0,465 %
	Global uncertainty B*	2,0 %	3,0 %
D	Carbon – C	42,81 %	24,470 %

	Oxygen – O	30,15 %	17,233 %
	Chlorine – Cl	15,30 %	8,475 %
	Hydrogen – H	6,07 %	3,470 %
	Sodium – Na	2,42 %	1,383 %
	Calcium – Ca	0,88 %	0,503 %
	Sulphur – S	0,70 %	0,400 %
	Nitrogen – N	0,15 %	0,086 %
	Fluor – F	0,024 %	0,014 %
	Níquel – Ni	0,002 %	0,001 %
	Titanium – Ti	0,002 %	0,001 %
	Copper – Cu	0,002 %	0,001 %
	Total characterized D	98,51 %	56,308 %
	Global uncertainty D*	2,0 %	3,0 %

* The stated global uncertainty is based on a standard uncertainty, multiplied by the coverage factor $k = 2$, for a 95% probability of coverage.

The lack of HCW segregation is a reality, thus the failing to perform a total stoichiometric analysis of the groups and subgroups of the elements in the mixture in the containment containers would be the reality found in HCW.

Upon analyzing Tab.2, it is observed that the main composition elements of the HCW in subgroup A1 are carbon and oxygen, corresponding to approximately 85,7 % of the composition of this waste. It is noted that the main composition elements of the HCW in subgroup A4, as well as in subgroup A1, are also carbon and oxygen, corresponding to approximately 86,9 % of the composition of this waste.

It is observed that the main known composition elements of Group B are also carbon and oxygen, corresponding to approximately 28,87 % of the composition of this waste. However, as approximately 91,04 % of this waste in the mixture of HCW consists of medications in tablet form, determining which medications these tablets belong to and, consequently, determining the active ingredient and its chemical elements is an extremely complex task, resulting in an uncertainty of approximately 71,13 % of the elements contained in this waste.

Despite this large uncertainty in the stoichiometric composition of Group B Waste, its proportion in the mixture of HCW is low, approximately 1,61 %, which means that the uncertainty of elements in the total mixture of HCW, due to Group B, is only 1,14%. The two most present elements in the composition of Group D are also carbon and oxygen, together corresponding to approximately 73,0 % of the mass, followed by chlorine, with approximately 15,3 %. The other elements have relatively low proportions within HCW D.

Considering that the lack of segregation of HCW is a reality in Brazil, failing to perform a stoichiometric analysis of all elements in the mixture of groups found in containment vessels would be concealing the true reality found. Therefore, in Tab.3, we have the stoichiometric chemical composition of the entire mixture found in the containment of the HCW defined by the simple sum of each proposition of chemical elements of the groups and subgroups of Tab (2).

Tab.3: Stoichiometric chemical proportion of the elements in the Total no-segregate HCW Mixture (A1+A4+B+D).

Chemical element	Proportion of the element in the total HCW mixture (A1+A4+B+D)
Carbon – C	52,526 %
Oxygen – O	25,349 %
Chlorine – Cl	9,851 %
Hydrogen – H	6,770 %
Sodium – Na	1,395 %
Calcium – Ca	0,528 %
Sulphur – S	0,400 %
Silicon – Si	0,155 %
Nitrogen - N	0,086 %
Fluor – F	0,053 %
Iron - Fe	0,042 %
Boron – B	0,018 %
Potassium – K	0,018 %
Chromium - Cr	0,011 %
Aluminium – Al	0,006 %
Nickel - Ni	0,001 %
Titanium – Ti	0,001 %
Copper - Cu	0,001 %
Total Characterized	97,211 %
Global uncertainty*	3,0 %

* The stated global uncertainty is based on a standard uncertainty, multiplied by the coverage factor $k = 2$, for a 95% probability of coverage

4. CONCLUSION

After obtaining information about the segregation of HCW into their groups and subgroups, it was possible to determine the stoichiometric chemical composition of the RSS components in subgroups A1, A4, B and D and in addition to the stoichiometric chemical proportions of the elements in the total non-secreted mixture; this condition reflects the reality found in practically all hospitals.

Regardless of whether the material is segregated or not, carbon and oxygen were the two main elements found in the HCW. They account for approximately 85,7 % in

HCW-A1, around 86,9 % in HCW-A4, about 28,9 % in HCW-B, and approximately 73,0 % in HCW-D. In the total mixture, without segregation of the HCW, carbon and oxygen represent together approximately 77,.8 % of the packaged mass.

The main chemical elements in no-segregated HCW were identified as carbon (52.53% weight percentage), oxygen (25.35%), chlorine (9.85%), hydrogen (6.77%), and sodium (1.39%). Other elements were found in individual proportions of less than 1.00% and collectively account for only 1.39% of the total mass weight. Computational dosimetry analyses using particle transport software may reveal the influence of elements with proportions lower than 1.00% on energy deposition in HCW. If these elements have negligible effects on dose deposition, the development of HCW simulator objects using only the five main elements (carbon, oxygen, chlorine, hydrogen, and sodium) can reduce costs and complexity in simulator objects.

With the determination of the stoichiometric chemical composition of segregated or non-segregated HCW, it becomes feasible to computationally simulate using Monte Carlo method-based particle transport software such as MCNP, PHITS, ERGS etc. the energy deposition within the HCW package. These simulations provide insights into additional physical characteristics of these materials, such as attenuation and absorption coefficients in the HCW, Dose coefficients, the percentage of dose deep within the package containing the HCW, particle type, and the most effective beam energy in the HCW irradiation process to deposit the pathogenic inactivation dose.

This facilitates the assessment of the technical and economic feasibility of using radiation sterilization as a treatment method of HCW, either as a substitute or in conjunction with current treatment techniques.

CONGRATULATIONS

We congratulate the funding agencies, CAPES, CNPq, Fapemig, CNEN, which directly and indirectly helped in the preparation of this project.

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