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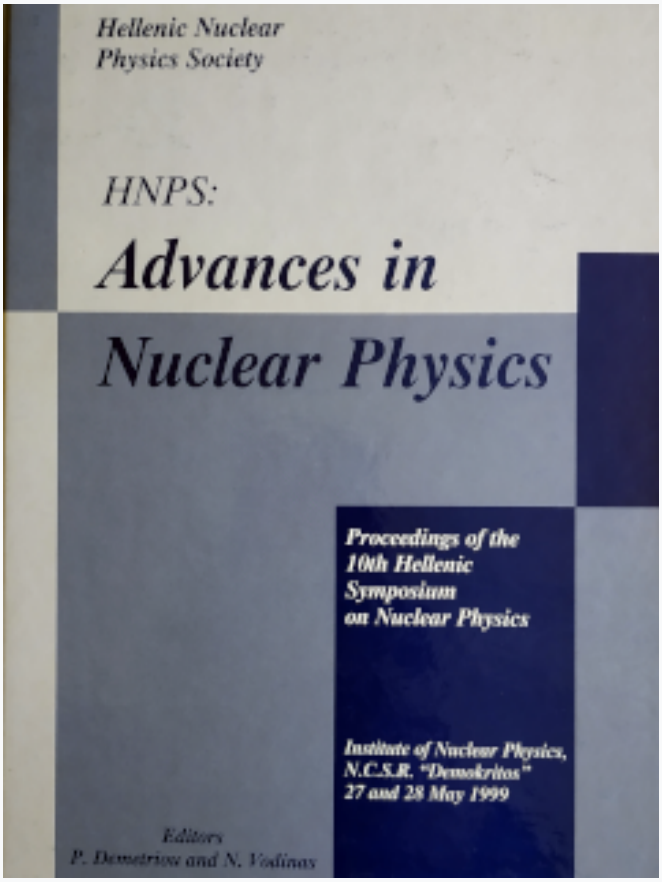

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Abstract

In recent years a new type of ammunition has been included in the modern arsenals of Western countries. Depleted Uranium is used in the A10's 30-mm gun and in a large variety of other projectiles used by Army, the Marines and Aviation. Due to the radioactive nature of this type of ammunition, it is important to know the distance of dispersion of the material produced. On account of its probable usage some hundred of km north from Greece we are interested in the evaluation of its impact on Greece. We assumed an amount of DU, equal to that daily released during the Gulf War, as being released in South Yugoslavia (Pristina). We examined the possibility of its transport to Greece at a distance more than 150 km far from the release point. For concentration, deposition, dose estimations and health effects evaluation COSYMA code is used. We assumed constant north winds of 5 m/s of speed, no rain, a mixing height equal to about 1000 m and D atmospheric stability conditions. Moreover taking account of the real wind situation during March and April 1999, we calculated the probable impact of daily releases, on selected days, to regions of Greece affected by air masses movement. The results indicate that in spite of the big amount considered as released in a single site, in no cases there has been found any appreciable radiological health effect.

1 Introduction

Depleted Uranium (DU) is a by-product of the enrichment of natural uranium in U-235, to use as a fuel in nuclear reactors and for nuclear weapons production. The remaining DU, is therefore poor in U-235 and rich in the other isotopes of U. It consists of about 0.2% U-235, 99.8% U-238 and of a negligible quantity of U-234. It is a dense and heavy metal and rusts when exposed to air. In projectiles it is often used in alloys with other metals, as titanium and it is put in aluminum shells.

As reported in textbooks [1] uranium is a highly toxic element on an acute basis and a recognized cancerogen [2]. The high chemical toxicity of U results in kidney damage, and acute necrotic arterial lesions. The rapid passage of soluble uranium compounds through the body tends to allow relatively large amounts to be taken in. The high toxicity effect of insoluble compounds is largely due to lung irradiation by inhaled particles. This material is transferred from the lungs of the animals quite slowly. U-238 is slightly radioactive. It emits beta and gamma radiation but it is mainly an "alpha" emitter. This is an important property because in case it is not inhaled or eaten, it is easily avoided by people if protected by clothes and gloves. In case it is inhaled it can be retained in the lungs. So its short range and high ionization may seriously damage the lung tissues. If shallowed it can be retained in the kidneys and damage them. Uranium is generally referred to as combustible metal because the ease of ignition of thin sections and fine particles or as a molten metal. Uranium scrap from machining operations is subject to spontaneous ignition [3]. Impact of DU munitions can produce shrapnel and dust which easily burns. It is therefore a precious material for ammunition construction. A fairly extensive report about properties, history, development, tests and effects of Depleted Uranium ammunition used in the Gulf War can be found in the U.S. Department of Defense site: http://www.gulflink.osd.mil/du/index.html. Relative information is also given in address: http://www.pica.army.mil/orgs/fsac/sad/1995/sepoct/art4pg1.html.

Using relations for the maximum horizontal distance from [4, 5] it has been calculated that fragments and dust could reach a maximum distance equal to about 700 m. Most of the fragments do not travel the maximum distance, but fall at distances between 0.3 and 0.8 of the maximum. Generally uranium presents a high explosion hazard by violently reacting with air [6]. As a result of the explosion heat is produced. This can cause a more violent and immediate DU fire. It is assumed that the majority of the uranium contained in munition burns following the impact and the subsequent explosion, producing smoke contaminated by mainly insoluble oxides of Uranium. Owing to the violent explosion, it is further assumed that a big number of the particles generated from the fire are small enough to be caught up in the thermal currents produced by the fire. Contamination thus arises, and depending on the atmospheric conditions it may disperse relatively far away from the impact point, contaminating soil and water and get inhaled by human. In the present work only the atmospheric dispersion is considered.

Pristina, located at the southern part of Jugoslavia (42° 40′ N, 21° 09′ E), 183 km from the nearest, northern, border of Greece, 270 km from Thessaloniki, 354 km from Larissa in the middle of Thessaliki plain and 565 km from Athens, the capital with about 3.5 million inhabitants, is the assumed site of release.

Consequence estimations are performed using the PC COSYMA [7,8] accident

Table 1
Upper limits of the distance bands (km)

1	5	20	40	60	100	150	170	190	250	290
350	370	530	590	610	700	740	800	900	1000	

consequence assessment code. Calculations of potential off-site consequences of the atmospheric releases of radioactive material, for the postulated accidents, are performed. The code simulates the progression of the released radioactive cloud and predicts its interaction with and influence on the environment and human beings. Recent Greek demographic data have been used.

2 Data used

Because of the luck of source data it has been assumed that a daily amount of U-238 equal to that used in the Gulf War on 1991, as reported in the literature (U.S, Department of Defense site), is released in Pristina. The scenario considered is very conservative because the total source is released in a single site. On the basis of the above reference, it has been assumed that 70% of the DU contained in the projectiles is transformed in small particles that oxidize and burn, which is the worst scenario found in the literature. There is an uncertainty about the size of the aerosols. Various tests exist giving different size distributions. Here it is assumed that 70% of the aerosol particles have diameters less than 10 μ, which is the maximum size for inhalable particles. So, taking into account that approximately 322 tons of DU have been released during 200 days in Gulf war [9], it follows that the daily release is equal to 9.725 E+9 Bq. Owing to code limitations all the amount has been released in six hourly and consecutive phases. Twenty one population bands, (see Table 1, have been considered up to a distance of 1000 km from the release point. The demographic data utilized are those of the 1991 national census of Greece, which for the area in study amount to about 10.244.042 inhabitants [10].

Two cases have been analyzed. Case 1: Calculations have assumed constant north winds (358°) of a speed 5 m/s (light winds), no rain, a mixing height equal to about 1000 m and D atmospheric stability conditions This constant direction would bring the cloud directly over Athens.

Case 2: In this case realistic weather conditions prevailing during the period in question have been used. Using HYSPLIT4 code [11] the movement of air masses during March and April 1999, at 00.00 and 12.00 UTC releases, have been examined. Table 2 reports the days during which Greek territory is affected by air masses originated at Pristina. Only trajectories spreading in the boundary layer have been considered.

Mixing heights have been estimated on the basis of their relation with atmospheric stability as shown in Table 3. These are PC COSYMA values slightly modified in order to take into account the weather conditions in southern Europe. For hourly stability categories the mean hourly values for Athens [12] have been used.

The most severe case is that of the 5/4/99 release, which arrived relatively early on 6/4/99, in the Greek territory, and remained for several days. Fig. 1 presents the trajectory for six days of a unitary mass, released at 12 UTC of 5/4/99 at Pristina.

The atmospheric dispersion and deposition model used by PC COSYMA is the so called "segmented plume model" MUSEMET which is an extension of the conventional straight line Gaussian plume model with regard to changing weather conditions, especially, wind direction [13]. Changes of wind direction are taken into account by turning the axis of the plume at the beginning of each time interval (1 hour). The model does not account for aerosol dynamics (agglomeration etc.).

The application considered injuries by inhalation only. Ingestion has not been included. No mitigation actions (countermeasures) have been taken into account. Short term doses are calculated for an integration time of 365 days. Cancer ICRP-60 risk factors have been used and the effective dose has been calculated according to ICRP-60 [14]. The dose integration time for skin contamination is 7 days. PC COSYMA default values have been used for the rest of the parameters.

3 Results

The results calculated include air concentration, ground deposition and individual doses. The consequences for the population of Greece of the above postulated release scenario from early and chronic exposure have also been estimated. The health effects considered include individual and collective population doses, cancer fatalities and injuries and risks from cancer death and cancer injury. For the calculation of both early and late effects, individual doses and risks, cloudshine, groundshine, inhalation, resuspension and skin and clothing irradiation have been taken into account.

In Table 4 mean and maximum air concentration and individual long term effective doses at various distances from the release point are reported for the two cases considered. Maximum values in the second case refer to the plume centerline path. We observe that at a distance of 180 km, the dose is low and well under the permissible limits. The activity concentrations on the ground (Bq/m^2), can be found by dividing air concentrations by 10^{-3}.

Table 2
Movement of surface air masses from Pristina towards Greece after 24/3/99 to 30/4/99. Only surface trajectories are considered.

Date of the release	Date of arrival in Greece	Locality	Days afte release
27/3/99 - 12 UTC	1/4	West Peloponissos	6th
28/3/99 -00 UTC	1/4	Ionia islands, South Peloponissos	4th
	2/4	Kriti	5th
29/3/99 - 00 UTC	30/3 morning	Ionia	2nd
	31/3	South of Crete	3th
29/3/99 - 12 UTC	31/3	Ionia ,West Sterea, North Peloponissos	3rd
	1/4	North Peloponissos	4th
	2/4	North Dodecanisa	5th
30/3/99 - 00 UTC	31/3 evening	Ionia islands - West Sterea	2rd
	1/4	Sterea - North Peloponissos	3rd
	2/4	Sterea- Central Aegean	4th
	3/4	North East Egeo	5th
30/3/99 - 12 UTC	1/4 early morning	Ionia islands- West Sterea-Central Sterea	3rd
	2/4	Central Greece-North Central Aegean, Sporades	4th
	3/4	North Sporades -East, north Aegean	5th
1/4/99 - 00UTC	3/ 4 early morning	Central Macedonia Thessaloniki	3rd
	4/4	Epirus,West Macedonia, West Peloponissos	4th
	5/4	West Sterea- Peloponissos	5th
1/4/99 - 12 UTC	3/4 morning	Central Macedonia Thessaloniki	3rd
	4/4	West Macedonia- Ipiros	4rd
	5/4	West Sterea- Peloponissos	5th
2/4/99 -00 UTC	3/4 middle day	Central Macedonia	2nd
	4/4	Western Macedonia	3rd
	5/4	Etolo -Acarnania	4th
	6/4	West Peloponissos	5th

2/4/99 - 12 UTC	4/4 end of the day	Florina, West Macedonia	3rd
3/4/99 - 00 UTC	5/4 afternoon	Ionia islands	3rd
	6/4	Ionia islands	4th
3/4/99 - 12 UTC	5/4 afternoon	Ionia islands	3rd
4/4/99 - 00 UTC	6/4	Ionia islands	3rd
	7/4	West Kriti	4th
4/4/99 - 12 UTC	6/4 middle day	Epirus	3rd
	7/4	West Sterea, Sterea	4th
	8/4	Sterea, Central Aegean	5th
	9/4	Central and North Aegean	6th
5/4/99 - 00 UTC	6/4 middle day	Florina,West Macedonia	2nd
	7/4	West Macedonia, North Aegean	3nd
	8/4	North Aegean, Eastern Thrace	4th
5/4/99 - 12 UTC	6/4 evening	Florina, Western Macedonia	2nd
	7/4	Western Macedonia Central Macedonia, North Aegean	3rd
	8/4	North Aegean, Thrace	4th
6/4/99 -00 UTC	7/4 middle day	Central and Eastern Macedonia	2nd
	8/4	Central Macedonia-Eastern Thrace	3rd
19/4/99 - 00 UTC	20/4	Eastern Thrace	2nd
	21/4	Eastern Thrace	3rd
19/4/99 - 12 UTC	20/4	North eastern Macedonia	2nd
23/4/99 - 12 UTC	27/4 middle of the day	Western Macedonia	5th
24/4/99 - 00 UTC	28/4	Western Macedonia, Thessalia	5th
24/4/99 - 12 UTC	27/4 early morning	Central Macedonia, North Aegean	4th
	27/4	North Aegean	5th
25/4/99 - 00 UTC	27/4 morning	Central Macedonia	4th
	28/4	North Aegean	5th
25/4/99 - 12 UTC	27/4 morning	Central Macedonia-Eastern Thrace	3rd
	28/4	Thrace	4th

Table 3
Mixing heights with stability category

Category	Mixing layer depth (m)
A	1600
B	1200
C	1000
D	800
E	320
F	200

According to ICRP 60 [11] the individual whole body dose per year should not exceed 1 E-03 Sv per year (50 E-03 Sv for 50 years). Our results give values well below the permissible limits. For comparison, the average radiation exposure to a member of the population from background radiation is 2.4 E-03 Sv (250 mrem) per year [14]. For Greece, our results are many times smaller than the background radiation.

4 Conclusion

As Greece is quite far away from the considered release point, in southern New Yugoslavia, no health effects have been found for the described accident scenaria. Given that U-238 is the heaviest natural metal, it deposits, as expected, relatively close to the source. Very low air concentrations and depositions have been found at medium range distances. The closest borders of Greece are at about 183 km from Pristina. So, the results indicate that in spite of the big amount of U-238 considered to be released in a single site (Pristina), the radiological impact on Greece is extremely low.

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Table 4
Mean and maximum air concentrations in the air near ground (Bq s/m^3) and total effective dose (Sv in 50 years), for general case and for release on 5/4/99 case with distance (km).

Dist.	Case 1			Case 2		
	Plume Concentration		Effective dose 50 years	Plume Concentration 5/4/99, 12 UTC release		Effective dose 50 years
	Mean	Maximum		Mean	Maximum	
0.5	7.80 E+03	1.03 E+05	9.750 E-06	1.32 E+04	1.34 E+05	1.650 E-05
3.	4.15 E+02	6.60 E+03	5.186 E-07	4.63 E+03	6.55 E+03	5.790 E-07
12.5	4.19 E+01	6.71 E+02	5.238 E-08	9.79 E+01	1.50 E+03	1.223 E-07
30.	2.03 E+01	3.24 E+02	2.533 E-08	5.29 E+01	8.41 E+02	6.613 E-08
50.	1.32 E+01	2.11 E+02	1.647 E-08	3.50 E+01	5.59 E+02	4.370 E-08
80.	8.64 E+00	1.38 E+02	1.080 E-08	2.29 E+01	3.66 E+02	2.860 E-08
125.	5.80 E+00	9.28 E+01	7.245 E-09	7.02 E+00	1.11 E+02	8.768 E-09
160.	4.61 E+00	7.38 E+01	5.758 E-09	4.27 E+00	6.66 E+01	5.331 E-09
180.	4.15 E+00	6.64 E+01	5.181 E-09	4.16 E+00	6.45 E+01	5.192 E-09
220.	3.44 E+00	5.51 E+01	4.303 E-09	4.27 E+00	6.50 E+01	5.332 E-09
270.	2.81 E+00	4.50 E+01	3.510 E-09	3.86 E+00	5.59 E+01	4.824 E-09
320.	2.37 E+00	3.79 E+01	2.962 E-09	2.65 E+00	3.25 E+01	3.307 E-09
360.	2.11 E+00	3.37 E+01	2.634 E-09	1.95 E+00	1.71 E+01	2.434 E-09
450.	1.67 E+00	2.68 E+01	2.091 E-09	2.72 E+00	1.99 E+01	3.394 E-09
560.	.32 E+00	2.12 E+01	1.655 E-09	1.77 E+00	1.04 E+01	2.210 E-09
600.	1.23 E+00	1.97 E+01	1.534 E-09	1.19 E+00	6.72 E+00	1.483 E-09
655.	1.11 E+00	1.78E+01	1.391 E-09	6.59 E-01	3.39 E+00	8.235 E-10
720.	1.00 E+00	1.60E+01	1.249 E-09	4.33 E-01	2.90 E+00	5.416 E-10
770.	9.26 E-01	1.48E+01	1.156 E-09	3.60 E-01	2.49 E+00	4.498 E-10
850.	8.24 E-01	1.32E+01	1.030 E-09	2.76 E-01	1.92 E+00	3.452 E-10
950.	7.19 E-01	1.15E+01	8.983 E-10	1.93 E-01	1.58 E+00	2.411 E-10

Figure 1. Trajectory of unitary mass released on 5/4/99, 12 UTC, at Pristina, for 120 hours (From Ready System of HYSPLIT4, 1997)