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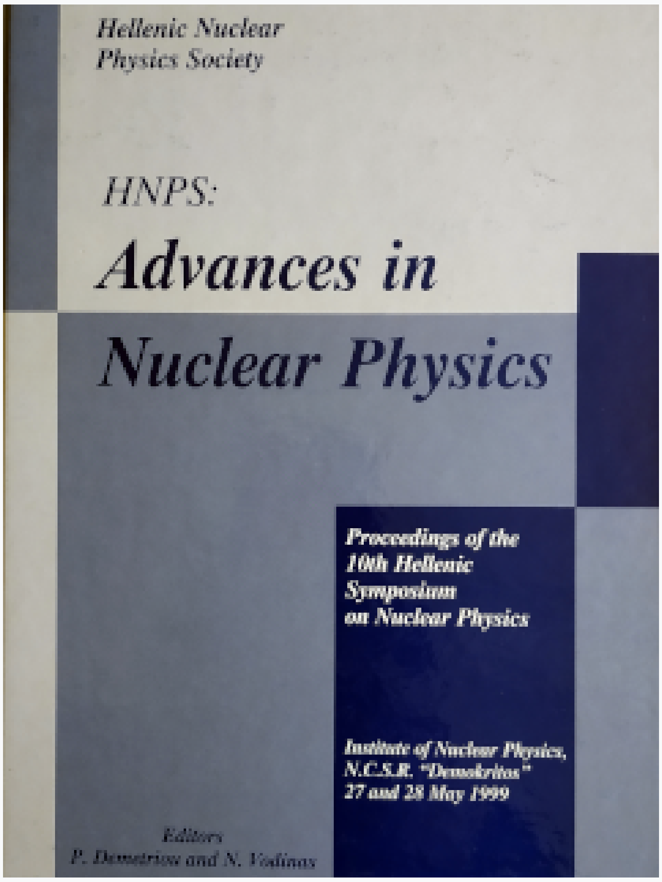

Assessing the risk from the depleted uranium weapons used in Operation Allied Force

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Abstract

The conflict in Yugoslavia has been a source of great concern for the neighboring countries, about the radiological and toxic hazard posed by the alleged presence of depleted uranium in NATO weapons. In the present study a worst-case scenario is assumed mainly to assess the risk for Greece and other neighboring countries of Yugoslavia at similar distances . The risk of the weapons currently in use is proved to be negligible at distances greater than 100 Km. For shorter distances classified data of weapons composition are needed to obtain a reliable assessment.

1 Introduction

Operation Allied Force (OAF) has been going on for weeks in Yugoslavia with certain environmental consequences for the neighboring countries. Unfortunately, the sophisticated weapons that are being used carry the spectrum of radiological contamination. Over the past decades there has been a tremendous effort in weapons laboratories to use depleted uranium (DU) in conventional weapons in order to enhance their penetrability or to strengthen armor panels (tanks, artillery etc.). Depleted uranium is used in a number of armor-piercing anti-tank munitions, such as those aboard American A-10 Warthog jets and Apache helicopters, and M-1 Abrams and Bradley tanks. US. and Allied forces fired approximately 315 tons of depleted uranium[1] during the Persian Gulf War. Yugoslav state news media have referred to "radioactive bombs" being launched by NATO. There is a strong likelihood that the weapons referred to are composed of depleted uranium (DU). Its ability to self-sharpen as it penetrates armor is the main reason why tungsten, which tends to mushroom upon impact, has been abandoned. Neverheless, the high temperatures caused

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by the high explosives (HE) detonated in the weapon or the friction between the ammunition and the target (armor, concrete....) lead to the generation of uranium oxides which along with the tiny fragments of the weapon case pose a serious radiological hazard to living beings. So far no measurement has shown any increase in the environmental radioactivity either in Yugoslavia or in Greece. As for the first claim one has to rely on the local scientific community to detect and assess the contamination. However, as there has been severe censorship on every sort of information by the Serbs, and most likely by the NATO officials, the scientific community should independently attempt to reliably verify and assess the possible implications of DU that have allegedly been dropped in the Balkans. Until some counter detects the contamination the only resort available are theoretical hazard prediction through computer simulations . By applying a worst case scenario, an initial emergency assessment , or safety analysis planning is possible. Although, precise data about the performance and the composition of these weapons are classified, in a worst case scenario one can use the available declassified data which can still yield the magnitude of the hazard and trigger an appropriate emergency planning and response. In the present work a very reliable computer code has been used which simulates explosions where nuclear material is involved. The code is "HOTSPOT"[2] produced in the well known US weapons laboratory: Lawrence Livermore National Laboratory by S.G.Homann. It is a very effective Gaussian plume model suitable for radiation risk assessments. Throughout the present work basic information is given about fundamental radiological properties or weapons characteristics. This is imperative as the results presented here are expected to be of interest to non-experts, as well.

2 NATO weapons overview in OAF

A thorough analysis of the weapons used by NATO against Serbia[3] indicates that some of them are specially designed to penetrate hard targets . Despite the fact that the precise composition of those missiles is classified there are some very strong arguments that point out to the use of DU in the missile casing.

a) Yugoslav state news media have referred to "radioactive bombs" being launched by NATO [4].

b) The Tomahawk currently in use is Tomahawk Block III with improved target penetration [5]. The only material that can improve target penetration nowadays is DU.

c) No data exist whatsoever about the composition of the Tomahawk high density penetrator which raises an eyebrow about the motives of this secrecy.

For example the US DoD has openly declared the DU as the main component of the penetrator of other weapons such the rounds of the AN/GAU-8 30mm Avenger seven-barrel gatling gun, mounted (only) on the A-10 attack jet.

Some very penetrating weapons used in the current war are [7]:

Tomahawk missile. An all-weather submarine or ship launched land-attack missile. It is been used to attack a variety of hard fixed targets , which explains why the missile has to be extremely penetrating (which makes it a DU sucpect). During the war in the Gulf, 288 missiles where fired (II generation) while so far more than 1000 (III generation and probably some experimental of the IV generation) are believed to have struck targets in Serbia and Kosovo. That highly sophisticated weapons carries a single conventional warhead or submunitions of 500 Kg of high explosives (HE). The BGM-109 model weighs 1192 Kg, has a length of 5.56 m, and a diameter of 51.8 cm (without the booster). A rough estimate of the typical weight of its airframe is 400 Kg [8]. Besides, in the same category we have to include the Air Force's Conventional Air Launched Cruise Missile CALCM . CALCM used to carry nuclear warheads and has been converted to conventiona weapons. It may have been fortified with DU to withstand the blast of anti-missile defences of the FUSSR. In any case, in a worst-case scenario, it must be considered a DU carrier though the US DoD is rather convincing when it speaks of a cylindrical Aluminum and Titanium case for the following reason: If we assume that the whole frame is made of DU (uniform density) then the geometry of the missile yields a 1.1mm skin of the airframe while the Aluminum assumption yields a 8.2 mm width which is more reasonable than the first result. The positive aspect of that weapons is that sample fragments of its casing, scattered in the vicinity of the explosion, may reveal its composition.

BLU-107 Durandal .The Durandal anti-runway bomb was developed by the French company MATRA, designed solely for the purpose of destroying runways. Once the parachute- retarded low-level drop bomb attains a nose-down attitude, it fires a rocket booster that penetrates the runway surface, and a delayed explosion buckles a portion of the runway. It can penetrate up to 40 centimeters of concrete, creating a 200 square meter crater causing damage more difficult to repair than the crater of a general-purpose bomb.

BLU-109/B. The BLU-109/B (I-2000) is an improved 2,000-pound-class bomb designed as a penetrator without a forward fuze well. Its configuration is relatively slim, and its skin is much harder than that of the standard MK-84 bomb. The skin is a single-piece, forged warhead casing of one-inch, high-grade steel. Its usual tail fuze is a mechanical-electrical FMU- 143. The 1,925-pound bomb has a 550-pound tritonal high-explosive blast warhead

Guided Bomb Unit-28 (GBU-28). The Guided Bomb Unit-28 (GBU-28) is a special weapon developed for penetrating hardened command centers located deep underground. The GBU-28 is a 5,000-pound laser-guided conventional munition that uses a 4,400-pound penetrating warhead. The bombs are modified Army artillery tubes, weigh 4,637 pounds, and contain 630 pounds of high explosives.

AGM-114 Hellfire II. Laser Hellfire presently is used as the main armament of the U.S. Army's AH-64 Apache and US. Marine Corps's AH-1W Super Cobra helicopters. For antiarmor roles, the AGM-114 missile has a conical shaped charge warhead with a copper liner cone that forms the jet that provides armor penetration. This high explosive, antitank warhead is effective against various types of armor including appliqué and reactive. Actual penetration performance is classified.

The PGU-14/B API ammunition. That Armor Piercing Incendiary round has a lightweight body which contains a sub-calibre high density penetrator of Depleted Uranium (DU). In addition to its penetrating capability DU is a natural pyrophoric material which enhances the incendiary effects. It is used by the AN/GAU-8 30mm Avenger (a 30mm seven-barrel gatling gun, mounted only on the A-10 attack jet, used primarily in the air to ground role as a soft target killer and tank buster) and also by the M230 automatic gun mounted on the Apache helicopter.

M256 120mm smoothbore cannon. It is the main weapon of the M1A1 battle tank. The primary armor-defeating ammunition of this weapon is the armor-piercing, fin-stabilized, discarding sabot (APDS-FS) round, which features a depleted uranium penetrators. Battle tanks have not been used yet by the NATO forces, therefore that scenario is not studied for the time being.

In our study we will focus our simulation on the Tomahawk missiles and the BLU-109 bomb as not only do they represent well our worst case scenario but also the available declassified information suffices for our risk assessment approach. Note that the bomblet dispersion version of Tomahawk is not expected to have an improved penetration capability and therefore our models will focus on the single warhead version.

3 A short description of DU

Depleted uranium[9] is the metallic remnant of a series of processes the uranium ore undergoes and it is roughly 60 percent as radioactive as naturally occurring uranium. On the other hand, Uranium, a radioactive element, is a silver-white metal in its pure form. It is a heavy metal nearly twice as dense as lead $\left(19\frac{gr}{cm^3}\right)$ compared with $\left(11.4\frac{gr}{cm^3}\right)$. On average, each of us takes in

$1.9\,\mu g$ $(0.65 \times 10^{-6} \mu Ci)$ of uranium a day from food and water, and inhales a very small fraction $7 \times 10^{-3} \mu g$ $(2.3 \times 10^{-9} \mu Ci)$ every day. In nature Uranium is composed of three isotopes (each has its own unique decay process emitting some form of ionizing radiation:alpha, beta, gamma radiation or a combination) in the following ratio:

NATURAL URANIUM COMPOSITION

$$^{234}_{92}U\,(0.0054\%)\,,^{235}_{92}U\,(0.7\%)\,,^{238}_{92}U\,(99.3\%)$$

In the gaseous diffusion process two fractions are produced in the form of UF_6 : one enriched in ^{235}U and the other depleted in ^{235}U. The former is further processed to give weapons-grade Uranium (WgU) whereas the latter is chemically transformed by weapons manufacturers into Uranium metal and alloys, suitable for ammunition and armor panels.

In fact, DU has a low content of ^{234}U, and ^{235}U which have been removed in the depletion process. Therefore the product and by-product of the enrichment are respectively [10]:

WEAPON-GRADE URANIUM COMPOSITION

$$^{234}_{92}U\,(1\%)\,,^{235}_{92}U\,(93.5\%)\,,^{238}_{92}U\,(5.5\%)$$

DEPLETED URANIUM COMPOSITION

$$^{235}_{92}U\,(0,2\%)\,,^{238}_{92}U\,(99,8\%)$$

After the enrichment process DU can used as a fusion tamper in the thermonuclear weapons. The fusion tamper prevents the escape of thermal radiation from the thermonuclear fuel thus enhancing the burn efficiency. Moreover, fast neutrons ($2.45 MeV$ and $14.1 MeV$) from the fusion processes fission the DU tamper. This extra boost accounts for half the yield of a fission-fusion-fission nuclear bomb [11].

The most important constituent of DU is $^{238}_{92}U$, an alpha emitter with a half-life of 4.5×10^9 years and a specific activity of $3.4 \times 10^{-7} \frac{Ci}{gr}$ (while the isotope ^{235}U has a specific activity of $2.2 \times 10^{-6} \frac{Ci}{gr}$)[12]. It has two short-lived daughters :(^{234}Th, half-life of 24.1 days) and (^{234}Pa, half-life of 1.17 minutes) which are beta and weak gamma emitters. Because of this constant nuclear decay process, very small amounts of these "daughters" are always present in DU. On the other hand ^{235}U (half-life 7×10^8 years) decays into ^{231}Pa (half-life 3.25×10^4 years), which is an alpha, beta, and gamma ray emitter. The ^{238}U and ^{235}U chains continue through a series of long-lived isotopes before terminating in stable, non-radioactive lead isotopes ^{206}Pb and ^{207}Pb. Note that regardless of its size (large fragments or small particles), once entering the body, DU is subject to various degrees of solubilization-it dissolves in bodily fluids, which act as a solvent. Its main toxic effects are cellular necrosis and renal failure. The American Conference of Governmental Industrial Hygienists (ACGIH) has established a Threshold Limit Value (TLV) [13]of $0.2\frac{mg}{m^3}$ (for both soluble and insoluble compounds). TLVs are based on the principle that there is a threshold below which no adverse health effects occur and are called time-weighted-average values because they are averaged over an 8-hour workday, for a 40-hour workweek over a working lifetime. Though TVLs were developed for the working environment , in the battlefield or in emergency planning they can still give a measure of the risk.

4 Simulation of Tomahawk attacks

In the present work we will limit our discussion in the conventional use of DU as this is currently employed in Yugoslavia. It is common sense that most of the attacks industrial facilities , bridges and government buildings need weapons with enhanced penetrability. That need spell the name of DU. Such is also the case for anti-tank munition, anti-radar bombs or weapons which destroy the runways of airports. The most infamous weapon is the Tomahawk missile used day after day by the NATO alliance.

Being consistent with our worst case scenario we assume that the whole frame of a Tomahawk missile is made of DU which is very plausible otherwise the missile might not withstand the blast of a nearby anti-missile explosion let alone the tremendous collision with the hard target. We also assume that the weather conditions are such that the Gaussian plume model can be applied.

As each Tomahawk missile is assumed to carry $400\,Kg$ of DU , the presence of ^{235}U is negligible, we have an activity of $0.136\,Ci$ per missile. After the impact only a small quantity will constitute the respirable fraction-defined as the fraction of the released material associated with an Activity Median Aerodynamic Diameter (AMAD) of $1\mu m$. The default ICRP-30[14] internal dosimetry conversion factors also assume an AMAD particle-size distribution of $1\mu m$. During the explosion a temperature of $5000\,^0C$ is reached (typical of HE[15]) which exceeds the boiling point of Uranium ($4700\,^0C$). That temperature will produce a large quantity of DU aerosols in the form of Uranium Oxides that may find their way into the respiratory tract.

The default respirable fraction of 20% , used in the HOTSPOT, is indeed a plausible scenario. That being the case, one comes to the conclusion that each Tomahawk carries a respirable radioactivity of $27\,\frac{mCi}{missile}$. To realize the magnitude of that activity, a typical radioactive quantity injected into a patient in a thyroid function test is $10\,\mu Ci$ that is approximately 2700 times less. On the other hand a typical amount of radioactivity released in a large scale reactor accident is $10^8 Ci$, [18]that is approximately 10^9 more.

If we take into account that for ^{238}U inhaled, the committed effective dose equivalent (CEDE) is $1.2 \times 10^8 \frac{rem}{Ci}$ and also that we have $5 \times 10^{-4} \frac{cancers}{rem}$[19] we arrive at the following result

$$27 \times 10^{-3} \frac{Ci}{missile} \times 1.2 \times 10^8 \frac{rem}{Ci} \times 5 \times 10^{-4} \frac{cancers}{rem} = 1620 \frac{cancers}{missile}$$

That is the total lethality per missile assuming that all the respirable fraction is inhaled by the population which of course is a not a realistic scenario but it only serves to show the maximum potential of a Tomahawk (assumed to carry DU) to cause cancer. The non- respirable fraction which consists of fragments scattered in the vicinity of the explosion, and particles much larger than $1\mu m$ were not taken into account. They will be ignored in the rest of this study though the are highly toxic and will definitely be localized and contaminate the vicinity of the explosion. Nor will we discuss the aggravation of lethality due to open wound or injuries during the rescue operations.

Of course during the explosion the distribution of the radioactive DU is governed by such factors as wind speed, amount of explosives , deposition velocity and so on that will further reduce the lethality of the missile.

In the model of this study we make the assumption that a single Tomahawk strike is actually a 400 Kgr DU explosion which involves the detonation of 500 Kgr of HE. The release fraction is 20% (that is the percentage of the airframe that can be inhaled after the explosion) and the wind speed is assumed to be 8 $\frac{m}{sec}$. The time of day is night (stability class D) , while the deposition velocity is $1\frac{cm}{sec}$. Moreover the concentration is measured on the ground for a sample time of 10 minutes. The "HOTSPOT" calculations yield the 50-years CEDE (due to inhalation as the ground shine is negligible) and the concentration of radioactivity on the ground at various distances. Note that the cloud effective height calculated in the present model agree well with the experimental data of detonations of a similar yield[16]

If we take into account that the current established protection standards are:[17]

a) 5 rems in a year for workers (to protect against cancer).

b) 50 rems in a year for workers to any organ (to protect against threshold effects, such as radiation burns, etc.).

c) 50 rems in a year to the skin or to any extremity.

Distance (Km)	0.1	0.2	0.5	1	2	5	10	20	50	75	100
50-CEDE ($mrem$)	1.6	1.4	1.0	0.7	0.46	0.25	0.15	0.088	0.037	0.025	0.018
Goncentration $\left(10^{-3}\frac{\mu Ci}{m^2}\right)$	13	11	7.7	5.4	3.4	1.8	1.1	0.53	0.16	0.09	0.06

d) 15 rems in a year to the lens of the eye (to protect against cataracts).

e) 0.1 rem in a year (70-year lifetime) for members of the public.

we come to the conclusion that people who are as close as $100m$ at the time of the explosion are expected to receive sixty time less than the maximum allowed dose per year. Needles to say, at distances larger than $20\,Km$ the doses are negligible. Of course, at close distances, the results of the blast wave will be devastating and will prevail over any other effect.

The ground deposition, on the other hand, reaches the concentration of $0.013\frac{\mu Ci}{m^2}$ at a distance of $100m$ where we have to remember that a concentration of $2\frac{\mu Ci}{m^2}$ is needed for land to be rendered unsuitable for cultivation[20], that is almost 150 times more.

To underline the impossibility of DU radiological contamination for countries such as Greece we can assume that 1000 such attacks are made against targets in Pristina in Northern Kosovo. That would cause a 50-CEDE of $0.018\,rem$ at a distance of 100 Km. Note that a CT exam administers a dose of $1.1rem$ (head and body). As Greece is at least 100 Km away from the closest point in Kosovo, that worst case scenario proves that there is no DU radiological hazard from the Tomahawk attacks in Yugoslavia at such large distances even if we assume that the weapon is loaded with DU.

5 Simulation of BLU-109/B bomb attacks

In that model , consistent with our worst case scenario, we also assume that the "skin" of the bomb is made entirely of DU though the US DoD speaks of a one-inch, high-grade steel. In that case we have the explosion of 651 Kg of DU with 243 Kg of HE. Therefore assuming the use of a quantity of 1000 BLU-109/B against targets in Pristina and the same conditions as in the Tomahawk case we obtain a 50-CEDE of $0.032\,rem$ at a distance of 100 Km. The combined dose is still very low $0.05rem$ (equal to 6 chest x-rays).

At distances of $150\,Km$ (Greek borders) the doses are practically negligible, even in those worst-case scenaria. In fact, if such was the case then those attacks would have dropped some 800 tons (160 respirable tons) of DU in Yugoslavia when according to the Iraqi authorities the war in the Gulf left 315 tons of DU in Iraq.

6 DU of the PGU-14/B API and the APDS-FS rounds

A typical combat load for the GAU-8 gun is 1,100 30 mm rounds. Each round contains $330gr$ of DU , alloyed with 0.75 weight percent titanium. The projectile is encased in $0.8\,mm$-thick aluminum shell as the final DU round[21], preventing any escape of the $a-$radiation emitted.. Consequently each round carries approximately $10^{-4}Ci$. That means that, if it all becomes respirable, it can induce a dose of $10^4 rem$ which amounts to $6.6\,\frac{cancers}{round}$. Upon impact, the shell is subject to high temperatures due to friction with the armor panel. Moreover, if the armored vehicle explodes or is set on fire then a worst-case scenario should include the respirable activity produced by the armor panel. For example, the Abrams battle tank's thicker armor is reinforced at the turret and flanks by DU panels inserted between regular steel armor. Another source of DU is the primary armor-defeating ammunition of the M256 120mm smoothbore cannon (main weapon of the M1A1 battle tank), which is an armor-piercing, fin-stabilized, discarding sabot round. It is imperative that battle tanks, attacked by NATO forces in Yugoslavia, are closely examined for radioactive traces. Note that the DU rounds always leave a distinctive radioactive trace on the entrance and exit holes. Each time an Apache fires its whole load, $79\,Kg$ of respirable DU will be released in the environment (worst-case scenario, 20% respirable DU). It would take 5000 such attacks to produce the amount of respirable DU we used in the Tomahawk scenario. It is rather unlikely that such a number of attacks has occured so far and even if that was the case people at distances greater than $100\,Km$ would not be endangered.

However, it should be stressed that the danger for people at close distances is expected to be significant, especially after "battle tank fires". Hence, the ground operations being contemplated at the moment are most likely to cause higher cancer mortality for NATO and Serbian troops alike.

7 The Hellfire case

Due to its low yield and weight (warhead weighs less than 10 Kg) it is not expected to produce any radiological or chemical risk at the distances studied here. If the classified composition of its armor-piercing structure is indeed DU , then it is expected to pose a serious hazard to people at close distances, especially during "battle tank fires". Since no solid evidence exists and no use of the weapon in question has been made yet, any assumption might further complicate the current situation.

8 Chemical toxicity of DU

A simple example of the toxic risk of DU can be known without knowing details of the population over which it is dispersed and the meteorological conditions. Suppose that 16 *tons* of respirable DU (one tenth of all the respirable quantity of our scenario) is dispersed uniformly over Greece which has an area of 132.000 Km^2 . We assume that all the aerosols have been concentrated in a volume with $1Km$ height. This gives a concentration of $1.2 \times 10^{-4} \frac{mg}{m^3}$ which is about 1600 times less than the threshold limit value.

A similar calculation yields an air concentration of $6.4 \times 10^{-4} \frac{mg}{m^3}$ for FYROM which should not cause much concern either.

The lifetime of the toxic cloud depends on the height and the rate at which the particles fall out. A deposition velocity of $1 \frac{cm}{\sec}$ is very plausible[22] while particles larger than $1 \mu m$ will fall faster. Rain or moisture will increase that velocity. In that scenario, particles from the top of the cloud will take 27 hours to reach the ground. It is very unlikely that the cloud will remain over a city for that long. Even a light breeze ($5 \frac{m}{\sec}$) will carry the cloud beyond a city the size of Thessaloniki in a few hours. During that time, a person breathing at a normal rate $1 \frac{m^3}{hr}$ would take in $3.2 \mu g$ of DU which is just the amounts one inhales in 1.2 years (natural background)

Of course an actual toxic cloud is not expected to have the above shape but the present model gives solid evidence that the fear of toxic poisoning at large distances, due to DU that is allegedly used in the present war, is groundless. Note that the amount of DU that could be inhaled is independent of the height and the extend of the cloud as shown in a similar study that disproved exaggerated allegations about Plutonium risks[23].

That absolutely worst-case scenaria show that there is no immediate hazard from the radiological or chemical toxicity of DU for the neighboring countries of Yugoslavia. Admittedly, localized DU can enter the food chain and reach inhabitants of other countries by means of exported goods or river streams. However, such aspects are regarded as less harmful than actual inhalation of the DU plume.

9 Conclusions

We have assumed a worst-case scenario mainly to assess the radiological and chemical risk of the alleged use of DU in OAF, for Greece and other neighboring countries of Yugoslavia at similar distances. The risk is found to be negligible for the time being at large distances. The use of the PGU-14/B API ammunition seems to be the most hazardous weapon in the theater of operations. Its use so far has been limited to the Avenger gun of the A-10 jet. If Apache helicopters move in, the effects will escalate and need further investigation. The present model cannot be used to quantitatively assess the hazards for the people of Yugoslavia, which is expected to be significant if the use of the API ammunition escalates . Accurate data about the composition of the weapons in question are needed in order to predict the radiological and chemical contamination of DU at short distances. Such data could be either obtained by the NATO authorities or by studying the fragments of the Tomahawk missiles (and the BLU bombs) in the scene of the explosion. Once DU is detected, the above simulation can be modified in order to perform a reliable risk assessment in the area.

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Simulating 1000 Tomahawk missile attacks against Pristina. Each missile is assumed to carry 400 Kg of DU (worst case scenario). The cigar-shaped dose contour of the Gaussian model is rotated to cover a 360^0 potential-hazard zone. Outside the circular zone (50 Km), the dose will be lower than that of a pelvis x-ray (44mrem).