HUMAN HEALTH RISK ASSESSMENT OF DIOXIN FROM SOIL CONTAMINATION IN DA NANG AIRBASE VICINITY

Le Thi Hai Le[1], Le Ke Son[1] Nguyen Duc Hue[1] and John Willcokson[2]

[1]Office of National Steering Committee 33, Ministry of Natural Resources and Environment, 83 Nguyen Chi Thanh, Hanoi, Vietnam; [2]Hatfield Consultants, Suite 201-1571 Bellevue Ave, British Columbia, Canada V7V 1A6.

Introduction

During the US-Vietnam war, herbicides popularly referred to as "Agent Orange" were used by the US Army to deny their military enemy cover in dense foliage. According to US reports, large quantities of herbicides were stored, mixed, and loaded on aircraft for aerial spraying at former US military airbases[1,2]. Due to the carelessness of their use and handling, a large quantity of herbicides were spilled, and then released into the surrounding environment[2]. Consequently, to this day, significant concentrations of 2,3,7,8-tetrachloride dibenzo-*p*-dioxin (TCDD), a contaminant in Agent Orange, are still detected in soils, sediments and biota at many former US military airbases. Elevated dioxin levels have also been recorded in blood, adipose tissues and blood and breast milk of people living adjacent to these airbases. Increasing concern has arisen regarding potential human health effects to local residents from exposure to residual environmental contamination. Da Nang airport was one of several former US military airbases utilized by Operation Ranch Hand (1961-1971) and the Pacer Ivy program (1970-1972)[1,2]. This airbase is also well-known as being one of the most significant "dioxin hotspots" in Vietnam. At the Da Nang airbase, concentrations of 2,3,7,8-TCDD in soil have been found to be several hundred times higher than Vietnamese and international standard levels[4,15].

The objective of this study is to assess potential human health risks to local residents (living adjacent to the Da Nang airbase), by applying internationally-recognized approaches for assessing human health risk (Health Canada 2004; USEPA 2008)[8,9]; POPs Toolkit (www.popstoolkit.com)6[,7], using data reported from Da Nang airbase and its vicinity[10,15-17].

Although the war ended almost 40 years ago, communities in the vicinity of Da Nang airbase are still at risk of dioxin exposure from soils and sediments. Therefore, risk management and mitigation measures are urgently needed, including targeted soil remediation, community education (to prevent and mitigate exposure), and the provision of improved medical and health systems. To our knowledge, this is the first human health risk assessment (HHRA) study on residents living adjacent to a major dioxin hotspot in Vietnam.

Methods and Materials

This study applied the World Bank POPs Toolkit[6,7] and other internationally-recognized guidance for performing preliminary quantitative human health risk assessments[8,9]. Recent dioxin/furan concentration data reported from inside and outside the Da Nang airport by Vietnamese and international researchers were used for the assessment[10, 15-17].

Risks were assessed following two distinct approaches:

1) Assuming 2,3,7,8-TCDD is a threshold contaminant. This is consistent with current Canadian guidance. Even though dioxins/furans can cause cancer, their toxicity profile suggests that effects are only observed once a specific threshold is achieved.

2) Assuming 2,3,7,8-TCDD is a non-threshold contaminant. This is consisting with current US guidance. This approach indicates that there is no set threshold, and that any incremental increase in exposure can result in a greater probability of getting cancer during one's lifetime.

Both approaches require the use of appropriate Toxicity Reference Values (TRV) to characterize the potency of the contaminants of concern and to facilitate calculation of numeric risk estimates. Using the threshold approach, risk is expressed as a Hazard Quotient (HQ). It is calculated by dividing the calculated total daily dose by a TRV called the Threshold Daily Intake (TDI) value, where: $Hazard\ Quotient\ (HQ) = \frac{Calculated\ Total\ Daily\ Dose}{Tolerable\ Daily\ Intake\ Dose\ (TDI)}$

Any concentration resulting in an HQ greater than 0.2 poses a potential risk to human health. ATDI of 2.0×10^{-9} mg TEQ/kg day was used for dioxins.

Using the non-threshold approach, risk is expressed as an Incremental Lifetime Cancer Risk (ILCR). It is calculated by assessing ILCR for each exposure pathway independently, and then taking the sum of all exposure pathways. Each ILCR is calculated by multiplying the estimated exposure via that pathway by the cancer slope factor for that pathway, where:

$$ILCR=[(Dose_{SoilIngested}+Dose_{Water\ Ingested}+Dose_{Food\ Ingested}) \times SF_{Oral}]+[Dose_{Particle\ Inhalation} \times SF_{Inhalation}]+[Dose_{DermalContact} \times SF_{Dermal}]$$

Following USEPA (2008), any calculated ILCR greater than 1×10^{-5}, indicates an unacceptable risk of cancer. It is assumed that exposure to dioxin via contaminated soil can occur a number of ways, including: soil ingestion, food ingestion, dermal absorption and particle inhalation. However, due to the poor solubility of dioxins in water, it has been assumed that this exposure pathway is relatively insignificant and has not been included in the hazard calculation.

Results and discussion

Problem formulation

Da Nang airbase is located in the city of Da Nang, located on the central coastal of Vietnam. Surrounding the airbase, there are three residential districts: Thanh Khe, Cam Le and Hai Chau. This study focuses on Thanh Khe District, since it is closest to the key hotspots at the north end of Da Nang airbase. Thanh Khe has an area of 9.27 km^2 and a population of 165,341. More than 50% of the land is mixed agricultural/residential (i.e.,"home-stead land")[5]. Most local residents are farmers, while the remainder work in offices, schools and small commercial businesses. There is no heavy industry in Thanh Khe[5].

During the War, large quantities of Agent Orange and herbicides were stored at Da Nang airbase. Records indicate that more than 86,700 liters of herbicide, including 52,700 liters of Agent Orange were stored, handled and/or loaded onto aircraft at the Da Nang airbase as part of Operation Ranch Hand[1,2,10]. These herbicides were loaded primarily onto C-123 aircraft for aerial spraying in central Viet Nam and Lao PDR; truck, backpack spray devices and helicopters also dispensed herbicides. In addition, from 1970 to 1972, Da Nang airbase was the site of an important Pacer Ivy operation, which was responsible for recovering and shipping 8,200 barrels of Agent Orange and barrel covers to Johnston Island[1,2]. During recovery operations, there was significant spillage due to improper handling and disposal of herbicides; these spills contributed to local environmental contamination[2]. A maximum soil TEQ concentration up to 365,000 ppt was found in the former Mixing and Loading Area on the airbase, which is 365 times the internationally accepted standard of 1,000 ppt[15]. In addition, recent investigation has shown that other areas in and around the airbase also have elevated concentrations of 2,3,7,8–TCDD in soils, sediments and biota (Table 1). Prevailing evidence suggests that dioxin from inside the airbase continues to enter the aquatic ecosystem, the general environment, the food chain and the human population living in close proximity to the contaminated site on the Da Nang airbase.

Table 1: Concentration of 2,3,7,8 –TCDD in soil, sediment, and biota collected in Da Nang airbase and vicinity [15-17].

Area	**Sample**	**Location**	**2,3,7,8 TCDD** (pg/g dry weight) **Min-Max**	**TEQ (pg/g)** (WHO 2005) **Min-Max**	**TCDD % of TEQ Min - Max**
Inside	Soil	Former Mixing and Loading area (MLA)	858 - 361000	899-365000	95-100
Outside/ Vicinity	Soil	Cultivated soils in Thanh Khe	9.06 - 227	24.7 - 269*	37 - 84
	Soil	Thanh Khe District	0.616 - 26	3.94 - 36.1	12 - 72
	soil	Dien Bien Phu Str.	0.649 - 1.26	5.91 - 7.36	9 - 21
	Soil	Thanh Khe Garden	0.616 - 26	5.34 - 36.1	12 - 72
	Soil	Hai Chau Garden	0.644	3.14	
Inside	sediment	Sen Lake centre / outlet to city	61.4 - 6240	68.6 - 6890	87 - 96
	Sediment	Sen Lake west	4.4 - 3730	18.9 - 4050	22 - 92
Outside	Sediment	Thac Gian Lake/Thanh Khe		16	
Inside	Fish Fat	Sen Lake 1 next to Thanh Khe	33.6 - 3000	53 - 3120*	93-96
	Fish muscle	Sen Lake 2 next to Thanh Khe	0.163 - 33.2	1.39 - 34.5	68-96
	Sweet potato	Sen Lake garden	ND-0.28	0.332	
	Lotus	Sen Lake	6.91	7.25	
Outside	Duck	Outside of airbase	0.45 – 1.52	0.54 – 1.57	71 - 83

*(*These concentrations to be used in the exposure model for exposure assessment)*

Hazard Identification

Dioxins are a family of 75 similar related compounds commonly referred to as polychlorinated dibenzo dioxins (PCDD) congeners. These compounds have varying harmful effects. This family is divided into eight groups of chemicals based on the number of chlorine atoms in the compound. 2,3,7,8-TCDD is the most toxic of the PCDDs to mammals and has received the most attention. Thus, 2,3,7,8-TCDD serves as a prototype for the PCDDs. PCDDs with toxic properties similar to 2,3,7,8-TCDD are called "dioxin-like" compounds.

The most notable characteristics of dioxin are their environmental persistence and their ability to accumulate within food chains. The lipophilic and hydrophobic properties of dioxin largely determine their distribution in the environment, as well as their fate and distribution in biological organisms, including humans.

Chemical half-life describes the rate at which a chemical concentration diminishes over time. Dioxin in the human body has a half-life roughly between 7 and 11 years. Paustenbach (1992) reported a half-life of dioxin of approximately 9-12 years for surficial soils (top 0.1cm), and 25–100 years for deeper soils. In sediments, dioxin can persist for several hundred years[13]. In water, dioxin is mainly attached to suspended particles, sorbed onto submerged surfaces of aquatic plants, and accumulated into aquatic animals such as fish. Fish bioaccumulation factors have been calculated in the range of 37,900–128,000[9]. At various former airbases studied (i.e., Da Nang, Bien Hoa, Phu Cat and A So) small concentrations of dioxins have been measured in rice, manioc and vegetable samples[10,15,16]. Conversely, exceptionally high TCDD levels have been measured in some fish fat and duck fat samples[10].

With respect to toxicology, dioxin has been shown to have an exceedingly high toxic potency to mammals. Furthermore, very small exposures of dioxin (TCDD) have been linked to rare forms of cancer in humans. According to the evaluation of IARC[11], 2,3,7,8-TCDD belongs to Group 1, the human carcinogenic compounds. Other congeners of PCDDs and PCDFs belong to Group 3, which are unclassified human carcinogens. In the human body, dioxin irreversibility combines with dissolved proteins called as Ah receptor (Ah-R: Aryl or Aromatic hydrocarbon receptor), located in the cytoplasm of human cells[11].

The carcinogenicity of 2,3,7,8-TCDD in humans has been demonstrated in numerous case-controlled and mortality cohort studies of chemical manufacturing and processing workers, phenoxy herbicide and chlorophenol applicators, Vietnam veterans exposed to Agent Orange, and residents of Seveso, Italy[12]. A 2006 study of U.S Army Chemical Corps Vietnam War veterans revealed statistically significant elevated TCDD levels in blood samples of veterans who reported spraying Agent Orange when compared to veterans who reported they had not sprayed Agent Orange[14]. Recent studies by Hatfield[12] and Vietnamese scientists provided evidence that 2,3,7,8–TCDD concentrations in blood of individuals who harvested fish and plants from the Da Nang airbase were more than 100 times globally acceptable concentrations. The maximum TCDD concentration measured in whole blood was 1,150 ppt lipid (1,220 ppt TEQ; 94% TCDD). This sample was collected from a 42-year old male who actively harvested fish and plants from the Da Nang Airport; two other individuals also had >500 ppt TEQ[16].

Exposure Assessment

The purpose of the exposure assessment is to quantify the daily exposure of 2,3,7,8-TCDD from individual specific routes of potential human exposure (inhalation, oral, dermal). Standard exposure rate data have come from studies on accidental, occupational, and residential exposure and from studies on the use of 2,3,7,8-TCDD-contaminated pesticides on agricultural land[11,12].

Studies conducted in the vicinity of former US Army airbases, include A So, Da Nang and Bien Hoa, demonstrated that TCDD contamination has spread from soils to humans via the food chain[10,15,16]. Recent studies on dioxin exposure through foods in Bien Hoa city demonstrated that local residents had consumed-locally raised food such as fresh-water fish, ducks, and other aquatic animals, resulting in very high risk according to daily dioxin intake[18]. Possible other modes of ingestion of TCDD include inhalation of dust, skin absorption, and unintentional direct ingestion of soil; in the case of very young children, ingestion may also occur from contaminated objects placed in their mouths. The evidence that foods, human blood and breast milk in Thanh Khe District were also found to have the highest dioxin content generates additional concerns related to nutritional and public health issues. These additional “hot spot strata” (i.e., food and humans) are a direct consequence of the mobilization and migration of TCDD from soil through foods (and/or direct contact) into humans[15,16].

The goal of the exposure assessment for the human health risk assessment is to determine the total daily exposure (or dose) of 2,3,7,8 TCDD (mg/kg body weight/day). The exposure model typically includes five independent dioxin exposure routes from contaminated areas: soil ingestion, food ingestion, water ingestion, dermal contact, and inhalation of contact particles. Due to the low water solubility of dioxins, the water ingestion route is typically ignored. Using results from published studies of dioxin exposure by humans in vicinity of Bien Hoa airbase[18], we estimated an average body weight for residents of Thanh Khe District of 50kg and 30kg for adult and children, respectively. Based on the referenced TDIs of $0.2.10^{-9}$ and other uncertainty factors values recommended by Health Canada (2004), HQs values for non-carcinogen for local adults and children were calculated (Table 2).

Table 2: Result of Risk characterization (assuming 2,3,7,8-TCDD is a threshold contaminant) for local residents in the Vicinity of Da Nang airport

	Calculated daily exposures	**Adult (mg/kg-day)**	**Children (mg/kg-day)**
1	Accidental soil ingestion dose	$1.07305E^{-10}$	$1.78842E^{-10}$
2	Food ingestion dose (for fish)	$4.53067E^{-07}$	$6.17819E^{-07}$
3	Inhalation of contaminated particles dose	$1.1898E^{-10}$	$1.41643E^{-11}$
4	Dermal contact with contaminated soil dose	$3.00455E^{-11}$	$1.25189E^{-11}$
5	**Hazard Quotient (HQ)**	**266**	**309**

The USEPA considers 2,3,7,8-TCDD to be a non-threshold carcinogen and consequently does not provide a threshold for daily intake (TDI in Canada). Instead, the USEPA approach involves the calculation of the ILCR. The sum of ILCR values (one for each exposure pathway) provides the overall Cancer Risk. The USEPA considers an ICLR of 1x10-5 or less (a probability of less than one in 100,000) acceptable. Based on the TRV selected in the hazard assessment (a cancer slope factor [SF] as 150.000/mg/day) and uncertainty factors recommended by USEPA 2008, the ILCRs for local adults and children were calculated (Table 3).

Table 3: Result of Risk characterization (assuming 2,3,7,8 TCDD is a non-threshold contaminant) for local residents in the Vicinity of Da Nang airport

	Calculated Incremental Lifetime Cancer Risk (ILCR)	Adult (mg/kg-day)	Children (mg/kg-day)
1	Accidental soil ingestion dose	$5.85301E^{-11}$	$9.755302E^{-11}$
2	Food ingestion dose (for fish)	$2.47128E^{-7}$	$3.36992E^{-7}$
3	Inhalation of contaminated particles dose	$6.48982E^{-11}$	$7.02361E^{-12}$
4	Dermal contact with contaminated soil dose	$4.63884E^{-11}$	$4.26782E^{-13}$
5	**Total ILCR**	**$5.05646E^{-5}$**	**$3.70901E^{-5}$**

Risk Characterization

As shown in Tables 2 and 3, HQs were as high as 266 and 307 for adult and child residents, respectively, or more than a thousand times higher than the 0.2 threshold level. Calculated ILCRs were $5.05x10^{-5}$ and $3.71x10^{-5}$ for adult and child residents, respectively, which are higher than the threshold of acceptable risk (1.10^{-5}, or a lifetime probability of 1 in 100,000). Results indicate that there is a significant human health risk to Thanh Khe residents due to dioxin exposure.

Supporting the risk analysis calculations above are actual measured concentrations of 2,3,7,8 –TCDD in humans. Elevated concentrations of 2,3,7,8 TCDD have been documented in blood, tissue and milk of people living at Thanh Khe and other districts in the vicinity of the Da Nang airport (Table 4).There is also a higher documented incidence of birth defects and reproductive problems amongst residence living near Da Nang airbase "hotspots[19-21].

Table 4: Concentration of TCDD (pg/g) and TEQ (pg/g) in human blood and breast milk, Thanh Khe District [15-17,19]

Location	Sample	2,3,7,8 TCDD (pg/g lipid) Min-Max	TEQ (pg/g) (WHO 2005) Min-Max	2,3,7,8 TCDD % of TEQ Min - Max
Thanh Khe	Blood (Male)	5.14 – 43.7	9.31 - 122	13 – 37
Thanh Khe	Blood (Female)	4.8 – 68.1	8.4 - 152	11 – 45
Thanh Khe	Blood (Children)	2.1 – 57.7	12.4 – 365.9	
Thanh Khe	Breast milk	2.34 - 6.76	7.41 – 42.4	16 – 48

In is important to note that the TRVs and uncertainty factors were obtained from data from developed countries; one would expect different factors (perhaps less conservative) for a developing country such as Viet Nam.

This preliminary quantitative risk assessment provides evidence of an increased human health risk for residents living near the Da Nang airbase as a result of residual 2,3,7,8-TCDD from historical use of dioxin-containing herbicides during wartime operations. HQ and ILCR values for adult and children residents of Thanh Khe District are several hundred times higher than the acceptable TRVs. Results of modelling also indicate that the ingestion of contaminated food, especially aquatic animals (such as fish) account for the greatest potential daily exposure. The results also suggest that the POPs Toolkit can be a useful tool for the assessment of human health risk at sites contaminated with dioxins.

Although the US-Vietnam war has now been over for almost 40 years, the results of this study confirm that the surrounding community is still threatened by dioxin exposure from residual historical contamination. Therefore, additional risk management/mitigation activities are urgently needed. Required risk management/mitigation measures include targeted soil remediation, community education (to prevent and mitigate exposure), and the provision of improved medical and health systems.

References

1. Stellman J.M, Stellman S.D., Christian R., Weber T., Tomasallo C (2003). *Nature, 422*.
2 Young, AL (2009). *The History, Use, Disposition and Environmental Fate of Agent Orange. Springer. 339* p.
4. National Standard for Dioxin threshold in the Soil and Sediment *TCVN: 8183-2009*.
5. Da Nang Statistical Yearbook. 2006
6. World Bank POPs Toolkits 2008. *http://www.popstoolkit.com*
7. UNEP 2001. *Standardized Toolkit for Identification and Quantification of Dioxin and Furan Releases*.
8. Health Canada (2004).Guidance on Human Health Preliminary Quantitative Risk Assessment.
9. USEPA (2008) Human Health Risk Assessment Risk based – Concentration.
10. Schecter, A., Quynh, HT., Pavuk, M., Papke, O., Malisch R., Constable, JD (2003). *JOEM., 45*.
11. International Agency for research on Cancer. *IARC.1997*.
12. ATSDR. 1997. *Interim Policy Guideline: Dioxin and dioxin-like compounds in soil*.
13. Paustenbach DJ., Wenning RJ., Lau U., Harington NW., Rennix DK., Parson AH (1992) *JTEHT, 36*.
14. Han K. K, Nancy A. D, Larry LN, Donald G. P, Jr., Peter S. J. Lees, Katherine Y, Genevieve M. Matanoski M (2006). *AJDM*.
15. Hatfield Consultants and 10-80 Committee (2005 and 2006).
16. Hatfield Consultants and Office 33. (2005, 2006, 2007 and 2009).
17. Vietnam – Russia Tropical Centre, *Reports from 1999-2005*.
18. Hanh TTT., Anh LV., Bich NN., Thomas T (2010) . *IJERPH*,
19. Ministry of Defense of Vietnam (MOD) *Report on Z2, 2002-2004*.
20. Dung PT., Hung TM., Thom LH., Nhu DD., Naganuma R., Kido T. and Tawara K (2007) *Organ. Compounds, Vol 69*.
21. Tuong NV., Thom LTH. 2004.