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نمذجة انتقال ملوثات اليورانيوم المنضّب جنوب العراق

Modeling Depleted Uranium Contamination in Southern Iraq 2019

د. سعاد ناجي العزاوي
استاذ مشارك في الهندسة البيئية

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Modeling Depleted Uranium Contamination in Southern Iraq



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الدكتورة سعاد ناجي العزاوي
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Summery

The environment and human population in Iraq have been exposed to radioactive contamination as a result of using depleted uranium (DU) weapons by US/UK armed forces during first Gulf War in 1991. Same weapons also were used during the military operations of Iraq's invasion and occupation in 2003 and its aftermath in 2004.

Since these weapons were used extensively in specific areas in southern Iraq during Gulf War, 1991, dozens of researches and studies were conducted during the Nineties by Iraqi researchers proved the existence of pollution in large areas of Basra and Nasiriyah and vicinity due to dispersion of the contamination by dust and rain storms. Contamination by Uranium radionuclides continues for hundreds or even thousands of years and its impact on human health is well identified in the international related literature .

The Department of Environmental Engineering at the University of Baghdad in 1996- 2002 conducted series of researches through graduate studies that include: site investigations

Keywords - ا ات ا تا
#Uranium # Depleted Uranium # Souad_Alazzawi #Southern_Iraq #depleted_uranium_contamination

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and exploration programs in areas of military engagements in southern Iraq, modeling radioactive pollution dispersion through environmental elements, and assessing the risk related to the received effective radioactive doses by Iraqi army and residents of contaminated area.

In this paper the mathematical modeling procedure of the pollution dispersion is presented. Modeling contaminants transport covered the areas of (Safwan, Northern Rumaila field, Southern Rumaila field, al Zubair and Jabal Sanam), where DU weapons heavily used during the military operations of the first Gulf War in 1991.

The field and laboratory tests carried out in 1996 were considered limited compared to vast areas of military operations. Therefore, the mathematical modeling process was used with reverse analysis to be able to calculate radionuclides concentration back in 1991 rather than the time of site and laboratory measurement in 1996, and to define further areas contaminated through natural weathering processes.

The simulation and modeling process included the adoption of a conceptual model and the application of a set of internationally recognized equations explained in this paper. The equations were converted into computer programs to calculate the concentration of Uranium radionuclides decay series such as radium-226, thorium-234, and others from time of exploration program in 1996 back to 1991.

Results of this modelling process indicated that contaminants from hundreds of destroyed tanks and artilleries by DU shells in the studied areas have been spreading by wind and rains storms continuously for the period (1991-1996). Calculated contaminated land was found to be 1718 Km². Also, quantities of contaminated water washed away from destroyed artilleries through rainstorms found to be (1886103) m³, and that deposited radionuclides in close by river or surface water channels bed like radium-226, found to be about 14 km²

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الخلاصة

إن ام ا و ات ا ي وا مت ي ا ي تم إ اؤه ام 1996 ن ودا ً ط
ال ا ال ت ات ت ل ا ال ل ات ال . لل ت ت االت ا ل ال ال ا
ا ا ر ً م 1991م ب ا ا ات ا ّ و و
1996م.

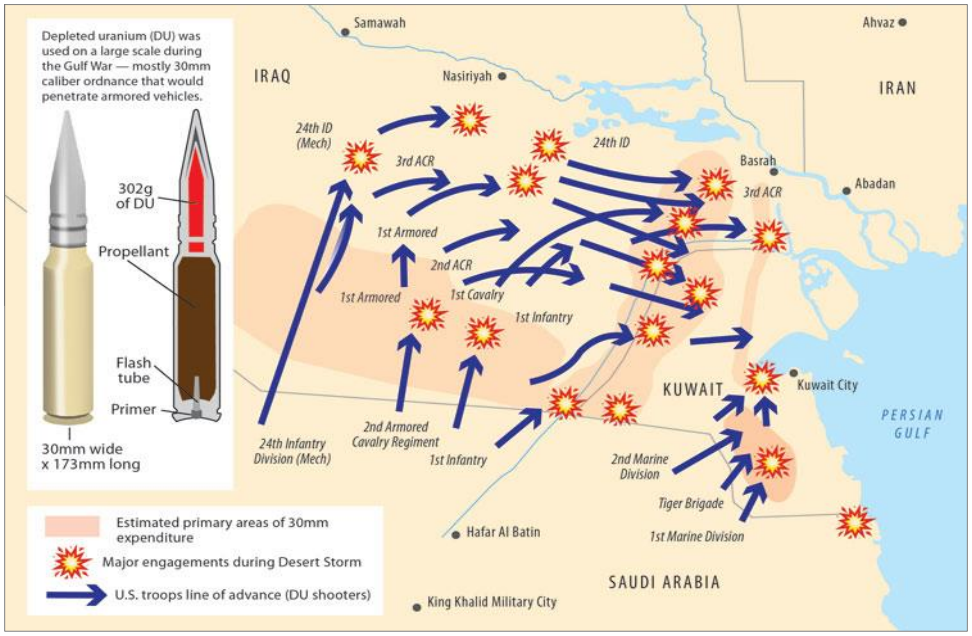
ا وا ا ا) Simulation and modelling(ا اد ذج
ا ا و ا دالت ا رف ً ا ا ل وا
تو ه ا ه ا ال . وت ت و ل ه ه ال ادالت ل ب ا ا وب إل اء اب ات ت ا
ال دات ل ا ل ل االل ال را م م ل)لل راد م – 226(و)ا ور وم-234(و
م م 1996م ر ً م 1991م. وم ه ه ات ا تم إ اد م ا ات ت وا م اه وا اء
ا ي ا ادا ّ ا أل ى ا ا ا وا
أ ا ا)1718(. ات اه ا ا ا ت
- و أ ء ل ا ّ إ ا ات ا ا . ت
ه ه ا اه ا)1,886,103(م3. أ ت ع أل ر ا ا ّ و ً
ا اد م – 226)14(م2. أ ا ا ادة ا رض ا ار ة ا اط
ا إل ا وز اد ن ال د ال ال ن د ان ل اث از)ل ادون-222(
ا روع ا ة ه أل و ار ا ا ا ا ا را م ا ّ
ا ا ات ا ا.

إن ا ت ا ّ إ د ال ل ا ا ت
ال ي ، ت ات دا ا إل ي اد االت االت ال ل ال اء ال ي و ا ا
ا ا وإ إل ن ا ُ ع إل ا وا ا ض إ و و ن
ه ا ط وا ات ا ّ ا ا وأل ث ال ، ً ن ه ا
ال زال ت ا ، أل ن ه ه ال ل ات ت ال ن ن ال ل ت ت ا اءات ال ت
ا ا ا اد ا .

Results of this modeling process were calibrated with site and laboratory tested samples and measurements, and then used to find transfer coefficients from land to vegetative cover and food chain stuff components. Transfer coefficients are important to define internal radioactive doses humans' body received as will explained in next related paper.

1.0

ُرّت ت ا ر ا م ا ّ ا اطال أ ء ا ت ا ب ا ألو ِ ا ات
ألم وال ا ام 991 ا)300-800(ط [1]، وأن ه ه ل اتت إطال ه ا ا اتِ ا ا
ا ا ا ي ا ي ا ة ب ا اق الً
ا ات ا اق) 1و 2([2] [3]. و و د ا ر ا م ا ّ ا ط ا ود ا و و ب
ا ة الً ذي ر وا ا ا اق.

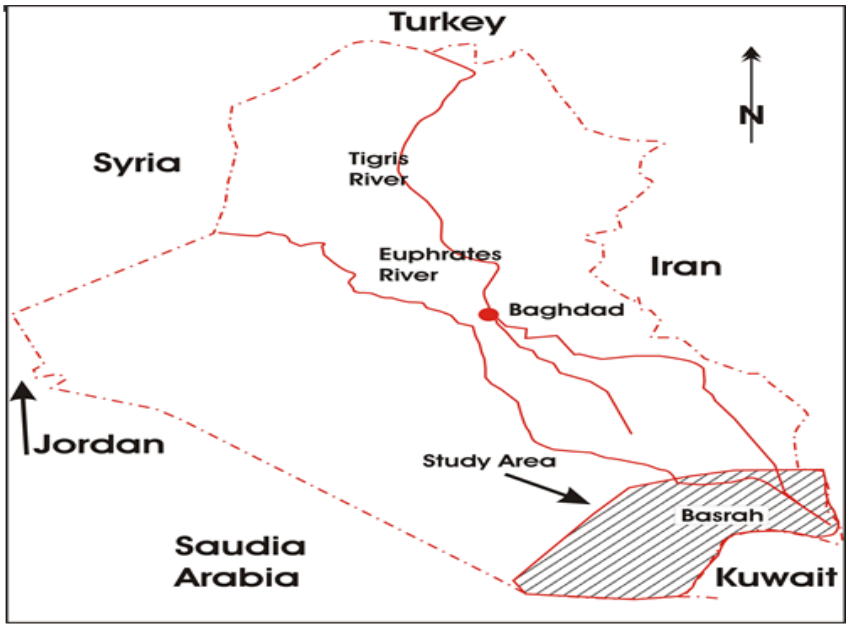


ش 1: ا ط ا ِلسَ ا ات أل وا ا را م
ا ّ ب ا 1991 [2].

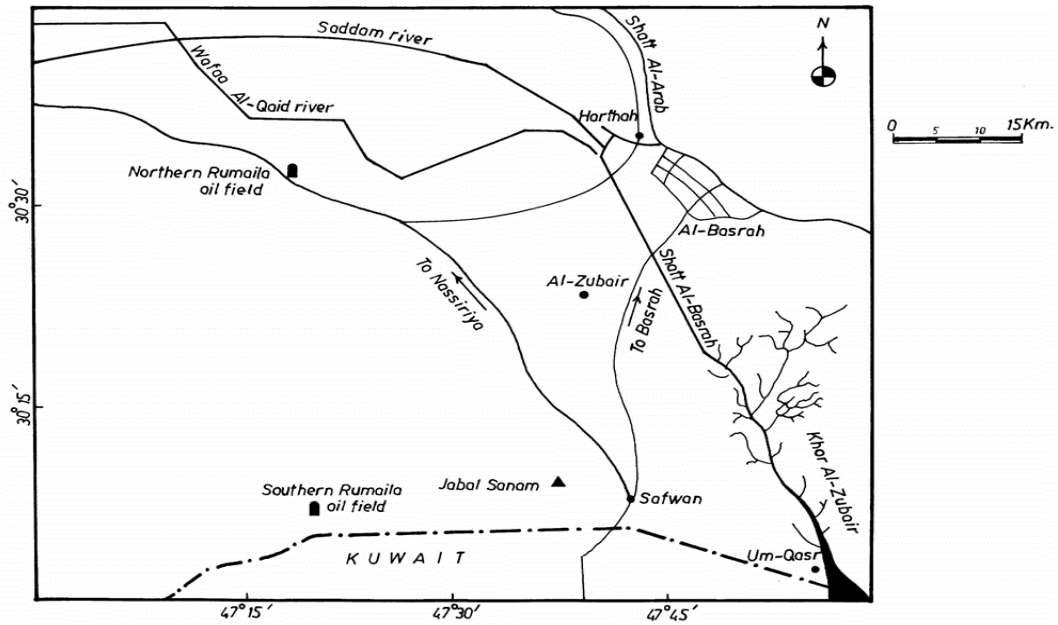


ش 2:) ط ا وت(ا و ت وا ة وا ي ِلسَ ا ات أل
وا ط ا را م ا ّ [3]

و ض إ د ت ا ث را م ا ّ وا ر ا ال أل ا)ال ه اء، ال اه،
ال ر (وأل ا و ن ن ا ان ن اط ال را ان ال ن إ اء ل ل ون ت ال لال ات
وا ع ال روع وآلل ات الع ر الت ة ا را م ا ّ (Depleted Uranium) ا اط
ل ت أ ت ا ا ات ا م ا ام 1996، وث و ود وث إ ا ا و ن اط) وان، ا ،
ام، ا م ا م ا ، ا م ا ( )3و 4(إ ا اط ا اورة [4].



ش 3: ا اطق ا ش ا ب ا اق



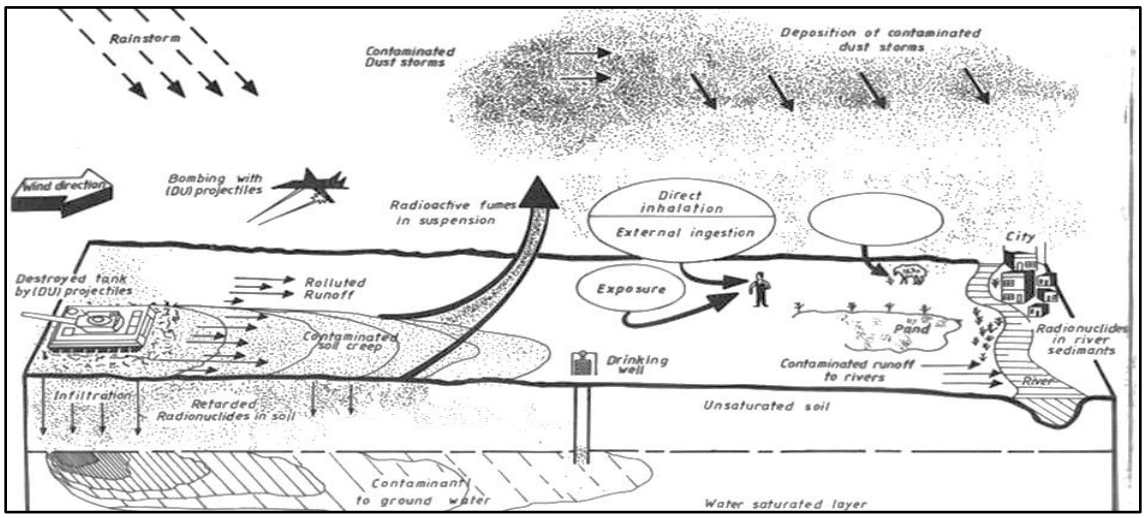
ش 4: ط ا ت ا ا و د ا ث را م ا ّ
ا ت ات وا وص ات ا ت [4].

و ت ا ا ات اض ا وات ت ت ا ا وت (Simulation and modelling) ال د ت الرا و م ا ه و ا ات ا را م ا ّ ا ا ت ا ه ه لل و ات وا البيئات واالل ات ال رة رب و وب الي رقل اط ل ا ة ال اورة.

ل ت 2.0 ل وال ال ا ل ت ات ال ل ل و ات ال ل ل اط ال ا ل :

إل جاز ق ذا ال و وذج ا ا (Conceptual Model) ( ) 5(ا ا وا ا وأل ى ا آ ت ا ل ا ت ا ّ ا آل ت ا ة.

وا ام ا دال ت ا ً ب ا ر ا ز ا ا ا ا ّ ا ا را م ا ّ اط ا روع ا رة إ ا واء، ا اء، وا ر ة ع ا وظ ا ه ه ال ادال ي ات ا لل ات نا لل ل ال ا إل اإلن ان [4] [5].



ش ل 5: ال ذج ال ت ا ل ل ال ات ا
ل ل ا را م ا ّ [5].

ل ض ال ت م اعتمد ال موذج ال ت ل ض ل وا ال ت ل وث ال م قتم ات ام تا ج ال ا ات ا وا و ات ا ت ال م أ ا ال ل ام 1996م) ال اول 2,3,1 ال اد ال ت ات ال ادال ت ا ل ت ا و ات ا را م ا ّ ط ا ورة. و أن ا ب ب أل رار ال م ا رة و ر ال م ا رة ا اء" م ام 1991م)، م ا ام ا (Reverse Analysis) ب ا ا ادا ّ ا ا رة أل ام) 1995م، 1994م، 1993م، 1992 م, 1991).

ول 1 ض ال ض ال ا ل ا ال اط ال [4] [5].

ر ا ذ ج	ا ض ش ا ي µR/h	ر ا ذ ج	ا ض ش ا ي µR/h	ر ا ذ ج	ا ض ش ا ي µR/h	ر ا ذ ج	ا ض ش ا ي µR/h	ر ا ذ ج	ا ض ش ا ي µR/h
S-1-1	7.9	**S-1-8**	7.7	**SN-2-4**	89.4	**R-1-1**	81.7	**RK-2-3**	51.3
S-3-1	7.6	**S-1-9**	7.7	**SN-2-6**	9.5	**R-1-6**	75.3	**RK-2-5**	98.3
SO-1-1	7.4	**S-1-10**	7.9	**SN-2-7**	9.3	**R-1-7**	8.4	**RK-2-6**	9.1
S-1-3	7.6	**S-2-1**	28.0	**S-3-2**	7.0	**R-1-8**	8.2	**RK-2-7**	8.9
SA-1-3	7.0	**S-2-2**	28.6	**S-4-1**	15.1	**R-2-1**	8.9	**RK-3-1**	42.0
SA-1-4	7.1	**S-2-3**	28.3	**S-4-2**	15.3	**R-3-1**	59.6	**RK-3-2**	43.1
SA-1-5	7.3	**S-2-4**	79.3	**S-4-3**	15.2	**R-3-2**	58.6	**RK-3-3**	42.8
SA-1-6	7.3	**S-2-5**	8.1	**S-4-4**	83.2	**R-3-3**	59.0	**RK-3-4**	92.1
SA-1-7	7.3	**S-2-6**	8.0	**S-4-5**	8.9	**R-3-5**	80.6	**RK-3-6**	9.8
SA-1-8	7.4	**S-2-7**	30.1	**S-4-6**	8.5	**R-3-6**	8.2	**RK-3-7**	9.3
SA-1-9	7.4	**S-2-8**	30.5	**S-5-1**	16.9	**R-3-7**	8.0	**RK-4-1**	43.0
SA-1-10	7.6	**S-2-9**	30.2	**S-5-2**	17.1	**R-4-1**	45.3	**RK-4-2**	43.3

S-1-4	7.3	**S-2-10**	82.4	**S-5-3**	16.3	**R-4-2**	46.1	**RK-4-3**	43.3
SA-1-11	7.2	**S-2-11**	8.2	**S-5-4**	92.1	**R-4-3**	43.2	**RK-4-5**	87.2
SA-1-12	7.5	**S-2-12**	8.1	**S-5-5**	9.3	**R-4-4**	78.2	**RK-4-7**	8.2
Z-1-2	7.1	**SN-1-1**	36.9	**S-5-6**	9.1	**R-4-5**	8.2	**RK-4-8**	8.2
Z-1-3	7.3	**SN-1-2**	36.8	**S-6-1**	14.3	**R-4-6**	8.2	**S-7-1**	49.5
Z-1-4	7.3	**SN-1-3**	36.9	**S-6-2**	14.5	**RK-1-1**	80.8	**S-7-2**	48.1
S-1-5	7.9	**SN-1-4**	184.5	**S-6-3**	14.4	**RK-1-2**	78.3	**S-7-3**	48.9
S-1-6	7.5	**SN-1-7**	9.4	**S-6-5**	75.4	**RK-1-3**	79.8	**S-7-4**	101.7
Z-1-5	7.4	**SN-1-8**	9.4	**S-6-6**	8.3	**RK-1-4**	152.3	**S-7-7**	9.5
Z-1-6	7.5	**SN-1-10**	9.0	**S-6-7**	8.2	**RK-1-6**	9.3	**S-7-8**	9.3
Z-1-7	7.6	**SN-2-1**	17.0	**R-1-3**	51.7	**RK-1-7**	9.0	**SH-1-1**	9.2
Z-1-8	7.1	**SN-2-2**	17.1	**R-1-4**	51.1	**RK-2-1**	51.3	**SZ-1-1**	10.3

ال لظ ابذج ال ظلل ل ل رض إلش ا أأل ل ل ل ال ل ال راس وال ل)7(µR/hr.

نولج2 : ات ا ت اذج لت اط ا 4 5.

Pb-214	**Bi-214**	**Ra-226**	**Th-234**	**U-235**	**ر ا ذج**

							RK-1-1	901	55700	36205	50.8	53.4
							RK-1-2	937	42100	25000	52.7	50.4
							RK-1-3	488	21100	13700	36.7	34.9
							RK-1-6	10.23	633	405	30.2	39.7
							RK-2-1	531	40900	21650	60.1	51.9
							RK-2-2	212	23300	17800	58.0	55.3
							RK-2-3	81	11800	7120	49.3	50.1
							RK-2-6	7.1	950	673	44.8	40.1
							RK-3-1	412	37350	19610	58.3	57.3
							RK-3-2	198	21700	15300	56.1	51.5
							RK-3-3	73	9125	6134	50.0	52.1
							RK-3-6	6.9	812	495	38.3	35.9
							RK-4-2	115	23010	11250	50.1	50.3
							RK-4-3	60	13200	8340	50.7	47.3
							RK-4-7	3.2	512	317	42.1	42.3

							S-7-1	86.3	6010	4310	44.9	47.1
							S-7-3	8.3	2120	1910	41.9	39.9

ول 3تـ ر ا و ات ا اذج اه وتـر ات ا وات ا ا وا اه اجو ا را [4، 6].

ر ا ذ ج	Ra-226	Bi-214	Pb-214
S1	81.6	175	62.5
	90.2	160	60.1
S2	102	207	62.7
	98	198	59.3
S3	70.6	158	148
	81.3	142	137
S4	32.5	12.4	30.2
	40.1	18.3	33.1
W1	48	114	37.7
	37	108	35.2
W2	23	47	39
	28	52	43

ذج ت ات ات ا : S ذج ه : W

2.1 ودراس وت ا ط ات ط ا ط :

ت ودرا ا ا و ات ا ا ا و را وا ا وا ا روو وا و ورو و
و ز آ ت ا ش ا ا ا ا ط ا را و ّ ه
ات ام ا ا ورا وم م ام موع ا . و رضت ام ا ات ك ت رت ا م ات ا را م
ا ّ درا ا ا وا ت ا ا را و :

2.1.1 ا ظ وف ا اخ :

ل دت دت درا دة ادة ال ا در ال ا دة د أل دار ودر دات ال درارة و د ة الت در ولل ردا و درت ا
وا وا ت ا و ا ا و ات ت ت ا اب ت ار وت ال ه ه لال و ات وا أل ه اف
ال ا إل أرا ال اط ال ا ال ط وال وات ال ا ول ط اء ال ت واء لل را أو ال ول
أو ا ه ا ، و . و ى ال ً ، أن ه ا ت ا ا إل ت

وا ارا ت ا ُ ع إل ا ا أ د ن ا و ب الت
ا رةا عة ه ه ا رع.

وال اول)4( )5()6 (تو ح ي ات ال ي ال ي وال ت لايا وك ا ك ا ي
ا را [7]. ل ح أل ال)6( )7(ك ا ات ا ا ا ا ة وا وا ا ا ة ام 1991م
وال نوات الت تلت ا. وال ن لال ة ن ا أن ك ا ات لك ا ال ا ة ل اق ن ال لل
إ ا وب ا ي أيها اه اط ا هي وا ي ا بي.

ول4 : ل ال ي ال ري لك ري ي ال را ب ا اق) ([7].

Total	ك1	ت2	ت1	ال ل	ا ب	ز	ا ن	ا ار	ن ن	اذار	ش ط	ك2	س
42.05	0.57	3.0	0	0	0	0	0	0.25	1.6	7.3	18.12	1 1.2	**1990**
241.4	21.75	2.1	61.65	2.9	0	0	0	0.001	14.95	32.4	39.3	56.3	**1991**
130.2		36.75	0	0	0	0	0	0.001	4.75	29.92	10.31	19.13	**1992**
163.3	3. 1	8.75	5.925	0	0	0	0	0.001	55.47	3.57	26.82	51	**1993**
132.7		38.875	18.5	0.001	0	0	0	1.37	6.325	14.3	1.12	25.1	**1994**
119.9	32.9	3.65	0	0.001	0	0	0	3.1	25.4	12.77	20.17	21 .9	**1995**

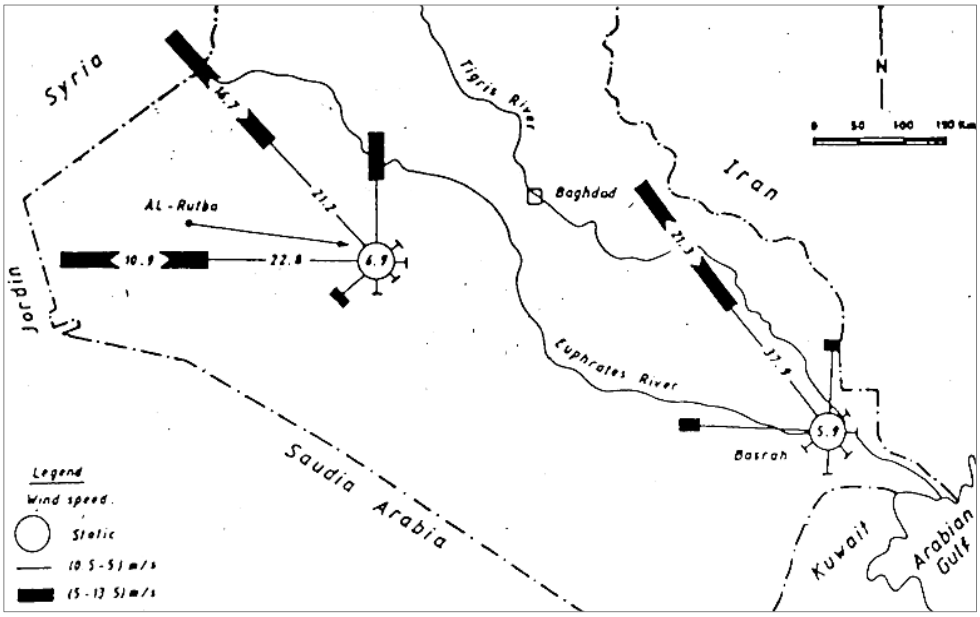
ول5 ات ا ات للر ا ال ا ة ال ل أ ر ال ة اط ال را ة [7].

ك1	ت2	ت1.	ال ل.	اب	ز	ا ن	ا ار	ن ن	اذار	ش ط	ك2	س
W	w	N W	W/N W	W/N W	NW/ W	NW/ W	NW N	NW/ W	NW/ W	NW	W/N W	**1990**
W	N W	NW	NW	NW	NW	NW	N W	NW/ W	NW/ W	W/N W	NW	**1991**

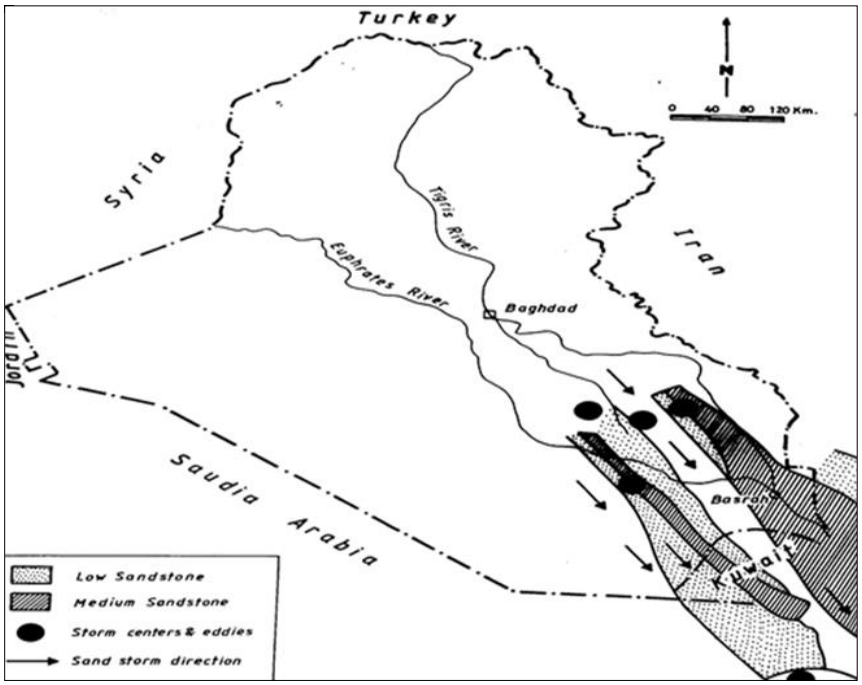
1992	NW	NW	NW	NW	NWN	NW	NW	W	NW	W	w	W
1993	NW	W	NW/W	SE/NW	NW	WNW	W/NW	NW	W	W	NW	NW
1994	W	W	W/SE	W/NW	W	W	W	W	W	NW	SE	W

ول 6 :م ل ل ا ال) م/ث(لل ات م 1990م - 1994 ا را 7.

ش / س	ك2	ش ط.	اذار	ن ن	ا ار	ان	ز	اب	ال ل	ت1	ت2	ك1
1990	2.7	3.4	4.3	4.6	5.4	6.2	5.3	5.7	4.8	3.1	2.5	2.6
1991	4.2	3.7	3.5	5.1	4.2	5.1	6.9	5.3	5.0	2.6	3.3	3.8
1992	3.3	4.1	3.4	4.2	4.3	5.8	6.9	3.7	2.6	2.4	2.6	3.3
1993	2.4	3.1	4.1	4.2	3.8	5.4	5.4	4.1	3.4	1.7	3.7	2.3
1994	3.9	3.6	3.7	3.4	4.1	5.5	5.4	5.5	2,5	2.9	4.1	3.2
Mean	3.3	3.6	3.8	4.3	4.4	5.6	5.96	4.9	3.7	2.5	3.2	3.1



ش ا ى ا ات ا ر اح اس ائ ة اط ق ا ر اس ة ب ا ر اق [7].

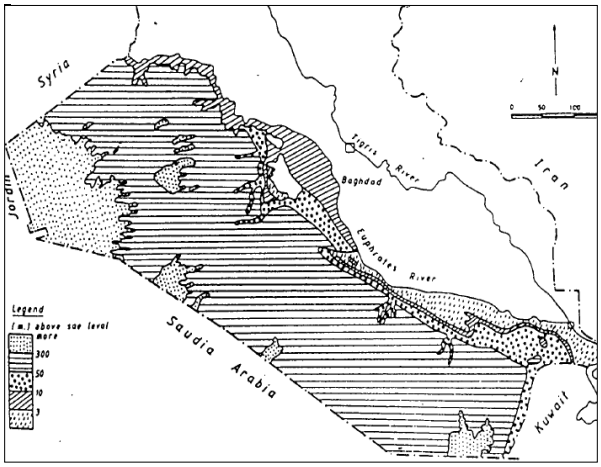


ش :7 اه ا واص ا ر ا وار اس ائ اط ا ر اس [8].

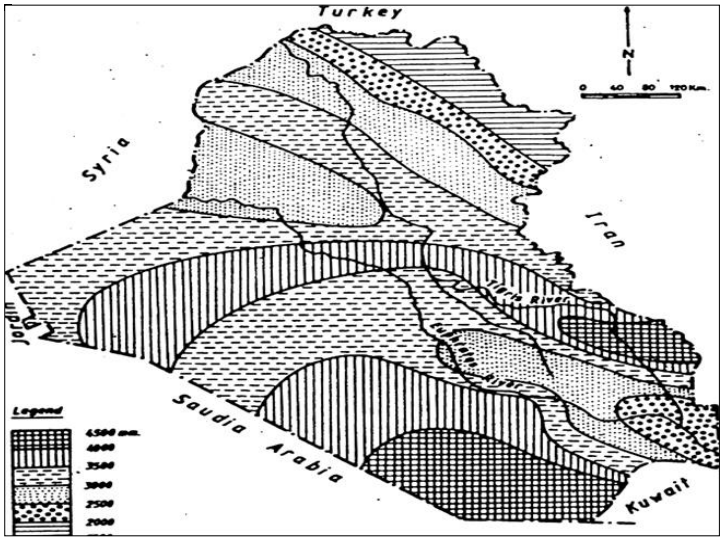
2.1.2 ل ل ات ال ا ألخ ى

دت دت در ا د ا د ا و دات وا دات و لت دار ر ا د لت ه ت د ا واد لت ا د :) و و دا
ا ط ، و ور و و اوط و ر ا ا ط ، ا ر و و و ر و و ا ا ط ، و ع ا ر
وال وا الرلي ، ل اء ال ري والتوزي ألي ا ي ل ال ر ا ، ل و ات أ ى(. وألل ال

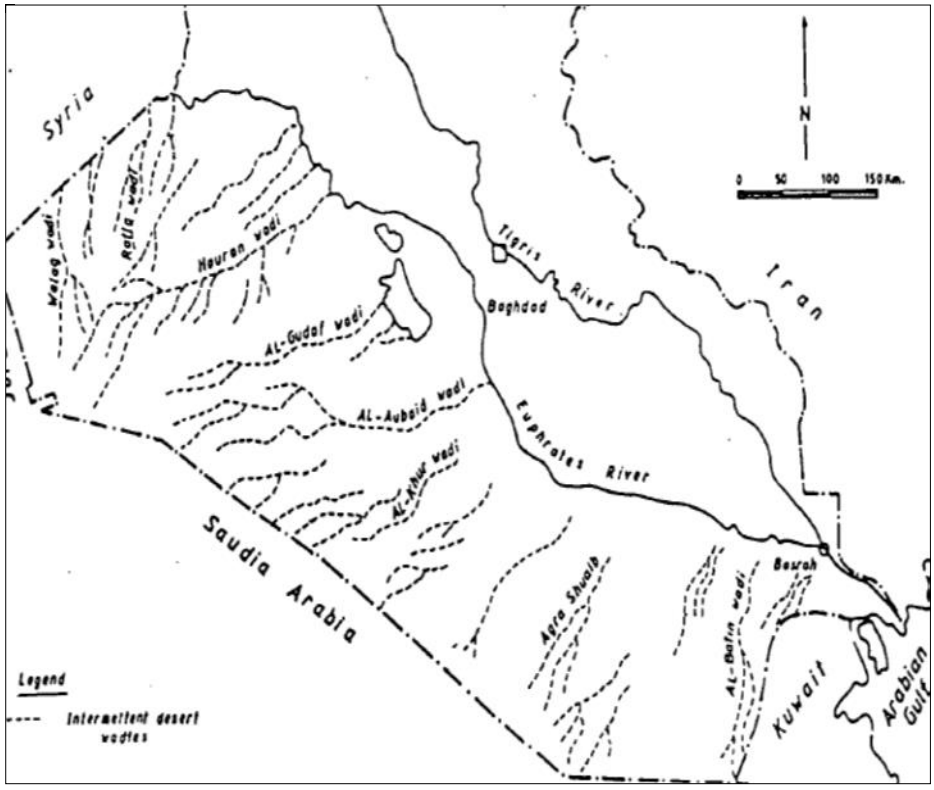
)8,9,10(ت ح ال اتـلـل ل دات الـتـد ت دت درا ت ا د ال د [9] . ا ط ا ط
و ر ا ي ا ه ا ي ط ي ا ه ا و ي و و ز ي ا ط ا ء ا ر ي و ط ي ا ر و ا ا ي ي ر ا
ت و ز ا ا ا ت ا و ك ا ج ا ت ال د ا ذ ج دول أل د د ا ف ك ل د ر ة ال د د ر ة د دور د ا أل ا د ف ـد
ا ا ت ا ر و ا ل ا ت ا ّ ا ا .



ش 8 : ا ار ط ا ط را ا راس [9].



ش 9 خ ار ط ة ني ل ق ل خ ر ل ي ي ال راق [9].



شكل 10: خارطة الوديان الرئيسية في العراق [9].

2.2 الانتشار والترسيب الجاف:

2.2.1 الانتشار الجاف:

وارتفاع معدل الانتشار الجاف في المناطق الصحراوية التي تزيد فيها نسبة الرطوبة عن 70% وتقل فيها سرعة الرياح عن 5 م/ث، وتزداد فيها سرعة الرياح عن 5 م/ث، وتزداد فيها سرعة الرياح عن 5 م/ث، وتزداد

)gm/m³(ا اء
Q: دار ا اث ا اد ا ث
ا ر)gm/s(
u : ا ا)m/s(
π: ا ا ا)3.14159(.
$\sigma_z\sigma_y$ االت االت ار والتتت
وتت ج ا ا ات لت
أل واء ال و و االت ل
.)m²(

لوف ال واء للنا عن و ود ال ا ا وأل داف ال ا ف الن : إن أ اء ال ا ف والدروع ال أن
الر م و ا راً أ (continuous source)لن اث از ال ادون
ا (Rn-222) ن الدرا . ل د اب ر ز از الرادون واء ال ب لالو ن الل
ا اد ا ا و وا از (Vibrating-reed Electrometer) [12]:

$$C_s(Z) = 5.15 \times 10^8 \times (V/R_x)P(\lambda_{R_n}T)_{exp}$$

:
$C_s(Z)$: ا ادون (Rn-222)
اء ا)Pci/ Cm³(
V: ا ا س از اس ز
ا ادون (mV).
R_x او ال وللل از(Ω) .
P_{exp}: ا ا ح ح اء
ا .
λ_{Rn}: ا لالل از ال ادون (s^{-1}).
T: ا و ا وا اس (s).

- أ س ل اث از ا ادون (Rn-222) ال اء اال اد ل ال (Ra-226)ا و ا اد ا ا [13]:

$$R_n = \lambda_{R_n} \times C_{soil\,R_a} \times \rho_{soil} \times F_r \times L_{R_n}$$

:
R_n: ل اث از ا ادون (Rn-222) .($B_q/m^2.\,s$)
λ_{Rn} : ا االل (Rn-222) ات (s^{-1}) و م ا ا ام ا اد [14]:
$t_{1/2}$: ا ة ا ّ (yr)
$C_{soil\,R_a}$: ا اد م ا .(Bq/kg)
ρ_{soil}: ا ا .(kg/m^3)
F_r: ول االن اث ل از ال ادون (Rn-222).

$$t_{1/2} = Ln2/\lambda$$

L_{R_n}: ط ل ار ا ار (Rn-222) الل ال (m) و ب L_{Rn} اد ا ا [15].
Δeff : ا ا ار (Rn-222) ات .(m^2/s)
$\rho_{soil,\,Ps}$: ا ا .

$$L_{R_n} = \sqrt{\Delta eff/\lambda_{R_n}\,\rho_{soil,P_s}}$$

2.2.2 ط ق ا ق ال ا ت ا ّ ا

ا ام إطال را م ّ (DU) ر ن 70% اإلطال و ه
أل ا د ل ل د ا ة دا ل و ول ال دف ال اب ويال ن أن 60% ن ه ه ا ا ن
أ)5(ا ون وأن ا وث ه ه ا ا وأل ا د ت لل ا ات ددة ت و
ا اد ا ا [16]:

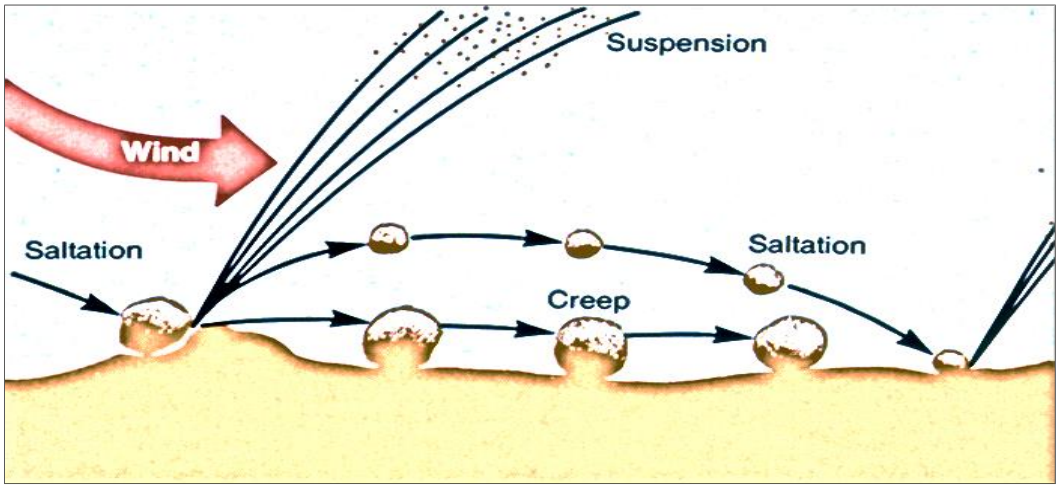
$$V_d = \frac{2GR^2(S-A)}{9C}$$

:
Vd: ا ا ا ا (cm/s).
G ال ل ألر)980 cm/s²(.
R: ا ا ا ا ة)Cm(.
S: ا ا ا (gm/cm³).
A: ا ا واء ا ا وي و ي
(1.213*10⁻³) (gm/cm³).
C: ا و ا واء وي وا و ي
(1.827*10⁻⁴) poise.
-5(أ ا ة أل اء وال ا ا دا ة
7) ل ال ف ال]10[.

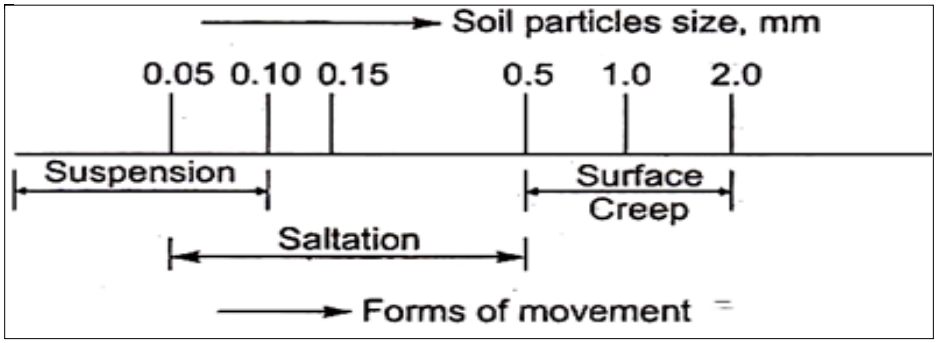
ن آل ت ال ه هلال ات ال ت تت ر ة رة ط ة ور ا ر ة و ر ة ا ر ا ا ا ة
ا ن ة، وإن ه ه ا ت ا ت اه ت ة ت ة ا و ة ه ه ا و ا ت تن ه ا ا ات ة أو
ط ا دا ّ ة ه ا و د ا وا ت، و م ن ا ل ا ت
ا ا ق ا ا :

الت ال ال ل لل ل ات ال ت (Surface Migration of Radionuclides with soil)
وذ ط [17]:
ا - ا (Saltation).
ب - ا (Creeping).
ج - ا ا اء (Suspension)

إن ان ت ال ال ت ول ل و ات إ ى ه ه آل ل ات)ال و ال ل11(ر ة رة ل ال ال ة
دا ا و و ا و ا ا ا ط ا ر ا .)ا 12(
ل ا و د ا ال ت ة ل ى ة إ دى ه ه آل ل ات ال ال ة ت ال ا وا ت ا ّ
ط ة ا ر ا ط ا اورة [18].



ش 11آل ات ات ال ت والت ل اح[17].



ا 12: ح ات ات ت تت ا اح ات ا اح أوا و أو ت[18].

د درا ا ا وا ا ا و ه ا ا ه و ر ا ر ا وا و و را
وط ا و[19] ا ان ا) 7(

ت ن أن ه ا ت ل ا ا ت ا ه ا ل ن و ل ا ر ، و ل إن ا ل ر ن ه ه ل ل و ا ت ر ت إ ل أ ل را
ا ل و ي ي ا ل وا ا ل ي ل ا ل ا ل و ي و ا ل ي أ ل ي ي ا ل ي ا ي ه ه أ ل ل .

أ ا ا ل ا د ا ل ت ا ت د د ا ا ل ت ا ل و ا ا ل ت ا ر ل ل ه ه ل ل و ا ت ا ل ت ر و ل ا ا ت ة ا ت ت
آ ل ي ة ا ل ل ي ا ل ا د ة و ا ة و و د ا ل وا ل ل ر ا ي ة ي ا ل ة و ا ل ي ي إ ل د ر ة ي ر ة ا ا ل
و ا ل ا ر ا ل و ا ء د ر د د)point source(، و ن ه ه ا ا و ن ا ر ه و
ا ا ا (Area Source)، و ا ا د)1(ا ذ ت ً ا وط
ا ل د و د ل ا آ ن ن ا ل ا ر أ ن د ل ر ل ل ر ا أ ل ر ا ض ا ا ل ن ا ل ا أ ل ر ا ل د ا د ا
ا وا ط ب ل وا) ز ا ن ف ت وز، آ ب(ا ت ب ت)6 / (7].

و إ د (Ca) إ د ا ا ت ا ً ح ا د [11]:
:

$V_d \times C_s = C_a$ ب Cs ا ا ت ح ط ا .(gm/m². s)

V_d: ا ا ا (m/s).

2.2.3 ا ل ا ت ا ّ ا (Migration through soil profile)

إن ح ه ا ت أو ا ا ّ ا الل ا ه ا (Surface runoff) التي تتر ح وت ري ين ا ات التر ال ات الأر ي الأ رى، ويج أن ه ه ال واد نا ر ي ل أل س و و ن ا ه أً، ن ا ف ه وإ ا ا التي تتم ل. ات دام م ادل ت ال لل ات) الال مل– ر (Advection – Dispersion Eq.)) ت ال ه ه لل و ات ال ت و ا ل[20]:

$$\frac{\partial s}{\partial t} + \theta \frac{\partial c}{\partial t} = \theta D_s \frac{\partial^2 c}{\partial x^2} - v \frac{\partial c}{\partial x} - Q$$

أن :

c: ا دة ا ّ ء ا (gm/cm^3).

Θ: ا ى ا ا (cm^3/cm^3).

D_s: ا ل ال ار ال ر لل ر (cm^2/h).

v: ا ح اه ا و أو ا اه ا (cm/h).

s: ة ا ادة ا و ة ا ة و دة ا (gm/cm^3).

Q: ل ال ان ن ر الل ث (gm/cm^3/h).

T: ا (hr).

x: ط ل د ال (cm).

و ض ا ا وازن ن (s, c):

$$\frac{\partial s}{\partial t} = \rho K \frac{\partial c}{\partial t}$$

: K: ا ا ز ث ا (Distribution Coefficient cm^3/g).

ρ: ا ا ا (gm/cm^3).

و ا ت ا ّ و د ال از (Adsorption) ح ا اد :

$$\theta D_s \frac{\partial^2 c}{\partial x^2} - v \frac{\partial c}{\partial x} - \lambda c = \theta \frac{\partial c}{\partial t} + \rho K \frac{\partial c}{\partial t}$$

2.2.4 ا ل ا ت ا ّ ا ه ا وا

ا ات ا ّ ه ا ط ا ل ا ا ا ا . إن ا ل ف ا ا ّ أل اف ا ا ا را م ا ّ إ أ ب ر

) ، ر، ة، إخ(و ا ر ا ا وا ادا ّ ا أو ي
اه ا ر لتر ات ا ا (Suspended load). إن ا ات ا ّ ه ا ت
و ً أو و ً (Chemical or Physical adsorption) أن ه ا ات ا و ن ً
ا ه، و ا دن ا . إن ال از ا د ا ا ات ا ّ ا ه
وا د د ا ا اد [21]:

$$K_d = \frac{\mu g/kg}{\mu g/m^3}$$:

(Distribution Coefficient) ا ا ز :K_d
ال و دة ال ة ول اء ول ة ددةل ل
ة.

أ ا ل و ة ا ادا ّ ا وا ت ألر ا ذة ا ه ا و
ا اد [22].

$$R\frac{\partial c}{\partial t} = D\frac{\partial^2 c}{\partial x^2} - v\frac{\partial c}{\partial x} - R\lambda_c$$:

R: ا ل اإل ا ي ال وي اوي : $1 + \frac{\rho K_d}{\theta}$

ρ)Kg/m^3(

K_d : ا ز)m^3/s(

Ɵ: ا ا ط)%(.

Ð ا اال ار وال)m^2/s(

c ت ا ات)gm/m^3(

x: ا ا)m(

v: ح أو ا ىء ا)m/hr(

t)yr(

λ : ا االلل)$Yr.d^{-1}$(

3.0 وا الر ا الت ال ل ل ات ال هص ر ل ال تل ال ربل :

3.1 . و ا ذج ال ا ز ا ا ّ ص ا ا (The conceptual model)

ل د و وا اد ال وذج ال ا ال و ح ال ل)5إل راء ل ا ات ت ال ول ت ار تل
ا را م ا ّ و ه أل ى ا ا و ا ا ر ا . و الل
ال ل ات ال ت ت ج ا ن ال ن ذج ال ت ا ح ا :

I. أو درع وا ا را م ّ ط ة أو ّ ا A-10 Thunderbolt.

II. إن ا ر ل م ا ا ل وع ال ا و ا) ول 7(زع ل
ار ا ا ا ف إ
د ان ر ادي إل ي ن ا ة ن ال ن ار وا راق ل وة ل ي ق و ر ل ال ر ة ال ي ة
د أن ن و ا اد)1(. أ أ اء ا وا ف ا ّ ا ي ّ و ّ ث ر م ا
ن 70% ه ه ا ا ا زع ع ا ع اع ض (5 × 8) 2 ا ا
رع ا ب ا د اً ا ف ا ي ا ي ه و أ ة ا ر ا م ا ّ
ا ا 10.

ول 7: أل ا ا ام ذ و ا ا ر ا م ا ّ ا ال ت ا ة أل 23

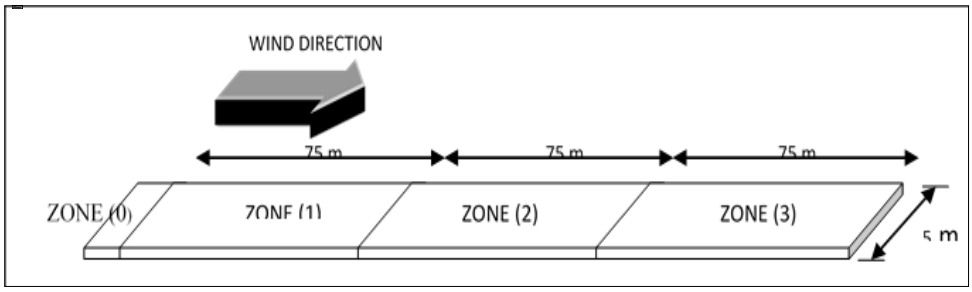
Cartridge	Caliber (mm)	Type of Weapon	DU Weight
GAU-8	30	Air Force A- 10A Thunder bolt II	300 gm
PGU-14	30	Navy Version	300 gm
M735A1	105	US Army – Tanks M1 and M60 equipped with an M68	2.2 kg
M774	105	US Army	3.4 kg
M827	120	US Army – Tanks M1, M60 and Tanks MIA1, MIA2, “abrams”	3.1 kg
M829 (E1&E2)	120	US Army – Tanks M1, M60 and Tanks MIA1, MIA2, “abrams”	4.0 kg
M829 (A1&A2)	120	US Army – Tanks M1, M60 and Tanks MIA1, MIA2, “abrams”	4.9 kg
M833	105	US Army – Tanks M1, M60 equipped by EX35-105 mm	3.7 kg

XM919	25	US Army – Bradley Fighting Vehicle	85 kg
XM900E1	105	US Army – Tanks M1, M60	10 kg
ADAM & PDM	Land Mines	US Army –155 mm howitzer	0.1gm

III. إن ا ا ّ ا و ت و ا ا
و (Environmental Pathways) :

1. ا اء – ة ا ال ة الل وث ا ة و) ادلة 1(أو
2. ا ا ا ً ا ا ف و)ا د 6(.
3. و ا ا ل ا ادا ّ إ ا ت ا ورة و ه ا ا ة ق:

- ا ا ة ا ة) ادة 6(،
- ال ، الو ، و أن ط ال نط رل لل ل االن ال ال والو وال 75% ا و ا ا ا أل رض ً ا)43.2%(ا ر ، أ ا ا ا ر ا و ر ار ادرا غ دود)75([24] ا ا ّ ط ه ا ا ة و إ ة أ ام، و ل م ا م ل أ األ وام، ال م األ ول م ل ال 1)Zone 1 (ا)13(وا ي م ت ار ا م ات ام 1991 ا م ا ا أو ا (Zone 2) وا ي م 1992 م و م 1996م ، و ل غ ض و طول ل (75m, 5m) ا ا [4].



ش 13: أ ة ح ر ة ا ر ة اس ة ا اه ا ر اح اس ائ ة ة ا راس ة [4]

4. ا ل ا ت ا ّ ا ه ف ا ل ا ا ا ا ا ا إ ا وات ا ا ة ا اورة، أو ت ر ح ا ا ر ط ر ا اه ا و ة ا ط ح ة اط إ ا ادروع) ع اد 11 و 12(أو ا اه ا و ا [6].

IV. أل ال ر ا ال ف ا ا ر ا م ا ّ أل اف ا ا ه ا ا م إ ط ل ت ا ر ا م ا ّ ا ا ،

واتالف عدد الإطال ات ل ت د لتد ر الدرع للوا د. وت ابترا للو ات ل ّ
ات ا اس µg/m2.

و ا ا اد ا ّ ا ا وا ول)7(
وع مع م ال روع أو آلل اتتم ات ام ثالث م ام ع م ت ا و ات ا و ا [25]:

A. ت ت ت 1234 آ ا را م ّ ة و .
B. ت ت 1430 آ ا را م ّ و .
C. ت ت 3060 آ ة ة ا را م ّ ة و واطئ.

لV بت ت ر ع آلل ات ال رة الت ا ة ألرا الع را ة ال 5724 آ و ء
آلل ات لت اد ت ال وات أل وال ا تد ا ل ا) ل وت(ات
ه ه آلل ات الت ده ال ش دا ا ا ة ا ا ة إ ا ة
الً وا ت) 2(، و ا ره ادر أ ر ا را
ال ات أل ات الت ال[26، 27].

و ل ن ن ان ال وان ار ه ا ت ا وا ا ا ذ ت ً
أس اس ال دف الوا د أوال رب ال ئ س ب س وى ل و)ع ، وسط، واطئ(ب أع داد الدروع
وآلل ات ال ورة أع اله ة الج وب الت راج ج وع ل ا ات الت ن و ت للت ب ة و ل
لم اه ل وال و ل مل و . إن ه ه الت ا ت ت دم ال إل اد م ام الت ت ال
ا اد ا ّ ا إ ا ت إ ا ت ا إل ن.

3.2 ت ز ا ت ا ّ ا اء وا وا ه :

و ب ا ا ا وب ب ب (BASIC) ب ا ا ا ت ا ّ ا ال ت
ا ا ذ ت ً ح ال ذج ا ال ا) ل 13(ل أل وام 1991 م و
1996 د و ال ام ال ا ل ال م ادال ت الت ا ل ال ا وث ا وا اه ا ا ه ا آ
ال ر ت ا ا أل و ا ر ع ا و و ا دة ا ّ ا دة
ال وال ا ل و ل ل ا و ل إد ال لو ات الت) ا ، ل ال (وت
ا و ا ا ا)ا وا و (وا أ ي، و ا ا ا و
ا ا ا ا ة، ب ا ادا ا ّ ا ً ا ر)ا 0(إ
ال اط رار ه ه ال ط ة ل ة آ ر ا ال ار ر ال را ال ر. و ال اول)8,9,10(
ا ا ادا ا ّ ا ات (µg/m2) ال ا ة أل اف ال ة ا) ل ة،
و طة، واط ة(و ل ال وال . أ ا ة ال اه ل ل و ة ر رة ل ة أل طار ل ا ط ة ل
ال ط و ل ط ع ل ت ر ل ل و و ات ه ا. ا ع و وع ل ه ه ال لو ات إل أل اه ار ول ط ات
ا أو إ ا ه ا ا ا دة ً ا ه ا أو ح
إل ال ات أل ر . و ال را ات ال ا ل ا ار 4.2% أل ار ل ا ل
إل ول ن ا ل ال ن وظ و ا ال ن ا وأن وال 26.3% ه ه أل ار ر ح ل ل اه ال ه [6].
ً أن إل (Retardation Factor) ت ا ّ ا ا وا ي

و ه ا ةً. و ا د)12(ا ث ا ه د ً ا ل ا
ال ول)11(وا ا ت ا ّ ا ا ه ا وا [6]

ول8: ا ات ا را م ا ّ ا ا ف ى ث (µg /m^2)[5]

ا	1991	1992	1993	1994	1995	1996	ا (m^2)
0	3.62*10^9	3.31*10^9	3.03*10^9	2.77*10^9	2.53*10^9	2.32*10^9	8
1	4.9*10^6	8.97*10^6	1.23*10^7	1.5*10^7	1.72*10^7	1.9*10^7	375
2	755.65	5.7*10^5	1.3*10^6	2.15*10^6	3.1*10^6	4*10^6	375
3	251.9	249.5	8.3*10^4	2.12*10^5	3.9*10^5	6.1*10^5	375
4	151	148.3	146.4	1.35*10^4	3.7*10^4	7.3*10^4	375
5	94.5	92.6	91.2	90	2.35*10^3	7.7*10^3	375
6	65	63.4	62.3	61.4	60.58	4.3*10^2	375
RS1	38.7	37.9	37.23	36	35.2	34.4	2925
RS2	7.18	7.03	6.85	6.68	6.54	6.4	45000
RS3	0.173	0.17	0.165	0.162	0.157	0.154	250000
ا ا ات ا وا و (m^2)	383	758	1133	1508	1883	2258	
ا ا ت ا وإ ادة ا س (m^2)	299800	299425	299050	298675	298300	297925	

ا ا ا ف وا (m^2)	300183	300183	300183	300183	300183	300183	

RS1:) (ف ا (415-1000) ألرا
RS2:) (ف ا (1000-10000) ا ألرا
RS3:) (ف ا (10000-60000) ا ألرا

ول9 : ا ات ا را م ا ّ ا ف ى ($\mu g /m^2$) 5

ا	1991	1992	1993	1994	1995	1996	Area (m^2)
0	$1.92*10^9$	$1.75*10^9$	$1.61*10^9$	$1.47*10^9$	$1.34*10^9$	$1.23*10^9$	8
1	$2.59*10^6$	$4.75*10^6$	$6.52*10^7$	$7.95*10^6$	$9.12*10^6$	$1.01*10^7$	375
2	400.5	$3.02*10^5$	$6.89*10^6$	$1.14*10^6$	$1.64*10^6$	$2.12*10^6$	375
3	133.5	132.24	$4.4*10^4$	$1.12*10^5$	$2.07*10^5$	$3.23*10^5$	375
4	80.03	78.6	77.6	$7.16*10^4$	$1.96*10^4$	$3.87*10^4$	375
5	50.085	49.08	48.34	47.7	$1.25*10^3$	$4.08*10^3$	375
6	34.45	33.6	33.02	32.54	32.11	228	375
RS1	20.5	20.1	19.73	19.08	18.66	18.23	2925
RS2	3.8	3.73	3.63	3.54	3.47	3.4	45000
RS3	0.092	0.09	0.087	0.086	0.083	0.082	250000
ا ا ا ات	383	758	1133	1508	1883	2258	

(m²) و							
ا ا ات ا وا ادة ا (m²)	299800	299425	299050	298675	298300	297925	
ا ا ف وا (m²)	300183	300183	300183	300183	300183	300183	

RS1:) (ف ا (415-1000) ألرا ا
RS2:) (ف ا (1000-10000) ألرا ا
RS3:) (ف ا (10000-60000) ألرا ا

ول10:ا ات ا را م ا ّ ا ا ف ى ث (µg /m² [5]

ا	1991	1992	1993	1994	1995	1996	Area (m²)
0	2.17*10⁸	1.99*10⁸	1.82*10⁸	1.66*10⁸	1.52*10⁸	1.39*10⁸	8
1	2.94*10⁵	5.38*10⁵	7.38*10⁵	9*10⁵	1.03*10⁶	1.14*10⁶	375
2	45.34	3.42*10⁴	7.8*10⁴	1.29*10⁵	1.86*10⁵	2.4*10⁵	375
3	15.114	14.97	4.98*10³	1.27*10⁴	2.34*10⁴	3.6*10⁴	375
4	9.06	8.898	8.784	810	2.22*10³	3.38*10³	375
5	5.67	5.556	5.472	5.4	141	462	375
6	3.9	3.8	3.738	3. 68	3.635	25.8	375
RS1	2.32	2.274	2.234	2.16	2.112	2.064	2925
RS2	0.431	0.422	0.411	0.4	0.392	0.382	45000
RS3	0.0104	0.0102	0.001	0.0097	0.0094	0.0092	25000

ا ا ات ا واو (m^2)	383	758	1133	1508	1883	2258	
ا ا ات ا وا ادة (m^2)	299800	299425	299050	298675	298300	297925	
ا ا ف (m^2)	300183	300183	300183	300183	300183	300183	

RS1:) (ف ا (415-1000) ألرا ا
RS2:) (ف ا (1000-10000) ألرا ا
RS3:) (ف ا (10000-60000) ألرا ا

ول11: ع ألرا ا را م ا ة)1996-1991 [25].

		ا					
		1991	**1992**	**1993**	**1994**	**1995**	**1996**
ع ا ا)m²(	**A**	472622	935372	1398122	1860872	2323622	2786372
	B	164690	1083940	1620190	2156440	2692690	3228940
	C	1171980	2319480	3466980	4614480	5761980	6909480
	D	$1.716*10^9$	$1.714*10^9$	$1.712*10^9$	$1.71*10^9$	$1.707*10^9$	$1.705*10^9$

A: ف ي يف ي ف ي ا ا ث ا ا **B:** ا ث ا ا ي ف ي ي ا

C: ف ي يف ي ف ي ا ا ث ا ا **D:** ت ث ا ا آ ت ا ا ت ا ّ اء اف أل اف ال ر ا ال را م ا ّ ط ا را

**3.3 ا ا اد م ا د ا ا اغ)40ك/ل (ل : ا ا ا

- إن ا ه ا اد ا ّ ا ا ت ا ط ا ل أل ام)1991-1996م( )423318م^3(ا روع ا رة را ع ا ة و)490591م^3(ا روع ا ة ا و و)972194م^3(ن ا روع ا رة را واطة،وع ذ ن وع ا اه ا و ة الت و ل ت ال ط ات ال ا ط ال ول ل ت)1,886,103م^3([6].
- إن ت ا ت ا ّ ا و ه ا وا ا ول) 11 (ا ا ذات أ وال أ ا إل ا ه ا ا وا ؤ ال ل إل ا ا ل األ دص اص (Adsorption) ات ت ، و رور ا و و ا إى ات أ ى ت ل ل ت والت ادل األ و تت ل ه ه ال و دات إل ال ياه ال وي األ م أوي م ي ا ي األ ال ي ال ي و م وم ل اءل ي ي ال م م ل األ اء األ ل ل ل ال ا ون ا إل ن ان.
- إن ا ت ا ّ ا ا ت ا ل أو ا ّ ا ا ا ات ا ا أ اء ا وا ا وت ا ت ت ه ه ا وات ا ا ا ور ل ب ر و ل رب وود ان اه األ ار ل و ان ب ل غ وال)14(أ ً ، و ذ ا ات ت وث دروع د رة ذائ ذات تر ع ا ، ت و ط، واطئ و ذ ا ا ّ (Ra-226, U235, U238).

4.3 ر ا ا ا ا ات ا ّ ا م 1996م ط إ ا ت ا و ات ال تر ة ال و ة ال ورة ول) 2(ووو أن ال ن اط إل ا ر م – 214 ا ي ي م اط ي ر ي م- 238 ا 0 ب ا ب ل ة ا رة ارب ا ا ي ا ي ا ي أ ي ي ا ا .

5.0 ا س ت ت ا ات :

5.1 أ ارت ا ا ر ا (Mathematical Modeling) ال ل ا ت ا ّ ط ال ت ة ال ة ال ة ا ت ت ا ات ة ال ا ال ت ادة ا ا ت د ر أل رار ال ة ل ت ل ل ا ال ا ال وال ت ه ل ل ه ه ال ا ل ت، و ل إل إ اء ال ال ات ال ا ل ت ا ه ه ا وث ات و إ اء ا ا وث ا و وا ت ت ت ا ا.

5.2 إ ا ات ل ال ل ل و ن ال ت ول ل ت ال ول ل ا ن ل ال ن ل ا)1718(أ)0.25%(ا و ا ا و)0.5%(ً ا و)99.25%(و ا واط . إن ا ا ا و ا و و ط غ وا)12.9 ² و)1(ر و در ر ال ن اث از ال رادون (R_{n-222}) ي ي ن ا اط ن .

5.3 ن ال ن اط ل ا ل و ا و ن و ات ل ال ل ال ا ور ل وم ال ّ ا در ث ة)continuous area source(، أل ح ا ا ا ر ا ا رض ال ان وال ة ال ا ة ل ر ات ا ا ة اض ا ة تر ن ت و ات ال ت ال ور ق ال ا ة أل راض ا ا ا ا ع ا ث.

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