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DEEP DATA-DRIVEN WEB TOOL FOR ASSESSING THE RISK OF RADIO-INDUCED CANCER FOLLOWING URBAN NUCLEAR EVENTS

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ABSTRACT

The study introduces an online computer program that leverages data from reports on the biological effects of ionizing radiation (BEIR V and VII). This program is specifically designed for conservative and initial radiological risk assessment in a simulated scenario of contamination/exposure by radioactive materials. It also estimates the lost life expectancy (LLE) due to cancers induced by exposure to low levels of ionizing radiation. To calculate the radiological risk, users need to input the dose (in Sv) to which the individuals were exposed, the age at which exposure occurred, and, depending on the model (solid tumors or leukemia), the sex and age of the individuals. The program, built using Ruby on Rails and the general-purpose programming language Ruby, is a fully functional web application with a PostgreSQL database. The fundamental goal of this study is to assess the potential impact of using a web application in expediting specific initial tasks, guiding the prioritization of early care, and thereby increasing decision-making accuracy through usability parameters.

1. INTRODUCTION

Radioactive materials can be dispersed into the environment as a result of accidents in nuclear power plants and radiological terrorist acts involving the use of radiological dispersion devices, commonly called dirty bombs. This study aimed to develop a functional web application to compute equations from the BEIR (Biological Effects of Ionizing Radiation) V and VII reports regarding the risk of developing cancer due to environmental radiological exposure and to estimate the Lost Life Expectancy (LLE) of affected individuals. The BEIR V and VII reports are radioepidemiological models created based on data on survivors of the atomic bombs at the end of World War II [10]. Through these models, with initial data provided by the user (age, sex, dose, etc.) and estimated data on local radiological contamination/exposure, it is possible to obtain information to support the initial decision-making process [5]. Ionizing radiation can come in high-energy electromagnetic radiation (such as X-rays and gamma rays) or energetic subatomic particles, including alpha particles, beta particles, and neutrons. The average energy deposited per unit length of the radiation's path is called linear energy transfer (LET). Charged particles typically exhibit higher LET values compared to X-rays or gamma rays. The International Commission on Radiological Protection (ICRP) sets radiation weighting factors (W_R) from 1 to 20 based on radiation type, to convert absorbed dose in grays to equivalent dose in sieverts. Photons have a W_R of 1, indicating low energy transfer, while alpha particles have a W_R of 20, indicating high energy transfer.

2. METHODS

The application simulates individuals' radiological contamination/exposure in a given location, determining the variables of interest to generate data to support initial decision-making in a radioactive scenario. The study also includes evaluating the application and considering some usability parameters to verify the effectiveness and quality of the web tool. The framework used is Ruby on Rails, often abbreviated to Rails. It is a robust development structure for web applications based on the dynamic object-oriented (OO) language, Ruby. Its speedy development capacity allows it to enhance high-traffic websites [3]. It is a full-stack framework. That is, it operates both the back-end and the front-end, which enables the creation of applications that collect information from the web server, talk to or query the database, and render ready-to-use models. As a result, Rails presents a routing system independent of the web server, working with the MVC (Model-View-Controller) architecture pattern [1].

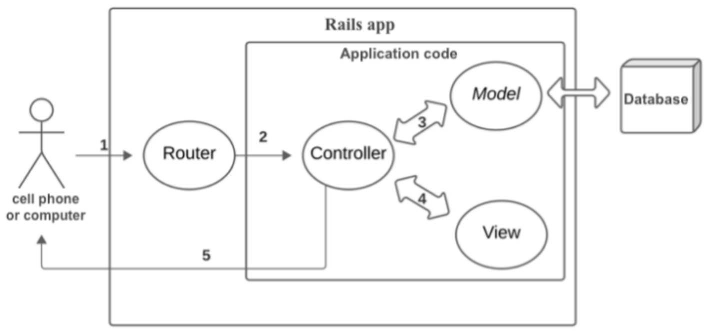

Fig. 1. MVC architecture pattern.

The MVC architecture pattern is widely used in the development of applications for mobile devices because it determines the separation of an application into three elements: Model, View, and Controller. The Model is a Ruby object that represents an element of the website, such as a user, and is responsible for communicating with the database. The View presents this data and captures user events. The Controller is the component that responds to external requests from the web server to the application by connecting the Model and the View, handling events, acting on the Model, and changing the elements of the View to render the new form of the data [13].

The back end consists of everything the user cannot see, such as the connection to the server, the calculation formulas and algorithms used to guarantee the application's functionality and the database in which the information is stored. It must ensure the security and agility in delivering the data the user requests. The front end is responsible for contacting the user and transforming the interface design ideas into code, with markup languages (HTML and CSS) and programming languages (JavaScript and jQuery).

2.1. User interaction

The application's home page introduces the user to two risk calculation models for cancer development: solid tumors and leukemia. Upon selecting a model, the user is directed to a form page to input required information such as dose, age, and gender (for the solid tumor model only). For the leukemia model, the age at diagnosis is also requested. After submitting the information, the user is directed to a results page displaying ERR (Excess Relative Risk), RR (Relative Risk), and PC (Probability of Causality), with a link to calculate LLE based on the provided information.

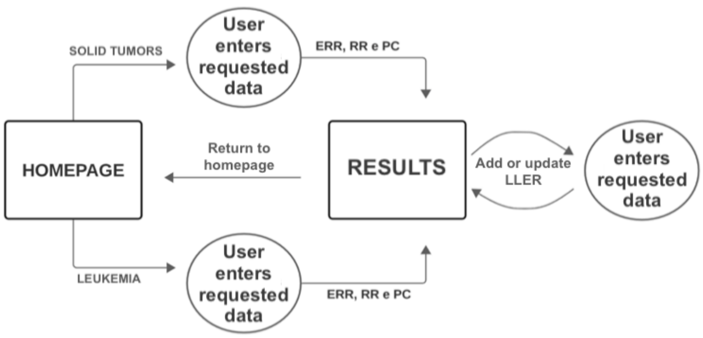

Fig. 2. Diagram showing how the application works.

To estimate the LLE, the user is presented with a new form page with new information to be filled out and submitted. The required information is the region's life expectancy (female and male) and the number of disease cases in that location per 100,000 inhabitants. Finally, the user is redirected to the third page, which is updated with information on the LLE results.

2.2. Equations

According to the BEIR VII committee [11], the general risk estimation model can be described as:

$$\lambda(c, s, a, b, d) = \lambda(c, s, a, b)[1 + \beta_S ERR(e, a)d] \quad (2.1)$$

where λ(c, s, a, b) represents the base rate, that is, the estimated risk because of background radiation and depends on the city (c), the sex of the individual (s), the attained age (a), birth cohort (b), and the weighted dose (d). The term β_SERR(e,a) is the risk estimate per dose unit to which the individual was exposed and also depends on sex (s), age when exposed (e) and age at the time of assessment (a).

The relative risk model for leukemia is presented in the equations in Tab. 1.

Tab. 1. Risk estimation equations according to the BEIR V [10].

Risk estimation equations	**Application interval**	**Equation**
$r_0(a,s)[1 + (\alpha_2 D + \alpha_3 D^2)exp(\beta_1)]$	e ≤ 20; t ≤ 15	(2.2)
$r_0(a,s)[1 + (\alpha_2 D + \alpha_3 D^2)exp(\beta_2)]$	e ≤ 20; 15 < t ≤ 25	(2.3)
$r_0(a,s)[1 + (\alpha_2 D + \alpha_3 D^2)]$	e ≤ 20; t > 25	(2.4)
$r_0(a,s)[1 + (\alpha_2 D + \alpha_3 D^2)exp(\beta_3)]$	e > 20; t ≤ 25	(2.5)
$r_0(a,s)[1 + (\alpha_2 D + \alpha_3 D^2)exp(\beta_4)]$	e > 20; 25 < t ≤ 30	(2.6)
$r_0(a,s)[1 + (\alpha_2 D + \alpha_3 D^2)]$	e > 20; t > 30	(2.7)

where r_0(a, s) is the basal mortality rate, **e** is the age at exposure, **t** is the time since exposure and where α_2= 0.243 Sv^{-1}, α_3= 0.271 SV^{-2}, β_1 = 4.885, β_2 = 2.380, β_3 = 2.367 e β_4= 1.638.

The RERF (Radiation Effects Research Foundation) [6] adjusted a relative risk model for each solid tumor site as follows:

$$r_0(a,s)[1+\alpha_S D.\exp(\beta(e-25))] \qquad (2.8)$$

where α_S is the age-specific excess linear relative risk per Sv, $\boldsymbol{D}$ is the dose (RBE for neutrons = 10), $\boldsymbol{e}$ is the age of exposure in years and $\boldsymbol{\beta}$ is the coefficient that determines the modifying effect of age of exposure. For male, α_S is equal to 0,45 and for females α_S is equal to 0,77.

According to Neves (2024) the LLE, measured in years, is expressed in the equation:

$$LLE = \sum_{t=a}^{EA}\{ERR(D,t,e,s)\gamma_0(EA-T) \qquad (2.9)$$

Where the ERR is found in the previous equations (leukemia and solid tumor risk models), the γ_0 is the number of cases per 100 thousand inhabitants and (EA - T) is the expected remaining lifespan in years for a person of age T.

3. RESULTS

For these examples, radiation-induced cancer development models for leukemia and solid tumors, defined for gamma radiation doses from 100 mSv to 3.99 Sv, complying with BEIR V and VII that work with exposure to low levels of ionizing radiation, were used.

(1) A male is diagnosed with leukemia now at age 68. He received a single uniform acute radiation dose of 100 mSv to the red bone marrow at age 43 (e > 20, T < 25). What is the relative risk (RR) that this particular dose was responsible for the development of leukemia?

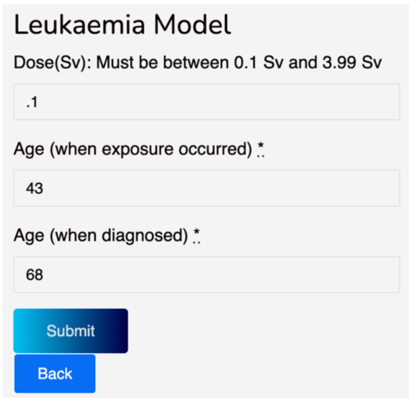

Fig. 3. Form for entering leukemia model data.

The BEIR V leukemia model for the case is equation 2.5 from Tab. 1. (e > 20, T < 25):
RR = 1 + (0.243D + 0.271D²) exp (2.367) = 1.288

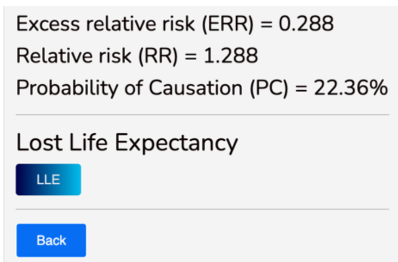

Fig. 4. Leukemia Model Result Page.

(2) In the first example, life expectancy in the region is 74 years for men and 78 years for women, and there are 2030 cases of leukemia per 100,000 inhabitants. What is the life expectancy lost (LLE) in days for this individual?

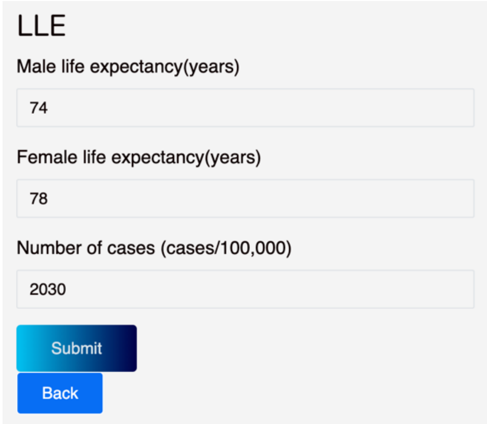

Fig. 5. Form for entering LLE data.

Adjusting equation 2.9 to answer in days instead of years, we have:
LLE = ERR x γ_0 x (EA - t)/360 = 10 days

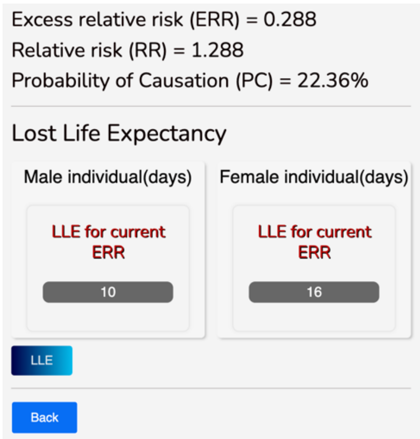

Fig. 6. Leukemia model result page with LLE.

(3) A radioactive dose of 160 mSv was accidentally released in a particular region. Determine the relative risk and probability of developing solid tumors for a 20-year-old female individual exposed to this dose of radiation.

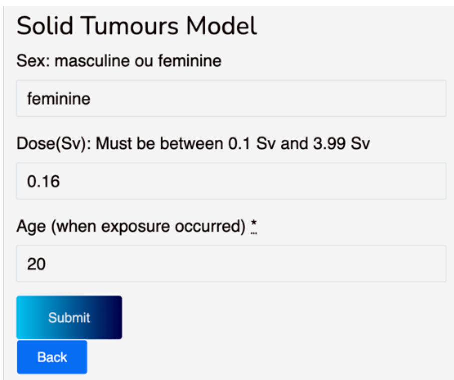

Fig. 7. Form for entering data from the solid tumor model.

The equation 2.8 for the solid tumor model (female individuals) is: RR = 1 + (0.77 x D x exp (-0.026 x (e – 25))), for D = 0.16 Sv, RR = 1.14

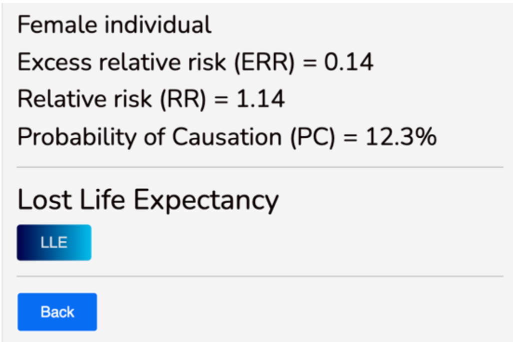

Fig. 8. Solid Tumor Model Result Page.

(4) Considering the same dose as in the previous example, for a region where life expectancy is 90 years, and there are 2,150 cases of solid tumors per 100,000 inhabitants, what is the life expectancy lost (LLE) in days for males and females aged 20, 30, 40, and 50?

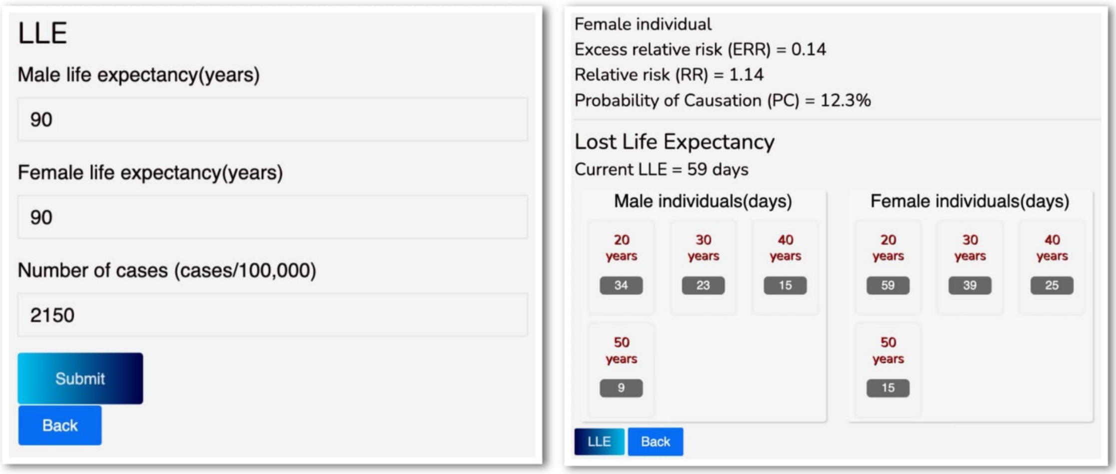

Fig. 9. Form for entering LLE data and Model result page for solid tumors with LLE for each age of exposure to the same dose.

Since the radiation dose for all individuals was maintained, sex-dependent forms of equation 2.8 for RR were used to calculate RR, where RR =1 + (0.45 x 0.16 x exp (-0.026 x (20 – 25))) and RR = 1 + (0.77 x 0.16 x exp (-0.026 x (20 – 25))), for male and female sexes respectively. For each ERR value, the equation LLE = ERR x γ_0 x (EA - t)/360 was applied to result in (a) individuals aged 20 years, 34 days (male), 59 days (female), (b) individuals aged 30 years, 23 days (male), 39 days (female), (c) individuals aged 40 years, 15 days (male), 25 days (female), (d) individuals aged 50 years, 09 days (male) and 15 days (female).

3.1. Usability testing

The ISO 9241-11:1998 standard focuses on human-computer interaction ergonomics, defining usability for visual devices based on performance, effectiveness, efficiency, and user satisfaction. This ISO-administered guideline also covers usability evaluation methods through interviews and task analysis conducted with 12 volunteers.

A. Interviews

The interview is a highly flexible method for collecting data. In an interview, one party collects data, and the other is the source of information. The SUS (System Usability Scale) Questionnaire was used for this stage.

B. Task Analysis

Task analysis involves evaluating the conditions and resources needed to perform a job to achieve a goal. It employs various techniques to collect, organize, and evaluate information, guiding judgments, diagnoses, or design decisions [12]. An example is a test consisting of four activities designed to be completed within a set time, using only a laptop and without external help. These activities aimed to apply task analysis principles, with observed errors mostly related to misunderstanding the tasks rather than the application's usability.

3.1.1 SUS Questionnaire

The System Usability Scale (SUS), created by John Brooke in 1986, is a usability assessment tool using a Likert scale through a 10-statement questionnaire. It evaluates usability [2], support, training needs, and perceived complexity across different platforms [8], with statements rated from 1 (disagree) to 5 (agree). The order and weight of statements are important for analysis.

User\Question	1	2	3	4	5	6	7	8	9	10
1	5	1	5	1	5	1	5	1	5	1
2	3	2	4	2	4	1	4	2	5	2
3	5	1	5	1	5	1	5	1	5	1
4	5	2	2	1	4	4	5	1	4	1
5	5	1	5	1	5	1	5	5	5	1
6	4	2	5	1	4	2	3	3	5	3
7	4	2	3	2	2	1	3	3	3	4
8	5	3	5	3	3	3	5	2	4	1
9	5	2	5	3	5	2	5	2	5	3
10	4	2	5	4	5	1	5	1	4	2
11	4	2	3	2	3	1	5	2	4	1
12	5	1	5	1	5	1	5	1	5	1

Fig. 10. Result of the application of the SUS questionnaire.

The SUS analysis used the formulas indicated by Brooke (1996). User satisfaction scores ranged from 57.5 points for users 7 to 100 points for users 1, 3, and 12. The average SUS score for overall usability was 82.9 points. According to Sauro and Lewis (2011), an average score of 68 points or higher is acceptable based on approximately five hundred studies.

4. DISCUSSION

The rise of portable devices like smartphones has increased recognition and usage in various areas, especially health. The International Labour Organization (ILO) and the World Health Organization (WHO) support the adoption and investment in mobile health for purposes such as monitoring, disease prevention, and remote patient support [4]. The ISO 9241 standard, adopted by the International Standard Organization (ISO) and the Brazilian Association of Technical Standards (ABNT) under the designation NBR 9241-11, defines usability as the extent to which users can use a product to achieve specific objectives with effectiveness, efficiency, and satisfaction in a particular context of use [14].

The text highlights the significance of creating user-friendly mobile apps tailored to users' needs, focusing on mobile-specific considerations like size and connectivity. It mentions the app's feature to calculate excess relative risk (ERR) and lost life expectancy (LLE), showing its effectiveness through a test with twelve volunteers. Only minor errors occurred, and high usability was confirmed by an SUS score of 82.9. Future improvements could include integrating regional life expectancy and comorbidity data to enhance emergency information access.

5. CONCLUSION

The growth of mobile computing and the Internet has led to widespread adoption. An application was created to provide care for populations exposed to radiological risk and facilitate information access. The development goals and usability criteria were met, but evaluators recommended expanding the app's functionalities and simplifying its use for the target population and emergency scenarios. They also suggested enriching the app with new models of comorbidities triggered by exposure to ionizing radiation in future versions.

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