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THE STATE OF RESEARCH CONCERNING THE DIESEL AND THE HEALTH OF MINERS

by

Paul Mogan*

SUMMARY

Prior to 1978, there was relatively little information on the health impact of exposure to diesel exhaust. Thus, Drs. French and Mildon, in their report on "Health Implications of Exposure of Underground Mine Workers to Diesel Exhaust Emissions" (1), had to rely on health effects studies of the various individual constituents of exhaust rather than whole exhaust itself. Their 1984 update (5) was able to draw on a greatly expanded pool of information which became available in the interval, including six new animal exposure studies and ten additional epidemiological investigations. None of the animal trials reported an increase in lung tumours, and only one of twelve (including two from the 1978 report) epidemiological studies found an elevated incidence of lung cancer (that among retired members of a heavy construction equipment operator's union).

For the 1989 addendum to "Health Implication of Exposure of Underground Mine Workers to Diesel Exhaust Emissions" (24), seven additional animal trials and two additional epidemiological studies were

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available. Six of the animal studies reported excess lung tumours in some (but not all) species of animals tested. The seventh exposed monkeys and rats to water-scrubbed diesel exhaust and reported lung abnormabilities and loss in function, but no excess tumours. Four of the six laboratories included exposure to filtered diesel exhaust. No excess lung tumours were found in these groups of animals with the exception of one group of mice (co-exposed with rats and hamsters). One laboratory noted an increased incidence of leukemic lymphoma of the spleen in rats exposed to filtered exhaust, however. The two additional epidemiological studies - underground workers in dieselized mines, and diesel exposed railroad workers - reported elevated levels of lung cancer relative to predictions (increasing with years of exposure in the latter study).

The above information prompted the US National Institute for Occupational Health and Safety to issue a "Current Intelligence Bulletin - Carcinogenic Effects of Exposure to Diesel Exhaust" in which diesel exhaust was described as possessing "a potential occupational carcinogenic hazard".

CONTENTS

In their 1977 survey of "Health Implications of Exposure of Underground Mine Workers to Diesel Exhaust" (1), Drs. French and Mildon found relatively little information on the health effects of direct exposure to diesel exhaust. The sole animal exposure study described (2), included co-exposure to radon and uranium-ore dust. Diesel exhaust's contribution to the many negative health effects noted (emphysema, fibrosis, metaplasia, adenomatous lesions with anaplasia, and squamous cell tumours) could thus not be isolated. They also reported on studies of cohorts of underground workers in dieselized mines (3) and railroad workers (4). Neither group exhibited any measurable differences from controls; an increased prevalence of bronchitis in the underground miners was noted, however. Drs. French and Mildon thus had to rely mainly on information on the health impact of the various constituents of diesel exhaust separately - carbon monoxide, nitric oxide, nitrogen dioxide, sulphur dioxide, sulphuric acid, hydrocarbons, and soot with its ab(ad)sorbed components - to make a judgement regarding appropriate exhaust dilutions required to minimize the risk to health.

Six years later, the anticipated increase in passenger car diesels (in response to the energy crisis) had produced a huge increase in diesel health-effects research. In their 1984 update (5), Drs. French and Mildon were able to summarize animal exposure studies at six different laboratories (6, 7, 8, 9, 10, 11). They also reported on an additional ten epidemiological studies involving some aspect of exposure to diesel contaminants (13, 14, 15, 16, 17, 18, 19, 20, 21, 22).

Animal Exposure Experiments to 1983

Two animal species (at the same laboratory, 7) were reported to have some degradation in lung function with exposure to 6.4 and 11.7 mg/m^3 of soot. Four of the six studies described lung tissue alterations which could be regarded as pathological (7, 9, 10, 12), although one group preferred to attribute the changes to an "exaggerated protective response" (12). One laboratory produced emissions typical of a "worn" engine by filing the injector tips (10). None of the studies reported an increased incidence of lung tumours over controls.

Epidemiological Studies to 1983

Of the twelve epidemiological investigations included in the 1978 report and 1984 update, four described subjective symptoms such as bronchitis, cough, or phlegm (6, 17, 18, 21); four reported some pulmonary function loss (18, 19, 20, 22), but this was statistically significant in only two studies (19, 22); and one noted widespread eye irritation (21). Only one study reported an elevated lung cancer incidence (22), and this only among the retired segment of the heavy equipment operator's union studied. Only liver cancer was elevated in the entire cohort.

The GMRC Experience

In one of the animal exposure programs (General Motors Research/ Southwest Research Institute), the investigators elected to retain three animal species (hamsters, A/J mice, and Fischer 344 rats) for eight months beyond the fifteen month exposure period (23). The exposure conditions selected were somewhat below those of other laboratories (0.25, 0.75, and 1.5 mg/m^3 soot), and in fact, spanned levels normally encountered underground. The hamster and mouse results were inconclusive, but the F344 rats (a species with a low spontaneous tumour rate), were found to have one lung tumour in the thirty low dose animals, three in the thirty intermediate dose, and one in the thirty high dose animals, in contrast none in the sixty controls. No tumours were identified in the one-hundred and eighty rats exposed for fifteen months prior to necropsy (i.e. without the additional 8 month period in clean air).

Animal Exposure Experiments to 1986

The GMRC findings set the stage for the next round of animal exposure studies in seven laboratories worldwide, as reported in the addendum to "Health Implications of Exposure of Underground Mine Workers to Diesel Exhaust Emissions" (24). The cost of each of these animal exposure studies is about $5 to $7,500,000 US, and an investigation spans about four years from planning to reporting. The laboratories undertaking studies in this 1983 to 1986 interval were the following:

The Lovelace Biomedical and Environmental Research Institute, Albuquerque, New Mexico.

The Fraunhofer Institute for Toxicology and Aerosol Science, Hanover, West Germany.

The Battelle Centre for Toxicology and Biosciences, Geneva, Switzerland.

The Japan Automobile Research Institute (JARI), Tsukuba, Ibaraki (Tokyo), Japan.

The Saitama Medical School, Saitama, Japan.

The Research Institute of Tuberculosis (RIT), Kiyose, Japan.

The National Institute for Occupational Safety and Health (NIOSH), at the Environmental Protection Agency's Health Effects Research Laboratory (HERL), Cincinnati, Ohio.

The first six studies were all similar to the GMRC model. Rats, mice, and hamsters were exposed to generally lower doses of dilute exhaust than those used in the first round. Groups of animals were retained and examined for up to two and one-half years. The seventh study, sponsored by NIOSH (25) was directed at the health impact of diesels in underground coal mines. At EPA's Health Effects Laboratory, monkeys and rats were exposed to dilute water-scrubbed diesel exhaust containing 2 mg/m^3 of soot, or 1 mg/m^3 of soot plus 1 mg/m^3 of coal dust.

Many of the findings were typical of those depicted by the

Lovelace researchers in their Figure 1 (26). Twenty of twenty-four lung tumours in the high-dose rats were detected between the twenty-fourth and thirtieth month of exposure (five of six at the intermediate dose), while the single tumour in the control group was found after eighteen months exposure. In studies where the animals were exposed to several concentrations of diesel exhaust, the tumours frequency was often proportional to the soot concentration, as presented in Figure 12 of the JARI paper (27).

The Lovelace group (26) exposed F344 rats and CD1 mice to diluted exhaust from an Oldsmobile 5.7 litre diesel operating over the USFTP cycle (Federal Test Procedure simulating urban/freeway driving). The animals were exposed seven hours per day, five days per week to dilute exhaust containing 7.1, 3.5, and 0.35 mg/m^3 of soot. There was evidence of degraded lung function and tissue damage in the high and intermediate exposure animals. The 7.1 mg/m^3 rats were found to have 14.7% excess tumours, the 3.5 mg/m^3, 3.2%. Malignant tumours were identified in 8.4% of the high dose rats; none were found in the intermediate group.

Fraunhofer researchers exposed Syrian golden hamsters, NMRI mice, and Wistar rats to diluted exhaust from a 1.6 litre Volkswaggen diesel operating over the USFTP for nineteen hours per day, five days per week (28). The soot level was maintained at 4.2 mg/m^3 in the exposure chambers. Degradation in lung function and tissue damage were detected in all species. No excess tumours were observed in the exposed hamsters, but 19% of the mice and 17.8% of the rats were found to have developed excess lung tumours. Excess malignant tumours were noted in 9.5% of the rats and 14.6% of the mice.

At Battelle, Syrian golden hamsters and F344 rats were exposed for 16 hours per day, five days per week to the dilute exhaust from a 1.5 litre Wolkswaggen diesel also operating on the USFTP (29). Chamber atmospheres were adjusted to 6.6, 2.2, and 0.7 mg/m^3 of diesel soot. Only the rats showed evidence of degraded lung function, but both species exhibited tissue abnormalities. While no tumours were detected in any of the hamsters, 37% of the high dose rats and 8% of the intermediate dose rats exhibited excess lung tumours.

Two parallel studies were carried in at the Japan Automobile Research Institute (27). F344 rats were exposed 16 hours per day, 6 days per week to the dilute exhaust from a 1.8 litre passenger car diesel (LD) at 1/3 load and 1700 rpm, and an 11 litre heavy duty (HD) engines at 1/3 load and 1700 rpm. Soot levels in the exposure chambers were adjusted to 0.1, 0.4, 1, and 2 mg/m^3 (LD) and 0.4, 1, 2, and 4 mg/m^3 (HD). The HD exposed animals exhibited 5.7% excess malignant lung tumours at 4 mg/m^3, and 2.5% at 2 mg/m^3. The LD study animals were found to have an abnormally high tumour incidence in the control group (3.3%) so only a small excess (0.8%) was observed in the 1 mg/m^3 animals. Abnormal lung changes were noted in all groups except the 0.1 mg/m^3 LD and 0.4 mg/m^3 HD.

Saitama medical school researchers exposed F344 rats, ICR mice, and C57BL mice to the idling exhaust of a small Yanmar diesel diluted to a soot level varying from 2 to 4 mg/m^3. Exposure was only four hours per day, four days per week. While there was evidence of lung tissue damage in all animals, only the mice developed excess lung tumours. The C57BL mice had 8% excess, the ICR, 6%. Excess malignant tumours were found in 2.6% of the C57BL mice and 2.8% of the ICR mice.

F344 rats at the Research Institute of Tuberculosis in Japan were exposed to the dilute exhaust of a light duty truck diesel for 8 hours per day, 7 days per week (31). An unusual speed/load combination was selected (1000 rpm/80%) to maximize soot without increasing NO_2 and SO_2; it is possible that this produced atypical levels of minor exhaust constituents as well - these may have contributed to the unusual increase in leukemic lymphoma of the spleen which occurred in both whole and filtered exhaust regimes. Rats exposed to whole dilute exhaust containing 4.9 mg/m^3 of soot exhibited lung tissue abnormalities and a 38% excess incidence of lung tumours (a 26.3% excess of malignant tumours). A 16.8% increase in malignant lymphoma of the spleen was also reported, but it was noted that the F344 rat was known to exhibit a spontaneous incidence of 8.3 to 18.8% (8.2% for the controls in this experiment).

Although some of the animal tumour rates are below the level of statistical significance, particularily at the lower exposure levels, the uniformity of the results worldwide, as illustrated by Figures 42 and 43 (24), suggests that most of the values are none-the-less valid. The similarity in rates of tumour production despite wide variations in engine type, loads, fuels, and daily exposure duration attests to the truth of "a gram of particulate is a gram of particulate" (24, from Gibbs, R, Hyde, J. and Whitby, R.) in the widest sense.

Additional Epidemiological Studies

Two further epidemiological studies were summarized in the 1989 addendum (24).

A decade long study of all employed residents of Finland uncovered a Standardized Mortality Ratio of 1.45 for lung cancer among workers in dieselized underground mines (32). Total dust levels underground measured in a subsequent study (33) varied from 0.9 to 27 mg/m^3 and benzo-a-pyrene levels ranged from 6 to 36 ng/m^3. Concentrations in Canadian nickel mines averaged 1.9 ng/m^3 (34).

A retrospective study of a cohort of 55,407 railroad workers yielded an apparent increase in the relative risk of lung cancer with years of exposure (35). The companion study (36, 37) suggested that soot exposures ranged from 0.07 to 0.33 mg/m^3, although historical records of NO_2 levels in repair shops indicated that early exposures could have been much higher for that segment of the cohort.

The NIOSH CIB

These recent animal exposure and epidemiological studies have prompted the U.S. National Institute for Occupational Health and Safety to issue Current Intelligence Bulletin 50 "Carcinogenic Effects of Exposure to Diesel Exhaust", in August 1988. The "Conclusions" of CIB 50 are as follows:

> "Recent animal studies in rats and mice confirm an association between the induction of cancer and exposure to whole diesel exhaust. The lung is the primary site identified with carcinogenic or tumorigenic responses following inhalation exposures. Limited epidemiologic evidence suggests an association between occupational exposure to diesel engine emissions and lung cancer. The consistency of these toxicologic and epidemiologic findings suggests that a potential occupational carcinogenic hazard exists in human exposure to diesel exhaust. Tumour induction is associated with diesel exhaust particulates. Limited evidence indicates that the gaseous fraction of diesel exhaust may be carcinogenic, as well."

Emission Control

The NIOSH animal study (25) exposed F344 rats and monkeys to the water-scrubbed exhaust from a Caterpillar 3304 diesel operated over a coal mine "tramcar" cycle. Exhaust was diluted to 2 mg/m^3 soot and exposure was 7 hours per day, 5 days per week. In contrast to the other six animal studies, no excess tumours were reported, and lung tissue damage was noted in the rats only. The monkeys exhibited some degradation in lung function parameters, however.

At Battelle (29), hamsters and rats were exposed to the same concentrations of particle-free exhaust. In contrast to the 37% excess tumour rate with whole exhaust, no excess tumours were discovered, and no degradation in respiratory function reported.

The Fraunhofer experiment (28) also included exposure to particle-free centrifuged and filtered exhaust. These animals showed no degradation in lung function and no excess lung tumours for the rats or hamsters. Although the mice exhibited the same tumour rate (31%) as those exposed to whole exhaust, less tissue damage was noted and control mice had a spontaneous tumour rate of 13%.

JARI researchers (27) exposed parallel groups of F344 rats to filtered and whole exhaust. They noted similar tissue changes for both groups except those specifically induced by an accumulation of particles. They did not report on the influence of soot on tumour formation.

The program at the Research Institute of Tuberculosis (31) also included a filtered exhaust/whole exhaust comparison. Mimimal tissue changes and no excess tumours were observed in the lungs of rats exposed to the filtered exhaust. The incidence of malignant lymphoma of the spleen increased from 25% with whole exhaust to 37.3% for the particle-free exposure. As noted previously, however, F344 rats are prone to develop this condition, which could have been fostered by exposure to an atypical spectrum of gaseous constituents.

COMMENTS

While the results of the animal studies with filtered or water-scrubbed exhaust are not absolutely unequivocal, they do provide a strong indication that these measures will reduce the hazards addressed in the NIOSH CIB 50.

A "hot" exhaust filter (adjacent to the exhaust manifold in a heavily-loaded mining vehicle) will inevitably not collect all of the lower-boiling materials which condense on soot, and which were, therefore, removed by the dilute exhaust filters used in the animal exposure comparisons. An "epigenetic" mechanism (as occurs with massive inhalation of "nuisance" dusts) has been suggested for diesel-soot-induced tumourogenesis (38, 39, 40), however. The uniformity of response illustrated in Figures 42 and 43, despite wide differences in engines, load (cycles), and fuels certainly provides strong indirect evidence supporting this "epigenetic" route, i.e. the ab(ad)sorbed materials on diesel soot have a minor role in tumourogenesis.

If the "epigenetic" mechanism is dominant, the cold filter/hot filter differential has little relevance. The generally reduced mutagenic response of "hot" filtered exhaust (41, 42) provides additional evidence of potential benefit.

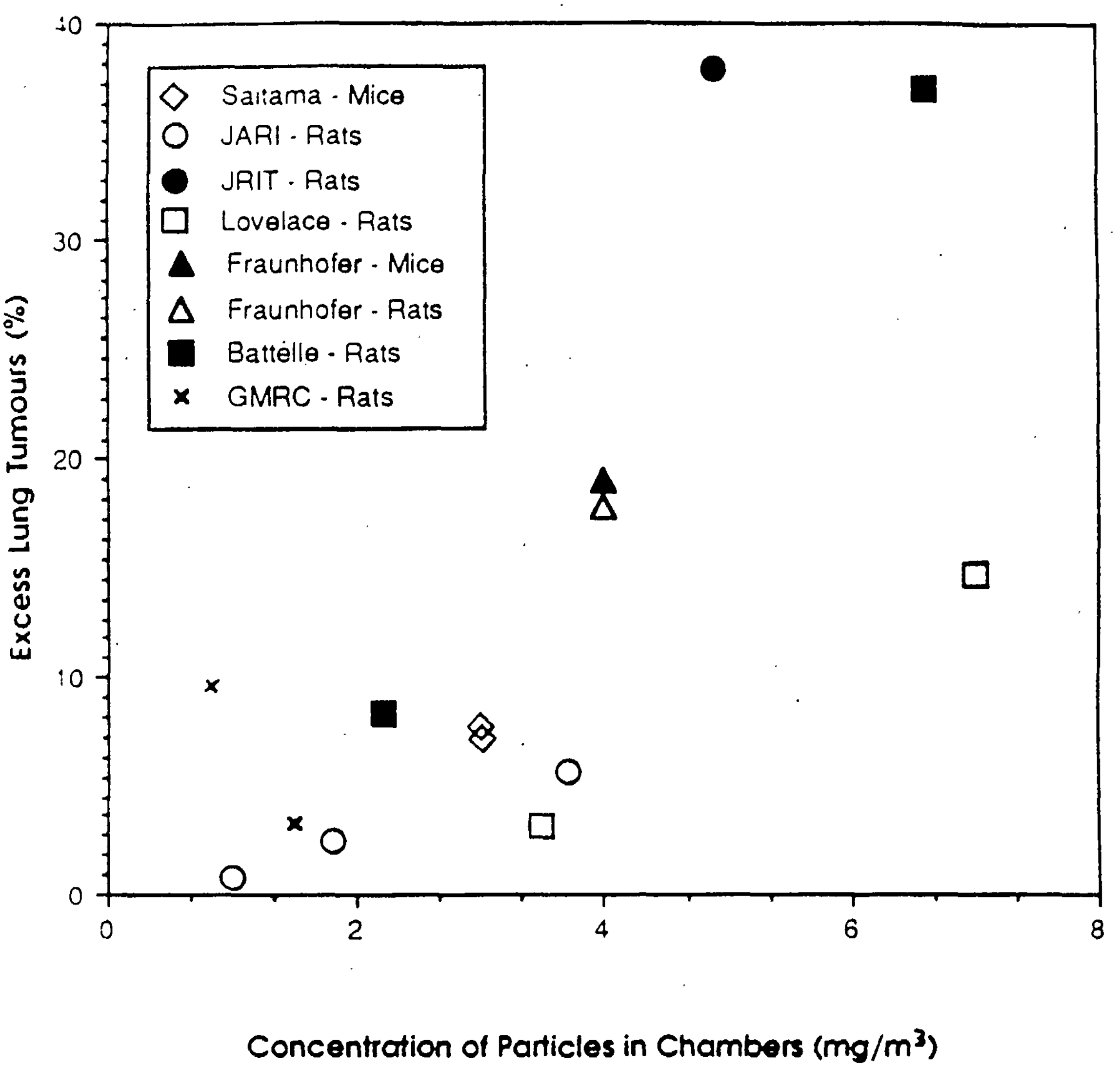

Figure "42". Tumour Frequency vs Soot Concentration

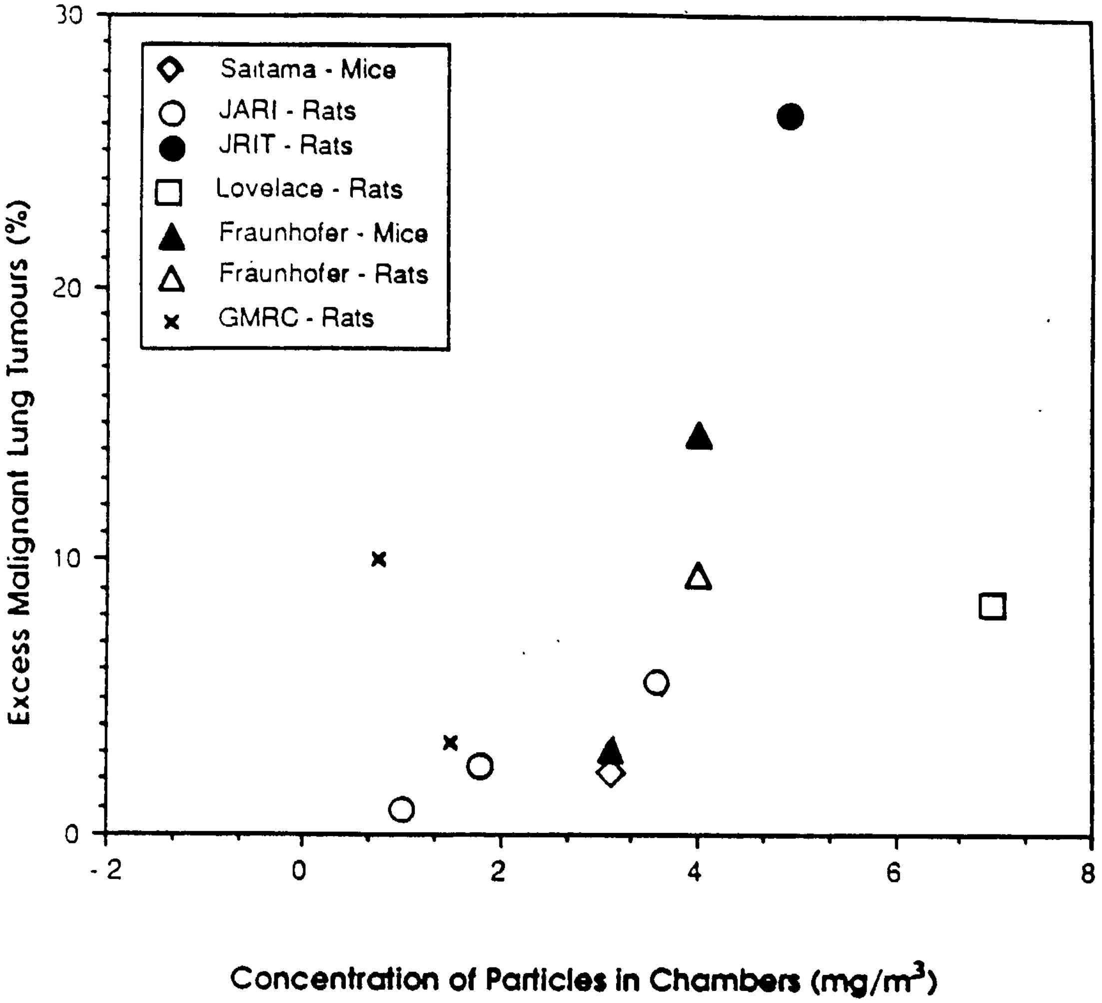

Figure "43". Malignant Tumour Frequency vs Soot Concentration

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