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Proposing an Approximate Mathematical Model to Conduct the Calculations of Radioactive Cs^{137} in the Plant

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A B S T R A C T

This study aims at calculating theoretically the radioactive of cesium Cs^{137} in the plant of Nineveh governorate by selecting 50 positions as samples of the study. The calculations are carried out by constructing a mathematical model that determines theoretically the radioactive of cesium Cs^{137} in the plant. In this paper, the main features and process of mathematical modeling is stated and used clearly in the process of constructing the mathematical model which conducts the determination of the radioactive of cesium Cs^{137}. The values calculated by the proposed mathematical model show that Cs^{137} radioactive range is: (1.0832 in (A_{42} & A_{42}) – 4.1020 in (A_{48})) Bq/kg in plant. These calculations are conducted by comparing the results, obtained from the constructed model, with the values of other references. The result of this comparison shows good agreement with other literatures.

1- Introduction

In the recent years; the process of the mathematical modelling has become an essential tool in understanding and solving many physical problems, i.e. mathematical modeling is a powerful tool for analyzing physical problems that allows one to develop and test hypotheses which can lead to a better understanding of the physical process. It is defined as the application of mathematics to address problems in real life, or problems in mathematics itself, or problems in other sciences by converting these problems into mathematical problem, and then treating and solving them. Then we should choose the best solutions that fit with the nature of the problem we are dealing with [1].

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Hence, the modelling process is always evolving so as to gain a deep understanding of the mathematical aspects of the problem. Moreover, the mathematical modeling is one of the modern trends in the development of mathematics education and having a societal role in addressing some of the issues and problems of society; it is the trend towards the applications of mathematics in other sciences, and the training of students to recruit mathematics to solve real problem [2].

Mathematical modeling is defined as a dynamic process that is used to analyze mathematically the problem or the situation in the field of physics, chemistry, biology or any area of human knowledge. It is simply known as a process of building a mathematical model to solve certain physical problem. Mathematical model is a description of a system where the relationships between variables of the system are expressed in mathematical form. Variables can be measurable quantities such as size, length, weight, temperature, unemployment level, information flow, etc. Most laws of nature are mathematical models in this sense. For example, Ohm's law describes the relationship between current and voltage for a resistor; Newton's laws describe relationships between velocity, acceleration, mass, force, etc. [3]

Connecting mathematics to other sciences like physics, engineering, medicine, etc., by using the mathematical modeling can help reduce the gap between theory and practice, and also help solve many problems in life. One of these problems is finding the calculation of radioactivity for cesium Cs^{137} in plant, which represents the main aim of this paper.

Cesium-137 is a valuable plant redistribution tracer for many environments [4]. Cs^{137} was present into the atmosphere as a result of nuclear weapon tests nuclear fission. Cesium-137 is a major radionuclide in spent nuclear fuel, high level radioactive wastes resulting from the processing of spent nuclear fuel, and radioactive wastes associated with the operation of nuclear reactors and fuel reprocessing plants. The main period of cesium from nuclear weapon was in the 1950s and 1960s with the maximum cesium deposition in 1963. Cs^{137} deposition depends on the latitude and amount of precipitation [4].

The aim of this study is thus to find the calculation of radioactive Cs^{137} concentrations in plant of Nineveh governorate through constructing a mathematical model. Mathematical model is a mathematical form like a formula or equation that reflects the important features of a given situation and is shown to fit within the general context of problem solving. The arts and crafts of mathematical modeling are exhibited in the construction of models that not only are consistent in themselves and mirror the behavior of their prototype, but also serve some exterior purpose [5]. The purpose of the current proposed model is to assist the physicists to conduct theoretically their calculations. The study area is the Environment of Nineveh Governorate, which is a north-west part of Iraq, and its altitude is ranging 730 F(223 m) above sea level [6].

2. The Model Formulation

In this study, the method of formulating the model is introduced through discussion of the techniques that are used in building the model. The mathematical model, which is proposed in this study, can be formulated through different forms. These forms depend on N, where N refers to the net area under the peak of the Gama energy used for measurement in the spectrum. Generally speaking, the mathematical model is a mathematical representation that includes constants, variables and mathematical functions, and is in the form of mathematical equation, inequality variance, graph, or table [7]. The mathematical models are based on the use of input equations and the mathematical concepts in its structure, where the final outputs of a particular research process are determined in terms of the various inputs, processes and involved activities, to take a form of a mathematical equation [7].

The mathematical model of the present study consists of a specific number of variables and parameters, the definition of these variables, measurement of these variables, and composing a mathematical relationship between these variables. It is a deterministic one and based on theoretical determinations. Each of the variables in the mathematical formulation is selected carefully and considered to assess their significance to the physical problem in the study, suggesting hypotheses or

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conclusions that can be tested physically. Upon comparison with experimental results, the model can be modified to more accurately emulate the problem. This iterative process of calculating model results and making physical comparisons can continue to the point at which the model suggests appropriate solutions to the problem and make realistic predictions.

In constructing the mathematical model, the current study counts on several steps and guidelines. In the first step, it is necessary to understand the problem and identify the data required in building the model. Then, it is important to make the necessary assumptions for the construction of the mathematical model: here what is needed is to consider and think carefully to reflect on the data, besides, studying the interrelations between variables, i.e., hunching the relationship between the variables and then formulating it in a mathematical image such as equation, variance, graphic shape. The next step is constructing the model through combining the parts of the model to

get the mathematical model, modifying it several times to get the best image of the model [8]. The mathematical model constructed in the present study is derived from finding a relationship between variables and parameters in a form of a mathematical equation. This equation is built manually through several manual trails [9-11] and revisions till we get the final form of the equation as shown in the following

$$R_c = 0.133\lambda \sqrt[3]{0.77N^2 - 1000} \quad , \quad (1)$$

where R_C is referring to radioactive, and N is referring to the net area under the highest light for Gama energy which is used in measuring the spectrum. λ is a parameter is appropriate for all R, $\lambda = 1$.

After formulating the mathematical equation that is needed in conducting the calculations, the model is applied by using input data (N) to obtain the output data. Then we compared the output data with the experimental values of other references [12]. The result of comparison proves that the error percent is very low, where we get the less error percent in the area (A_{25}), which is 0.000 as shown in the following table.

Table 1. Comparison between the values of the Rc in plant, which are determined by the proposed approximation mathematical model, and the experimental values [12].

No.	Area (A)	N	R_C Exp. [12]	R_C Det.	%
1	A_1	96	2.52	2.4296 1.5231 2.2270	0.036
2	A_2	57	1.49	1.5231	0.022
3	A_3	86	2.26	2.2270	0.014
4	A_4	76	1.99	2.0092	0.009
5	A_5	59	1.55	1.5812	0.02
6	A_6	81	2.13	2.1203	0.004
7	A_7	72	1.89	1.9164	0.013
8	A_8	69	1.8	1.8442	0.024
9	A_9	80	2.1	2.0985	0.0009
10	A_{10}	99	2.6	2.4881	0.043
11	A_{11}	60	1.58	1.6094	0.018
12	A_{12}	80	2.1	2.0985	0.0009
13	A_{13}	78	2.05	2.0542	0.001
14	A_{14}	58	1.52	1.5524	0.021
15	A_{15}	84	2.21	2.1848	0.011
16	A_{16}	77	2.02	2.0318	0.005
17	A_{17}	68	1.79	1.8195	0.016
18	A_{18}	88	2.31	2.2686	0.018
19	A_{19}	79	2.07	2.0765	0.002
20	A_{20}	75	1.97	1.9863	0.008
21	A_{21}	66	1.73	1.7693	0.022
22	A_{22}	78	2.05	2.0542	0.001
23	A_{23}	87	2.28	2.2479	0.014
24	A_{24}	64	1.68	1.7176	0.022
25	A_{25}	81	2.12	2.1203	0.000
26	A_{26}	88	2.31	2.2686	0.018
27	A_{27}	52	1.36	1.3654	0.003
28	A_{28}	47	1.23	1.1814	0.039

Note: (A) refers to the samples of (28) areas.

To clarify the relationship between the output values obtained from the constructed mathematical model and the experimental values [12], the figures are plotted to show a comparison between these obtained values and experimental one depending on the area (N) as shown in the following figures.

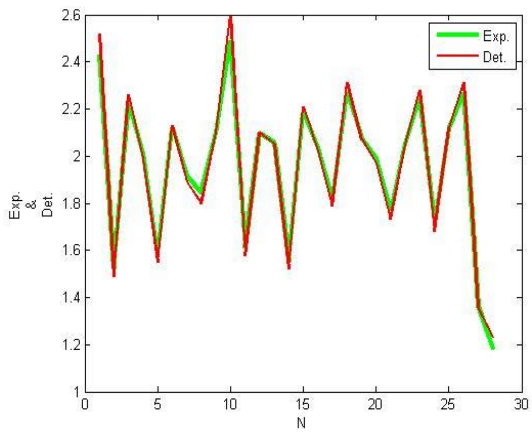


Fig.1 Compression between the values obtained via the proposed approximate mathematical model in table 1, and the experimental values [12].

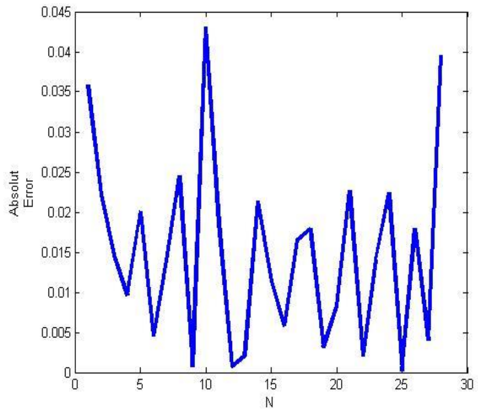


Fig.2 Errors between the values obtained by the proposed approximate mathematical model in table 1, and the experimental values [12].

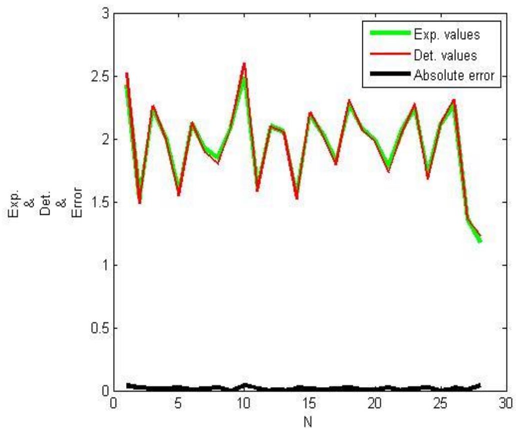


Fig.3 Comparison between proposed mathematical model and the experimental value [12], and errors

After building the model, it is necessary to solve the mathematical model by using Algebraic and analytical methods, differentiation, and graphic shapes. The current model is solved by the section method as shown in the following:

$$R_C = 0.133\lambda\sqrt[3]{0.77N^2 - 1000}$$

Define f (N) and g (N) are two functions of N.

$$f(N) = 0.133\lambda\sqrt[3]{0.77N^2 - 1000}$$
$$0 = 0.133\lambda\sqrt[3]{0.77N^2 - 1000}$$
$$0 = 0.77N^2 - 1000$$
$$1000 = 0.77N^2$$
$$1000 = (0.77N)N$$
$$N = \frac{1000}{0.77N}$$
$$2N = \frac{1000}{0.77N} + N$$
$$N = \frac{1}{2}\left(\frac{1000}{0.77N} + N\right)$$
$$g(N) = \frac{1}{2}\left(\frac{1000}{0.77N} + N\right)$$
$$g'(N) = 0.1 < 1$$
$$g(N) = \frac{1}{2}\left(\frac{1000}{0.77N} + N\right)$$
$$N_i = g(N_i - 1)$$
$$N_0 = 42$$
$$g(N_0) = N_1 = \frac{1}{2}\left(\frac{1000}{0.77 \times 42} + 42\right) = 36.46$$
$$N_2 = g(N_1) = \frac{1}{2}\left(\frac{1000}{0.77 \times 36.46} + 36.46\right) = 36.039$$
$$N_3 = g(N_2) = \frac{1}{2}\left(\frac{1000}{0.77 \times 36.039} + 36.039\right) = 36.0374985391$$
$$N_4 = g(N_3) = 36.0374985078$$

$$\varepsilon = \left|\frac{N_4 - N_3}{N_3}\right| = 0.0000000009$$

3- The relative and absolute errors:

One commonly distinguishes between the relative error and the absolute error.

Given some value of Rc and its $Rc_{\text{approximation}}$, the absolute error is

$$\varepsilon = \left| Rc_{approximation} - Rc \right|,$$

where the vertical bars denote the absolute value. If

$Rc \neq 0$, the relative error is

$$\eta = \frac{\varepsilon}{|Rc|} = \left| \frac{Rc_{approximation} - Rc}{Rc} \right| = \left| \frac{Rc_{approximation}}{Rc} - 1 \right|$$

and the percent error is

$$\delta = \eta \times 100\% = \frac{\varepsilon}{|Rc|} = \left| \frac{Rc_{approximation} - Rc}{Rc} \right| \times 100\%$$

In words, the absolute error is the magnitude of the difference between the exact value of Rc and the Rc approximation. The relative error is the absolute error divided by the magnitude of the exact value of Rc. The percent error is the relative error expressed in terms of per 100 [13].

4- Mathematical Model Validity:

To test the validity of the proposed mathematical model, the data has been extended to include extra (20) positions as study samples. The calculations are conducted by using eq. (1).

$$R_c = 0.133\lambda \sqrt[3]{0.77N^2 - 1000} \quad , (1)$$

where R_C is referring to radioactive, and N is referring to the net area under the highest light for Gama energy which is used in measuring the spectrum. λ is a parameter is appropriate for (A_{29} - A_{36}, $\lambda = 1.082$), and ($A \geq A_{37}$, $\lambda = 1.1467$).

The resulted calculations for some of these positions (about eleven positions) have been compared to the experimental values of other references. It is found that there is a well conformity between the data readings obtained from the proposed mathematical model and the experimental values as shown in table2.

While the calculations of the other extended positions (9) are conducted approximately which proved the applicability of the model to calculate the radioactive theoretically. Conducting theoretical calculations are very important as they do not require physical laboratories or going to the positions themselves, so the process of calculating becomes easy to the physicists. This represents the aim of the current study.

No.	Area (A)	N	R_C Exp.[12]	R_C Det.	%
29	A_{29}	42	1.1	1.0832	0.015
30	A_{30}	42	1.1	1.0832	0.015
31	A_{31}	45	1.18	1.1867	0.004
32	A_{32}	105	2.75	2.8181	0.023
33	A_{33}	106	2.78	2.8384	0.019
34	A_{34}	109	2.86	2.8985	0.012
35	A_{35}	110	2.89	2.9183	0.008
36	A_{36}	112	2.94	2.9578	0.005
37	A_{37}	117	3.07	3.0550	0.006
38	A_{38}	125	3.28	3.2064	0.023
39	A_{39}	130	3.41	3.4929	0.024

40	**A_{40}**	**135**	**3.55**	**3.5891**	**0.010**
41	**A_{41}**	**142**	**3.73**	**3.7212**	**0.002**
42	**A_{42}**	**129**	**-**	**3.4734**	**-**
43	**A_{43}**	**131**	**-**	**3.5122**	**-**
44	**A_{44}**	**133**	**-**	**3.5508**	**-**
45	**A_{45}**	**142**	**-**	**3.7212**	**-**
46	**A_{46}**	**147**	**-**	**3.8139**	**-**
47	**A_{47}**	**157**	**-**	**3.9954**	**-**
48	**A_{48}**	**163**	**-**	**4.1020**	**-**
49	**A_{49}**	**150**	**-**	**3.8688**	**-**
50	**A_{50}**	**160**	**-**	**4.0489**	**-**

The extension and comparison of the data of the Rc in plant, which is obtained from the proposed mathematical model, with the experimental values of other references [12].

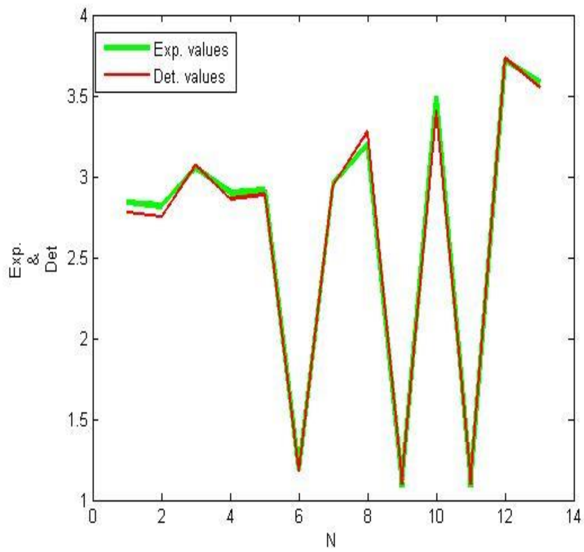


Fig.4 Errors between the values obtained by the proposed approximate mathematical model in table 2, and the experimental values [12].

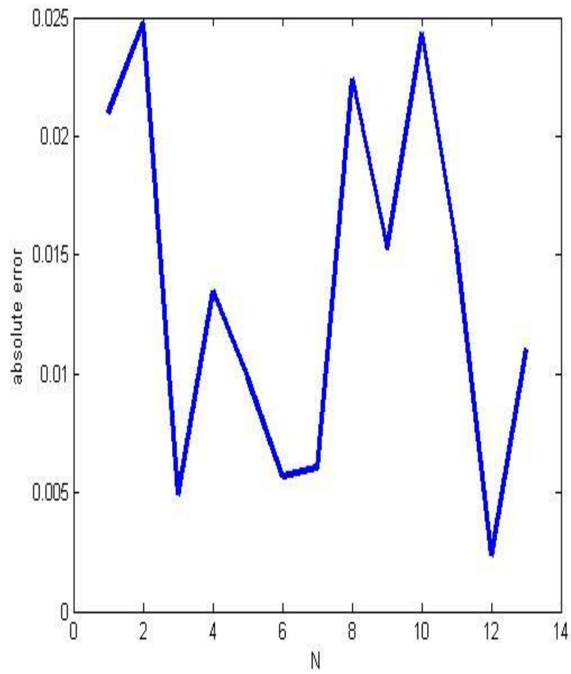


Fig.5 Errors between the values obtained by the proposed approximate mathematical model in table 2, and the experimental values [12].

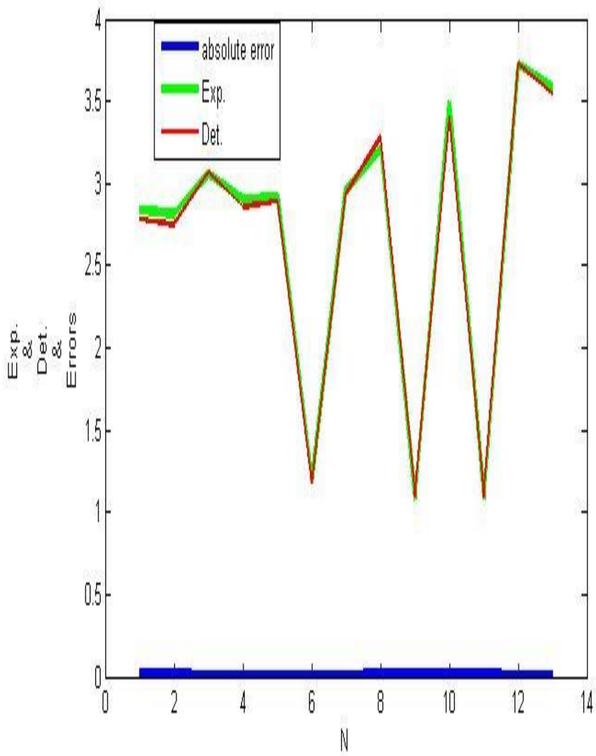
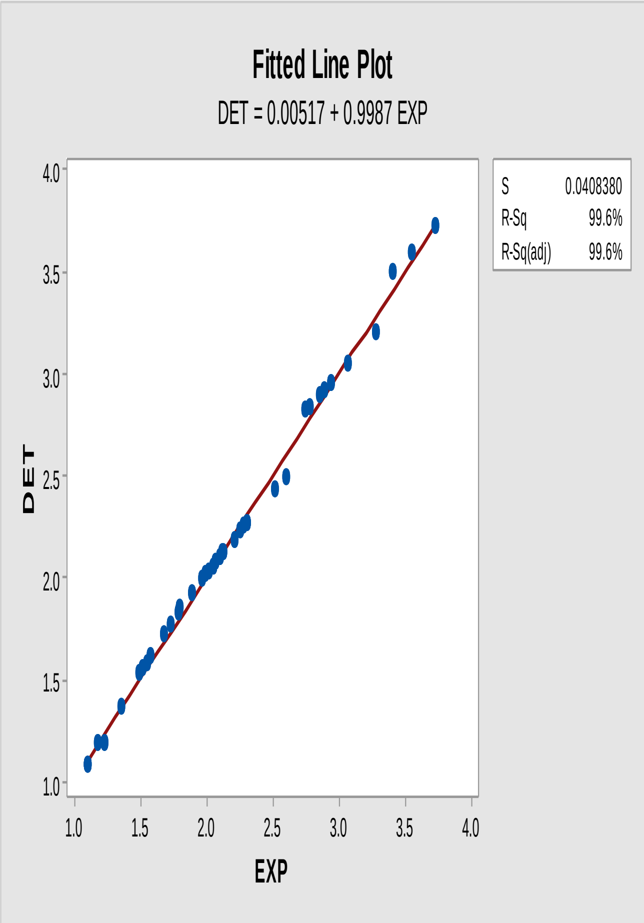


Fig.6 Comparison between proposed model and experimental values in [12], and errors.

5- Statistical analysis:

To make a more reliable model, a statistical analysis is conducted on the proposed model. We found out that R-Sq is 99.6 % where the range of R-Sq should not be less than 35%; this shows that the equation of the model is appropriate to desired aim of the study as shown in the following regression analysis:



LINEAR

Regression Analysis: DET versus EXP

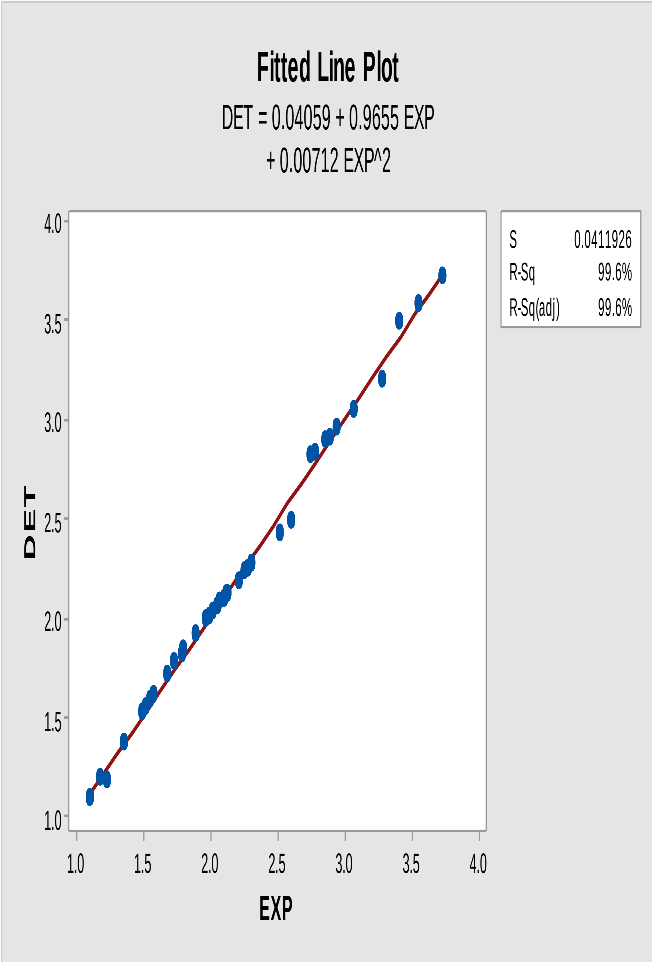
The regression equation is

DET = 0.00517 + 0.9987 EXP

S = 0.0408380 R-Sq = 99.6% R-Sq(adj) = 99.6%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	17.9003	17.9003	10733.30	0.000006
Error	39	0.0650	0.0017		
Total	40	17.9654			



QUADRATIC

Polynomial Regression Analysis: DET versus EXP

The regression equation is

DET = 0.04059 + 0.9655 EXP + 0.00712 EXP^2

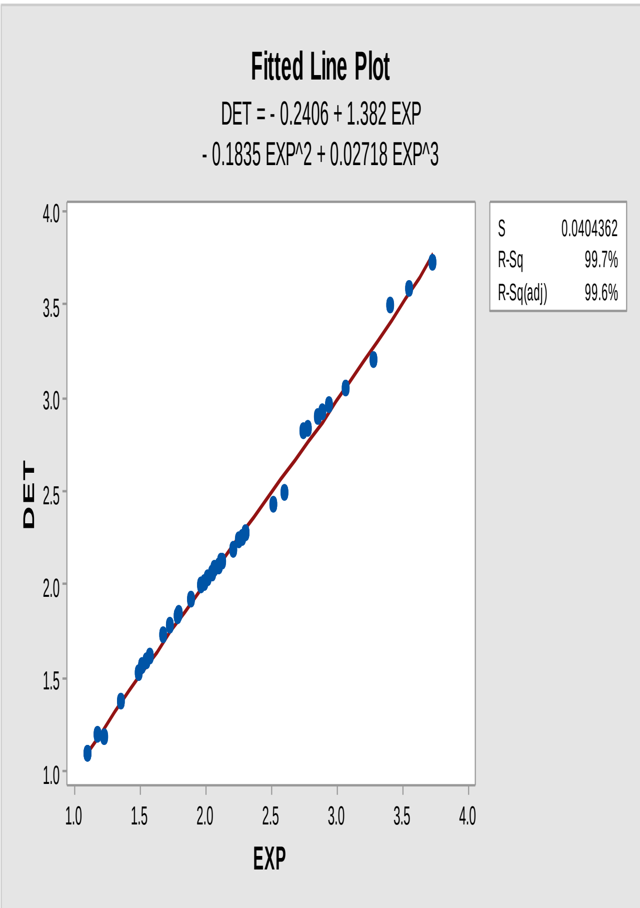
S = 0.0411926 R-Sq = 99.6% R-Sq(adj) = 99.6%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	17.9009	8.95046	5274.82	0.00008
Error	38	0.0645	0.00170		
Total	40	17.9654			

Sequential Analysis of Variance

Source	DF	SS	F	P
Linear	1	17.9003	10733.30	0.000006
Quadratic	1	0.0006	0.33	0.568



C U B I C

Polynomial Regression Analysis: DET versus EXP

The regression equation is

DET = - 0.2406 + 1.382 EXP - 0.1835 EXP^2 + 0.02718 EXP^3

S = 0.0404362 R-Sq = 99.7% R-Sq(adj) = 99.6%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	17.9049	5.96830	3650.14	0.00003
Error	37	0.0605	0.00164		
Total	40	17.9654			

Sequential Analysis of Variance

Source	DF	SS	F	P
Linear	1	17.9003	10733.30	0.000
Quadratic	1	0.0006	0.33	0.568
Cubic	1	0.0040	2.43	0.127

Orthogonal Regression Analysis: DET versus EXP

Error Variance Ratio (DET/EXP): 0.05

Regression Equation

DET = - 0.002 + 1.002 EXP

Coefficients

Predictor	Coef	SE Coef	Z	P	Approx 95% CI
Constant	-0.00236	0.0220283	-0.1073	0.915	(-0.045538; 0.04081)
EXP	1.00217	0.0096737	103.5974	0.000	(0.983210; 1.02113)

Error Variances

Variable Variance

DET 0.0000774

EXP 0.0015473

Finally, it is worth mentioning that the good mathematical models must have the following: of a number of variables; clear and precise definition of these variables; accurate measurement of these variables; and finding a mathematical relationship of some sort between these variables [14]. The current model is proved to have the above characteristics; this states that it is a suitable to achieve its aim of calculating the effects of radioactivity of Cs ^{137} on the plant.

6- Mathematical formula by using Nevill's method:

By using Nevill's formula we get:

$N_0 = 42$, $R_{C0} = 1.1$

$N_1 = 142$, $R_{C1} = 3.73$

$$= \frac{(N-42)3.73-(N-142)1.1}{142-42}$$

$$R_C = \frac{(N-N_0)R_{C1}-(N-N_1)R_{C0}}{(N_1-N_0)}$$

$$= \frac{3.73N-156.66-1.1N+156.2}{100}$$

$$= \frac{2.63N-0.46}{100}$$

$$R_C = 0.0263\,N - 0.0046$$

Comparison between the values, determined via the proposed Novell's formula, to determination the R_c in plant, and the experimental values of other references [12], as shown in the following table 3.

Table 3. Comparison between the values, determined by the proposed Novell's formula, to calculation the R_c in plant, and the experimental values [12].

No.	Area (A)	N	R_C Exp. [12]	R_C Det.	%
1	A_1	117	3.07	3.072	0.00065
2	A_2	109	2.86	2.862	0.0007
3	A_3	110	2.89	2.888	0.000692
4	A_4	45	1.18	1.178	0.001695
5	A_5	112	2.94	2.941	0.00034
6	A_6	125	3.28	3.282	0.00061
7	A_7	96	2.52	2.520	0.00000
8	A_8	57	1.49	1.494	0.00268
9	A_9	86	2.26	2.257	0.001327
10	A_{10}	76	1.99	1.994	0.00201
11	A_{11}	59	1.55	1.547	0.001935
12	A_{12}	81	2.13	2.125	0.002347
13	A_{13}	72	1.89	1.889	0.000529
14	A_{14}	69	1.8	1.810	0.00556
15	A_{15}	80	2.1	2.099	0.000476
16	A_{16}	99	2.6	2.599	0.000385
17	A_{17}	106	2.78	2.783	0.00108

18	**A_{18}**	**60**	**1.58**	**1.573**	**0.00443**
19	**A_{19}**	**80**	**2.1**	**2.099**	**0.000476**
20	**A_{20}**	**78**	**2.05**	**2.046**	**0.001951**
21	**A_{21}**	**58**	**1.52**	**1.520**	**0.00000**
22	**A_{22}**	**84**	**2.21**	**2.204**	**0.002715**
23	**A_{23}**	**77**	**2.02**	**2.020**	**0.00000**
24	**A_{24}**	**68**	**1.79**	**1.783**	**0.003911**
25	**A_{25}**	**88**	**2.31**	**2.309**	**0.000433**
26	**A_{26}**	**79**	**2.07**	**2.073**	**0.00145**
27	**A_{27}**	**75**	**1.97**	**1.967**	**0.001523**
28	**A_{28}**	**66**	**1.73**	**1.731**	**0.00058**
29	**A_{29}**	**78**	**2.05**	**2.046**	**0.001951**
30	**A_{30}**	**87**	**2.28**	**2.283**	**0.00132**
31	**A_{31}**	**64**	**1.68**	**1.678**	**0.00119**
32	**A_{32}**	**81**	**2.12**	**2.125**	**0.00236**
33	**A_{33}**	**88**	**2.31**	**2.309**	**0.000433**
34	**A_{34}**	**105**	**2.75**	**2.756**	**0.00218**
35	**A_{35}**	**52**	**1.36**	**1.363**	**0.00221**
36	**A_{36}**	**47**	**1.23**	**1.231**	**0.00081**
37	**A_{37}**	**42**	**1.1**	**1.1**	**0.00000**
38	**A_{38}**	**130**	**3.41**	**3.414**	**0.00117**
39	**A_{39}**	**42**	**1.1**	**1.1**	**0.00000**
40	**A_{40}**	**142**	**3.73**	**3.73**	**0.00000**
41	**A_{41}**	**135**	**3.55**	**3.545**	**0.001408**

Note: (A) refers to the samples of (41) areas.

By using Novell's formula, the relationship between the radioactive and the area has been found as linear equation. While in the approximate mathematical model, the equation is nonlinear, which is preferred in the application of the mathematical model because the radioactive is nonlinear phenomenon as well as the linear equation is considered weak in the application.

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'' اقتراح نموذج رياضي تقريبي لحساب التأثير الاشعاعي للسيزيوم على النبات''

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الخلاصة:

تهدف هذه الدراسة إلى حساب نظري للتأثير الاشعاعي للسيزيوم ^{137} Cs على النبات في محافظة نينوى عن طريق اختيار 50 موقع كعينات من الدراسة. يتم إجراء الحسابات من خلال بناء نموذج رياضي يحدد نظريا التأثير الاشعاعي للسيزيوم Cs^{137} في النبات. في هذا البحث، تم ذكر الملامح الرئيسية وعملية النمذجة الرياضية واستخدامها بشكل واضح في عملية بناء النموذج الرياضي الذي يقوم بتحديد القيم المحسوبة للتأثير الاشعاعي للسيزيوم Cs^{137} في النبات. القيم التي حسبت بالموديل المقترح تراوحت بين 1.1814 في (A_{28}) و 2.4881 في (A_{10}). تمت مقارنة النتائج التي تم الحصول عليها من النموذج المبني مع قيم المراجع الأخرى. وظهرت نتيجة هذه المقارنة اتفاقا جيدا مع الدراسات الأخرى.