COMMITTEE ON TOXICITY OF CHEMICALS IN FOOD, CONSUMER PRODUCTS AND THE ENVIRONMENT

STATEMENT ON CHLORINATED DRINKING WATER AND REPRODUCTIVE OUTCOMES

Introduction

1. The Committee considered the issue of chlorinated drinking water and adverse reproductive outcomes in 1998 and produced a statement which was published in 1999 [1]. In May 2001 we were asked to consider the findings in a draft report of the first phase of a Government-funded epidemiological study[5] conducted in England by the Small Area Health Statistics Unit (SAHSU), along with additional relevant studies published since 1998 [8 9 12 13 20]. Our conclusions were unchanged. An updated Committee statement was drafted, for release on publication of the English study. In response to peer-reviewers' comments, however, the study was not published but was reanalysed following remodelling of the exposure data, inclusion of additional years, and revision of the links between postcodes and the boundaries of water supply zones. In April 2004, we were asked to consider the results of the reanalyses, together with the additional relevant studies and reviews published since 1998 [7-14 16-33]. The SAHSU study, incorporating additional results, has now been published[15]. We were asked to restrict our evaluation to pregnancy outcomes. We were also advised that a second phase of the SAHSU study, in progress and expected to report in 2005, would include data on congenital anomalies (which were not considered in the first phase). We were informed that we would be asked to advise on the results of the second phase in due course, and that therefore it was appropriate to defer reassessment of the scientific literature on chlorinated drinking-water and congenital anomalies until then.

1998 Evaluation

2. In 1998, at the request of the Drinking Water Inspectorate, we were asked to consider the evidence linking the consumption of chlorinated tapwater and adverse reproductive outcomes. We had not previously considered the health effects of chlorinated water or the by-products of chlorination. However, the Committee on Carcinogenicity of Chemicals in Food, Consumer Products and the Environment (COC) had reviewed cancer epidemiology data in 1992. At that time the COC concluded that the 1986 opinion of CASW, the Department of Health Committee on the Medical Aspects of Air, Soil and Water, (that there was no sound reason to conclude that the consumption of by-products of chlorination in drinking water increased

the risk of cancer in humans) was adequately founded and that more recent studies did not alter that conclusion [2]. COC also in 1999 reviewed additional relevant epidemiological studies of cancer published since the 1992 evaluation, and issued a revised statement [3]. COC did not find "persuasive evidence of a consistent relationship between chlorinated drinking-water and cancer" but noted that "it remains possible that there may be an association" and therefore advised that "efforts to minimise exposure to chlorination by-products remain appropriate, providing that they do not compromise the efficiency of disinfection of drinking-water".

3. The 1998 request to us followed the publication of two prospective epidemiological studies conducted in three geographic regions of California, USA. One study reported a weak to moderate association between high consumption of tapwater and the incidence of spontaneous abortion, albeit in only one of the three regions [4]. The second study, taking data from all three regions together, reported a weak to moderate association between high exposure to certain chlorination by-products in tapwater and spontaneous abortion [6].

4. As most of the drinking water in the United Kingdom is chlorinated and similar levels of certain chlorination by-products could occur in UK tapwaters, we were asked to comment on the relevance of these data for public health in the UK.

Consideration of the epidemiological and toxicological data

5. In 1998 we considered available epidemiological information on the association of chlorination by-products in drinking water and a range of adverse reproductive outcomes. Of the seventeen reviewed studies concerned with consumption of drinking water, eight had examined a potential association with chlorinated water or chlorination by-products in the tapwater. Of these, particular attention was focused upon the study from California [6], which the Committee considered to be particularly well-designed and well-conducted.

6. This study, taking data from all three regions together, reported a weak to moderate association (adjusted odds ratio 3.0, 95% confidence interval 1.4-6.6) between high exposure to certain chlorination by-products in tapwater and spontaneous abortion. Nevertheless, the study did not exclude unidentified biases and other confounding factors and the findings, along with information from earlier studies, did not provide persuasive evidence of a causal association between exposure to chlorination by-products in drinking water and adverse reproductive outcomes.

7. Exposure to chlorination by-products could occur not only through drinking but also through showering, bathing and so forth, especially for the more volatile compounds; also these would tend to be removed by boiling. In addition, the available reproductive toxicity studies with some of the individual chlorination by-products indicated that the levels of exposure to these

substances in drinking water are about four orders of magnitude (ie 10,000 times) lower than levels at which adverse effects may occur in animals.

1998 Conclusions

8. In 1998 we concluded as follows:

- We *consider* that there is insufficient evidence to conclude that the presence of chlorination by-products in tapwater increases the risk of adverse reproductive outcomes.

- We *recommend*, however, that the claimed associations between patterns of drinking-water intake and the incidence of adverse reproductive outcomes be investigated further, since any causal association would be of significant public health concern.

- We therefore *consider* that efforts to minimise exposure to chlorination by-products by individuals and water authorities remain appropriate, providing that they do not compromise the efficiency of disinfection of drinking water.

The SAHSU study (first phase) and 2004 evaluation

9. Following our 1998 recommendation for further investigations, the Small Area Health Statistics Unit (SAHSU), in collaboration with, and supported by, UK water supply companies, undertook a major study using small area statistical methodology. The first phase of the study utilised routinely collected trihalomethane (THM) measurements in drinking water (as an index of exposure to chlorination by-products) and available health statistics on stillbirths and birthweight, to examine the possible effects[15].

10. Modelled estimates of quarterly THM concentrations in water zones from 3 water companies in England (Northumbrian Water, Severn Trent Water and United Utilities [formerly North West Water]) were linked to about 1 million routine birthweight and stillbirth records based on location of maternal residence at the time of birth. THM estimates corresponding to the final three months (93 days) of pregnancy were used. Three total THM exposure categories were defined: low (below 30 μg/l), medium (30-60 μg/l) and high (above 60μg/l).

11. The findings, for low birthweight (less than 2500g), very low birthweight (less than 1500g), mean birthweight and stillbirth, were different in the three water supply areas.

12. In the North West (United Utilities), where there was increasing social deprivation as exposure increased, there was a graded, inverse association between level of exposure and mean birth weight, and a direct association with stillbirth rate and the prevalence of low and very low birthweight. After adjustment for maternal age, deprivation, year of study (for birthweight data) and sex of baby (for low birthweight data), the risk of very low birthweight (in

the high versus the low exposure categories) was elevated (adjusted odds ratio = 1.20, 95% confidence interval 1.07-1.34). Similarly, the risk of low birthweight (in the high versus the low exposure categories) was elevated (adjusted odds ratio = 1.19, 95% confidence interval 1.14-1.24) as was the risk of stillbirth (adjusted odds ratio = 1.21, 95% confidence interval 1.03-1.42). In this area, but not in the other two areas, adjustment for deprivation reduced odds ratios by up to about one-half, suggesting the possibility of residual confounding.

13. In contrast, in the Severn Trent region, the risk of very low birthweight was decreased in the high versus the low exposure categories (adjusted odds ratio = 0.90, 95% confidence interval 0.82-0.99). There was no association between level of exposure and deprivation, stillbirth rate, or prevalence of low birthweight. No statistically significant associations were found in the Northumbrian region, but the number of births included in the study was much smaller than in the other regions and the confidence intervals were therefore wide.

14. In a random-effects model to obtain overall summary estimates, allowing for heterogeneity in THM exposure effects across the three regions, a statistically significant elevated risk was found in the high compared to low exposure areas for stillbirths (adjusted odds ratio 1.11, 95% confidence interval 1.00-1.23). For low birthweight (adjusted odds ratio 1.09, 95% confidence interval 0.93-1.27) and very low birthweight (adjusted odds ratio 1.05, 95% confidence interval 0.82-1.34), the risks were elevated but not statistically significant. The authors concluded that their findings overall suggest a significant association of stillbirths with maternal residence in high total THM exposure areas. Nonetheless, they could not exclude residual confounding by socio-economic deprivation. They noted that adjusted excess risks in areas of high deprivation relative to areas of low deprivation were, on average, 15 to 20 times those found in areas of high relative to low total THM exposure. Further work was recommended, to help differentiate between alternative (non-causal) explanations for the association with THMs and those that may be due to the water supply.

Evaluation

15. In the North West total THM exposure showed an inverse association with mean birth weight, a direct association with prevalence of low and very low birthweight, and a direct association with the prevalence of stillbirths. However, there was evidence of confounding by social deprivation, adjustment for which may not have been completely successful in this analysis. In the Severn Trent region, in contrast, the prevalence of very low birthweight decreased with increasing total THM exposure, and there was no association for prevalence of low birthweight or stillbirth rate. In the Northumbrian region, there was no evidence of associations between total THM levels and any of the pregnancy outcomes, but the number of births included in the study was relatively small.

16. We note that the SAHSU study was confined to THM concentrations and that data on other chlorination by-products in water were not routinely available. We note also that data on other sources of exposure to THMs, such as swimming pools, were not available.

17. We have reviewed data from thirteen other epidemiological studies[7-14] [16-20] which were reported after our evaluation in 1998, and which also investigated associations between chlorinated drinking water and pregnancy outcomes (other than congenital malformations, on which we have not yet reassessed the data). The pregnancy outcomes considered were: low and very low birthweight, stillbirth, spontaneous abortion, perinatal death, infant death, Apgar score, infant's head circumference at birth, infant's body length, pre-term delivery, length of gestation, neonatal jaundice and neonatal hypothyroidism. Results from these studies were inconsistent and inconclusive and we consider that further research is needed on this issue. In particular, prospective studies with appropriate assessment of exposure, with a better assessment of confounding factors and allowance for seasonal variations in chlorination by-product concentrations, should be considered.

18. We have also noted the findings in recent papers on exposure to and uptake of chlorination byproducts[21-23], recent studies in laboratory animals[24-30], and recent reviews[31-33].

19. We conclude that the data which we have evaluated do not show a causal relationship between chlorinated drinking-water and adverse pregnancy outcomes. This conclusion excludes congenital malformations, the data on which we have not yet reassessed.

20. The Committee statement published in 1999 advised that "…efforts to minimise exposure to chlorination by-products by individuals…remain appropriate…". We were asked for clarification. We recalled that bathing and showering may result in greater exposure to some volatile chlorination byproducts in drinking-water than the use of the water for drinking and cooking. Other sources of exposure, such as chlorinated swimming-pools, may also be important. Effective avoidance of chlorination byproducts could therefore require major changes in behaviour. We agreed that the evidence does not justify any such changes, and that advice to pregnant women to minimise exposure to chlorination byproducts is not warranted. We consider, however, that it remains prudent for water companies to minimise consumers' exposure by restricting the concentrations of chlorination byproducts in tapwater, provided always that this is consistent with effective disinfection to protect public health.

Overall conclusions

21. We *conclude* that the data which we have evaluated do not show a causal relationship between chlorinated drinking-water and pregnancy outcomes, namely: low and very low birthweight, stillbirth, spontaneous abortion, perinatal death, infant death, low Apgar score, infant's head circumference at birth, infant's body length, pre-term delivery, length of

gestation, neonatal jaundice and neonatal hypothyroidism. We have not yet reassessed the data on congenital malformations.

22. We *recommend*, however, further research to reduce uncertainties in the interpretation of the reported associations between patterns of drinking-water intake and the incidence of adverse reproductive outcomes. In particular, we *recommend* prospective study designs which include more precise assessment of individual exposures, allowance for seasonal variations in chlorination byproduct concentrations, and more comprehensive analyses of the influence of other potential causative agents and confounding factors.

23. We *consider* that, while research to determine the effects of chlorinated drinking water continues, efforts by water companies to minimise consumers' exposure to chlorination by-products remain appropriate, providing that such measures do not compromise the efficiency of disinfection of drinking water.

COT Statement 2004/08
October 2004

References

1 Committee on Toxicity of Chemicals in Food, Consumer Products and the Environment (2000). Chlorinated Drinking Water and Reproductive Outcomes. 1998 Annual Report of the Committees on Toxicity Mutagenicity Carcinogenicity of Chemicals in Food, Consumer Products and the Environment: pp 7-8. London: Department of Health

2 Committee on Carcinogenicity of Chemicals in Food, Consumer Products and the Environment (1993). Epidemiology of Chlorinated Drinking Water and Cancer. 1992 Annual Report of the Committees on Toxicity Mutagenicity Carcinogenicity of Chemicals in Food, Consumer Products and the Environment: pp 55-56 and Correction issued September 1993. London: HMSO

3 Committee on the Carcinogenicity of Chemicals in Food, Consumer Products and the Environment (2000). Drinking Water. 1999 Annual Report of the Committees on Toxicity Mutagenicity Carcinogenicity of Chemicals in Food, Consumer Products and the Environment: pp 59-61. London: Department of Health

4 Swan SH, Waller K, Hopkins B, Windham G, Fenster L, Schaefer C, Neutra RR (1998). A prospective study of spontaneous abortion: relation to amount and source of drinking water consumed in early pregnancy. *Epidemiology*; 9: 126-133

5 Toledano MB, Nieuwenhuijsen M, Bennet J, Best N, Whitaker H, Cockings S, Fawell J, Jarup L, Briggs DJ, Elliott P (2001). Chlorination

disinfection by products in relation to birthweight in three water areas in England (unpublished draft)

6 Waller K, Swan SH, DeLorenze G, Hopkins B (1998). Trihalomethanes in drinking water and spontaneous abortion. *Epidemiology*; 9: 134-140

Recent epidemiological studies

7 Dodds L, King W, Allen AC, Armson BA, Fell DB, Nimrod C (2004). Trihalomethanes in public water supplies and risk of stillbirth. *Epidemiology*; 15: 179-186

8 Dodds L, King W, Woolcott C, Pole J (1999). Trihalomethanes in public water supplies and adverse birth outcomes. *Epidemiology*; 3: 233-237

9 Fabiani L, Materazzo F, Ensabella F, Giuliani AR, Patacchiola F, Oleandri V, Leoni V (2003). [Low birth weight, life style of mothers during pregnancy and chlorinated drinking water]. *Ann Ig*; 15: 933-43

10 Gallagher MD, Nuckols JR, Stallones L, Savitz DA. (1998). Exposure to trihalomethanes and adverse pregnancy outcomes. *Epidemiology*; 9: 484-489

11 Jaakkola JJK, Magnus P, Skrondal A, Hwang B-F, Becher G, Dybing E (2001). Foetal growth and duration of gestation relative to water chlorination. *Occup Environ Med*; 58: 437-442

12 Kallen BAJ, Robert E (2000). Drinking water chlorination and delivery outcome - a registry-based study in Sweden. *Rep Tox*; 14; 303-309

13 King WD, Dodds L, Allen AC (2000). Relation between stillbirth and specific chlorination by-products in public water supply. *Env Health Perspec*; 108; 883-886

14 Righi E, Fantuzzi G, Montanari M, Bargellini A, Predieri G, Aggazzotti G (2003). [Exposure to water disinfection by-products and adverse pregnancy outcomes: results of a case-control study carried out in Modena (Italy).] *Ann Ig*; 15: 649-62

15 Toledano MB, Nieuwenhuijsen M, Best N, Whitaker H, Hambly P, de Hoogh C, Fawell J, Jarup L, Elliott P (2004). Relation of trihalomethane concentrations in public water supplies to stillbirth and birth weight in three water regions in England. *Env Health Perspec*; doi:10.1289/ehp.7111. [Online 21 October 2004]
http://ehp.niehs.nih.gov/docs/2004/7111/abstract.html

16 Waller K, Swan SH, Windham GC, Fenster L (2001). Influence of exposure assessment methods on risk estimates in an epidemiologic study of total trihalomethane exposure and spontaneous abortion. *J Exp Anal and Env Epidem*; 11: 522-531

17 Wright JM, Schwartz J, Dockery DW (2003). Effect of trihalomethane exposure on fetal development. *Occup Environ Med*; 60: 173-180

18 Wright JM, Schwartz J, Dockery DW (2004). The effect of disinfection by-products and mutagenic activity on birth weight and gestational duration. *Env Health Perspec*; 112: 920-5

19 Yang CY (2004). Drinking water chlorination and adverse birth outcomes in Taiwan. *Toxicology*; 198: 249-54

20 Yang C-Y, Cheng B-H, Tsai S-S, Wu T-N, Lin M-C, Lin K-C (2000). Association between chlorination of drinking water and adverse pregnancy outcome in Taiwan. *Env Health Perspec*; 108; 765-768

Recent papers on exposure and uptake

21 Backer LC, Ashley DL, Bonin MA, Cardinall FL, Kieszak SM, Wooten JV (2000). Household exposures to drinking water disinfection by-products: whole blood trihalomethane levels. *J Exp Anal and Env Epidem*; 10: 321-326

22 Lynberg M, Nuckols JR, Langlois P, Ashley D, Singer P, Mendola P, Wilkes C, Krapfl H, Miles E, Speight V, Lin B, Small L, Miles A, Bonin M, Zeitz P, Tadkod A, Henry J, Forrester MB (2001). Assessing exposure to disinfection by-products in women of reproductive age living in Corpus Christi, Texas and Cobb County, Georgia: Descriptive results and methods. *Envir Health Perspect*; 109: 597-604

23 Miles AM, Singer PC, Ashley DL, Lynberg MC, Mendola P, Langlois P, Nuckols JR (2002). Comparison of trihalomethanes in tap water and blood. *Environ Sci Technol*; 36: 1692-1698

Recent studies in laboratory animals

24 Bielmeier S, Best DS, Guidici DL, Narotsky MG (2001). Pregnancy loss in the rat caused by bromodichloromethane. *Tox Sci*; 59: 309-315

25 Bielmeier S, Best DS, Narotsky MG (2004). Serum hormone characterisation and exogenous hormone rescue of bromodichloromethane-induced pregnancy loss in the F344 rat. *Tox Sci*; 77: 101-108

26 Chen J, Douglas GC, Thirkill TL, Lohstroh PN, Bielmeier SR, Narotsky MG, Best DS, Harrison RA, Natarajan K, Pegram RA, Overstreet JW, Lasley BL, (2003) Effect of bromodichloromethane on chorionic gonadotrophin secretion by human placental trophoblast cultures. *Tox Sci*; 76: 75-82

27 Chen J, Thirkill TL, Lohstroh PN, Bielmeier SR, Narotsky MG, Best DS, Harrison RA, Natarajan K, Pegram RA, Overstreet JW, Lasley BL, Douglas GC (2004). Bromodichloromethane inhibits human placental trophoblast differentiation. *Tox Sci*; 78: 166-174

28 Christian MS, York RG, Hoberman AM, Diener RM, Fisher LC, Gates GA (2001a). Biodisposition of dibromoacetic acid (DBA) and bromodichloromethane (BDCM) administered to rats and rabbits in drinking water during range-finding reproduction and developmental toxicity studies. *Int J Toxicol*; 20: 239-253

29 Christian MS, York RG, Hoberman AM, Diener RM, Fisher LC (2001b). Oral (drinking water) developmental toxicity studies of bromodichloromethane (BDCM) in rats and rabbits. *Int J Toxicol*; 20: 225-237

30 Christian MS, York RG, Hoberman AM, Fisher LC, Ray Brown W (2002) Oral (drinking water) two-generation reproductive toxicity study of bromodichloromethane (BDCM) in rats. *Int J Toxicol*; 21: 115-146

Recent review papers

31 Bove F, Shim Y, Zeitz P (2002). Drinking water contaminants and adverse pregnancy outcomes: A review. *Env Health Perspec*; 110 (Suppl 1): 61-74

32 Graves CG, Matanoski GM Tardiff RG (2001). Weight of evidence for an association between adverse reproductive and developmental effects and exposure to disinfection by-products: A critical review. *Reg Tox and Pharm*; 34: 103-124

33 Nieuwenhuijsen MJ, Toledano MB, Eaton NE, Fawell J, Elliott P (2000). Chlorination disinfection by-products in water and their association with adverse reproductive outcomes. *Occup Environ Med*; 57: 73-85