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

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Quirra is a village located in the Italian island of Sardinia, close to a big military polygon where ballistic missiles and weapons are tested. In the past years and recently too, 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 a possible cause of the above situation in the military use of Depleted Uranium. The paper carries out a statistical assessment to verify if the "Quirra syndrome" exists, in order to evaluate health effects. Moreover, other causes of possible pollution like electromagnetic fields and teratogenic chemical substances due to military rockets tests are addressed. In particular, the question of electromagnetic fields pollution and the associated health risks in the Quirra area have been examined, using also experimental measurements carried out on site.

INTRODUCTION

In the south-eastern part of the Italian island of Sardinia lays the "Poligono Sperimentale Interforze del Salto di Quirra" (PISQ), the biggest military polygon in Italy and Europe (an area of about 130 Km^2). It is an experimental polygon for ballistic missiles and a training base in charge to the Italian army, used by NATO alliance forces too, and also utilised by the private military industries that rent the training range for weapons testing.
The PISQ area is divided into two zones: an elevated one, the "land range" (116 Km^2), and a seaside zone, the "sea range" (11 Km^2); moreover, as shown in Fig. 1, observation and telecommunication stations are located along 40 Km on the coast.
The military area is also of great natural interest: it hosts, for example, the karst cave system of *Is Angurtidorgius*, and a lot of endemic and endangered species.

In recent years, the Quirra polygon has been driven to the attention of the Italian media [1] due to the so called "Quirra Syndrome", an apparently off-normal incidence of illness reported among the population who lives close to the military area, mainly cancer to the hemopoietic system and natal genetic malformation. In the small village of Quirra, close to seaside part of the Polygon, 13 cases of cancer to the hemolymphatic system have been reported, while in the village of Escalaplano, on the west boundary of the land range, 8 children with serious natal genetic malformation were born in just one year (over a yearly total birth rate of 21 children). In addition to this, some cases of cancer are reported among military men who served in that base for just one year.

ENVIRONMENTAL POLLUTION AND HEALTH EFFECTS AROUND THE PERDASDEFOGU-QUIRRA AREA

Some possible exposition factors Quirra Syndrome: toxic and teratogenic chemical substances generated by rockets propulsion systems; Arsenicum contamination from past mining activity; radiological contamination from Depleted Uranium used in "penetrator" bullets and missiles heads; heavy metal nanoparticles generated at very high temperatures, such as those reached during the

combustion of rockets' propellent or impact of depleted uranium head bullets against armours; electromagnetic pollution originated by military radars and electronic warfare devices.
An evaluation of the DU contamination effects has been performed by Zucchetti in 2006 [2], while Gatti in 2007 has found heavy metal nanoparticles in the cooling basin for rockets engines in the tissues of ill-formed animals and of both military and civilians, tumour affected, living in the PISQ surroundings [3].
It should be underlined that the environmental context of the PISQ area is very complex, characterized by the contemporary presence of different sources of pollution, and the pathologies affecting residents can also be due to the joint effects and the possible mutual interdependency of the above mentioned risk factors.
In this paper, we present the results of a quantitative assessment of the " Quirra Syndrome", and a first evaluation of electromagnetic pollution evidenced in inhabited area at the boundaries of the seaside part of the military base.

"QUIRRA SYNDROME" QUANTITATIVE ASSESSMENT

A first investigation on the causes of death, in the years between 1980-1999, among the population of the town of Villaputzu (5048 people) has been performed in 2004 by the Italian Institute of Healt (ISS) [4], using data from the National Statistical Institute (ISTAT) database. The study has not highlighted any statistically significant increasing risk of death from cancer; however, not the whole Villaputzu population lives strictly close to the military polygon activities. Then, as specified in ref. [4] conclusions, further investigation, restricted to those groups of subjects actually exposed to the PISQ activities, are needed.
ISS results have been substantially confirmed by a subsequent epidemiological investigation on the health of the Sardinian population [5]. The death causes in the 1981-2001 years range have been studied using data from ISTAT database, both for the whole Sardinian population and for some sub-areas selected for their possible contamination. The Military Quirra area, formed by ten municipalities in the PISQ boundaries (Armungia, Ballao, Castiadas, Escalaplano, Muravera, Perdasdefogu, San Vito, Tertenia, Villaputzu and Villasalto, with 26.183 residents throughout) has been selectively studied, founding an excess of hemolymphatic system tumors (+28% male, +12% female), not statistically significant.

Here we present a first attempt to cohort study, following the ISS [4] recommendations. Our study is based on data collected by reported diagnosis by a local association ("Circolo RUSPA" in the Villaputzu town). Examining the collected data, two sub-group of the population actually exposed to the PISQ military activities effects can be clearly identified:

- **Group (A)** – People who live and/or work in the small Quirra village, very close to the missiles launching areas, composed of approximately 400 people, male and female equally distributed.
- **Group (B)** – PISQ civil workers, composed of approximately 400 people, all males.

The risk of death from cancer has been evaluated in the 1998-2008 period for both the sub-groups, and the results are compared with the Sardinian population average risk of death for some type of cancer reported in [5]. To perform the comparison, the Poisson distribution is adopted for the Sardinian population expected values, then the range corresponding to the given confidence level has been computed and reported in table 1.

Table 1

All types of cancer				
	Observed	Expected	Confidence level 80%	Confidence level 95%
Group (A) 200 M + 200 F	7 M 3 F	5,7 M 2,9 F	M (2,6 – 8,8) F (0,7 – 5,1)	M (0,8 - 10.6) F (0 – 6.5)
Group (B) 400 M	5 M	11,4 M	M (7,1 – 15.7)	M (4,7 – 18,1)
Cancer to the hemolymphatic system				
	Observed	Expected	Confidence level 80%	Confidence level 95%
Group (A) 200 M + 200 F	5 M 3 F	0,44 M 0,26 F	M (0 - 1.6) F (0 – 1.1)	M (0 – 2.4) F (0 – 1.9)
Group (B) 400 M	3 M	0,88 M	M (0 – 2.1)	M (0 – 3.2)
Leukemia only				
	Observed	Expected	Confidence level 80%	Confidence level 95%
Group (A) 200 M + 200 F	3 M 2 F	0,21 M 0,10 F	M (0 – 0.99) F (0 – 0.88)	M (0 – 1.8) F (0 – 1.5)
Group (B) 400 M	3 M	0,41 M	M (0 – 1.5)	M (0 – 2.3)

statistically significant increasing risk of death for hemolymphatic tumors, leukemia in particular. It is remarkable that the two groups (A) and (B) are completely different as to age, occupation and habits: exposition to PISQ activities is their only common characteristic.

Despite the rough procedure in the data collection, the results seem to be robust, and could give us some indication about the "Quirra Syndrome" possible causes. For instance, the Arsenicum contamination from past mining activity, that has been considered as a possible cause, should be disregarded, because it does not cause hemolymphatic tumors (only liver, kidnly, lung, bladder and skin tumors are reported in literature [4]).

These results have to be improved in future, by repeating these cohort studies having access to the comprehensive medical documentation. The investigations should be extended to other population sub-groups exposed to the PISQ activities, like, for instance, the farmers operating in the Quirra plateau and the military personnel who served in PISQ. Also natal genetic malformation, abortions, and low mortality diseases have to be investigated, in order to obtain a complete picture of the state of health of that part of the population actually exposed to the PISQ activities.

EVALUATION OF THE ELECTROMAGNETIC POLLUTION IN THE QUIRRA POLYGON AREA

Since the main activities of the PISQ are related to development, experimentation and assessment of missile system and electronic warfare devices, a complex system of radar, TLC, electronic warfare devices operate in the training range area. Military radars emit short pulses of microwaves, usually in the few GHz frequency range, with a peak power of hundreds of KW.

Microwave (300 MHz-300 GHz) exposition effects depend on the power density S of the emitted field and the amount of energy actually absorbed by the human body [6]. The Acute exposure effects to high levels of microwave radiation (up to S ~10 W/m^2) can be distinguished from low level, long term, exposure effects (less then S ~10 W/m^2).

Acute exposure effects are well known, and consist mainly of serious and immediate injures to the eye, local lesions and necrosis, particularly in brain and gonads, and hyperthermia. Long term exposure to microwaves at levels lower than acute effect limits constitutes still a problematic issue.

Low level, long term exposure can cause genetic and teratogenic effects that have been observed in animals and plants, but for human exposure epidemiological studies are very poor. Increased rates of leukaemia and lymphoma have been reported among military personnel exposed to high frequency e.m. fields [7,8], but studies in this context are rare and it is not easy to carefully evaluate the actually absorbed dose rate.
For this reasons, following the guidelines of International Health Organisations [6], the health authorities fixed limits for both the acute and long term exposures. In Italy the limits in the 3-300 GHz frequency range were set for power density S and electric field E; they hold $S = 4$ W/m^2 and $E = 40$ V/m for the Acute effects, $S = 0.1$ W/m^2 and $E = 6$ V/m for the low level, long term, exposure.

Some factors which could be indicative of the presence of high frequency e.m. fields have been continuously reported by people living near the PISQ, such as anomalous behaviours of bees' swarms [9], microwaves auditory effects [10] and interferences with electronic devices.
A first survey about the microwave field was performed in May 2007, in the proximity of the Quirra village, around the PISQ seaside zone. We used a broad band equipment to detect the field, consisting in a Narda EMR-300 Radiation meter equipped with two electric field probes with different bandwidth: the Narda E-11 (10 MHz-60 GHz) and the Narda E-18 (100 KHz-3 GHz). Electric field was sampled every two seconds, data was transmitted to a laptop computer through a optical fibre connection and stored. Finally, the reported measurements were averaged over a six minutes time interval.
Field measurements pointed out the presence of electromagnetic fields in the places shown in fig. 3. Because the field was detected by the E-11 probe, but not by the E-18, it can be argued that it it oscillates at frequency higher than 3 GHz. The very high frequency characteristics of the measured signal allowed us to exclude a civil origin of the evidenced e. m. fields: their origin should be ascribed to the devices used inside the military base.

As previously mentioned, a number of Radar, TLC, electronic warfare devices operate in the PISQ military area, but their location and characteristics are not known. The only exception is the RIS-3C Tracking radar (produced by Selenia), whose characteristics are reported in table 2

Table 2

RIS-3C Tracking radar parameters	
Peak Power	$P_{max} = 240$ KW
Frequency	$f = 5475 – 5800$ MHz
Wave length	$\lambda = 5{,}5\text{-}5{,}2$ cm
Pulse duration	$\tau = 0{,}5$ or 2 μsec
Pulse Repetition Frequency	$f_{PRF} = 1640$ or 410 Hz
Antenna gain	$G = 42$ db
Angular width	$\varphi = 1{,}2° \pm 20\%$
Reflector diameter	d = 12 feet = 3,66 m

Duty Cycle $DC = \tau \cdot f_{PRF}$, that can assume three different values: $2.05 \cdot 10^{-4}$, $8.2 \cdot 10^{-4}$ and $3.28 \cdot 10^{-3}$.
The time averaged Power field density $S(R)$ can be computed in the far field approximation, for distances R exceeding the near field limit $d_{lim} = \text{Max}(\lambda, 2d^2/\lambda) = 520$ m, as

$$S(R) = P_{max} \cdot G \cdot DC / (4 \pi R^2)$$

If the far field condition is verified, magnetic *H* and electric *E* components of the field are closely related and connected to the power density by the relation:

$$S = E^2 / R_0$$

where $R_0 = 377\ \Omega$ is the void characteristic impedance.

The biological effect depends linearly on *S(R)*, except in case of very short pulses. ICNIRP guidelines [6] specify as the biological effect starts to increase for pulses with Duty Cycle DC<1/1000, in this case, following the suggestions of the standard DIN VDE 0848, we apply a biological effect correction coefficient β for short pulse duration: $\beta = 10^{-3}/DC$ if $DC<10^{-3}$, else β=1. Then the distance R_{lim} at which the safety limit value S_{lim} is reached, is given by

$$R_{lim} = (\beta \cdot P_{max} \cdot G \cdot DC / (4 \pi S_{lim}))^{1/2}$$

The distances at which the Italian law safety limit are reached, computed through this last equation, are reported in Table 3. Note as the Acute effects safety limit results at a distance lower than d_{lim} , which it is only an approximation of the real value. The atmospheric absorption has been neglected, because it results in a decrease of the distances lower than 1%

Table 3

Pulse duration	Acute effects E=40 V/m, S= 4 W/m^2	Low level, long term, exposure E=6 V/m, S=0.1 W/m^2
DC = 2.05 ·10-4 , or DC = 8.2 ·10-4	$R_{lim} \cong 270$ m	$R_{lim} = 1780$ m
DC = 3.28 ·10-3	$R_{lim} \cong 480$ m	$R_{lim} = 3220$ m

In fig 3 the six RIS-3C Tracking radar stations are shown, together with the safety limits. It can be observed as three stations are located near the small village of Quirra, and the other are near the Arbatax town and the Perdasdefogu and Tertenia villages.

Our measurements on 4 May 2007, close to the Quirra village, performed by the broad-band probe Narda E-11 (10 Mhz-60 GHz), highlighted microwave electric field amplitudes similar to those expected by this evaluations. Measurements calibrated for 5.5-5.8 GHz source frequency are compared in table 4 with the electric field inside the microwave beam generated by some, close, RIS-3C stations, operating with $DC = 2 \cdot 10^{-4}$. It can be noted that the observed and the expected values are comparable. Obviously, it does not mean that we detected exactly a signal from the RIS-3C radar stations, because lot of other, unknown, radar, TLC and warfare devices operate in the same bandwidth.

Table 4

Measurement place	E field detected	Possible source	Source distance	Expected field (far field approximation)
Baccu Buidu	3.1 ± 0.9 V/m	Torre Murtas Station	5.44 Km	3.5 V/m
Su Binu	1.9 ± 0.5 V/m	Serra Longa	5.75 Km	3.3 V/m

OTHER POSSIBLE CAUSES OF THE QUIRRA SYNDROME

Reasons for the Quirra Syndrome should be looked for elsewhere than Depleted Uranium and Electromagnetic Pollution too.

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 no trace of the military part of these tests; however, some papers concerning the civilian applications are available. For instance, in recent years, the Quirra Polygon has hosted the Zefiro Static Firing Test Bench, a Test Facility, located inside the base, devoted to perform the static firing tests of VEGA 2nd and 3rd stage Solid Rocket Motors [11,12].

Secondly, the now abandoned arsenic mine of Baccu Locci is located in the area, quite close to the town of Perdasdefogu [13]. In particular, lead-arsenic-sulfide ore deposits are present in that area, being galena and arsenopyrite the only economic minerals. Both lead and arsenic are highly toxic and carcinogenic metals, some kind of contamination of environmental and trophic matrices by those two metals and their compounds occurs. However, Arsenicum contamination, from past mining activity, does not cause hemolymphatic tumors (only liver, kidney, lung, bladder and skin tumors are reported) and then should be disregarded as one of the concurring causes of the Quirra syndrome.

IMPACT OF MILITARY ACTIVITIES ON ENDEMIC AND FLAG SPECIES IN THE QUIRRA AREA

In the Quirra- Perdasdefogu Area, there are several fauna endemic species, whose survival is at serious risk due to the military activities.

For instance, two "*Amphibia, Caudata*", endemic in the caves of Angurtidorgius:

- *Euproctus platycephalus* (Gravenhorst, 1829) [Sardinian Brook Newt];
- *Speleomantes imperialis* (Stefani, 1969) [Imperial Cave Salamander].

See for instance [14] for their detailed description. In the same volume, two further important endemic species of "*Amphibia, Anura*" present in the area are indicated, and their survival is at risk as well:

- *Discoglossus sardus Tschudi* in Otth, 1837 [Thyrrenian Painted Frog];
- *Hyla sarda* (De Betta, 1857) [Tyrrhenian Tree Frog].

In the same area, also the presence of "*Reptilia, Serpentes*" has been detected, probably a "*bona species*":

- *Natrix natrix cetti*, Gené, 1839 [Grass snake] [15]

Furthermore, military activities have resulted in explosions that caused important falls in the underlying caves. For the moment, this did not halt the reproduction of the Sardiniam Triton (*Euproctus platycephalus*), that is considered an endangered species. No recent news are available however of the other Triton (*Speleomantes imperialis*), which is considered a "Vulnerable at lower risk" (VU/LR) species.

The presence of these two "Flag species", as defined in European and Italian Law [16] advocates the need to immediately stop all the military activities from the Quirra-Perdasdefogu area.

CONCLUSIONS

In the Italian island of Sardinia, the "Poligono Sperimentale Interforze del Salto di Quirra" (PISQ), the biggest military poligon in Italy and Europe is located. The area is of great natural interest too.

In recent years, the PISQ polygon has been driven to the attention of the Italian media due to the so called "Quirra Syndrome", an apparently off-normal incidence of illness reported among the population who live close to the military area, mainly cancer to the hemolimphatic system and natal genetic malformation.
"Quirra Syndrome" possible causes may be toxic and teratogenic chemical substances generated by rockets propulsion systems, radiological contamination from Depleted Uranium used in "penetrator" bullets and missiles heads, electromagnetic pollution from military radars and electronic warfare devices.
A quantitative assessment of the Quirra Syndrome has been carried out from the statistical point of view: a statistically significant increasing risk of death from hemolymphatic tumors, leukemia in particular, has been detected in the selected groups.
An evaluation of the electromagnetic pollution in the area has been carried out. Impact of military activities on endemic and flag species in the Quirra area has finally been put into evidence.

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Figures and captions

Fig 1
The Quirra area and surroundings in Sardinia (Italy)

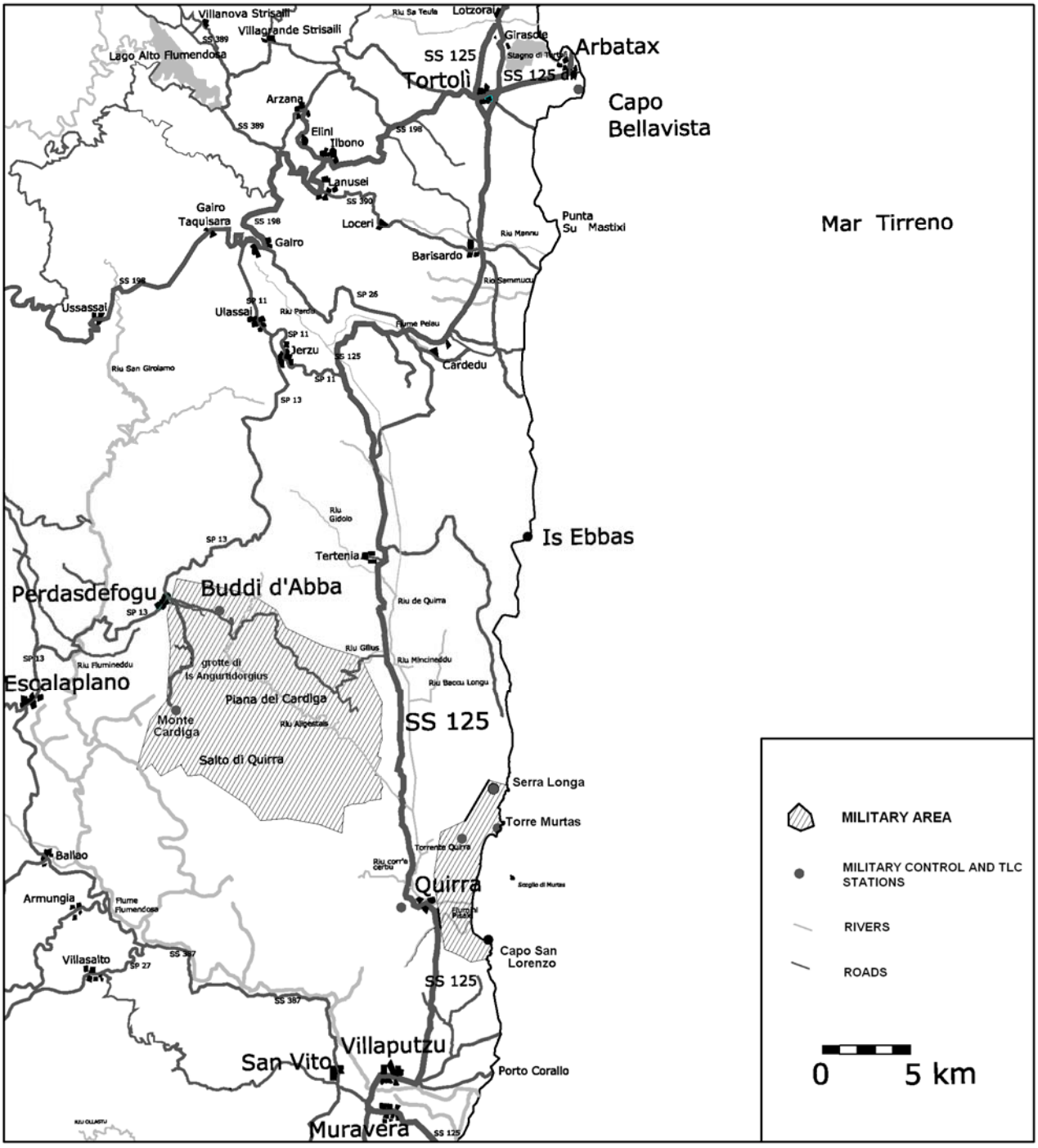

Fig 2
RIS-3C Tracking radar in the "*Torre Murtas*" station, the parabolic antenna reflector is visible

Fig 3

Emissions from Radar RIS-3C stations: left panel is relative to the short pulses (DC = 2,05 10^{-4} or 8,2 10^{-4}) and the right panel to the long pulses (DC = 3,28 10^{-3}). Far field approximation is assumed