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Radiological risk assessment for Al-Twuaitha nuclear site in Iraq

Abdul Hameed M. J. Al Obaidy[1], Bashair AR Mohammed[2], Hisham M.J. Al Sharaa[3]

[1] Environmental Research Center, University of Technology, Baghdad, Iraq.
[2] Department of Physics, College of Science, University of Baghdad, Baghdad, Iraq.
[3] Geomatic Engineering Division, University of Technology, Baghdad, Iraq.

Abstract
In this paper, the contamination level of U, ^{137}Cs, ^{60}Co, ^{40}K and ^{90}Sr from different soil samples of the destroyed nuclear reactor at Al-Tuwaitha site south of Baghdad investigated and four contaminated spots identified. The obtained values of the ^{40}K in soil samples are within normal concentration values and close to the environmental levels. The skewness coefficient for the U series, ^{137}Cs and ^{60}Co distribution indicates asymmetric distribution tailing slightly towards higher concentration. However, the activity of U series, ^{137}Cs, ^{60}Co and ^{90}Sr in the soil samples exhibit higher variability and above the regulated environmental levels.

Keywords: Risk assessment; Nuclear sites.

1. Introduction
The information of radionuclide distribution and radiation levels in the environment is important for assessing the terrestrial radiation exposure affects due to, cosmogenic and human activities. Therefore, it becomes necessary to study the radioactivity levels in soil and the released dose to the population in to determine the health risks and to obtain a baseline for future changes. The soil, which is the main part of the terrestrial ecosystem, defined as a heterogeneous mixture of different organisms and minerals, organic, and organo-mineral substances present in three phases: solid, liquid and gas [1]. Simultaneously, soil is perhaps the most endangered component of our environment open to potential contamination by various pollutants arising from human activities such as nuclear, industrial, agricultural, etc., [2]. The trace elements in soil are very important for the quality of soil and environment, excessive level of trace elements can cause pollution of waters, toxicity in plants, foods and ultimately in animals and humans that feed upon them [3]. In 1956 Iraq was established the Iraqi Atomic Energy Commission (IAEC). During the period 1956 to 1965 the main activity of IAEC focused on building up the basic infrastructure in various fields of nuclear science and technology. Al Tuwaitha Nuclear Research Center served as the foundation of Iraq's nuclear research and development from 1967 until its closure in 2003. Originally a facility for radioisotope production with a Russian supplied 2-MW IRT-2000 research reactor [4]. The IRT-2000 has upgraded by Russian contractors to a 5-MW IRT-5000 in 1978, simultaneously two French designed light water reactors, the 40-MW Tammuz-1 and the 500-KW Tammuz-2, have constructed in the early 1980s. During 2003 events, looters breeched the damaged installation and carried off contaminated scrap metal, scientific equipment and tens of contaminated barrels. The residents

poured the yellow cake on the ground, in sewer, and in the waterways of area surrounding the Al-Tuwaitha compound and on village outskirts. Since the IRT-5000 reactor bombardment, long-lived of U, ^{137}Cs, ^{60}Co, ^{40}K and ^{90}Sr are still eminent in the environment, mainly in the surface soil. Therefore, the aim of the present work is to evaluate the risk of radioactivity in the contaminated soil using crystal ball software and samples taken at different points from the surrounding areas of the research reactor.

2. Materials and methods

2.1 Radioactivity data

The data for soil samples used in this paper provided by Ministry of Science and Technology (MOST). Soil samples have collected from inner and outer perimeters of Al-Tuwaitha complex, storage location and the ditches along the outer perimeter highway Figure 1. Radiation level determined using radiation measurement equipment. While the background levels defined from soil samples collected within Baghdad city 18 km far from Al-Tuwaitha site. Soil samples were analysis for gamma, beta and Alfa spectra.

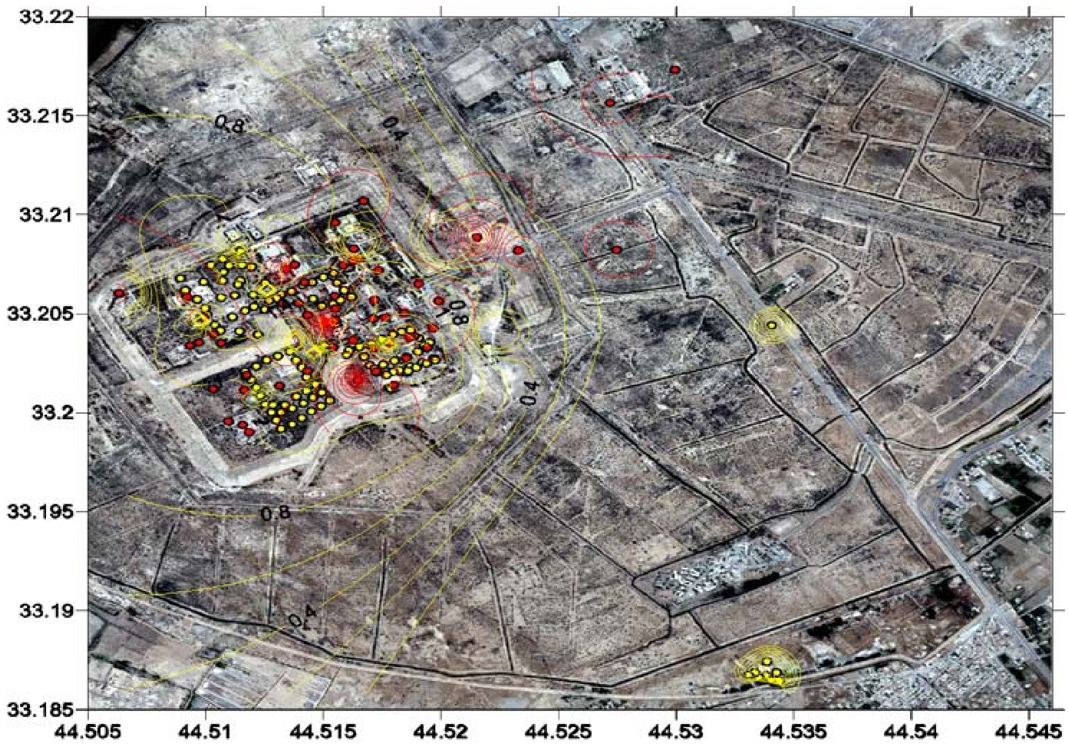

Figure 1. Soil samples locations

2.2 Risk Assessment

One aspect is to use Crystal Ball (CB) software to simulate the data distribution for the selected parameters. CB allows the user to assign a probability distribution from a built-in menu or to customize its own probability distribution according to the best knowledge of the data that wants to be represented.
CB is a spreadsheet-based application suite for scenario predictive modeling, forecasting, simulation, and optimization. It gives unparalleled insight into the critical factors affecting risk. True variability and uncertainty for each variable and parameter could be introduced as probability distributions. The probabilistic method has considered as a scientific improvement since it can quantify the variability and uncertainty, identifying the largest influence factors, can produce output with more ecological meaning and even provide an alternative to field tests [5].

3. Results and discussion

3.1 Distribution of radioactivity in surface soil samples

The obtained values of 40K in soil samples are within normal environmental levels of the UNSCEAR (2000). While for Usum the level exceed the permitted level by (75) times and for ^{60}Co by (5000) times and for ^{137}Cs by (3850) times and for ^{90}Sr (97) times. The skewness coefficient for the distribution of U,

^{137}Cs and ^{60}Co indicates a relatively asymmetrical distribution tailing slightly towards higher concentration. However, the activity level of ^{137}Cs in the soil samples exhibit higher variability and ranged 2.7E-4 to 76.947 Bq/g with an average value of 0.728 ± 6.512 Bq/g. Similarity, it is observed that the activity level of ^{60}Co in the soil samples of the study area was also exhibit large variability and ranged 0.02 to 250 Bq/g with mean values of 1.264 ± 17.635 Bq/g. Whereas, the activity level of 90Sr ranged 0.11-1.94 Bq/g with an average value of 0.1191 ± 0.12907 Bq/g, indicating that the activity level of U, ^{137}Cs, ^{60}Co and ^{90}Sr in the soil samples was above the normal environmental levels of the UNSCEAR [6].

3.2 Risk analysis

Risk analysis assumption for the probability distribution is essential to characterize the key parameters and variables with a decision to estimate the risk profile and to estimate the uncertainty of the endpoints of the risk assessment, according to defend scenario. Statistical technique with 1000 trials samples have randomly taken from each distribution, and the results are combined in the form of a probability density function, to obtain 95% confidence interval for the mean of annual doses rate. The beta distribution has assumed for the four hotpots locations as in Figure 2, while the activity concentration values taken from Table 1. Figure 3 shows the Crystal Ball output trials as well as the best fit to these data, with 95% confidence interval. The risk assessment and sensitivity analysis for hotspot 1, 2, 3, 4 and total risk are calculated for beta function at the mean of 1.34, 488, 20.1, 0.123 and 469 mSv/y respectively.

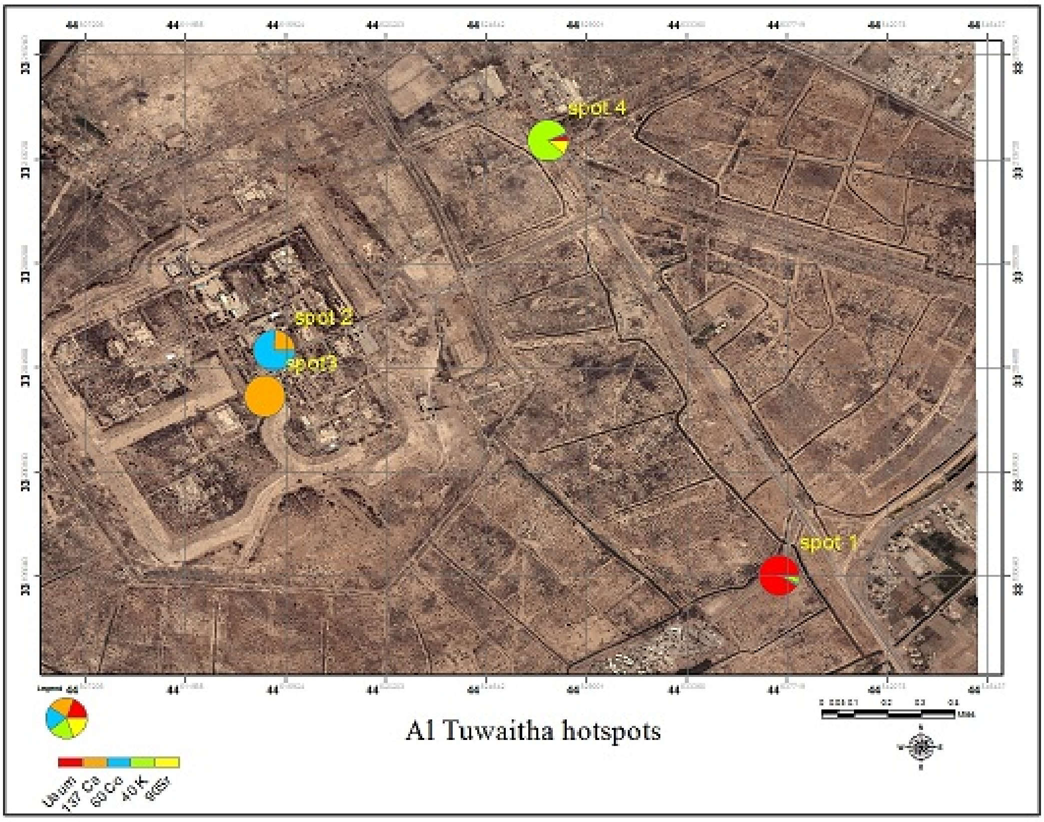

Figure 2. Hotspot locations

Table 1. Activity concentrations (Bq/g) used for risk assessment

Element	Area			
	Spot 1	Spot 2	Spot 3	Spot 4
Usum	6.12	0.044	0.433	0.046
^{40}K	0.31	0.233	0.218	0.784
^{137}Cs	0.02	76.947	47.292	0.003
^{60}Co	0.11	250.047	0.02	0.02
^{90}Sr	0.119	1.94	0.11	0.11

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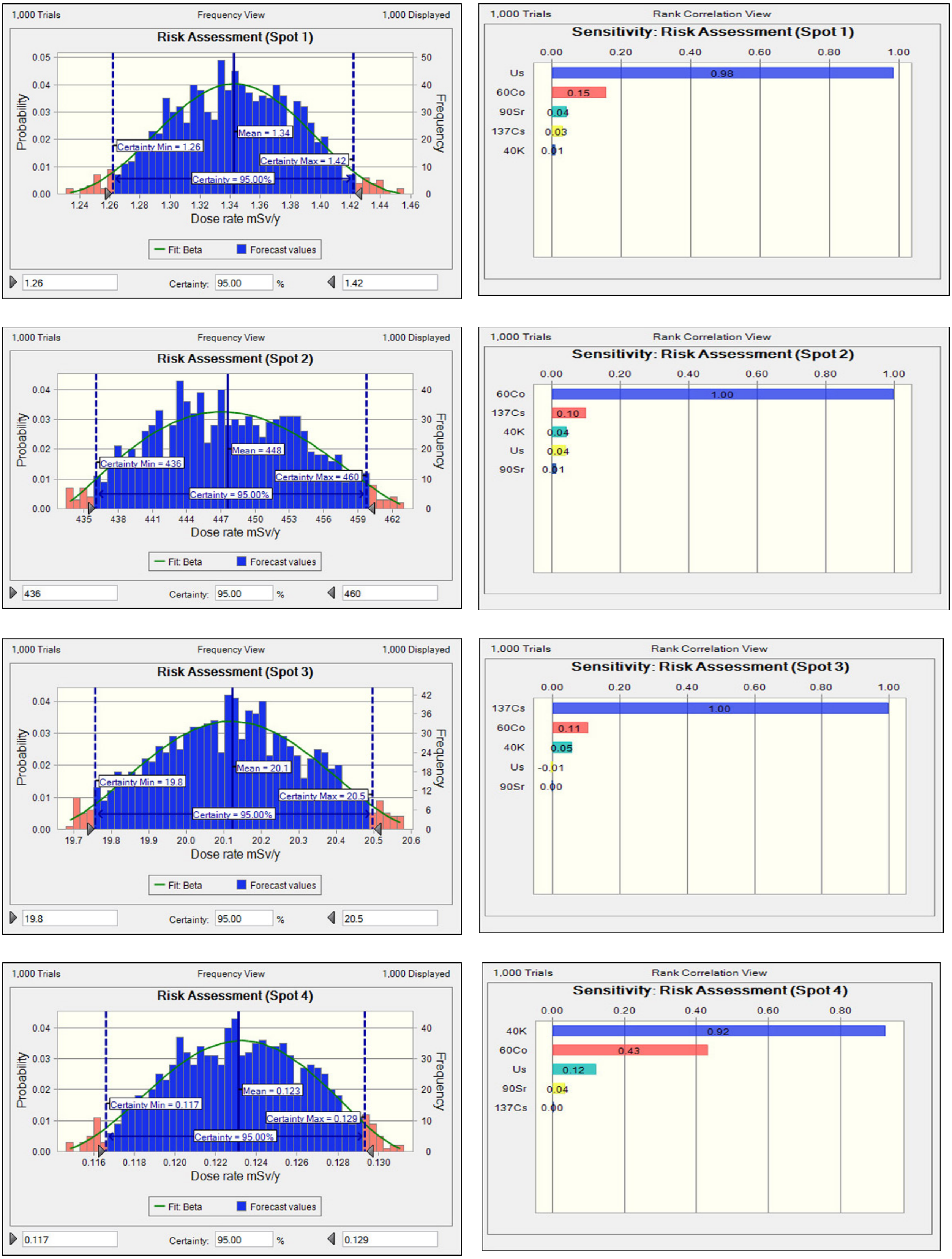

Figure 3. (Continued)

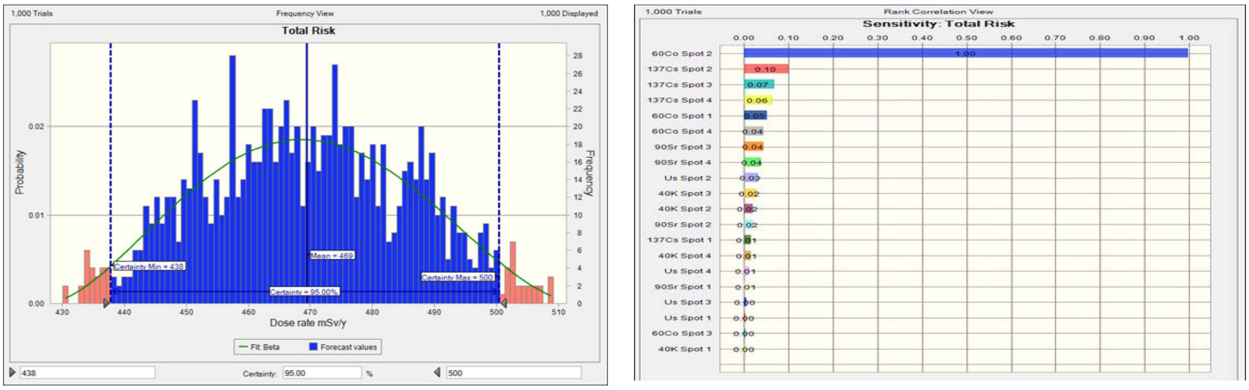

Figure 3. Risk and sensitivity analysis for the contaminated hotspots

Sensitivity analysis performed to determine which parameter has the greatest effect on model estimations. Sensitivity charts are very important in order to define probable correlations between variables and the importance of each variable in the model output. Sensitivity analysis shows the important variables that contribute significantly to the outputs at each step. CB calculates sensitivity by computing rank correlation coefficients between every assumption and every forecast while the simulation is running. It means that the assumption has a significant impact on the forecast (both through its uncertainty and the model sensitivity).

Sensitivity analyses allow studying the contribution of individual risk factors to the variance of the target forecast. Thus, the question of what are the most important risk factors can be answered depends decisively upon the risk measure employed. The present results indicated that risk in the hotspots 1, 2, 3 and 4 was mostly influence by Usum, ^{60}Co, ^{137}Cs and ^{40}K respectively, while the total sensitivity analysis indicated that ^{60}Co and ^{137}Cs were the most influence parameters.

4. Conclusion

The risk assessment and sensitivity analysis charts shows significant risk for the selected hotspots zones. The total risk is dominated by effect of the hotspot near the IRT 5000 reactor, while the sensitivity analysis indicated that ^{60}Co and ^{137}Cs are the most influenced parameters. High correlations were found with U, ^{60}Co, ^{137}Cs and ^{40}K in hotspots 1,2,3,4 respectively.

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Abdul Hameed M. Jawad Alobaidy Ph.D. in Environmental Hydrology 2004 .work in many environmental fields from 1982 , Assistant Professor in University of Technology from 1999 . He has conducted and published many researches related to environmental and hydrology. He is now working as a head of Environmental Research Center in University of Technology, Baghdad, Iraq.
E-mail address: jawaddhy@yahoo.co.in

Bashair Abdul Rahman Mohammed Graduated from department of physics University of Al Mustansiriyah B.Sc. 1983 and M.Sc. 1990. She has been worked for scientific research council Space Research Center between 1983-2003. She has conducted and published many researches related to ionosphere and troposphere layers. She is now working at the department of physics university of Baghdad.
E-mail address: BashairAM@gmail.com

Hisham Mohammd Jawad Al Sharaa graduated from B.Sc. (Building and Constrictions Engineering Dept. 2010, University of Technology. M.Sc. Geomatics Engineering 2012.
E-mail address: hishamalsharaa@live.com

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