American Industrial Hygiene Association Journal

ISSN: 0002-8894 (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/aiha20

Polychlorinated biphenyl exposure in transformer maintenance operations

C.L MOSELEY , C.L GERACI & J. BURG

To cite this article: C.L MOSELEY , C.L GERACI & J. BURG (1982) Polychlorinated biphenyl exposure in transformer maintenance operations, American Industrial Hygiene Association Journal, 43:3, 170-174, DOI: 10.1080/15298668291409569

To link to this article: https://doi.org/10.1080/15298668291409569

Published online: 04 Jun 2010.

Polychlorinated biphenyls (PCBs) have been used in the electrical industry for almost 50 years, primarily as an insulating fluid in transformers and capacitors. NIOSH has estimated that as many as 100 000 electrical workers are occupationally exposed to PCBs. The purpose of this study was to assess maintenance electrician exposure to PCBs during transformer maintenance, and to determine pre- and post-maintenance ambient PCB concentrations to which other building inhabitants might be exposed. Breathing-zone PCB concentrations during the maintenance of the transformer and in surrounding areas ranged from 2.1 to 60.0 $\mu g/m^3$. Background PCB concentrations ranged from 0.2 to 0.9 $\mu g/m^3$ in the transformer room, and from nondetectable to 0.6 $\mu g/m^3$ in areas immediately outside the trnasformer room. During maintenance operations, PCB concentrations ranged from 1.9 to 55.0 $\mu g/m^3$ in the transformer room, and from nondetectable to 1.4 $\mu g/m^3$ outside the transformer room, but eventually declined to pre-maintenance levels.

Polychlorinated biphenyl exposure in transformer maintenance operations

C.L. MOSELEY, C.L. GERACI and J. BURG
U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, 4676 Columbia Parkway, Cincinnati, OH 45226

introduction

Polychlorinated biphenyls (PCBs) have been used in the electrical industry for almost 50 years.[1-3] PCB-filled transformers are used predominantly in indoor locations such as transformer rooms or vaults. PCBs received heavy use in this area because of their ability to reduce the fire and explosion hazard presented by conventional mineral oil-filled transformers.

Health effects from exposure to PCBs have been documented, and there are a number of literature reviews on the subject.[4-8] Controversy exists over whether or not reported human health effects are due to PCB exposure alone, or are caused wholly or in part by contaminants found in commercial PCB preparations.[9-11] Moreover, PCBs have low vapor pressures and can be absorbed through the skin. The skin absorption route may account for a significant percentage of the total exposure to an individual. PCBs are nearly ubiquitous in the environment, and PCB levels have been documented[12-14] in indoor settings unrelated to manufacturing or direct use of PCBs.

With the exception of capacitor and transformer manufacture, there is very little information available concerning PCB exposure levels in the electrical industry.[15-18] NIOSH has recommended that workplace exposures be maintained as low as possible and, in any event, not exceed 1.0 $\mu g/m^3$ time-weighted average (TWA). This recommendation was based on the potential carcinogenic effects of exposure. This study evaluated airborne PCB exposure to U.S. Government General Services Administration electricians during repair and maintenance of PCB-filled transformers. The workforce consisted of approximately 55 male electricians. However, the number of workers required for a single transformer repair operation was only 3 to 5 in addition to a supervisor.

GSA maintenance electricians are periodically required to field-service PCB-filled transformers. Usually this involves yearly inspection of each transformer and testing of the dielectric strength of the askarel (a generic term for a broad class of synthetic chlorinated hydrocarbon insulating fluids). The dielectric strength (a measure of insulating ability) may decrease due to the electrically induced breakdown of the askarel during use, or by the accumulation of moisture or debris. Filtering removes the contamination and restores the dielectric strength. If any leaks are noticed during inspection, these are repaired.

Transformer repair can be broken down into four main components:

1. *Draining the transformer*. In order to gain access to the leak, the transformer is gravity drained (via a hose through the oil drain plug located at the bottom) into 55-gallon drums. The location of the leak determines how much askarel is removed because the fluid level must be brought below the leak.
2. *Actual transformer repair*. This phase could involve partial disassembly of the transformer to gain access to the leak, as in a secondary oil leak, or simply removing the slight gauge cover to replace the gasket. If it is a leak in a metal seam, it may be welded or hammered shut. The extent of this phase, and hence the time it takes to complete it, represents the primary difference between maintenance procedures.
3. *Refilling the transformer*. The askarel is forced back into the transformer by pressurizing the 55 gallon drum with nitrogen from a compressed gas cylinder.
4. *Cleanup*. Prior to draining the transformer, any askarel on the transformer or vault floor is dissolved with an organic solvent. Vermiculite is then spread on the solution. It is not picked up at this time, however. Cleanup is left until last. The PCB soaked

vermiculite is shovelled into a 55-gallon drum, and the area and repair equipment are wiped down with solvent-soaked rags.

Depending on the location and complexity of the leak, the operation may take from two to ten hours to complete.

During this evaluation, workers were provided with certain personal protective equipment. Items included rubberized "rain" suits, rubber gloves, eye shields, respirators (half-face chemical cartridge-type or airline respirators, at the discretion of the individual worker), and occassionally rubberized forearm coverings. Shoe coverings were not provided.

Askarel in transformer applications is generally a mixture of chlorinated (primarily tri- and tetra-) benzenes and PCB. PCBs are usually Aroclor (a Monsanto tradename) 1242, 1254, or 1260, representing 42, 54, and 60% chlorination, respectively. Aroclor 1016, a mixture of tri- and tetra-chlorinated biphenyls, has been used as a substitute in some cases.

study design

In designing this study, it was not known to what levels of PCBs the electricians would be exposed, and whether or not the backgound levels of PCBs would constitute a significant portion of this exposure. Therefore, before the study of the actual maintenance operation was undertaken, a preliminary ambient air sampling survey of the transformer vault and surrounding environment was conducted. It was useful to determine the post-repair background PCB levels to see if repair operations added substantially to pre-repair levels. The study also was designed to categorize the potential PCB exposure to building residents.

An independent consulting firm had determined that over 200 of 1100 transformers subject to service by the GSA electricians required some type of repair, and an additional 200 had minor leaks which would require some decontamination. It was expected that an intensive cleanup operation would be mounted to avoid the spread of the PCBs into the environment. Accordingly, the study was expanded to include the evaluation of an operation that consisted of vault cleanup only.

The buildings containing the transformer vaults were large multistoried Federal government offices located in Washington, DC. Vault sizes depended on the number of transformers contained within; vaults in this study varied from 26.5 to 62.7 m^2 (285 to 675 ft^2) with a ceiling height of 3.7 to 6.1 m (12 to 20 ft) [average 4.6 m (15 ft)], and contained from two to four transformers with approximately 1230 liters (320 gal) of askarel each.

Ventilation in the vaults was usually provided by thermostatically controlled general exhaust fans. No attempt was made to evaluate the efficiencies of the exhaust systems since their function was more to reduce the heat in the vaults than to remove contaminants, although it is recognized that there is some contaminant-removal capacity.

All samples were taken at a breathing-zone height of 1.2 to 1.8 m (4 to 6 ft). For reporting and comparison purposes, the sampling locations were grouped in three categories: those taken within the confines of the vault; those taken in public areas outside the vault, but no further than 5 feet from the vault entrance; and those taken in public areas further than 5 feet from the vault entrance. Sampling times for pre- and post-maintenance area samples were generally in excess of 10 hours, which is a reasonable estimate of the maximum time a worker would spend in the building each workday. Sampling times for area and personal samples taken during the repair operation were for the duration of the procedure (1.5 to 6.5 hrs).

Area and personal air samples were collected with Dupont® P-4000 personal portable sampling pumps operating at a 1.0 Lpm flowrate. Deactivated Florisil® (30-40 mesh) solid sorbent tubes were used as the collection medium. These were standard 7-mm (4-mm I.D.) tubes with a 100-mg front section preceeded by glass wool and separated from the 50-mg backup section by a urethane foam plug. The NIOSH criteria document "Occupational Exposure to PCB's" gives a detailed description of the sampling technique.[19]

Bulk samples of the askarel from each transformer location were obtained and analyzed for type of PCB, particular contaminants, and associated solvents.

sample analysis

askarel characterization

A number of bulk samples of askarel from each transformer location were initially screened qualitatively to determine the actual PCB in use. Since it was not known if a single PCB or several PCB mixtures were involved, this characterization of the bulk askarel was necessary. Information gained from the bulk samples then allowed a more accurate determination of PCB materials in airborne samples.

A sample of each askarel collected was weighed, dissolved in hexane, and diluted to a known volume. An aliquot of each sample solution was then analyzed by gas chromatography (GC). A Tracor Model 560 GC equipped with an electron capture detector (^{63}Ni foil) was used for the initial characterization.

Separation of the PCB mixture into its major isomer groupings was accomplished with a 6-foot by 1/4-inch glass column packed with 3% OV-210 on 100/200 mesh Chromosorb W-MP. The column was used isothermally at 200 °C with nitrogen as the carrier gas at a flow rate of 90 mL/min. The instrument conditions noted allowed adequate resolution of the askarel sample components for a qualitative analysis. The chromatograms of each sample were compared to standard samples of Aroclor 1242, 1254, and 1260.

Matching the major isomer patterns and retention times of major isomer peaks of samples to standards allowed a qualitative identification of Aroclor 1260 in four of five bulks, with the fifth bulk identified as Aroclor 1254. Aroclor 1242 was not found in any of the bulks obtained from transformers in which repair operations would be evaluated. However, Aroclor 1242 was found in a bulk liquid obtained from the electricians' shop, indicating that exposure to Aroclor 1242 was possible.

The amount of Aroclor 1260 or 1254 in each sample was then determined by a comparison of major isomer peak areas of each sample to corresponding peaks obtained from a series of standards containing known weights of the Aroclors. The limit of detection for both Aroclors in the askarel mixture was 0.0003% (wt/wt). The amount of Aroclor 1260 determined in the oils ranged from 41 to 56%, and Aroclor 1254 was quantitated in the one oil at 54%. The qualitative and quantitative work done on the bulk transformer oils allowed an optimization of the sampling and analysis systems used for the remainder of this study.

An askarel supposedly not containing PCB was also analyzed. It was found to contain 75 ppm by weight Aroclor 1260. This finding proves that cross contamination of non-PCB equipment with PCBs can occur. It further supports the (EPA) philosophy[20] that all equipment should be assumed to be PCB-containing unless proven otherwise.

contaminant characterization

Earlier literature indicated the presence of dibenzodioxin and dibenzofuran compounds, and theorized that they were wholly or in part responsible for the health effects seen in PCB exposures. Further, it has been reported that polychlorinated dibenzofurans (PCDF) have been formed by heating Aroclor 1248 to 300 °C in an oxygen atmosphere.[21] Therefore, selected samples, both bulk askarel and air, from each vault were also analyzed for 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) and 2,3,7,8-tetrachlorodibenzofuran TCDF).

The bulk askarels were initially screened for TCDD and TCDF by gas chromatography/mass spectrometry (GC/MS). A Hewlett-Packard (HP) 5985A GC/MS/DS was used in this initial screening. The GC interfaced to the MS was an HP 5840 using a 1.8-m x 2-mm glass column packed with 3% Dexsil 400 on Chromosorb W-MP. This analysis allowed the identification of any TCDD or TCDF in the samples or gross tetrachloro isomers. The indicated presence of either compound would lead to further work by high resolution GC/MS (HRGC/MS).

An aliquot of each bulk askarel was weighed, dissolved in petroleum ether, acid- and base-washed, and given a final cleanup on an alumina microcolumn. In the GC/MS analysis, only ions characteristic of TCDD or TCDF were monitored, and quantitation was based on retention time of the samples compared to authentic TCDD and TCDF. The limit of detection of TCDD was 1 ng/g (ppb), and 2.5 ng/g (2.5 ppb) for TCDF. TCDD was not detected in any of the bulk oils. TCDF was detected and ranged from 13 to 116 ppb by weight. Additional information on the contribution of 2,3,7,8-TCDF to the gross TCDF isomers obtained from the highest sample was obtained using HRGC/MS. A Varian MAT 212/200P GC/MS/DS was used to further characterize the TCDF as 2,3,7,8-TCDF. A 50-meter Silar 10c capillary column was used to separate the various TCDF isomers.

At least 10 tetrachloro isomers were present in the sample, with 2,3,7,8-TCDF being quantitated at 31 ppb. It became apparent that a significant portion of the TCDF originally detected was due to isomers other than the 2,3,7,8-TCDF.

air samples

The air samples were prepared for analysis by placing the glass wool and front section of Florisil in a glass crimp-top desorption vial. The backup section and retaining urethane plugs were placed in a second vial. Each section of Florisil was then separately desorbed with 2 mL of pesticide grade toluene and analyzed by gas chromatography. A Tracor Model 560 gas chromatograph equipped with an electron capture detector was used for the analyses. A 1.8-m x 6.4 mm glass column packed with 3% OV-101 on 80/100 mesh Supelcoport was used isothermally at 230 °C. The chromatograms obtained from the air samples confirmed the presence of Aroclor 1260, 1254, and 1242, based on major isomer retention times when compared to standards of Aroclor 1260, 1254, and 1242. The Aroclors were quantitated by comparison of peak areas of major isomers with peak areas of corresponding major isomers in standards. Aroclor standards were prepared on Florisil sampling tubes in order to obtain a recovery efficiency along with the calibration. The limit of detection for the subject Aroclors was 0.1 μg/sample for each.

A representative number of air samples previously analyzed for PCB were also analyzed for TCDF. No TCDF was found in any of the samples (detection limit was 1 ng/sample).

results and discussion

ambient PCB levels

Table I contains the ambient air PCB levels in the transformer vaults, adjacent areas, and areas some distance away from the indoor entrance to the vault. Results are presented as total μg PCBs/m^3. Values from the four operations evaluated have been grouped together according to location relative to the vault. Pre-maintenance PCB levels were all below NIOSH-recommended exposure criteria. Since, with the exception of inside the transformer vault, the areas evaluated could be considered workplaces for the other workers in the building, comparison of the data to the NIOSH workplace criteria is considered appropriate. In areas normally travelled by non-maintenance personnel [areas designated "immediately outside vault" - up to 1.5m (5 ft) from vault door, and "generally occupied areas" - more than 1.5m (5 ft) from the vault door] 55% (6/11) of the samples were nondetectable at the 0.1 μg/sample LOD. Using the Wilcoxon test[22] (a non-parametric statistical test of difference), there is no significant difference ($p \leq 0.05$) between pre-maintenance levels inside and those immediately outside the transformer vault. Although there is a ~~difference~~ indicated between vault levels and levels in generally occupied areas, visual inspection of the data in Table I shows that this is due to the low levels of the generally occupied area levels relative to vault levels.

A recent article[23] reported that urban outdoor airborne PCB levels range from 0.5-30 ng/m^3. It has also been reported[24] that PCBs contained in caulking material used in a general ventilation system of a chemistry laboratory contaminated the indoor air up to 0.3 g/m^3. Pre-maintenance

TABLE I
Environmental PCB Levels ($\mu g/m^3$) Determined by Long-Term (> 10-Hour) Air Sampling

	Pre-Maintenance	During Maintenance	Post-Maintenance
Breathing-Zone	0.9	55.0	1.9
Level Inside	0.8	25.0	1.6
Vault	0.7	17.9	1.1
	0.5	12.1	0.7
	0.2	2.8	0.1*
	0.1*	2.1	0.1*
		2.1	0.1*
		1.9	
Immediately	0.6	2.6	0.1*
Outside Vault	0.5	1.1	0.1*
	0.4	0.4	
	0.1*	0.3*	
	0.1*	0.2*	
Generally	0.2	1.4	0.2
Occupied Areas	0.2	0.5	0.1*
	0.1*	0.5	0.1*
	0.1*	0.3	
	0.1*		
	0.1*		

*Maximum estimation, extrapolated from LOD of 0.1 μg/sample. Conventionally reported as non-detectable.

levels reported in this study do not differ greatly from these data.

Fifty-eight percent (7/12) of all post-maintenance PCB samples were below the limit of detection; 80% (4/5) of those taken in non-vault areas were below the LOD. The Wilcoxon Test suggests no statistical difference between levels in the three areas. By comparing the pre-maintenance and post-maintenance inside vault values, it appears that the repair operation contributes to the ambient environment PCB burden. However, this difference is not statistically significant. Ambient PCB levels are greatly increased during repair operations in all areas; 65% are in excess of the NIOSH exposure limit. The post-repair PCB levels indicate a decline to prerepair levels after a 4-month period of time (the time delay between repair and follow-up evaluation). It would have been interesting to determine the "decay rate" of the PCB levels; however, lack of resources prevented it. The decline is assuredly due to the vault ventilation system and the general air conditioning system of the building dissipating the PCBs through, and eventually eliminating them from, the building.

personal exposures

Personal sampling results are presented in Table II. Since the various duties necessary to complete the repair work were not individually but collectively performed, the data have been categorized by the type of repair rather than by individual job descriptions.

Personal exposure levels have been listed as exposure levels for the period sample and converted to 8-hour time-weighted averages for comparison to the NIOSH criteria of 1 $\mu g/m^3$. Considered as a group, 79% (19/24) of the personal exposures exceeded the NIOSH criteria. Eight-hour TWAs ranged from 0.01 to 24 $\mu g/m^3$. The Kruskal-Wallis test[25] indicates the four sample sets (Table II) are not equal ($p \leq 0.05$). The Dunn multiple comparison procedure[26] indicates the samples related to the "sight guage and oil drain

TABLE II
Personal Breathing Zone Samples

Sample Duration (Hours)	Concentration ($\mu g/m^3$)	8-Hour TWA Concentration ($\mu g/m^3$)
Oil Drain Plug Repair and Cleanup		
3.2	60.0	24.0
3.2	55.7	22.3
3.1	43.1	16.7
Sight Gauge and Oil Drain Plug Repair and Cleanup		
3.2	17.4	7.0
3.2	14.7	5.9
3.2	7.9	3.2
Cleanup of PCB Leak Only		
1.0	3.1	0.4
1.0	3.1	0.4
1.0	0.1	0.01
Secondary Oil Leak Repair and Cleanup (2 Vaults)		
5.8	17.1	12.4
5.9	12.3	9.1
5.4	10.6	7.2
6.5	8.7	7.1
5.9	8.0	5.9
4.5	7.4	4.2
3.8	8.3	3.9
5.2	4.7	3.1
5.0	4.7	2.9
3.7	5.5	2.5
5.5	3.3	2.3
5.2	4.8	2.1
3.5	3.2	2.1
2.7	2.1	0.7
1.5	3.6	0.7

plug repair" component are significantly higher ($p \leq 0.10$) than those samples related to "secondary oil leak repair", "oil drain plug repairs," or "spill cleanup operations."

Why these values are so high is unclear, since an operation which included both a sight gauge and oil drain plug repair and cleanup only had an average PCB exposure level of 5.4 $\mu g/m^3$ TWA. Data concerning temperature variations from vault to vault, variations in vault size, ventilation rates, amounts of askarel transferred, and variations in team work practices were collected, but failed to reveal any consistent explanation. Further, individual work practices did not seem to be a factor. A higher exposed individual on one operation would not be the higher exposed on another operation.

The cleanup component offered the least PCB exposure with average of 0.3 $\mu g/m^3$ TWA.

summary

The results of this study demonstrate that these electricians involved in transformer maintenance and repair are exposed to PCB concentrations in air many times the level recommended by NIOSH. The current OSHA standards, adopted from the 1968 ACGIH TLVs, are 1.0 mg/m^3 for Aroclor 1242, and 0.5 mg/m^3 for Aroclor 1254. There is no OSHA standard for Aroclor 1260. The operations studied were not in violation of the law. Repair operations do not seem to have a long-term effect on indoor ambient PCB levels, and non-maintenance building inhabitants are minimally exposed.

This study also demonstrates the need for a closer evaluation of the work process to pinpoint the steps of the operation which contribute the most of the PCB exposures, the need for better engineering control in transformer vaults, and the need for worker education in dealing with hazards in the workplace. Further, evaluation of clothing sufficient to protect workers from PCB exposure via skin absorption is needed.

acknowledgements

The authors wish to thank the following groups who contributed to this study: United State General Services Administration, switch gear employees, for their cooperation and assistance in data collection; Mr. Michael King, for field survey assistance; and Utah Biomedical Test Laboratory and Monsanto Research Corporation, for sample analyses.

references

1. **Clark, F.M.**: The Development and Application of Synthetic Liquid Dielectrics. *Transactions of the Electrochemical Society 45*:59-67 (1957).
2. **Clark, F.M.**: Nonflammable Dielectric Organic Compounds. *Industrial and Engineering Chemistry 29*:698-702 (1937).
3. **Clark, F.M.**: *Insultating Materials for Design and Engineering Practice.* John Wiley and Sons, Inc., New York (1962).
4. Criteria for a Recommended Standard . . . Occupational Exposure to Polychlorinated Biphenyls. DHEW (NIOSH) Publication No. 77-225, (September, 1977).
5. **Kikuchi, M. and Y. Masuda**: The Pathology of Yusho, in Higuchi, K. (ed); *PCB Poisoning and Pollution.* pp. 69-86. Academic Press, New York (1976).
6. **Oaw, H.K., G.R. Simpson and D.S. Sigali**: The Use and Health Effects of Aroclor 1242, a Polychlorinated Biphenyl in an Electrical Industry. *Arch Environ. Health 31*:189-194 (1976).
7. **Kimbrough, R.D.**: The Toxicity of Polychlorinated Polycyclic Compounds and Related Chemicals. *CRC Critical Reviews in Toxicology*, pp. 445-498. January, 1974.
8. **Kimbrough, R.D.**: Toxicity of Chlorinated Hydrocarbons and Related Compounds. *Archives of Environmental Health 25*:125-131 (1972).
9. **Vos. J.G., J.H. Koeman and H.L. Van Der Maas**: Identification and Toxicological Evaluation of Chlorinated Dibenzofuran and Chlorinated Napthalene in Two Commercial Polychlorinated Biphenyls. *Food Cosmet. Toxicol. 8*:625-633 (1970).
10. **op cit**, NIOSH Criteria Document.
11. **op cit**, Kikuchi and Masuda, pp. 69-86.
12. **Staiff, D.C., G.E. Quinby, D.L. Spencer and H.C. Starr, Jr.**: Polychlorinated Biphenyl Emission from Fluorescent Lamp Ballasts. *Bull. Environ. Contam. Toxicol. 12*:455-463 (1974).
13. Sources of Emissions of Polychlorinated Biphenyls into the Ambient Atmosphere and Indoor Air. U.S. Environmental Protection Agency Publication No. 600/4-79-022. (March, 1979).
14. **Williams, D.T., G.L. LeBel and T. Furmanczyk**: Polychlorinated Biphenol Contamination of Laboratory Air. *Chemosphere 9(1)*:44-50 (1980).
15. **Schwartz, L.**: An Outbreak of Halowax Acne (cable rash) among Electricians. *JAMA 122*:158-161 (1943).
16. **Hervin, R.L. and A.B. Smith**: Health Hazard Evaluation Determination Report No. 77-7A and 7B, (NIOSH). Union Electric Company, St. Louis, MO. (April, 1978).
17. **Good, C.K. and N. Pensky**: Halowax Acne (cable rash) — A Cutaneous Eruption in Marine Electricians Due to Certain Chlorinated Napthalenes and Diphenyls. *Arch. Dermatol. Syphilol. 48*:251-257 (1943).
18. **Levy, B.S.B., C.R. Meyer, L. Lowry and A. Smallwood**: Health Hazard Evaluation Determination Report No. 76-52-386, Hazard Evaluation Services Branch, Division of Technical Services, Westinghouse Electric Corporation, Bloomington, IN. (April, 1977).
19. **op cit**, NIOSH Criteria Document.
20. Final Ban Rule for Polychlorinated Biphenyls (PCBs) Manufacturing, Processing, Distribution in Commerce and Use Prohibitions. *Federal Register* (44 CFR 31514). (May 31, 1979).
21. **Morita, M., J. Nakagawa and C. Rappe**: Polychlorinated Dibenzofuran (PCDF) Formation From PCB Mixture by Heat and Oxygen. *Bull. Enviro. Contam. Toxicol. 19(6)*:665-670 (1978).
22. **Gibbons, J.D.**: *Nonparametric Methods for Quantitative Analysis.* Holt, Rinehart and Winton, New York (1976).
23. **Eisenweich, S.J., B.B. Looney and J.D. Thorton**: Airborne Organic Contaminants in the Great Lakes Ecosystem. *Environ. Sci. Technol. 15(1)*:30-38 (1981).
24. **op cit**, Williams.
25. **op cit**, Gibbons.
26. **ibid.**