Guidelines for Ozone Mitigation at the APS

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Advanced Photon Source

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Introduction

The Advanced Photon Source (APS) will produce x-ray beams of sufficient power to generate considerable amounts of ozone. Appropriate measures must be taken to ensure that personnel are not exposed to ozone concentrations that exceed the maximum permissible limits of applicable regulations. The purpose of this document is to give APS users the necessary information to formulate plans to deal with the ozone production on their beamlines.

In the following, the pertinent regulations will be discussed, ozone production calculations will be described and the results given, and examples for mitigating problem levels of ozone will be given.

Ozone Exposure Guidelines

The U. S. Department of Energy requires that its facilities use the requirements of ACGIH (American Conference of Governmental Industrial Hygienists) in matters of industrial hygiene.[1] The relevant passages of the ACGIH guidelines[2] are reproduced as Appendix A. Care should be exercised in the reading of the ACGIH document; current values are given, along with a notice for intended changes. Ozone is one of the substances for which ACGIH proposes changing the recommended exposure levels. The proposed changes will probably be adopted at the annual ACGIH meeting to be held on May 24, 1994. The following assumes that the proposed guidelines (with respect to ozone) were adopted and that the APS will be obligated to follow the new guidelines.

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[1] DOE Order 5480.4, attachment 2, page 2.

[2] 1993-1994 Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices, ACGIH, Cincinnati, Ohio (1993).

Definitions

In this section, working definitions are given for the various guideline terms. The exact definitions are given in Appendix A.

Exposure limits are of the following types:

TLV-TWA	Threshold Limit Values–Time-Weighted Average
TLV-STEL	Threshold Limit Values–Short-Term Exposure Limit
TLV-C	Threshold Limit Values–Ceiling

The TLV-TWA is the maximum time-average concentration for a normal 8-hour workday and a 40-hour workweek to which workers may routinely be exposed. It is not clear from the guidelines over what period the time averaging should be done for ozone. Because synchrotron workers are well known for not having a normal 40-hour workweek, this value must be adjusted to reflect anticipated shift durations.

The TLV-STEL is the maximum TWA concentration to which a worker may be exposed. Exposures above the TLV-TWA, but below the TLV-STEL should not exceed 15 minutes. There should be at least 60 minutes between such exposures with a maximum of four occurrences per day. The maximum exposure level during a TLV-STEL period is not explicitly given in the ACGIH guidelines. The APS intends to set this maximum at the TLV-STEL limit; i.e., no worker may be exposed to a concentration of ozone above the TLV-STEL at any time.

A TLV-C is a limit above which workers cannot be exposed to for any length of time. This is not a time-weighted average.

Threshold Value Limits for Ozone

The current ACGIH TLV for ozone is a TLV-C of 0.1 ppm (0.2 mg/m^3). The proposed change is for a TLV-TWA of 0.05 ppm (0.1 mg/m^3) and a TLV-STEL of 0.2 ppm (0.4 mg/m^3). As stated above, the APS will follow the proposed TLVs.

The new guidelines are actually less restrictive, because they provide flexibility for dealing with short-term exposures. An example of this at the APS would be a user entering an experimental station in which a concentration exists that is over the TLV-TWA but below the TLV-STEL. With adequate ventilation, the concentration will drop quickly to levels below the TLV-TWA while the user is working in the station. Under a TLV-C guideline, the user would have to wait for the ozone concentration to drop to below the TLV-C level before entering the station.

Ozone Production

There are two typical situations in which ozone may be produced by a beamline. The obvious case is an experiment in which the white beam travels through an air path. In this situation, the ozone concentration can quickly exceed the TLV-STEL if appropriate steps are not taken. A second case occurs when a white beam inside a vacuum chamber strikes a component and the consequential scatter ionizes some of the oxygen in the air surrounding the vacuum chamber. Although the rate of production for ozone from scattered radiation is much lower than that for the open white beam, the levels can exceed the TLV-STEL if the ozone concentration is allowed to reach saturation with no ventilation.

Monochromatic beams (defined as below 0.1% bandpass) do not present an ozone problem. Beams that have been reflected from mirrors ("pink beams") will usually produce ozone in a similar way as white beams from the same source. Unless explicit calculations are done to prove otherwise, a white beam that is reflected from a mirror and travels through an air path should be treated as a white beam.

White Beam Directly into Air

The ozone production rate was calculated for three APS sources: Undulator A, Wiggler A, and a bending magnet. Two sets of independent calculations were made; one using the PHOTON program[3] and a second using spectrum generation and absorption routines developed for Mathematica.[4] The results obtained from both methods essentially agreed in all cases. Unless noted

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[3] D. Chapman, N. Gmür, N. Lazarz, and W. Tomlinson, NIM A266, 191 (1988).

[4] These routines are availiable upon request from D. R. Haeffner.

otherwise, for the results that follow the values are from the Mathematica routines because fewer assumptions were needed.

All calculations were done for a storage ring energy of 7.0 GeV and a storage ring current of 100 mA. Also, for all cases it was assumed that the beam passed through a 250-μm Be window. For the Mathematica routines, values from McMaster, et al.[5] were used to calculate the coherent and incoherent cross sections, while the photoelectric absorption coefficients where calculated using the FPRIME[6] program.

The ozone production rate is the energy absorbed by the oxygen (in the air) multiplied by the "G" value. Reported values for G range from 2.69 to 13.8 O_3 molecules per 100 eV.[7] For the current study, a somewhat conservative value of G = 10 O_3 molecules per 100 eV was used. This value is consistent the G value used in preliminary calculations of ozone at the APS.[8]

An Undulator A spectrum was produced by the program US.[9] The undulator parameters were for the maximum power situation (K=2.78) given in a recent APS report describing the enhanced capabilities of Undulator A.[10] This spectrum was fed into Mathematica, and the oxygen absorption and ozone production were calculated. (The comparison calculation using PHOTON approximated the undulator as a bending-magnet.)

The Wiggler A photon spectrum was calculated (in Mathematica) following Dejus, et al.[11] using the wiggler parameters given in an APS Technical Bulletin.[12] The method accounts for the horizontal-angular dependence of the radiated power of the wiggler (i.e., it is not a bending-magnet approxima-

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[5] W. H. McMaster, N. K. Del Grande, J. H. Mallet, and J. H. Hubbell, "Compilation of X-Ray Cross Sections," UCRL-50174 Sec. II Rev. 1, Lawrence Livermore Laboratory (1969).

[6] D. T. Cromer, J. Appl. Cryst. 16, 437 (1983).

[7] C. Weilandics, N. Rohrig, and N. F. Gmür, NIM A266, 691 (1988).

[8] H. J. Moe, "Advanced Photon Source: Radiological Design Considerations," APS/LS/141 Revised (1991).

[9] R. J. Dejus, unpublished.

[10] R. J. Dejus, B. Lai, E. R. Moog, and E. Gluskin, "Undulator A Characteristics and Specifications: Enhanced Capabilities," ANL/APS/TB-17 (1994).

[11] R. J. Dejus, A. M. Khounsary, D. A. Brown, and P. J. Viccaro, NIM A319, 207 (1992).

[12] B. Lai, A. Khounsary, and E. Gluskin, "Wiggler A Characteristics and Specifications," ANL/APS/TB-11 (1993).

tion). The input parameters for the calculation where for a 2.1-cm gap: peak magnetic field–1.0 Tesla, number of periods–28, undulator period–8.5 cm.

The APS bending magnet was calculated for a field of 0.599 Tesla. A horizontal-angular width of 4 milliradians was used.

The ozone production for the three sources as a function of air-path length is shown in Table 1 and Figure 1.

Table 1 Ozone Production by APS Sources

Air path (cm)	Undulator A (g/min)	Wiggler A (g/min)	Bending Magnet (g/min)
0.1	0.00322	0.00413	0.000261
0.5	0.0157	0.0201	0.00127
1	0.0304	0.039	0.00246
2	0.0576	0.074	0.00466
5	0.126	0.162	0.0102
10	0.215	0.276	0.0172
20	0.347	0.442	0.0274
50	0.607	0.760	0.0465
100	0.880	1.09	0.0658

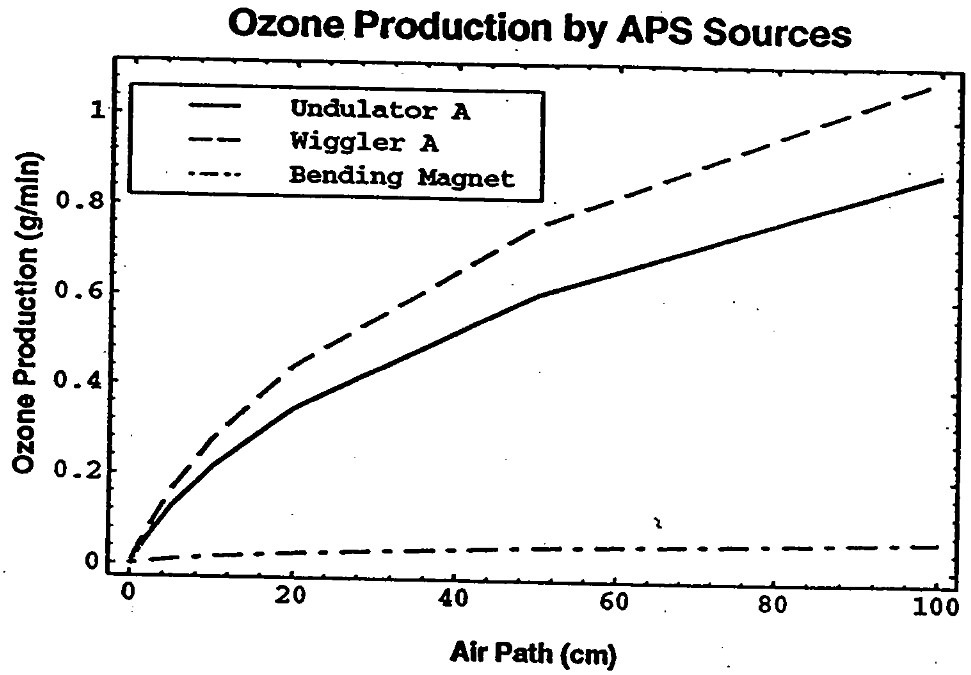

Figure 1 The production of ozone from APS sources as a function of air-path length.

Ozone Production by Scattered Radiation

The ozone production by scattered radiation was calculated for the following situation: a white beam strikes a 50-mm thick piece of copper inside a vacuum chamber made of iron; the thickness of the chamber walls is 2 mm. PHOTON was used to estimate the amount of energy absorbed by a volume of air around the vacuum chamber. The results are given in Table 2. (Please note the change in units for production.)

Table 2 Ozone Production by Scattered Radiation

Source	Production µg/min
Undulator A	190
Wiggler A	410
Bending Magnet	2

Ozone Concentrations in Experimental Stations

The concentration of ozone can be written as

$$C(t)=\frac{P}{V(\alpha+\beta+kP)}\left[1-e^{-(\alpha+\beta+kP)t}\right],$$

where $C(t)$ is the ozone concentration as a function of time, t is time, P is the ozone production rate, V is the station volume, α is the chemical decay constant for ozone, β is the ventilation rate divided by the effective volume, and k is a constant related to the destruction of O_3 by the synchrotron beam. The value for k is not well established[7] and was taken to be 0 for the current study. For α, a measured value of $3.1 \times 10^{-4}\ s^{-1}$ was used.[7]

As defined above, the TLV-TWA level of 0.05 ppm of ozone is for an 8-hour day, 40-hour workweek. It is common for workers at synchrotron facilities to work much longer hours. However, it is unlikely that a worker will spend more than eight hours in a day inside a station with ozone levels much above those of the Experiment Hall. Therefore, the 0.05 ppm ozone concentration will be considered to be appropriate for the TLV-TWA in an experimental station.

In a station, the ozone concentration level has a strong dependence on β. To illustrate this, results from several examples will be given.

Ozone Concentrations with No Ventilation

White Beam Directly into Air

For calculations of ozone concentration, a station volume of 50 m^3 (1765 ft^3) will be assumed. Once a white beam is let into a station, the ozone concentration will gradually build up to a saturation level. The ozone build up for a 10-cm air path of Undulator A with no ventilation ($\beta = 0$) is shown in Figure 2. Saturation occurs after approximately three hours at a level of 118 ppm of ozone. Once this level has been reached, it would take nearly seven hours after the beam has been turned off for the level to drop to 0.05 ppm. This is obviously an unacceptable situation.

With the assumption of $k = 0$, all values of $C(t)$ will simply scale with the production rate. For the same situation described above, the Wiggler A saturation level will be 152 ppm and that of the bending magnet will be 9.4 ppm. Even for the bending magnet, it will take over 4.5 hours for the ozone concentration to drop to an acceptable level.

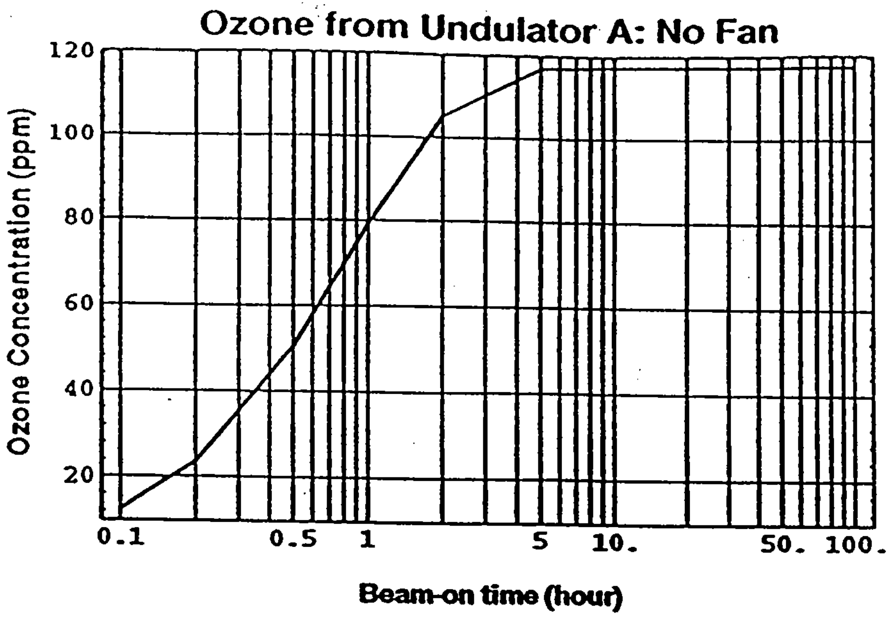

Figure 2 **The concentration of ozone inside a 50 m^3 station with no ventilation. The photon source is Undulator A.**

Scattered Radiation

The situation for the scattered radiation in the FOEs is considerably less drastic. For the values given in Table 2, the saturation levels (with no ventilation) are 0.10 ppm, 0.22 ppm, and 0.001 ppm for Undulator A, Wiggler A, and the bending magnet, respectively. Even moderate amounts of ventilation will reduce ozone concentration from undulators and wigglers to very low levels (see below). The concentration levels in the bending-magnet FOEs are two orders of magnitude below any level of concern. Consequently these FOEs require no ventilation for ozone removal.

Ozone Concentrations with Ventilation

White Beam Directly into Air

The results given above show that for white-beam-in-air situations ventilation is needed in experimental stations. To reach a saturation level of 0.05 ppm for an Undulator A beam with a 10-cm air path, a β of 0.75 is needed. For a 50 m^3 station volume this requires a removal rate of 35.7 m^3/s (75,613 cfm). To reach the TLV-STEL level of 0.2 ppm a β of 0.19 is needed, requiring a removal rate of 9.5 m^3/s (20,121 cfm). Both removal rate values are unrealistic. It is clear from this result that local ventilation must be used.

The effective volume that is being exhausted must be reduced significantly. This is a common technique in industrial hygiene and has been used successfully at other synchrotron facilities.[13] The amount of removal needed scales with the effective volume. Hence, an effective volume of one m^3 requires a removal capacity of 0.75 m^3/s (1589 cfm) for a concentration of 0.05 ppm or a removal capacity of 0.19 m^3/s (402 cfm) for a concentration of 0.2 ppm. The removal rate for the 0.05 ppm level is still rather high, but the rate for the 0.2 ppm level is achievable. If the ozone concentration level for the entire 50 m^3 station is 0.2 ppm, a 0.19 m^3/s removal rate will reduce the level to 0.05 ppm in less than six minutes. This is well under the time limit for a TLV-STEL exposure. (The limit of four TLV-STEL exposures per day, each separated by at least one hour, still applies.)

For the situation given above, the Wiggler A beam (10-cm air path) requires a β of 0.95 for 0.05 ppm ozone and a β of 0.24 for 0.2 ppm ozone. The wiggler beam removal requirements are somewhat higher, but similar to those for the undulator. The bending magnet (10-cm air path) values are a β of 0.06 for 0.05 ppm ozone and a β of 0.015 for 0.2 ppm ozone. The bending magnet removal rates are still high enough that local exhaustion is required, but may allow for less strident methods in reducing the effective volume. A summary of the example calculation results are given in Table 3.

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[13] N. Gmür, L. Berman, M. Iarocci, and C. Weilandics, "Controlling Ozone in White Beam Hutches," NSLS Technical Note 435 (1991).

Table 3. Ventilation Rates for a White Beam in 10 cm of Air

Source	Saturation Levels	β	Effective Volume	Removal Rate	
	ppm	s^{-1}	m^3	m^3/s	cfm
Undulator A	0.05	0.75	50	35.7	75,613
Undulator A	0.2	0.19	50	9.5	20,121
Undulator A	0.05	0.75	1	0.75	1589
Undulator A	0.2	0.19	1	0.19	402
Wiggler A	0.05	0.95	1	0.95	2012
Wiggler A	0.2	0.24	1	0.24	508
Bend. Mag.	0.05	0.06	1	0.06	127
Bend. Mag.	0.2	0.015	1	0.015	32

The size of the effective volume is strongly dependent on the arrangement of a particular experiment. If it is possible to get an air-removal spout close to the entire length of the air path, it should be possible to have effective volumes considerably smaller than one m^3. In this case, the air flow rate may be relatively low. If, on the other hand, there is nonstationary equipment near the air path (e.g., a diffractometer), it may be difficult to get a removal spout near the beam. In this case, it may be more effective to build a shroud around the experiment and have enough negative pressure inside the shroud to prevent the ozone from reaching the rest of the experimental station. In all cases, it is important to have to shortest beam-in-air path possible.

Scattered Radiation

Ozone produced by a scattered beam from Wiggler A can be kept to 0.05 ppm with a β of 0.0012 (assuming a 50 m^3 FOE). A removal capacity of 0.06 m^3/s (127 cfm) will adequately ventilate the entire station volume to the TLV-TWA level. The is only 4.32 air exchanges per hour, which is a very modest exchange rate. To achieve 0.05 ppm ozone for Undulator A requires a β of 0.0004, with a corresponding removal capacity of 0.02 m^3/s (42 cfm).

Ozone Disposal

The ozone removed from an FOE or experimental station must be appropriately disposed. There are two choices for disposal: to ventilate into the Experiment Hall, or to ventilate to the atmosphere outside of the Experiment Hall. In either case, the exhausted air may be passed through activated carbon filters to reduce the ozone concentration.

For the Experiment Hall, the TLV-TWA levels must be adjusted for likely worker shift durations. A shift of 16 hours per day and 80 hours per week will be assumed. The corresponding TLV-TWA for the Experiment Hall becomes 0.025 ppm of ozone.

The first case to be considered will be the ozone from the scattered beams in FOEs. For simplicity, it will be assumed that there are 34 wiggler white beams generating ozone at 410 μg/min* and that there is complete mixing of air in the Experiment Hall. This will be a total ozone production of 0.014 g/min. The Experimental Hall has a volume of approximately 84,000 m^3 (3 x 10^6 ft^3). With no ventilation, the saturation level is 0.0045 ppm ozone. This is 20% of the TLV-TWA and should be acceptable. The FOEs can be vented directly into the Experiment Hall.

The capacity for producing ozone from white beam experimental stations is much higher. If just one station has an Undulator A beam in 10 cm of air, it produces 0.215 g/min. If vented directly into the Experiment Hall a saturation level of 0.07 ppm will occur (using the entire Experiment Hall volume), which is higher than the TLV-TWA. With effective carbon filtration, this value can be reduced by approximately 90%, but is still higher than would be acceptable if several stations were producing ozone simultaneously. It is recommended that the ozone produced in insertion-device stations by white beam in air be vented directly (without filtration) to outside the Experiment Hall.

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* This is a worst-case calculation. It is currently estimated that there will be five wigglers (out of a total of 16 insertion devices) during the first phase of APS operation.

For a bending-magnet experimental station the production levels are low enough to allow for options. Thirty-four bending magnet stations, each with 10 cm of white beam in air, will produce enough ozone to have a Experiment Hall level of 0.19 ppm. With 90% effective filtration, this can be reduced to 0.019 ppm, which would be within the TLV-TWA guidelines. Since it is unlikely that there will ever be 34 bending-magnet white-beam stations operating simultaneously, the actual concentration of ozone in the Experiment Hall would probably be considerably lower than 0.019 ppm. For bending-magnet stations with a white-beam-in-air path there are two recommended options: vent directly to the air outside of the Experiment Hall, or use carbon filtration and vent into the Experiment Hall. In the latter case, a the amount of ozone in the exhaust after filtration should not exceed 0.00172 g/min. This level will be checked by the APS.

Maximum Ozone Emission from the APS Experiment Hall

The maximum amount of ozone that could be produced in the Experiment Hall and released into the atmosphere was calculated with the following assumptions:

1. There are 35 Wiggler A experimental stations.
2. There are 35 bending-magnet experimental stations.
3. In each station, a white beam travels through 10 cm of air.
4. All 70 stations are operated for 24 hours per day, 280 days per year (6720 hours/year).
5. All of the ozone produced in the stations is vented to the atmosphere outside of the APS Experiment Hall.

These assumptions give an ozone production rate of 10.26 g/min for all the stations together. The specified number of hours gives a maximum production of 4137 kg of ozone per year from the APS Experiment Hall. The assumptions are very conservative. The actual amount of ozone released to the atmosphere will be far lower.

General Practices to Reduce Ozone Production

Several operating practices will help to keep the ozone production to a minimum. These should be followed even when the ozone concentrations are below acceptable levels.

All beam-in-air paths should be kept to a minimum.

The effective evacuation volumes should be made as small as possible.

If the experiment is conducted at sufficiently high energies, low energy photons can be absorbed in a filter rather than in the air.

For ozone produced by scattered radiation, a small amount of shielding around the scattering point may reduce the energy in the scattered beam significantly.

APS Ozone Mitigation Policy

The following are required by the APS as means to achieve adequate ozone protection for personnel:

1. The APS shall abide by applicable ACGIH TLV guidelines for ozone. Personnel should not enter a station when the ozone level is above the TLV-STEL for any length of time.
2. The TLV-TWA for the Experiment Hall shall be 0.025 ppm of ozone. (A 16-hour day and 80-hour work week were used to determine this level.)
3. First optical enclosures (FOEs) shall have adequate ventilation to ensure that the build up of ozone due to scattered white beam is not above 0.05 ppm.
4. Experimental stations capable of having white beam in air shall have an ozone monitor that produces an audible tone when the station is capable of personnel entry and the ozone concentration is above an APS-specified level
5. Insertion-device experimental stations capable of white beam in air shall have a local ventilation system that vents directly to the outside of the Experiment Hall. An air flow switch shall be used to monitor air flow in the ventilation system. This switch shall be part of the personnel-safety system for the station.
6. Bending magnet experimental stations capable of white beam in air shall have a local ventilation system that either vents directly to the outside of the Experiment Hall or vents into the Experiment Hall after adequate filtering to reduce its ozone emission to no more than 0.0017 g/min of ozone. An air flow switch shall be used to monitor air flow in the ventilation system. This switch shall be part of the personnel-safety system for the station.

Appendix A

ACGIH Today

INSIDE ACGIH Today

Newsletter of the American Conference of Governmental Industrial Hygienists

Committee Chairs and Board Meet — New Partnership Guide Introduced

In order to form a more perfect partnership between the Board of Directors and the ACGIH Committees, a Joint Meeting of the Committee Chairs and Board Members was recently held at ACGIH headquarters. Among a number of relevant conclusions and planned enhancements was a clear desire for more members to volunteer to serve on Committees within their area of expertise.

"While there are not enough seats on ACGIH Committees to allow every Member or even a large percentage of the Members to serve, the Board continually seeks offers to volunteer on a Committee from qualified individuals. The technical committees, in particular, have tapped the expertise of the Members and, in large measure, the products of these Committees account for ACGIH's reputation and success," noted ACGIH Chair John Martonik.

Current ACGIH Committees are:

- **Agricultural Health and Safety**
- **Air Sampling Instruments**
- **Air Sampling Procedures**
- **Awards**
- **Bioaerosols**
- **Biological Exposure Indices**
- **Computers in Safety and Health**
- **Construction**
- **Editorial Review Board**
- **Finance**
- **Hazardous Waste**
- **Industrial Ventilation**
- **Infectious Diseases**
- **Membership**
- **Mining Safety and Health**
- **Nominating**
- **Permanent Conference Committee (PCC)**
- **Professional Regulation Steering Committee (PRSC)**
- **Research Needs in Industrial Hygiene**
- **Small Business**
- **TLV's for Chemical Substances**
- **TLV's for Physical Agents**

Members wishing to serve should write to Mr. Martonik at ACGIH headquarters. Name the Committee for which you are volunteering and be sure to include your Curriculum Vitae.

During the recent meeting, the Committee Chairs reviewed the newly introduced "ACGIH PARTNERSHIP GUIDE: A Reference Manual for Committees" which had been assembled for their use by the Board of Directors. The "PARTNERSHIP GUIDE" is an extensive document in thirteen sections providing guidance and policies for use by all Committees in an effort to make them more efficient and to make service on a Committee more productive, more rewarding, and more enjoyable.

Committee Chairs offered several suggestions for improving the "PARTNERSHIP GUIDE" which the Board will now consider. Committee Chairs were charged with drafting a Mission Statement for the work of their Committees and an Annual Work Plan with more specific details of its goals and activities.

As the "heart and soul" of ACGIH, the Committees and all of their Members were recognized by the Board with thanks for the countless hours and volumes of work they produce for the benefit of all ACGIH Members and for the protection of workers throughout the world.

Rajhans, Vice Chair of the Industrial Ventilation Committee, and Jerry Sherwood, Acting Chair of the Biological Exposure Indices Committee were two of the 18 Committee Chairs at the March meeting.