

**ehp**

**ENVIRONMENTAL  
HEALTH  
PERSPECTIVES**

ehponline.org

**Dioxin Exposure and Cancer Risk in the  
Seveso Women's Health Study**

---

**Marcella Warner, Paolo Mocarelli, Steven Samuels,  
Larry Needham, Paolo Brambilla, Brenda Eskenazi**

**<http://dx.doi.org/10.1289/ehp.1103720>**

**Online 2 August 2011**



**NIEHS**

National Institute of  
Environmental Health Sciences

National Institutes of Health  
U.S. Department of Health and Human Services

## Dioxin Exposure and Cancer Risk in the Seveso Women's Health Study

Marcella Warner<sup>1\*</sup>, Paolo Mocarelli<sup>2</sup>, Steven Samuels<sup>3</sup>, Larry Needham<sup>4</sup>, Paolo Brambilla<sup>2</sup>, Brenda Eskenazi<sup>1</sup>

<sup>1</sup>Center for Environmental Research and Children's Health (CERCH), School of Public Health,  
University of California at Berkeley, Berkeley, CA, USA

<sup>2</sup>Department of Laboratory Medicine, University of Milano-Bicocca, School of Medicine, Hospital  
of Desio, Desio-Milano, Italy

<sup>3</sup>State University of New York, Albany, NY, USA

<sup>4</sup>Division of Environmental Health Laboratory Science, National Center for Environmental Health,  
Centers for Disease Control and Prevention, Atlanta, GA, USA

\*Correspondence to: Marcella Warner, Ph.D., University of California, School of Public Health,  
Center for Environmental Research and Children's Health, 1995 University Avenue, Suite 265,  
Berkeley, CA 94720-7392, telephone: (510) 642-9544, fax: (510) 642-9083, email:  
mwarner@berkeley.edu

Running title: Dioxin Exposure and Cancer Risk

Key words: cancer, cohort studies, dioxins, environmental carcinogens, female, neoplasms, tetrachlorodibenzodioxin

Acknowledgments: We gratefully acknowledge Aliza Parigi for coordinating data collection at Hospital of Desio. We would like to acknowledge the significant contributions made by Larry L. Needham to the Seveso Women's Health Study. He passed away in October 2010 and is greatly missed. This study was supported by Grant Numbers R01 ES07171 and F06 TW02075-01 from the National Institutes of Health, R82471 from the U.S. Environmental Protection Agency, EA-M1977 from the Endometriosis Association, 2P30-ESO01896-17 from the National Institute of Environmental Health Sciences, and #2896 from Regione Lombardia and Fondazione Lombardia Ambiente, Milan, Italy.

B.E. received a grant from the Endometriosis Association, an advocacy group comprised of affected parties, for initial study instrument development. The remaining authors declare they have no actual or potential competing financial interests.

#### Abbreviations

AhR	Aryl hydrocarbon receptor
BMI	body mass index
CI	confidence interval
EPIC	European Prospective Investigation into Cancer and Nutrition
ER	Estrogen receptor
HER2	Human epidermal growth factor receptor 2
HR	Hazard Ratio
IARC	International Agency for Research on Cancer
OC	oral contraceptive
ppt	parts per trillion
PR	Progesterone receptor
RR	Rate Ratio
SWHS	Seveso Women's Health Study
TCDD	2,3,7,8-tetrachlorodibenzo- <i>p</i> -dioxin

## ABSTRACT

**Background:** 2,3,7,8-Tetrachlorodibenzo-*para*-dioxin (TCDD), a widespread environmental contaminant, disrupts multiple endocrine pathways. The International Agency for Research on Cancer classified TCDD as a known human carcinogen, based upon predominantly male occupational studies of increased mortality from all cancers combined.

**Objectives:** After a chemical explosion on July 10, 1976, in Seveso, Italy, residents experienced some of the highest levels of TCDD exposure in a human population. In 1996, we initiated the Seveso Women's Health Study (SWHS), a retrospective cohort study of the reproductive health of the women. We previously reported a significant increased risk for breast cancer and a non-significant increased risk for all cancers combined with individual serum TCDD, but the cohort averaged only 40 years old in 1996. Herein we report results for risk of cancer from a subsequent follow-up of the cohort in 2008.

**Methods:** In 1996, we enrolled 981 women who were 0 to 40 years in 1976, lived in the most contaminated areas, and had archived sera collected near the explosion. Individual TCDD concentration was measured in archived serum by high-resolution mass spectrometry. A total of 833 women participated in the 2008 follow-up study. We examined the relation of serum TCDD with cancer incidence using Cox proportional hazards models.

**Results:** In total, 66 (6.7%) women had been diagnosed with cancer. The adjusted hazard ratio (adj-HR) associated with a ten-fold increase in serum TCDD for all cancers combined was significantly increased (adj-HR=1.80 (95% CI 1.29, 2.52)). For breast cancer, the HR was increased, but not significantly ((adj-HR=1.44 (95% CI 0.89, 2.33)).

**Conclusions:** Individual serum TCDD is significantly positively related with all cancer incidence in the SWHS cohort, more than 30 years later. This all-female study adds to the epidemiologic evidence that TCDD is a multi-site carcinogen.

## INTRODUCTION

The compound, 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD or dioxin) is a widespread environmental contaminant (Birnbaum 1994; Birnbaum 1995; Zook and Rappe 1994). In animals, TCDD is a potent multi-site carcinogen and has been shown to disrupt multiple endocrine pathways (Birnbaum 1994; Birnbaum 1995; Birnbaum and Fenton 2003; IARC 1997). In 1997, the International Agency for Research on Cancer (IARC) classified TCDD as “carcinogenic to humans” (Group 1) based on limited evidence of carcinogenicity in humans, sufficient evidence in animals, and strong evidence in humans and animals for a common mechanism of action via initial binding to the aryl hydrocarbon receptor (AhR) (IARC 1997). Binding of the AhR leads to changes in gene expression, cell replication, and apoptosis. In 2009, IARC reconfirmed the classification of TCDD as a Group 1 carcinogen, citing sufficient epidemiological evidence for all cancers combined (Baan et al. 2009). This conclusion was based upon male occupational cohort studies of increased mortality from all cancers combined, but no particular cancer sites were predominant.

Animal studies report a higher incidence of tumors associated with TCDD exposure in females than males (Kociba et al. 1978). However, there are few studies in humans that have investigated cancer in women associated with TCDD exposure. Two occupational cohort studies of workers employed in the production of chlorophenoxyherbicides have examined the relationship between TCDD exposure and cancer risk in females (Flesch-Janys et al. 1999; Kogevinas et al. 1993; Kogevinas et al. 1997; Manz et al. 1991). Although limited by small sample size and lack of individual exposure data, both studies report increased risks for mortality or incidence from all cancers combined in the subset of female workers who were employed in

the production of TCDD-contaminated phenoxyherbicides (Flesch-Janys et al. 1999; Kogevinas et al. 1993; Manz et al. 1991).

The results of the occupational cohort studies are supported by the most recent follow-up of the Seveso population (Consonni et al. 2008; Pesatori et al. 2009). On July 10, 1976, an explosion at a trichlorophenol manufacturing plant near Seveso, Italy, resulted in the highest TCDD levels known in human residential populations (Mocarelli et al. 1988). Up to 30 kilograms of TCDD were deposited over the surrounding 18-km<sup>2</sup> area (Di Domenico et al. 1980), which was divided into exposure zones (A, B, R, non-ABR) based on TCDD measurements in soil. After 20 years (1976-1996), cancer incidence was non-significantly increased in residents of the most exposed zone, Zone A, for a wide range of cancer sites, including breast cancer (Pesatori et al. 2009). After 25 years (1976-2001), all cancer mortality was significantly increased in Zone A when the analysis was limited to deaths occurring 20 or more years after the explosion (Consonni et al. 2008). Exposure estimates for these ecologic cohort studies were based on zone of residence and thus, lacked individual-level exposure data.

The Seveso Women's Health Study (SWHS), a historical cohort study of the female population residing around Seveso at the time of the explosion in 1976, represents the largest female population with known individual TCDD exposure (Eskenazi et al. 2000). Previously, using data from the SWHS, we examined the association between individual-level TCDD exposure, measured in archived serum collected soon after the explosion, and cancer risk twenty years later (Warner et al. 2002). We found a non-significant increased risk for all cancer incidence (hazard ratio (HR)=1.7; 95% CI 0.90, 3.4) and a significant increased risk for breast

cancer incidence (HR=2.1; 95% CI 1.0, 4.8) associated with a 10-fold increase in individual serum TCDD levels. In 1996, however, the SWHS cohort was relatively young, averaging 40 years of age. Herein we report results for risk of cancer incidence with TCDD exposure from a subsequent follow-up of the cohort in 2008.

## **METHODS**

### **Study Population**

The Seveso Women's Health Study is a historical cohort study of the female population residing around Seveso at the time of the explosion in 1976. Details of the study design are presented elsewhere (Eskenazi et al. 2000). Briefly, eligible women were 0 to 40 years old in 1976, had resided in one of the most highly contaminated zones, A or B, at the time of the explosion, and had adequate stored sera collected soon after the explosion. Enrollment began in March 1996 and was completed in July 1998 for Study I. Of the 1,271 eligible women, 33 women were deceased or ill, 17 women were not reachable, and 240 refused to participate. A total of 981 (80%) participated in the first follow-up.

In 2008, we initiated a second follow-up study of the SWHS cohort (Study II). Enrollment began in April 2008 and was completed in December 2009. Of the 981 eligible women, 16 (1.6%) were deceased and 36 (3.7%) could not be located or contacted. Of the remaining women who could be contacted, 833 (84.9%) agreed to participate.

### **Procedure**

Details of the study procedure for the first follow-up study (Study I) are presented elsewhere (Eskenazi et al. 2000). Briefly, participation included written informed consent,

fasting blood draw, personal interview, and for a subset, a gynecologic examination and transvaginal ultrasound. Additional data was abstracted from medical records.

Participation in the second follow-up study (Study II) included written informed consent, fasting blood draw, anthropometric and blood pressure measurements, personal interview, and for a subset, a bone density examination. Additional data was also abstracted from medical records.

For both Study I and II, personal interviews were conducted by trained nurse-interviewers who were blinded to serum TCDD levels and zones of residence. During the interview, information was collected on the woman's detailed reproductive and medical history as well as demographic and lifestyle factors. Reproductive information collected included reproductive diseases, pregnancy history, history of hormone use, menopause status, medications use, and family history of cancer. Current information on other risk factors included use of cigarettes, alcohol or caffeine, calcium and other supplements, and social class factors (education, occupation, income). In addition, in Study II, the European Prospective Investigation into Cancer and Nutrition (EPIC)-Italy food frequency questionnaire was administered (Pisani et al. 1997).

Medical history information obtained on the questionnaire included a diagnosis of cancer. During the interview each woman was asked a series of cancer questions following the format, "Has a doctor ever told you that you had breast cancer?" If she answered "yes" to any of the cancer questions, past medical records were obtained and were reviewed by a cancer pathologist

who was blinded to the woman's exposure. The death certificates were requested for all 16 deaths and if cancer was indicated as a cause of death (n=14), medical records were also requested. This study was approved by the Institutional Review Boards of the participating institutions.

### **Laboratory Analyses**

TCDD was measured in archived sera by high-resolution gas chromatography/ high-resolution mass spectrometry methods (Patterson et al. 1987). Values are reported on a lipid-weight basis in parts-per-trillion (ppt) (Akins et al. 1989). Details of serum sample selection are presented elsewhere (Eskenazi et al. 2000; Eskenazi et al. 2004). Briefly, from the archived serum samples collected between 1976 and 1985 and stored at -20°C, we preferentially selected for analysis the first sample available that was collected between 1976 and 1981 and was of adequate volume (>0.5 mL) to measure TCDD. We measured TCDD in sera collected in 1976 or 1977 for 894 women (91%); between 1978 and 1981 for 59 women (6%), and in 1996 or 1997 for 28 women (3%) with insufficient volume in earlier samples. For women with detectable post-1977 TCDD measurements greater than 10 ppt, the TCDD exposure level was back-extrapolated to 1976 using the first-order kinetic model (Pirkle et al. 1989) for women who were older than 16 years in 1976 (n=40) or the Filser model (Kreuzer et al. 1997) otherwise (n=30). For eight women whose post-1977 TCDD values were detectable but  $\leq 10$  ppt, the measured value was used. For non-detectable values (n=96), a serum TCDD level of one-half the detection limit was assigned (Hornung and Reed 1990). For the study median serum sample weight of 0.65 g, the median limit of detection was 18.8 ppt, lipid-adjusted.

### Statistical Analyses

Serum TCDD was analyzed both as a continuous variable ( $\log_{10}$ TCDD) and a four-category variable. The cut-point for the lowest group was set at  $\leq 20$  ppt, because 15-20 ppt was the average TCDD level in serum pools collected from unexposed Italian women in 1976 (Eskenazi et al. 2004). The three remaining categories were defined by calculating tertiles of exposure  $>20$  ppt, giving groups:  $\leq 20$ , 20.1-47.0, 47.1-135.0 and  $>135$  ppt.

We used Cox proportional hazards modeling for the main analyses. Age was the underlying time variable, with entry defined as the subject's age on the explosion date, July 10, 1976, and exit defined as her age at cancer diagnosis or censoring (death, last follow-up). Women who refused or were not able to be located were censored at the age at last follow-up (1996-98). We report the measure of effect as the hazard ratio (HR) and 95% confidence interval (CI).

We examined the effect of a broad range of potential confounders identified in the cancer and breast cancer literature (ACS 2010; Brody and Rudel 2003; Hulka and Moorman 2001; Key et al. 2001; Salehi et al. 2008; Travis and Key 2003). We considered education, marital status, gravidity, parity, age at first full-term pregnancy, lactation history, family history of breast cancer in a first degree relative, age at menarche, body mass index (BMI), weight, height, oral contraceptive (OC) use, menarche status at explosion, time from explosion to first full term pregnancy, age at explosion, menopause status, age at menopause, hormone replacement therapy use, history of thyroid disease, physical inactivity, smoking and alcohol consumption. Covariate information for each woman was based on data collected at her last follow-up. We also

considered age at menopause as a time-dependent variable. Covariates were included in Cox models if they changed the coefficient for  $\log_{10}\text{TCDD}$  by at least 10% or if they were independently associated with the cancer outcome at  $p < 0.10$ . We also considered possible interaction of menarche status at explosion.

In sensitivity analyses, we repeated the final models for cancer and breast cancer, stratifying on study follow-up period (Study I - 1976-1996; Study II - 1997-2009), on time between initial exposure and disease diagnosis or latency period (0-10 years; 11-20 years; 21-32 years), on menopause status at diagnosis, and on estrogen or progesterone receptor status. We also repeated the final models, excluding women whose individual TCDD level was measured in serum collected after 1977 and excluding women with individual TCDD levels derived by extrapolation. Finally, we repeated the final models assuming all non-participants (refusals, loss-to follow-up) in Study II were non-cases.

Standard errors were estimated using the robust Huber-White sandwich estimator. The proportional hazards assumption was tested using scaled Schoenfeld residuals. We conducted tests for linear trend by including categorical TCDD as a continuous term in the models. All statistical analyses were performed using STATA 11.0 (Stata Corp 2009).

## RESULTS

Table 1 presents the distribution of TCDD exposure by select characteristics of the SWHS cohort. On the date of the explosion, 232 women (24%) were less than 10 years old and 284 (29%) were premenarcheal. At last follow-up, the average age of the cohort was 50.8

( $\pm 11.8$ ) years, about half of the women (51%) were post-menopause, and 152 (16%) were nulliparous. The mean age at first pregnancy for the 829 parous women was 25.4 ( $\pm 4.6$ ) years, and 711 (86%) had ever lactated. About 10 percent of women reported a family history of breast cancer in a first degree relative (mother, sister, daughter). The majority (63%) of women had never regularly smoked or consumed alcohol. The average BMI at last follow-up was 26.4 ( $\pm 5.4$ ) kg/m<sup>2</sup> and 22% were obese. Serum TCDD levels were higher among women who were youngest or premenarche at explosion. TCDD levels were also higher among women who at last follow-up were nulliparous, current OC users, never married, more educated, or pre-menopause, but these are all also age-related characteristics.

In total, 66 women (6.7%) in the SWHS cohort had been diagnosed with cancer. Of the 66 incident cases, 21 were diagnosed by the first follow-up (1996-8) and 45 were diagnosed by the second follow-up (2008-9). Of the 66 cases, 65 (98%) were confirmed by pathology and one (2%) by surgery report alone. The average age of cases ( $n=66$ ) at diagnosis was 48.8 ( $\pm 11.3$ ) years and at explosion was 25.5 ( $\pm 10.9$ ) years. The cases were diagnosed an average of 23.4 ( $\pm 7.2$ ) years after the explosion, with the shortest interval being seven years. The geometric mean serum TCDD level for the 66 cancer cases ( $95.3 \pm 4.0$  ppt, lipid-adjusted) is somewhat greater than the concentration for the non-cases ( $n=915$ ,  $67.9 \pm 4.2$ ) (ANOVA for  $\log_{10}\text{TCDD}$ :  $p = 0.06$ ).

The distribution of cancer sites among the 66 cases is presented in Table 2. Breast cancer ( $n=33$ ) was the most frequent site, representing half of the cases. Thyroid cancer ( $n=7$ ) was the

second most frequent site. The remaining cases were represented by a wide variety of cancer sites.

All breast cancers were confirmed by pathology. The average age of breast cancer cases at explosion was 26.4 ( $\pm 8.7$ ) years, with a range from 10 to 39 years. The average age at diagnosis was 48.3 ( $\pm 8.5$ ) years, with a range from 31 to 69 years. The average interval between explosion and diagnosis was 21.9 ( $\pm 7.3$ ); the shortest interval was eight years. A majority of the 33 breast cancer cases ( $n=18$ , 55%) were diagnosed pre-menopause. For the breast cancer cases for whom receptor status of tumors was available, 20/23(87%) were estrogen receptor (ER) positive; 19/22 (86.4%) were progesterone receptor (PR) positive; and 6/12 (50%) were human epidermal growth factor 2 (HER2) positive. Of the 22 cases who had both ER and PR data, 82% were ER+PR+. There was no significant difference in receptor status of pre- and post-menopause cases.

Because of the small numbers of cases of specific cancer types, in multivariate analysis we were only able to examine the relation of serum TCDD levels to all cancers combined and to breast cancer. For thyroid cancer, in a univariate Cox model, the unadjusted HR associated with a 10-fold increase in TCDD ( $\log_{10}$ TCDD) was 2.1 (95% CI 0.6, 6.7). Table 3 presents the unadjusted and adjusted results of Cox proportional hazards modeling for the association between lipid-adjusted serum TCDD level and all cancers combined and breast cancer risk.

For the all cancers combined analysis, in single-covariate Cox models, cancer risk was positively associated with premenarche status at explosion, never married, current alcohol

consumption, physical inactivity, lower gravidity, lower parity, and never lactating. As presented in Table 3, after adjusting for age at explosion and marital status, the adjusted HR associated with a 10-fold increase in TCDD ( $\log_{10}\text{TCDD}$ ) for all cancers combined remained significantly increased to 1.80 (95% CI 1.29, 2.52). When TCDD was considered as a categorical variable, there was still evidence of a significant dose-response trend ( $p=0.002$ ). Compared to the lowest exposure group ( $\leq 20$  ppt), the adjusted HR (95% CI) for the three dose groups, 20.1-47 ppt, 47.1-135 ppt, and  $>135$  ppt, were 1.23 (0.48, 3.16), 2.50 (1.02, 6.09), and 2.77 (1.11, 6.90), respectively. We found no evidence of interaction by menarche status at explosion ( $p = 0.89$ ). When stratified by zone, although the number of cases from Zone A is small, we found no difference in risk of all cancers associated with serum TCDD levels by residence in Zone A ( $n=13$ ; adj-HR=1.55; 95% CI 0.86, 2.80) or Zone B ( $n=53$ ; adj-HR=2.30; 95% CI 1.32, 3.99). The  $p$ -value for an interaction of TCDD and zone was  $p = 0.27$ .

For the breast cancer analysis, in single-covariate Cox models, breast cancer risk was positively associated with younger age of menarche, lower gravidity, lower parity, never lactating, older age at first pregnancy, and family history of breast cancer. As presented in Table 3, after adjusting for parity and family history of breast cancer in a first-degree relative, the adjusted HR (95% CI) for breast cancer associated with a 10-fold increase in exposure ( $\log_{10}\text{TCDD}$ ) was non-significantly increased to 1.44 (0.89, 2.33). When TCDD was categorized, there was some evidence of a dose-response, but it was not statistically significant ( $p = 0.09$ ). Compared to the lowest exposure group ( $\leq 20$  ppt), the adjusted HR (95% CI) for the three higher dose groups were 0.94 (0.28, 3.14), 1.95 (0.64, 5.95), and 1.98 (0.62, 6.32), respectively.

If we consider the group “all cancers combined excluding breast cancer” (n=33), the adjusted HR (95% CI) associated with a 10-fold increase in exposure ( $\log_{10}$ TCDD) was significantly increased to 2.08 (1.34, 3.23). When TCDD was categorized, there was evidence of a significant dose-response trend ( $p = 0.02$ ). Compared to the lowest exposure group ( $\leq 20$  ppt), the adjusted HR (95% CI) for the three higher dose groups were 1.78 (0.38, 8.33), 3.29 (0.72, 14.92), and 3.96 (0.87, 18.24), respectively.

Table 4 presents the results of Cox proportional hazards models for all cancers and breast cancer, stratified by study follow-up period (Study I -1976-1996; Study II – 1997-2009) and by latency period (0-10 years, 11-20 years, 21-32 years). Although the small numbers of cancer cases within strata limit power, the hazard ratios presented for all cancer incidence do not differ by study follow-up period or latency period. For breast cancer, however, the significant increased risk reported for breast cancer incidence during Study I, is diminished in the last decade of follow-up, and is no longer significant. Further, in sensitivity analyses, we found no difference in risk by menopause status at diagnosis or receptor status, but the numbers are small (data not shown).

We repeated the final models first limiting the analysis to the 894 women with TCDD measured in samples collected in 1976 or 1977, and then excluding 78 women with extrapolated TCDD measures and the results were not different (data not shown). Finally, we assumed all non-participants (refusals, loss-to follow-up) were non-cases, and the results did not change (data not shown).

## DISCUSSION

We observed a statistically significant, dose-related increased risk in overall cancer incidence associated with individual serum TCDD level in the Seveso Women's Health Study. Specifically, we reported a significant increased hazard ratio of 1.8 associated with a 10-fold increase in serum TCDD. This result is similar to our previous observation, although the association was not statistically significant in the earlier follow-up in 1996-98 (Warner et al. 2002).

The validity of the findings is strengthened by the fact that the results did not change and remained significant after adjusting for potential confounding factors. Participation in Study II was high (over 85%), 12 years after Study I and more than 30 years after the explosion. In addition, loss to follow-up was low (3.7%). Participants and non-participants (refusals, loss to follow-up) did not differ in terms of age at explosion or serum TCDD level.

The results of this study are consistent with those from earlier studies suggesting an association but lacking individual exposure data. The two occupational cohort studies of workers employed in the production of chlorophenoxyherbicides both reported increased risks for mortality and incidence from all cancers in the subset of female workers who were employed in the production of TCDD-contaminated phenoxyherbicides (Flesch-Janys et al. 1999; Kogevinas et al. 1993).

The results are also consistent with those reported for Zone A, but not Zone B, in the most recent cancer incidence study of the larger Seveso population (Pesatori et al. 2009). After

20 years (1976-1996), non-significant increased risks for cancer incidence were reported in Zone A for a wide range of cancers. In Zone A after a 15-year latency, all cancer incidence for males and females together was non-significantly increased (n=19; Rate Ratio (RR) =1.27; 95% CI 0.81, 2.00), but sex-specific risks were not presented. Our results, however, are not consistent with those reported for Zone B, which in contrast to Zone A, after a 15-year latency there was no increase in all cancer incidence for males and females together (n=92; RR=1.02; 95% CI 0.83, 1.26). The lack of consistency for Zone B is likely in part due to exposure misclassification. Individual serum TCDD measurements from the SWHS suggest a wide range of individual TCDD exposures within zones (Eskenazi et al. 2004). Exposure misclassification based on zone of residence would be expected to be non-differential, potentially resulting in an underestimate of effect. Although the number of cases from Zone A is small in our study, we found no difference between Zone A and Zone B in risk of cancer associated with serum TCDD levels.

The results are also somewhat consistent with the most recent cancer mortality study of the larger Seveso population (Consonni et al. 2008). After 25 years of follow-up (1976-2001), the number of cancer deaths in Zone A was small (n=42), but with a 20 year-latency, mortality from cancer among Zone A women was non-significantly increased (n=5; RR=1.17; 95% CI 0.49, 2.83). Similar data were not presented for Zone B women. Note that there is likely little overlap in cases between the mortality study and SWHS. The SWHS cohort included women who were 0 to 40 years in 1976, while the larger Seveso cohort included women who were 20 to 74 years. In addition, we included incident cases diagnosed between 1976 and 2009; 14 of the SWHS women were deceased but only one case died before 2001, the end of follow-up for the mortality study (Consonni et al. 2008).

An advantage of SWHS is that we were able to examine the relationship between serum TCDD concentration and cancer incidence, not mortality, thus eliminating potential biases associated with variations in disease survival. In addition, we were able to collect information on confounding factors during the interview that were not available in the mortality study. Finally, we were able to measure individual serum TCDD concentrations near the time of exposure, thus minimizing exposure misclassification.

A limitation of the SWHS study is the small number of cancer cases (n=66). However, this number is greater than the number in any other single study of cancer in TCDD-exposed women (Flesch-Janys et al. 1999; Kogevinas et al. 1993; Pesatori et al. 2009). These other studies with numbers of cases ranging from 9 to 57, reported increased cancer risks similar to the hazard ratios reported here. These studies classified exposure based on job history, company production records, and for a subset of workers, TCDD in serum or adipose measured many years after last exposure.

Although we observed a wide range of cancers in this study, only breast cancer had enough cases for an examination of the association with TCDD. We found a non-significant increase in the hazard ratio (HR=1.44; 95% CI 0.89, 2.33) associated with a 10-fold increase in serum TCDD over the 32-year follow-up period. Our earlier observation of a significantly increased risk of breast cancer with 20 years of follow-up (Warner et al. 2002), was not sustained with the additional 12 years of data. In categorical analysis, although not significant, the highest risks were observed for the highest dose groups.

The results for breast cancer in this study are somewhat consistent with those from the 20-year incidence study of the larger Seveso population, which reported a non-significant increased risk for breast cancer in Zone A (n=8; RR=1.43; 95% CI 0.71, 2.87), but not Zone B (n=30; RR=0.85; 95% CI 0.59, 1.22) (Pesatori et al. 2009). Pesatori et al (2009) found no difference in risk by age at diagnosis of breast cancer before or after 50 years, a proxy for menopause status (<50: n=3; RR=1.50; 95% CI 0.48, 4.67 versus 50+: n=5; RR=1.39; 95% CI 0.58, 3.36). Consistent with that report, we found no difference in risk of breast cancer with TCDD exposure by menopause status at diagnosis. The two studies, however, are not directly comparable. The SWHS cohort is younger; at explosion, the 33 breast cancer cases in SWHS averaged 26.4 years while the 8 breast cancer cases in Zone A in Pesatori et al (2009) were 20 to 49 years.

When we compared the observed breast cancer incidence in the SWHS cohort with that expected for the area using 1985-2009-age-specific breast cancer incidence rates from the Lombardy Cancer Registry in Italy (Italian Association of Cancer Registries 2010), the expected number of breast cancer cases would be 27; we found 33 for an overall SIR for the 981 women of 1.22. Further, the observed excess of cases was highest in the 45 to 49 year age group (10 observed versus 5 expected).

Of the breast cancer cases for whom receptor status data was available, the distribution of ER+ and PR+ but not HER2+ was similar to that reported by the Tuscany Cancer Registry among all the invasive breast cancer cases diagnosed during the period 2004-2005 (Calderella et

al. 2011). Given the limited number of cases (n=12) with HER2+ data available for SWHS, however, it is difficult to determine whether there is any difference in receptor status.

It is possible the increased risk for breast cancer observed in earlier decades of follow-up reflects a mechanism of action of TCDD as a cancer promoter. It is also worth noting that the cohort has not yet been followed to the time of greatest onset of breast cancer - post-menopause. With additional follow-up, we will be able to better discern whether the window of increased risk for breast cancer observed in the earlier follow-up period is in fact past.

Additional follow-up is also needed for the observed cancers other than breast. There is evidence in animals of an effect of TCDD on thyroid function including an increase in thyroid follicular cell hyperplasia (Nishimura et al. 2002; Nishimura et al. 2003; Yoshizawa et al. 2010). The number of thyroid cancer cases is small, but it is noteworthy that the observed increase in hazard ratio is consistent with the animal studies. We also observed two cases of lung cancer (one in a non-smoker) and three cases of lymphatic and hematopoietic cancers, both types of cancer previously reported to be associated with TCDD exposure (Consonni et al. 2008; IARC 1997; Pesatori et al. 2009), but we were unable to examine the relation of TCDD due to the small number of cases.

In summary, we have shown that individual serum TCDD measurements are significantly positively related to overall cancer incidence among women in the SWHS cohort. The results of this study are consistent with TCDD as a potent multi-site carcinogen in animals and with increased cancer mortality risks reported in the male occupational cohort studies and used by

IARC in its classification of TCDD (IARC 1997; Steenland et al. 2004). Thus, this study extends the results of the recent IARC reassessment to include women. SWHS women were 0 to 40 years at exposure and almost a third of the women were premenarche at exposure. With continued follow-up of SWHS, we will begin to be able to examine the carcinogenic effects of TCDD during potentially susceptible windows of exposure such as premenarche or time between menarche and age at first full pregnancy.

**REFERENCES**

- ACS. 2010. Cancer Facts & Figures 2010. Atlanta, GA: American Cancer Society.
- Akins JR, Waldrep K, Bernert JT, Jr. 1989. The estimation of total serum lipids by a completely enzymatic 'summation' method. *Clin Chim Acta* 184:219-226.
- Baan R, Grosse Y, Straif K, Secretan B, El Ghissassi F, Bouvard V, et al. 2009. A review of human carcinogens--Part F: chemical agents and related occupations. *Lancet Oncol* 10:1143-1144.
- Birnbaum L. 1994. The mechanism of dioxin toxicity: relationship to risk assessment. *Environ Health Perspect* 102 Suppl 9:157-167.
- Birnbaum L. 1995. Developmental effects of dioxins and related endocrine disrupting chemicals. *Toxicol Lett* 82-83:743-750.
- Birnbaum LS, Fenton SE. 2003. Cancer and developmental exposure to endocrine disruptors. *Environ Health Perspect* 111:389-394.
- Boers D, Portengen L, Bueno-de-Mesquita HB, Heederik D, Vermeulen R. 2010. Cause-specific mortality of Dutch chlorophenoxy herbicide manufacturing workers. *Occup Environ Med* 67:24-31.
- Brody JG, Rudel RA. 2003. Environmental pollutants and breast cancer. *Environ Health Perspect* 111:1007-1019.
- Caldarella A, Crocetti E, Bianchi S, Vezzosi V, Urso C, Biancalini M, et al. 2011. Female Breast Cancer Status According to ER, PR, and HER2 Expression: A Population Based Analysis. *Pathol Oncol Res*, doi:10.1007/s12253-011-9381-z [Online 10 April 2011].
- Consonni D, Pesatori AC, Zocchetti C, Sindaco R, D'Oro LC, Rubagotti M, et al. 2008. Mortality in a population exposed to dioxin after the Seveso, Italy, accident in 1976: 25 years of follow-up. *Am J Epidemiol* 167:847-858.
- Di Domenico A, Silano V, Viviano G, Zapponi G. 1980. Accidental release of 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) at Seveso, Italy. II. TCDD distribution in the soil surface layer. *Ecotoxicol Environ Saf* 4:298-320.
- Eskenazi B, Mocarelli P, Warner M, Samuels S, Vercellini P, Olive D, et al. 2000. Seveso Women's Health Study: a study of the effects of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin on reproductive health. *Chemosphere* 40:1247-1253.

- Eskenazi B, Mocarelli P, Warner M, Needham L, Patterson D, Samuels S, et al. 2004. Relationship of serum TCDD concentrations and age at exposure of female residents of Seveso, Italy. *Environ Health Perspect* 112:22-27.
- Flesch-Janys D, Becher H, Manz A, Morgenstern I, Nagel S, Steindorf K. 1999. Epidemiologic investigation of breast cancer incidence in a cohort of female workers with high exposure to PCDD/F and HCH. *Organohalogen Compounds* 44:379-382.
- Hornung R, Reed L. 1990. Estimation of average concentration in the presence of non-detectable values. *Appl Occup Environ Hyg* 5:48-51.
- Hulka BS, Moorman PG. 2001. Breast cancer: hormones and other risk factors. *Maturitas* 38:103-113.
- IARC. 1997. Polychlorinated Dibenzo-*para*-Dioxins and Polychlorinated Dibenzofurans. In: IARC Monogr Eval Carcinog Risks Hum, 33-342.
- Italian Association of Cancer Registries. 2010. I Tumori in Italia. Available: <http://www.tumori.net/it/> [accessed 26 August 2010].
- Key TJ, Verkasalo PK, Banks E. 2001. Epidemiology of Breast Cancer. *Lancet Oncol* 2:133-140.
- Kociba RJ, Keyes DG, Beyer JE, Carreon RM, Wade CE, Dittenber DA, et al. 1978. Results of a two-year chronic toxicity and oncogenicity study of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin in rats. *Toxicol Appl Pharmacol* 46:279-303.
- Kogevinas M, Saracci R, Winkelmann R, Johnson ES, Bertazzi PA, Bueno de Mesquita BH, et al. 1993. Cancer incidence and mortality in women occupationally exposed to chlorophenoxy herbicides, chlorophenols, and dioxins. *Cancer Causes Control* 4:547-553.
- Kogevinas M, Becher H, Benn T, Bertazzi PA, Boffetta P, Bueno-de-Mesquita HB, et al. 1997. Cancer mortality in workers exposed to phenoxy herbicides, chlorophenols, and dioxins. An expanded and updated international cohort study. *Am J Epidemiol* 145:1061-1075.
- Kreuzer PE, Csanády GA, Baur C, Kessler W, Pöpke O, Greim H, et al. 1997. 2,3,7,8-Tetrachlorodibenzo-*p*-dioxin (TCDD) and congeners in infants. A toxicokinetic model of human lifetime body burden by TCDD with special emphasis on its uptake by nutrition. *Arch Toxicol* 71:383-400.
- Manz A, Berger J, Dwyer JH, Flesch-Janys D, Nagel S, Waltsgott H. 1991. Cancer mortality among workers in chemical plant contaminated with dioxin. *Lancet* 338:959-964.

- Mocarelli P, Pocchiari F, Nelson N. 1988. Preliminary report: 2,3,7,8-tetrachlorodibenzo-*p*-dioxin exposure to humans--Seveso, Italy. *Morb Mortal Wkly Rep* 37:733-736.
- Nishimura N, Miyabara Y, Sato M, Yonemoto J, Tohyama C. 2002. Immunohistochemical localization of thyroid stimulating hormone induced by a low oral dose of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin in female Sprague-Dawley rats. *Toxicology* 171:73-82.
- Nishimura N, Yonemoto J, Miyabara Y, Sato M, Tohyama C. 2003. Rat thyroid hyperplasia induced by gestational and lactational exposure to 2,3,7,8-tetrachlorodibenzo-*p*-dioxin. *Endocrinology* 144:2075-2083.
- Patterson DG, Jr., Hampton L, Lapeza CR, Jr., Belser WT, Green V, Alexander L, et al. 1987. High-resolution gas chromatographic/high-resolution mass spectrometric analysis of human serum on a whole-weight and lipid basis for 2,3,7,8-tetrachlorodibenzo-*p*-dioxin. *Anal Chem* 59:2000-2005.
- Pesatori AC, Consonni D, Rubagotti M, Grillo P, Bertazzi PA. 2009. Cancer incidence in the population exposed to dioxin after the "Seveso accident": twenty years of follow-up. *Environ Health* 8:39-49.
- Pirkle J, Wolfe W, Patterson D, Needham L, Michalek J, Miner J, et al. 1989. Estimates of the half-life of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin in Vietnam veterans of Operation Ranch Hand. *J Toxicol Environ Health* 27:165-171.
- Pisani P, Faggiano F, Krogh V, Palli D, Vineis P, Berrino F. 1997. Relative validity and reproducibility of a food frequency dietary questionnaire for use in the Italian EPIC Centres. *Int J Epidemiol* 26:152-160.
- Salehi F, Turner MC, Phillips KP, Wigle DT, Krewski D, Aronson KJ. 2008. Review of the etiology of breast cancer with special attention to organochlorines as potential endocrine disruptors. *J Toxicol Environ Health B Crit Rev* 11:276-300.
- Stata Corp. 2009. *Stata Statistical Software: Release 11.0*. College Station, TX: Stata Press.
- Steenland K, Bertazzi P, Baccarelli A, Kogevinas M. 2004. Dioxin Revisited: Developments Since the 1997 IARC Classification of Dioxin as a Human Carcinogen. *Environ Health Perspect* 112:1265-1268.
- Travis RC, Key TJ. 2003. Oestrogen exposure and breast cancer risk. *Breast Cancer Res* 5:239-247.

- Warner M, Eskenazi B, Mocarelli P, Gerthoux PM, Samuels S, Needham L, et al. 2002. Serum dioxin concentrations and breast cancer risk in the Seveso Women's Health Study. *Environ Health Perspect* 110:625-628.
- World Health Organization. 1980. International Classification of Diseases, 9<sup>th</sup> Revision. Geneva: World Health Organization.
- Yoshizawa K, Walker NJ, Nyska A, Kissling GE, Jokinen MP, Brix AE, et al. 2010. Thyroid follicular lesions induced by oral treatment for 2 years with 2,3,7,8-tetrachlorodibenzo-*p*-dioxin and dioxin-like compounds in female Harlan Sprague-Dawley rats. *Toxicol Pathol* 38:1037-1050.
- Zook D, Rappe C. 1994. Environmental Sources, Distribution, and Fate. In: *Dioxins and Health* (Schechter A, ed). New York: Plenum Press, 79-113.

**Table 1.** Distribution of 1976 serum TCDD levels (ppt, lipid-adjusted) by select characteristics in the Seveso Women's Health Study, Italy, 1976-2009.

Characteristic	n (%)	TCDD (ppt) Median (Interquartile range)
Total	981 (100.0)	55.9 (28 – 157)
Zone of Residence*		
A	167 (17.0)	272.0 (93 – 883)
B	814 (83.0)	47.1 (25 – 106)
Age at explosion (years)*		
0-10	232 (23.7)	165.0 (61 – 344)
11-20	279 (28.4)	48.8 (24 – 100)
21-30	241 (24.6)	43.8 (23 – 101)
31-40	229 (23.3)	45.2 (28 – 99)
Menarche status at explosion*		
Premenarche	284 (28.9)	142.5 (57 – 300)
Postmenarche	697 (71.1)	44.4 (24 – 97)
Age at menarche (years) <sup>b</sup>		
< 12	228 (23.2)	57.7 (29 – 167)
12-13	461 (47.0)	54.8 (26 – 156)
> 13	289 (29.5)	55.8 (30 – 150)
Parity*		
0	152 (15.5)	97.6 (36 – 267)
1-2	648 (66.1)	54.9 (27 – 151)
≥ 3	181 (18.5)	43.2 (25 – 92)
Age at first full-term pregnancy (years) <sup>a</sup> *		
< 20	67 ( 8.1)	32.7 (18 – 74)
20-25	396 (47.8)	45.1 (26 – 106)
> 25	366 (44.2)	66.7 (32 – 196)
Lactation History <sup>a</sup>		
Never	118 (14.2)	45.1 (28 – 122)
Ever	711 (85.8)	52.9 (27 – 139)
Menopause status <sup>b</sup> *		
Premenopause	484 (49.3)	75.0 (33 – 213)
Postmenopause	496 (50.6)	45.2 (24 – 105)

Table 1 (continued)

Characteristic	n (%)	TCDD (ppt) Median (Interquartile range)
HRT Use <sup>b</sup>		
Never	867 (88.4)	59.4 (29 – 165)
Ever	87 ( 8.9)	45.2 (27 – 92)
Family history of breast cancer		
No	877 (89.4)	57.6 (28 – 159)
Yes	104 (10.6)	51.6 (29 – 121)
Education*		
≤ Required	651 (66.4)	49.6 (26 – 120)
High school	288 (29.4)	76.5 (34 – 256)
> High School	42 ( 4.3)	72.4 (30 – 251)
Marital status*		
Never	76 ( 7.8)	140.3 (48 – 353)
Ever	905 (92.3)	53.3 (28 – 142)
Oral contraceptive use*		
Never	443 (45.2)	46.5 (27 – 117)
Former	453 (46.2)	66.2 (31 – 165)
Current	85 ( 8.7)	112.0 (37 – 272)
Cigarette smoking		
Never	619 (63.1)	54.8 (28 – 156)
Former	194 (19.8)	63.3 (29 – 163)
Current	168 (17.1)	55.1 (29 – 155)
Alcohol use		
Never	618 (63.0)	53.5 (28 – 153)
Former	44 ( 4.5)	59.7 (30 – 122)
Current	319 (32.5)	61.1 (29 – 164)
Body mass index (kg/m <sup>2</sup> )*		
Underweight (<18.5)	26 ( 2.6)	116.5 (33 – 352)
Normal (18.5- 24.9)	437 (44.6)	71.4 (37 – 185)
Overweight (25-30)	302 (30.8)	45.5 (24 – 119)
Obese (>30)	216 (22.0)	45.9 (25 – 119)

Table 1 (continued)

Characteristic	n (%)	TCDD (ppt) Median (Interquartile range)
Physical Activity*		
Active	326 (33.2)	49.3 (26 – 117)
Moderately Active	297 (30.3)	70.0 (30 – 214)
Inactive	358 (36.5)	57.9 (28 – 164)

\*  $p < 0.05$  (ANOVA significant difference in  $\log_{10}$ TCDD by covariate)

<sup>a</sup> Parous women only.

<sup>b</sup> Numbers do not add to 100% of total because of missing data.

**Table 2.** Distribution of Cancer Cases, Seveso Women's Health Study, Italy, 1976-2009.

Cancer Site (ICD-9 Code) <sup>a</sup>	n (%)
All Cancers	66 (100)
Digestive organs and peritoneum (150-159)	8 (12.1)
Esophagus (150)	1
Stomach (151)	2
Colon (153)	3
Rectum (154)	1
Other digestive (159)	1
Respiratory and intrathoracic organs (160-165)	2 ( 3.0)
Lung (162)	2
Bone, connective tissue, skin and breast (170-175)	36 (54.5)
Melanoma of Skin (172)	3
Breast (174)	33
Genitourinary organs (179-189)	8 (12.1)
Cervix (180)	1
Placenta (181)	1
Uterus (182)	3
Ovary (183)	2
Kidney (189)	1
Other and unspecified sites (190-199)	9 (13.6)
Thyroid (193)	7
Ill-defined (199)	2
Lymphatic and hematopoietic tissue (200-208)	3 ( 4.5)
Lymphoma (202)	2
Myeloid Leukemia (205)	1

<sup>a</sup>International Classification of Diseases, 9<sup>th</sup> Revision (World Health Organization 1980)

**Table 3.** Hazard ratios (HR) from Cox proportional hazards model for association between lipid-adjusted serum TCDD levels and all cancer and breast cancer risk over 32 years of follow-up, Seveso Women’s Health Study, Italy, 1976-2009.

Exposure	All Cancers			Breast Cancer		
	Cases/Total	HR (95% CI)	Adjusted HR <sup>a</sup> (95% CI)	Cases/Total	HR (95% CI)	Adjusted HR <sup>b</sup> (95% CI)
Log <sub>10</sub> TCDD <sup>c</sup> (ppt)	66/981	1.86 (1.34, 2.59) <i>p</i> <0.001	1.80 (1.29, 2.52) <i>p</i> =0.001	33/981	1.49 (0.93, 2.38) <i>p</i> =0.10	1.44 (0.89, 2.33) <i>p</i> =0.13
TCDD (ppt)						
≤ 20	6/154	1.00	1.00	4/154	1.00	1.00
20.1-47.0	14/276	1.16 (0.45, 3.02)	1.23 (0.48, 3.16)	7/276	0.91 (0.27, 3.08)	0.94 (0.28, 3.14)
47.1-135.0	25/278	2.53 (1.04, 6.18)	2.50 (1.02, 6.09)	13/278	2.07 (0.68, 6.30)	1.95 (0.64, 5.95)
> 135	21/273	2.92 (1.18, 7.24)	2.77 (1.11, 6.90)	9/273	2.04 (0.64, 6.48)	1.98 (0.62, 6.32)
		<i>p</i> -trend = 0.001	<i>p</i> -trend = 0.002		<i>p</i> -trend = 0.07	<i>p</i> -trend = 0.09

<sup>a</sup> Adjusted for marital status and age at explosion.

<sup>b</sup> Adjusted for parity and family history of breast cancer in a first degree relative.

<sup>c</sup> Hazard ratio (HR) for a 10-fold increase in serum TCDD concentration.

**Table 4.** Hazard ratios (HR) from Cox proportional hazards model for association between lipid-adjusted serum ( $\log_{10}$ ) TCDD levels and all cancer risk and breast cancer risk stratified on follow-up period, Seveso Women's Health Study, Italy, 1976-2009.

Follow-up	All Cancers				Breast Cancer			
	Cases	p-y <sup>a</sup>	Unadjusted HR <sup>b</sup> (95% CI)	<i>p</i>	Cases	p-y <sup>a</sup>	Unadjusted HR <sup>b</sup> (95% CI)	<i>p</i>
1976 – 2009	66	29,722	1.86 (1.34, 2.59)	<0.001	33	29,838	1.49 (0.93, 2.38)	0.10
Study I (1976 – 1996-8)	21	20,118	1.71 (0.93, 3.14)	0.08	15	20,168	2.13 (1.11, 4.09)	0.02
Study II (1996-8 – 2008-9)	45	9,604	1.83 (1.25, 2.67)	0.002	18	9,670	1.12 (0.61, 2.06)	0.71
0-10 years (1976 – 1986)	6	9,802	2.39 (1.13, 5.06)	0.02	3	9,808	2.91 (0.90, 9.44)	0.08
11-20 years (1987 – 1996)	13	9,699	1.61 (0.72, 3.59)	0.25	10	9,737	2.23 (1.09, 4.56)	0.03
21-32 years (1997 – 2009)	47	10,221	1.77 (1.21, 2.58)	0.003	20	10,293	1.06 (0.58, 1.93)	0.86

<sup>a</sup>p-y: person-years

<sup>b</sup>Hazard Ratio (HR) for a 10-fold increase in serum TCDD concentration.