ENVIRONMENTAL POLLUTION AND HEALTH EFFECTS IN THE QUIRRA AREA, SARDINIA ISLAND (ITALY) AND THE DEPLETED URANIUM CASE

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Abstract

Quirra is a village located in the Italian Sardinia Island, close to a big military polygon where ballistic missiles and weapons are tested. Recently, the zone has been driven to the attention of the media due to the so-called "Quirra syndrome", an apparently off-normal incidence of illnesses in that zone. The media indicated in the military use of Depleted Uranium a possible cause of the above situation. The paper carries out the following: a statistical assessment, to verify if the "Quirra syndrome" exists, simulations with an atmospheric dispersion and dose code (HOTSPOT) in order to evaluate health effects of the supposed Depleted Uranium airborne dispersion. The conclusion is that the "Quirra Syndrome" exists, however it is probably not entirely due to Depleted Uranium. Other possible causes are briefly accounted for

Keywords: Depleted Uranium, Health Effects, Radioprotection, Atmospheric dispersion.

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1. Introduction: The Quirra Area and the "Salto Di Quirra" Polygon.[1]

Quirra is a small village located in the south-eastern part of the Italian Sardinia Island (Sardegna), in the centre of the Mediterranean Sea. It is close to the sea shores (Capo San Lorenzo), and surrounded by other small villages like *Perdasdefogu* and *Escalaplano*.

In that area, it is located the biggest military polygon of Italy and Europe, the "*Poligono sperimentale di addestramento interforze del Salto Quirra*" ("Salto di Quirra Polygon" and firing range). It is an experimental polygon for ballistic missiles, and a training base, in charge to the Italian Aeronautics Armed Forces, and at disposition of NATO. The area is also of great natural interest: it hosts, for example the Natural Park of "Brùncu Santòru", in the area close to Perdasdefogu village.

Figure 1 shows a detail of the "Salto di Quirra Polygon". It is divided into two zones: an elevated one (11,600 hectars) close to the villages of Quirra and Perdasdefogu, and a seaside zone (1,110 hectars). In figure 1, the two zones are delimited by a red line, with a yellow caption "PERIMETRI DEI POLIGONI" (Polygon boudaries, in italian).

The Polygon is used – since at least fifty years – for missiles and weapons testing. Usually, ballistic missiles and weapons are shot from the first zone to the second one, that is, from the elevated zone close to the Cardiga mountain to the small Quirra islands, facing the Sardinan seashores.

2. The "Quirra Syndrome" and a Depleted Uranium review

In the recent years, the Quirra zone has been driven to the attention of the Italian media due to the so-called "Quirra Syndrome".[2]

In practice, it deals with an apparently off-normal incidence of illnesses in the population in that zone, mainly cancers to the lymphatic system (lymphomas) and natal genetic malformations. Also some cases in military men that served in that base for just one year have been reported.

The media and public opinion have indicated in the military use of Depleted Uranium (DU) a possible cause of the above situation.[2]

Depleted Uranium[3] is mostly composed by the natural radioactive isotope U^{238} and it is a by-product of the enrichment process, that part of the nuclear reactors fuel cycle that produces the nuclear fuel ("enriched uranium") to be used in nuclear power plants like Light Water Reactors and other ones[4,5]. DU characteristics are: low specific radioactivity (with emission of alpha particles), high specific weight, low cost, wide availability[3].

Military use of DU for "penetrators" (i.e., bullets with high capability of penetrating shields) has widely spread during the nineties[6,7]. U.S. Army tested it during the seventies and eighties[8,9], and DU-based weapons were first used in the "Desert Storm" War in Kuwait-Iraq (1991).[10,11] Since then, DU weapons have been used in the Mediterranean area during the Balkan wars[12] (Bosnia 1995, and Kosovo 1999). During the last war in the Balkan area (Kosovo-Serbia War, spring-summer 1999), NATO forces admitted the use of weapons containing Depleted Uranium. [13,14] In particular, 30 mm bullets being fired by A-10 anti-tank aircrafts. Most probably, also some Tomahawk Cruise missiles in those wars had depleted uranium reinforced heads. DU was used again in more recent Afghanistan and Iraq campaigns.

It is widely held that the weak radioactivity of DU – lower than natural Uranium – makes its radiological dangers slight. However, DU radiation is indeed "feeble" (i.e. low specific radioactivity, and radiation with low penetration capacity) as compared to several other sources, however its biological effects (chemical and radiological) cannot be neglected if its concentration is sufficiently high – like for any other pollutant. The radiological effects of uranium are well known since fifty years due to its civilian use, [15-26] while also US army studies have studied those effects before use.[8,9,27].

In fact, the first study of the military use of radioactive powders[28] is as old as nuclear age: the Report "Use of Radioactive Materials as a Military Weapon" was compiled by James Conant, a member of the Manhattan project, and transmitted to general Leslie Groves, the head of the Manhattan project, in 1943.

When DU bombs detonate, uranium oxide is formed in particulates of between 0.5 and 5 microns. These can be windborne several hundred miles or suspended electrostatically in the atmosphere. The size of the particles varies greatly; larger fragments can be easily observed, while very fine particles are smaller than dust and can be inhaled and taken into the lungs.[29,30] Whether large enough to see, or too small to be observed, DU particles and oxides contained in the body are all subject to various degrees of solubilisation — they dissolve in bodily fluids, which act as a solvent. Once dissolved in the blood, about 90% of the uranium present will be excreted by the kidney in urine within 24-48 hours. The 10%

of DU in blood that is not excreted and retained by the body. Insoluble uranium oxides can remain in the lungs for years.

Concerning chemical toxicity, Uranium, being an heavy metal, is known to have toxic effects on specific organs in the body:[29-32] in particular, the organ that is most susceptible to damage is the kidney. The uranyl-carbonate complexes decompose in the acidic urine in the kidney. This reaction forms the basis for the primary health effects of concern from uranium. The effects on the kidney from uranium resemble the toxic effects caused by other heavy metals, such as lead or cadmium.

Concerning DU radiotoxicity, U-238 is a long-lived alpha-emitter, with a weak emission of beta and gamma rays. External exposure hazards mainly regard military personnel using tanks with DU shields, while it is negligible in other occasions. The most important pathways for DU exposure are therefore in case of ingestion or inhalation.[15-27]

Personnel in or near an armoured vehicle at the time these vehicles are struck by depleted uranium munitions can receive significant internal DU exposures. On the other hand, army officials believe that DU-related health risks are greatly outweighed by the risks of combat. This is not the case, however, for the exposure of public due to DU contamination, or for peace-keeping actions after war.

Recent studies have demonstrated the so-called “bystander effect”, in which unirradiated cells close to irradiated cell populations can exhibit genetic alterations. The bystander effect is predominant at low tissue doses, where few cells experience an alpha particle passage. At higher doses, recipient cells increasingly experience alpha passages themselves, with a high probability of cell killing and almost certainty of inducing other changes, thus reducing the relative effectiveness of the bystander effect. For this reason, uranium particles, which emit few alphas, would have a greater chance of inducing effects through the bystander mechanism than "hotter" particles. It may, therefore, be prudent to examine the question of whether focal sources of irradiation could induce a spectrum of effects that differs from that induced by more uniform irradiation. In the specific context of uranium, it is of interest also to consider whether the enhanced soluble uranium concentrations that could exist in the vicinity of individual particles or aggregates could interact synergistically with the localised irradiation of tissues, particularly if some of the effects of irradiation are mediated by substances released from the irradiated cells. In considering whether such effects could occur, it is appropriate to recognise that particles could accumulate or aggregate in interstitial tissues of the lung, in pulmonary lymph nodes or in reticuloendothelial tissues.

This is not a situation that has been experienced in any exposure situation for an alpha or any other emitter in the lung. It is therefore difficult to extrapolate the risk of such an exposure from human experience. In particular the risk to the lung of exposure to DU dusts cannot be easily inferred from the experience gained from uranium miners, or from survivors of Hiroshima and Nagasaki, upon which the current ICRP radiological protection standards are based.

Alpha particle radiation is known to be a potent cause of bystander effects, particularly in the form of genomic instability and, since heavy metals can also cause instability, there is a strong case that the mixed radio-chemical exposure may be acting in this context.

The implication of the combined chemical and radiological transforming capability of uranium and the bystander effect, means that, in estimating its significance in causing cancer, the simple assumptions, based on committed effective dose, ie (committed absorbed dose to the lung, modified by a radiation weighting factor for the fact that the radiation arises from alpha particles) would probably underestimate risks.

The DU bullets were used in the Gulf War. Many publications and studies have put into evidence that, subsequently, the incidence of leukaemias, cancer, and birth defects have risen sharply in that area and in other DU-polluted battlefields during the nineties.[29,33-37] About 80,000 Allied-army Gulf War veterans now suffer from the so-called Gulf War syndrome.[38-40]. However being probably a concurring cause, it is not probable that this syndrome could be only due to DU radiation exposure.

3. Research activity carried out in this study

The goal of our research activity has been to determine whether a “Quirra Syndrome” really exists, and, if so, whether it could be attributed to the use of DU in the Quirra Polygon.

Since no information was available from the military forces, apart from a generic deny of any use of DU in that zone, the following determinations have been carried out:

- A statistical assessment, in order to verify if the cancer and genetic malformation occurrences are effectively out of statistical average.
- The Quirra zone is simulated with a atmospheric dispersion code to determine the amount of DU that had been ideally necessary in order to cause the above occurrences.

4. Statistical assessment

According to Italian and local (Sardinia) statistical data,[1] we have determined that, for the considered period:[2]

- *Salto di Quirra Polygon*: 6 military men dead due to leaukaemia, 3 ill; 1 cancer case expected according to statistics.
- *Quirra*, 13 people with lymphomas; 3 cancers (all kinds) expected according to statistics.
- *Escalaplano*: 8 children born with serious natal genetic malformations in one year, over a yearly total birth rate of 21 children; 15 thyroid tumors in 7 years (1994-2001). 44 tumors (all kinds) and less than 1 malformation expected according to statistics.

The conclusions are the following:

1) The amount of cases we are dealing with are – fortunately – quite small. This makes statistical relevance assessments more difficult.

2) Quirra Polygon leukaemias among soldiers, Quirra lymphomas and Escalaplano malformations in population appear to be out of statistics, that is, unattended if no specific agent (or agents) have caused them.

3) Escalaplano tumors among population – on the other hand – appear to be normal, and therefore are discarded from any further assessment in our study.

5. Simulations

The HOTSPOT code (created by the Lawrence Livermore National Laboratory),[41] has been used to simulate the release of Depleted Uranium for military tests in the Base, according to some different scenarios.

Radiotoxicity does not have, for delayed and stochastic effects to happen, any threshold: we must to calculate the risk due to an higher exposure to radiation and then evaluate if this is relevant or negligible. For this, we must evaluate the Effective Dose Equivalent (EDE) to man, and then the collective dose (CEDE) to population.

The base scenario has been the following:

- Exposure pathways: all. Inhalation, external irradiation, ingestion through food chain and contamination, etc.
- Release of a specific mass quantity (1 kg) of DU at ground level, in order to obtain as a result the “Collective dose to population per kilogram of DU released” (called since now Mass Specific Collective Dose = MCEDE)
- Atmospheric dispersion was evaluated by the HOTSPOT code by means of the well-known Pasquill model. Statistic distribution of wind directions and speed, and of atmosphere conditions were collected from data available from meteorological stations in the area; see figure 1: “*Stazioni Anemometriche*” – in italian – located in Siurgus Donigala, Villasalto and Muravera).
- Distribution of population around the release point was also available from national and regional data bases. Correct data for this point are essential to obtain good collective dose data. Thanks to the collaboration between our University and the University of Cagliari (Regional Capital of Sardinia, Italy), data have been collected and used for meteorology and population distribution in the area. Human body and doses have been modelled and computed by HOTSPOT following ICRP recommendations[42-44], both for the internal and external (however negligible) dose calculations.

We have mentioned before that the health hazards due to this kind of exposure may probably be underestimated by the ICRP models and recommendations, however there is presently no scientifically credible alternative to them.

Concerning the most targeted organs, they are mostly the lungs, and all the organs that are included in the “lung” compartment in our model: among them, the mediastinum lymph-nodes. Kidneys and gut are also exposed to dose, because this is the pathway uranium follows during the excretion from human body. There are some other organs which are exposed, in particularly the surface of bones and the bone marrow.[1,29] These results, in particular the value of the dose to lungs and mediastinum lymph-nodes, and to bone marrow, are proof that at least in principle there can be a link between DU inhalation and the insurgence of Hodgkin lymphoma and leukaemia.

After the calculation of the MCEDE, we applied the risk factors recommended by ICRP in order to compute the casualties (lethal cancers, non-lethal cancers, genetic malformations) and, subsequently, we computed the amount of DU that in theory should have been used and released in the Quirra Polygon in order to cause the off-normal illnesses of the “Quirra syndrome”.

The main results of the assessment are visible in Table 1, where we have, for the exposed populations and soldiers, the amount of DU theoretically necessary – in some cases, according to two different scenarios with different “targets” of the supposed weapons test – to cause the reported off-statistics illnesses, casualties or malformations.

6. Comments to the DU results

We have assessed, by means of a statistical survey, that – in some cases – the reported “Quirra Syndrome” really refers to off-normal occurrences of cancer cases or malformations among the population of the area and soldiers of the “Quirra Polygon”. The related numbers, however, are fortunately quite small, and this makes statistical assessments quite difficult.

We have determined the DU quantities that would have been necessary to cause all the off-statistics illnesses of the “Quirra Syndrome” by means of HOTSPOT code simulations.

The following conclusions may be drawn:

- Concerning the people of Quirra and Escalaplano, the quantities of necessary DU are very high ones (several tens of tons of DU even in the most conservative case, up to hundreds of tons of DU).
- If we compare those numbers to the total quantity of DU used in the Balkans in 1999 (15 tons), it seems very unlikely that such an amount of DU (or even more) was used in the Quirra area.
- Concerning the Military Men of the “Quirra Polygon”, DU quantities are lower (around 1 ton in the most conservative case) and compatible with the possibility of DU being a cause of the reported illnesses among young soldiers; however, no further estimate or assessment can be made after this evaluation, since the interested zone is a military one. As we mentioned before, military authorities deny any use of DU in that zone.

7. Conclusions and further assessments

The above results for DU may be summarised as follows: DU may only be a concurring cause for the “Quirra Syndrome” in the population, that is most probably not entirely caused by DU; reasons for the Syndrome should be looked for elsewhere also. A couple of examples will be given in the following.

First of all, the Quirra Polygon is a well-known air force rocket range, where new rocket propulsion systems – for both military and civil use – are tested. Airborne release of toxic and teratogenic chemical substances is a quite probable effect of these tests. For instance, environmental contamination with dioxins and other rocket combustion products cannot be excluded. In literature, there is obviously no trace of the military part of these tests; however, some papers concerning the civilian applications are available. For instance, in the recent years, the Quirra Polygon has hosted the Zefiro Static Firing Test Bench: it is a Test Facility, located inside the base, devoted to perform the static firing tests of VEGA 2nd and 3rd stage Solid Rocket Motors.[45-46].

Secondly, the now abandoned arsenic mine of Baccu Locci is located in the area, quite close to the Perdasdefogu village[47]. In particular, lead-arsenic-sulfide ore deposits are present in that zone, being galena and arsenopyrite the only economic minerals.

Both lead and arsenic are highly toxic and carcinogenic metals: if some kind of contamination of environmental and trophic matrices by those two metals and their compounds could occur, this could also be an explanation for the Quirra Syndrome. For instance, sediment samples from the abandoned mine of Baccu Locci, being rich in As and Pb, have been recently used for testing of innovative fractionation methods for heavy metals[48]. More specifically, recent assessments carried out by the Italian University of Cagliari (Sardinia)[49] point out that mine-waste materials and stream sediments from the Baccu Locci stream catchment are affected by serious As contamination as a consequence of past mining. Results indicate that solid-state speciation of As is mainly dominated by the presence of Fe(III) hydroxides (arsenical ferrihydrites with various Fe/As molar ratios) occurring as coatings of silicate grains, in which As is contained as sorbed or co-precipitated species. Scorodite ($FeAsO_4 \cdot 2H_2O$) is common too, whereas arsenopyrite is generally subordinate but, owing to its relatively rapid oxidation, environmentally significant. Moreover, some unidentified arsenates of Ca-Fe or K-Fe were also detected. Arsenic contained in these phases is slowly, but continuously, released in relatively small amounts. The flotation tailings are widely scattered and distributed in the middle–lower Baccu Locci stream catchment, and represent the most dangerous As-generating contamination source in the study area.

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EXPOSED GROUPS	Number of off-statistics cases	Tons of DU necessary to determine the cases:
150 inhabitants of Quirra Target 1	5 tumors	85,6
150 inhabitants of Quirra Target 2	5 tumors	89,8
2500 inhabitants of Escalaplano Target X	8 genetic mutations	48,3
2500 inhabitants of Escalaplano Target 2	8 genetic mutations	145,9
Personnel of the base	5 tumors	1,4

Table 1 – Main HOTSPOT simulations results: for the exposed populations and soldiers: amount of DU theoretically necessary – in some cases, according to two different scenarios with different “targets” of the supposed weapons test – to cause the reported off-statistics illnesses, casualties or malformations.

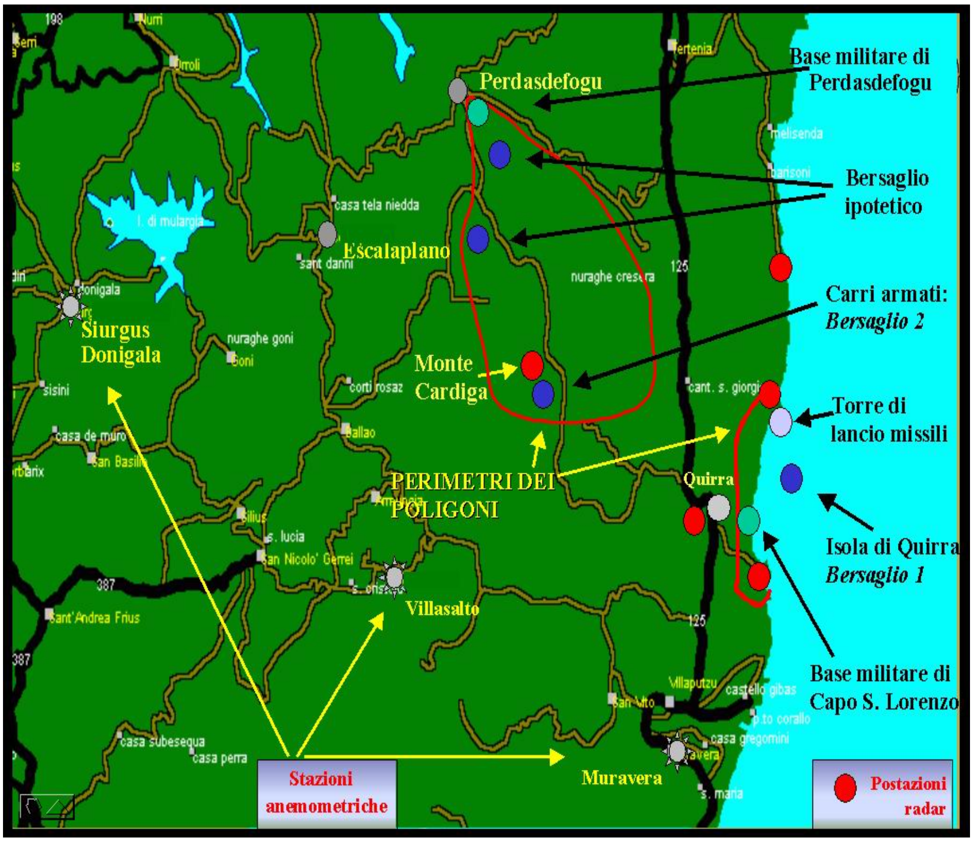

Figure 1 - The “Salto di Quirra” military polygon in Sardinia Island (Italy).