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Versar INC

December 14, 1983

Ms. Denise Keehner
Chemical Regulations Division
Office of Toxic Substances
U.S. Environmental Protection Agency
Room 341, East Tower
Waterside Mall
Washington, D.C. 20460

Subject: PCB Capacitor Explosion in Finland

Dear Denise:

I am enclosing several writeups of the events surrounding an explosion of PCB capacitors that occurred in Finland on August 2, 1982. I just received these from Dr. Dinçler of Zurich Insurance in Zurich, Switzerland. Items of major interest include:

Analytical results indicating that about 10% of the TCDFs were 2,3,7,8-TCDF.

Cleanup methods used and protective clothing for workers.

Reoccupancy criteria: 100 μg/m² PCBs
100 ng/m² total furans
10 ng/m² 2,3,7,8-TCDF

Medical surveillance program and results.

I do not see anything in these reports that is surprising in light of what we have seen and experienced in One Market Plaza and Binghamton. Apparently, banks of capacitors can act just like transformers. Please let me know if you have any questions concerning these reports.

Very truly yours,

Bob Westin

Robert A. Westin
Senior Chemical Engineer

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715C-75
Encl: Ruohio, V. "On the Brink of Catastrophe." <u>Industrial Insurance</u>. 1983. Pp. 8-13.

Elo, O.A. and P. Vuojolahti. "Capacitor Fire in a Paper Mill at Imatra, Finland." undated manuscript.

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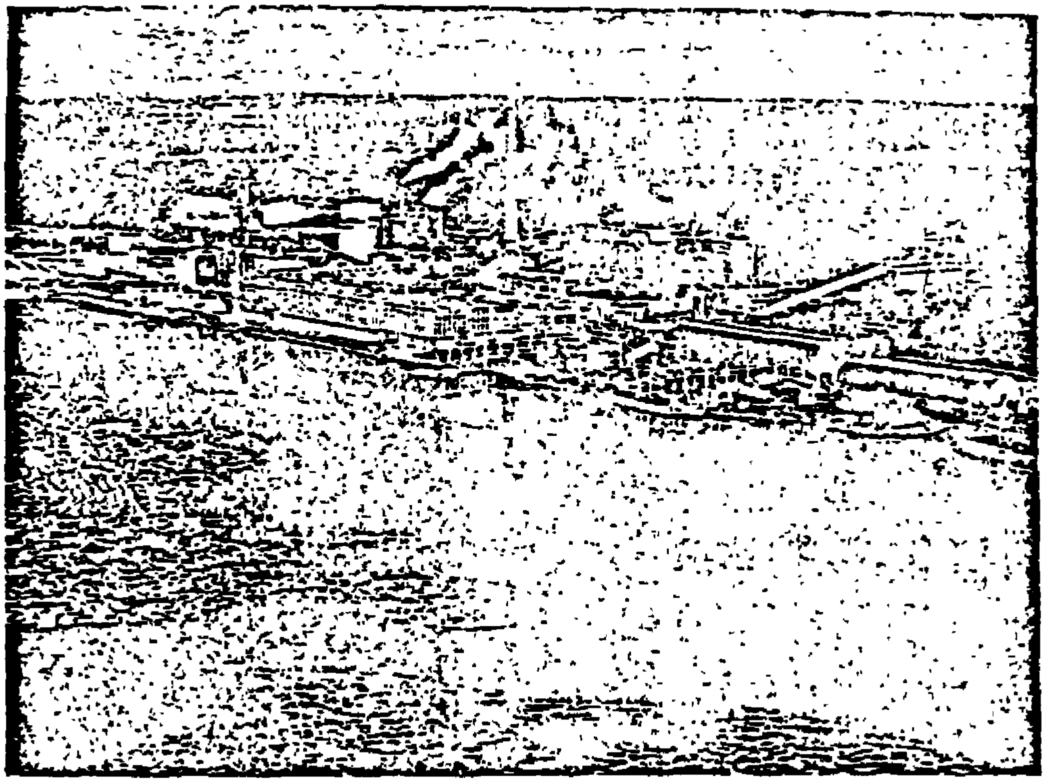
ON THE BRINK OF CATAS



Enso-Gutzeit Oy's Kaukopää Mills is one of the largest forest industry production facilities in Finland.

BY VEIKKO RUOHIO

[illegible]

ROPHE

Veikko Ruohio is safety manager at Enso-Gutzeit Oy's Kaukopää Mills

EXPLOSION IN THE CAPACITOR ROOM

A little after midnight the night shift supervisor of the paperboard line heard two successive loud explosions from the mill's electrical switchgear room. He notified the fire brigade and the mill electrician on duty from the line's control room. Soon after this, heavy smoke forced the paperboard line supervisor and the personnel on duty in the adjoining pulp tank room to vacate the control room.

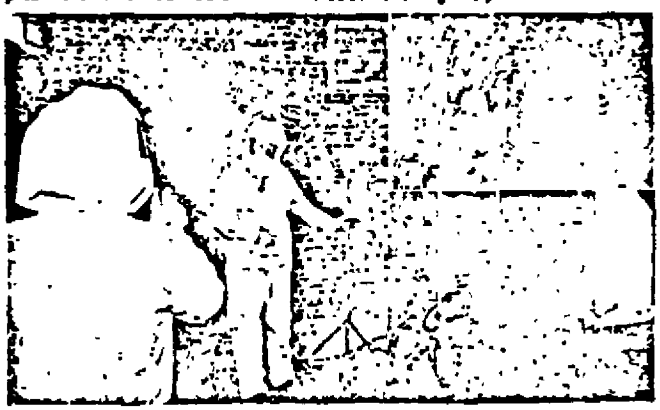
The fire brigade made a swift response, but since no flames could be seen, it took almost half an hour to pinpoint the site of the explosion, a capacitor bank behind a 10 kV switchgear facility.

INITIAL UNCERTAINTY ABOUT THE TOXIC EFFECTS OF PCBS

Oil containing PCBs is used in capacitor banks as a dielectric and coolant. In the accident at Kaukopaa, the gasified liquid surged with explosive force into the open. A couple of hours after the explosion ten people were taken to hospital. They were all suffering from the same symptoms: nausea, heavy perspiration and headache. By this time it was clear that the gasified liquid contained PCBs, but

The oil containing PCB which leaked onto the floor from the damaged capacitor banks was cleaned up using plastic buckets and absorbent.

The pressure wave created by the explosion escaped through the door from the capacitor facility seen in the background into the 10 kV switchgear room seen in the foreground. The areas from which samples were taken can be seen in the soot covering the floor.



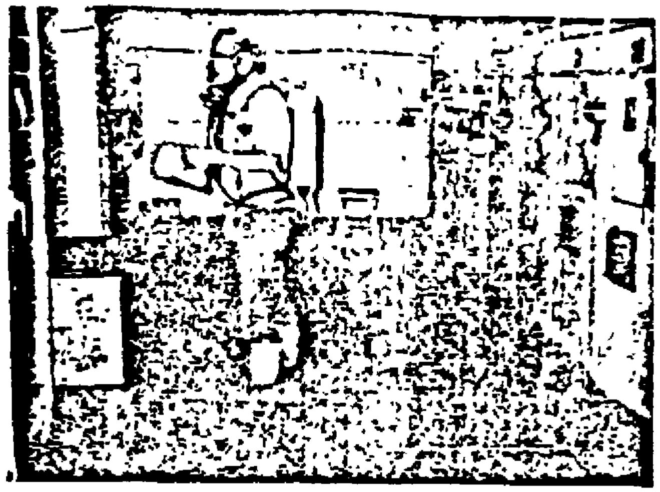
Airborne PCB concentrations were measured almost constantly during the first few days. The picture shows a measuring team looking for a suitable location for one of the suction pumps used in the sampling. The PCB and furan samples from surfaces were collected from areas measuring 10 cm x 10 cm using cotton wadding dipped in acetone or alcohol.

no one on the site was familiar with the effects of exposure to PCBs or with its treatment. Initial information about the potential effects of exposure to the gas was found in the library of the mill's doctor.

As the night when the explosion occurred was warm, those exposed to the reaction products of PCBs waited for treatment on the hospital grounds. Their symptoms disappeared in the fresh air.

The first symptoms may have been caused by exposure to chlorine and hydrochloric acid, which had also been produced in the decomposition of PCBs.

As soon as the first symptoms were reported, the fire brigade closed off the contaminated area with warning signs. Because of the initial uncertainty about the effects of exposure to PCBs, several mill employees moved about in the contaminated area without proper personal protection. The total number of people who had been in the contaminated area and who therefore had at least a theoretical chance of slight exposure was estimated at 150, among them industrial hygienists and cleaning personnel. All these people were later interviewed. Their movements and lengths of stay in the contaminated area were noted and samples of their blood were taken. Follow-up studies have indicated that the exposure to PCBs and its reaction products was at a low level, very likely thanks to the speedy action taken immediately after the incident.



The importance of skin protection was not fully understood immediately after the accident

Scaffolding and plastic sheet was used to create a makeshift shelter for donning protective wear and equipment

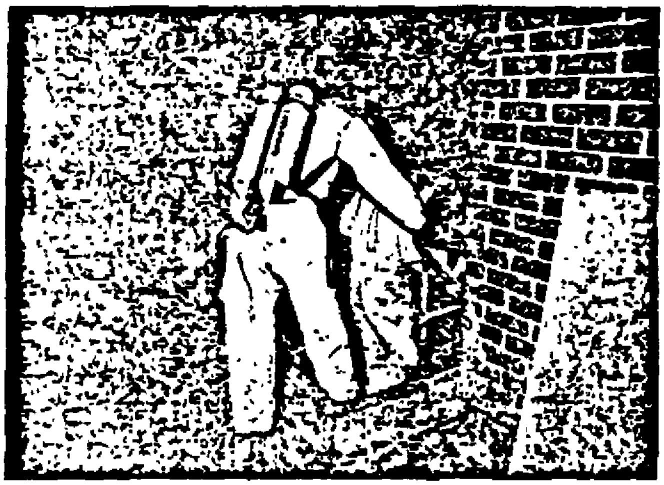
INFORMATION STARTS TRICKLING IN

The first outside expert to reach the site of the explosion was an industrial hygienist from the Lappeenranta Regional Institute of Occupational Health. He initiated gas concentration sampling during the early morning hours. The results, which indicated that the level of PCB concentrations in the form of gas in the contaminated area was sufficient to require personal protection, were received on the afternoon of the day after the explosion. Two chemical safety experts from Industrial Insurance arrived on the morning following the explosion. They brought with them literature on PCBs acquired from abroad and on the hazards of its decomposed elements. On the afternoon of the same day samples of soot were flown to the Chemical Instrument Center of The University of Helsinki for analysis. The preliminary results indicating the presence of dibenzofurans were received on the evening of the same day. The capacitor manufacturer arrived at the mill at about the same time, bringing with him information on the construction of the capacitor banks and on the amounts of PCBs used in them.

CLEAN-UP AND MEASUREMENTS HAND IN HAND

A large number of samples were analyzed to establish the size of the contaminated area and the concentrations of haz-

Change of clean-up shifts. The two "spacemen" on the right-hand side have just returned from a one-hour clean-up shift while the two men on the left are getting ready for their turn on duty.



Protective clothing and equipment were used in areas which had been cleaned up until sufficiently low concentrations were registered.

ardous substances. The Institute of Occupational Health undertook to measure the PCB concentrations, and the Chemical Instrument Center of the University of Helsinki the furan concentrations. The extent of the measurements performed is shown by the fact that the number of PCB concentrations analyzed amounted to twenty and the number of individual samples taken went far beyond 200.

The clean-up operations, which were started without delay, were performed by an outside company. The immediate problem was to train the clean-up personnel. The importance of skin protection and the use of self-contained breathing apparatus were emphasized.

The clean-up work focused first on the area where the pulp tanks were located because they are of crucial importance to the operation of the board machines. The operation of this department requires the continual presence of personnel, whereas occasional work on electrical installations can well be done wearing protective clothing and using protective devices.

The pulp tank department, including the control room, underwent thorough cleaning, which consisted of alternating vacuum cleaning and washing. In less than a week, the concentrations in that area had fallen below hazardous levels, and the department was out of danger.

Measurements indicated that vacuuming, water blasting and wiping with alcohol were sufficient for areas with low concentrations and for painted metal surfaces. The PCBs adhered so strongly to concrete floors in areas which contained electrical installations and to plastered and brick walls that the only solution was to resurface them with epoxy paint. During the first few days there was uncertainty about the level of PCB concentrations that should be reached in the clean-up, as no official maximum allowable concentration of PCBs in air or on surfaces had yet been established in Finland or elsewhere. The maximum allowable concentration of airborne PCBs without protection, issued three days after the incident by the local labor protection district, was 10 $\mu g/m^3$. The maximum allowable concentrations of PCBs on surfaces, which were obtained from the local labor protection district one month later, were 100 $\mu g/m^2$ for PCBs, 100 ng/m^2 for furans as a whole and 10 ng/m^2 for 2, 3, 7, 8 tetrachlorodibenzofuran. No instructions have been issued as to how samples from surfaces are to be taken, an omission which has prompted some debate.

WHAT REALLY HAPPENED?

Capacitor bank explosions do not occur everyday. Fuse burns in elements inside capacitors are not rare, but an explosion which destroys an entire capacitor bank, requires the presence of several simultaneous factors. At Kaukopää these factors may have included increased use of thyristors with the acquisition of a new paper machine, exceptional distribution in the electrical network and a long period

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of warm weather. The combined effect of these factors could have set off a number of element fuse burns. The unbalance current protection device was defective, and as a result, one capacitor unit blew up. Before the overcurrent relay was able to disconnect the supply of electricity to the defective capacitor bank, voltage had increased considerably as a result of harmonics. This caused a chain reaction that destroyed yet other capacitor units.

The capacitor bank consists of 96 capacitor units. Two of them were destroyed by the electric arc, another two units were destroyed mechanically, and a further 11 units were damaged by pressure. The overcurrent relays cut off the supply of electricity to the capacitor bank two seconds after the electric arc.

The incident immediately stopped the operation of three board machines, one paper machine, an external pulper station and some machinery used in the conversion of paperboard. Because of the contamination in the area housing the pulp tanks, pulp production had to be halted the day after the accident. This led to considerable losses in production.

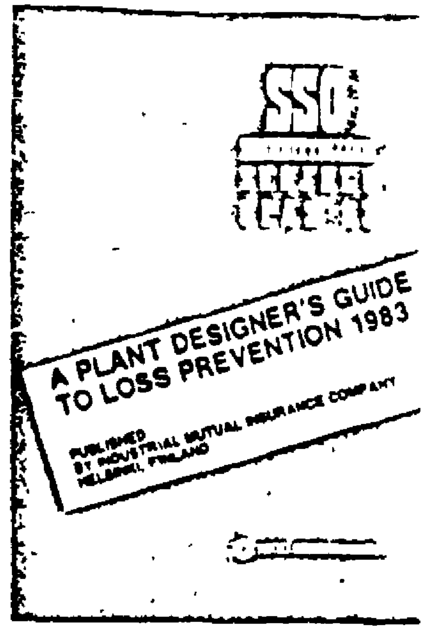
Two board machines were back in operation within three days thanks to a by-pass arrangement. Other affected production machinery was operating at full capacity within seven days of the explosion.

NATIONWIDE CONCERN

As soon as investigations had indicated that a risk of similar accidents exists wherever capacitors and transformers containing PCBs are used, the matter became a topic of national concern. A quick survey showed that there are nearly 100,000 PCB-filled capacitors and 250 PCB-filled transformers in Finland.

At the moment, the situation is under control. An ample supply of guidance material has been issued by both insurance companies and manufacturers. Public discussion in the aftermath of the accident has been

A Guide to Loss Prevention



The scope of industrial safety in Finland has expanded at a fast rate. Consequently, the number of laws, statutes, regulations and instructions, and the volume of research have grown steadily. As a result, even safety professionals have found it hard to keep up with the ever-increasing wealth of reference material.

The situation has been particularly difficult for plant designers who are expected to design safe plants, machinery, and equipment but who seldom know where to find the relevant information.

Years ago, the participants at a safety meeting sponsored by Industrial Insurance expressed the wish that Industrial Insurance compile a list of laws, statutes, regulations, and instructions pertaining to industrial safety. The decision was taken to pool efforts and resources and, under the leadership of Industrial Insurance, to compile a guidebook containing the principal sources of information on industrial safety and fire protection. Two working groups were set up for the task: one for industrial safety, the other for fire protection.

extensive, and the participants have included numbers of private organizations and public bodies. The media have spared no effort in covering issues involving PCBs. If there are any people still working in electrical engineering, fire protection, or industrial safety today who are unaware of the discussion on PCBs, they must be deaf and blind.

Regardless of the intensity of the discussion, the approach to the issue has been basically sound. Various committees have investigated risks involved in the use of equipment containing PCBs and the reduction of such risks. The Labor Protection Fund has received grant applications which contain proposals for developing ways to measure PCB concentrations, the concentrations of its reaction products, and investigation of their effects. In summary, one can say that the warm August night shook the nation

PROTECTION CANNOT BE REDUCED

Perhaps the most difficult task to be faced in accidents of this type is how to motivate staff to use protective wear and equipment. This problem is enhanced when the substance against which protection is required cannot be seen, smelled, or felt.

At Kaukopää, familiarity with protection required in the use of chlorine bleaching turned out to be helpful. Because of the risk of accidental chlorine emissions, the mill has to maintain a sufficient stock of protective wear, self-contained breathing apparatus and gas masks. Employees must also be trained to wear protective clothing on the job. The outside clean-up personnel had to be given this training and they required frequent forceful reminding about the importance of personal pro-

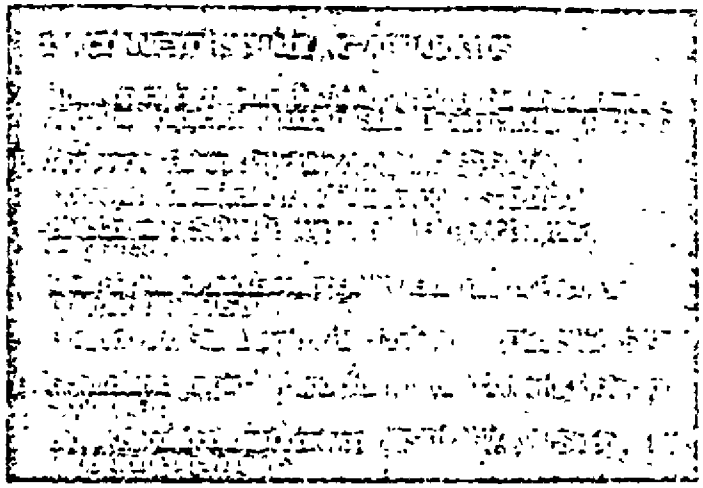
Since the first edition of the Guide in 1977, two supplements have been issued, in 1978 and 1980. It was initially agreed that a revised edition should be published five years later, in 1982. The bulk of the practical revision was in the hands of loss prevention experts from Industrial Insurance with the help of a supporting organization consisting of active safety and fire protection professionals representing Industrial Insurance's policyholders.

A Plant Designer's Guide to Loss Prevention is a source book, a bibliographic work of reference listing relevant items of legislation, statutes, government decisions, regulations and instructions. Loss prevention is divided into four subfields:
— industrial safety
— fire protection
— environmental protection
— civil defense.

The same major headings are used in the industrial safety and fire protection sections. Letter symbols (P = Fire Protection, T = Industrial Safety) keep information in the two subfields distinct from each other.

Information on each subject is subdivided into three sections. section A lists laws, statutes, government decisions, regulations, and instructions; section B lists Finnish Standards, data sheets issued by insurance companies, and other similar items, section C lists lectures, articles in journals, short reports, and studies published outside Finland (e.g. NSC Data Sheets).

Although the compilation aims at practicality and simplicity, as is reflected in the choice of entries, the formulation of each entry, and the disposition of the Guide, Industrial Insurance recommends a short introductory meeting with the users of the Guide. The charge to policyholders for the Guide covers only the printing costs. The Guide is available to non-policyholder enterprises, organizations, and individuals at a slightly higher price.



A sample page from the Guide.

tection. The main point in protection against PCBs and its reaction products is the protection of skin and the respiratory organs. Great care must also be taken not to spread the toxic substances to non-contaminated areas.

Disposable overalls and hoods, rubber boots, plastic gloves and disposable footwear covers turned out to be handy basic protective wear. Disposable overalls were sufficient alone in low concentrations, while higher concentrations required additional protective overalls developed for civil defense use.

The disposable hood gave good protection to hair and neck, and the filter-equipped facial mask could also be worn under it. Immediately after use the disposable overalls, hoods, gloves and footwear covers were placed in special trash bags for hazardous waste. The light protective overalls developed for civil defense use, the self-contained breathing apparatus and the gas masks were washed with the utmost care before reuse.

The extent of the Kaukopää incident is also demonstrated by the following statistics on the materials required in the clean-up, measuring, inspection and related work.

Item	Used
respiratory filters	3,300
disposable overalls	4,900
protective hoods	1,200
footwear covers	4,100
disposable gloves	2,800
glass jars (for samples)	600
foam sealant	129 kg
absol absorbent	4,000
civil defense overalls in use at one time (in laundry about 350 pairs)	93
compressed air cylinders (filled)	2,000
paint for resurfacing	2,300 l

Follow-up examinations have shown no cause for alarm. As indicated above, the number of people with possible exposure to PCBs was about 150. As no medical treatment was known for such exposure, medicinal carbon was prescribed. If taken in large amounts, it speeds up the removal of toxic substances from the body. The amount of medicinal carbon taken was considerable, as the daily dose for each exposed person was 50 g for one week.

In addition to the ten people exposed to PCBs and taken to the hospital, five other exposed employees showed some similar symptoms of exposure soon after the accident. This group of 15 has been under closer supervision. So far analyses of blood, fat tissue and other samples have not revealed anything alarming. Follow-up studies of this group are still in progress.

CAPACITOR FIRE IN A PAPER MILL AT IMATRA, FINLAND

O.A.Elo and P. Vuojolahti

I. INTRODUCTION

1. Early stages

After two consecutive and strong explosions in the electricity room, the control room of the pulp mill storage department sounded an alarm at 12:10 AM on 3 August 1982. The control room became filled with smoke, which caused the shift supervisor, the storage department attendant, and their assistants to leave the room. When the fire brigade arrived, the formation of smoke was abundant. After some thrity minutes of investigation, the explosion was found to have taken place in the capacitor bank situated behind the 10 kV contactor station.

The damaged capacitor caused all three board machines and paper machine No. 8 to stop almost immediately.

2. Persons immediately exposed

The capacitors contain a liquid known as polychlorinated biphenyls (PCB). PBC is used both as an insulating and a cooling agent.

An electric arc caused the ~~PBC~~ PCB to gassify and to decompose. One substance given off was hydrochloric acid, which causes acute irritation. Immediately after the explosion, it was not known that the damaged parts contained PCB. Thus respirators were not used. Only after some 15 people had symptoms of irritation did it become obvious that toxic gases were spreading as a consequence of the explosion. The most common symptoms reported by this group were headache, smarting and redness of the eyes, nausea, irritation of the throat and respiratory tract, and itching and smarting of the skin. Due to these symptoms, ten people were taken to the out-patient department of the Imatra District Hospital some two hours after the explosion. The symptoms resolved slowly in fresh air. About five hours after the explosion, the ten most heavily exposed were interviewed at the company health service center in Vuoksenniska. Blood and urine samples were taken in the laboratory the next morning. Within 24 to 48 hours all ten reported that the symptoms had slowly disappeared. As investigations proved that not only PCB but also dibenzofurans had been given off by the explosion, it was decided that the exposed persons should be carefully examined and followed. The test program arranged for this purpose is based on the findings of both foreign and Finnish specialists; also considered were the views of the physicians who participated in the work.

3. Persons exposed later

Since at the initial stages there was no knowledge of the presence or the effects of PCB or its disinitegration products, many members of the mill staff moved about in the polluted areas without the proper protective equipment or clothing. Some of the people who thus became exposed had come to restart the machines and operations. Also, despite the clear smell of gas in the area, people moved about and inspected the affected area without protective clothing. Some of the exposed were merely people who out of curiosity wanted to get as close to the explosion area as possible even though posters prohibiting entry had been erected at an early stage. The exposed also included one person who was there to take samples for industrial hygienic measurements and others who were cleaning up. Altogether some 150 people were thus slighly exposed. All of them have been interviewed and records made of the places and times at which they were in the areas. In addition, blood samples have been collected from all of them for later determination of the levels of ~~Pae~~ PCB. Similar tests will be carried out simultaneously with a control group of about 200 people in order to determine the present level of PCB in the blood of a normal Finnish population.

4. Examination and treatment of the exposed

In this study those immediately and more heavily exposed form group A, and those later and less heavily exposed comprise group B. Group A was initially examined at intervals of a few days and later at about monthly intervals. Group B was interviewed and examined during the early stages. No clinical follow-up tests have been carried out for group B. In future, tests to determine the levels of PCB in the blood will be carried out; decisions about further measures depend on their results. There is no treatment recommended for this sort of exposure. Animal tests have indicated that large doses of carbon tablets during the acute stages could help clear the substances from the body. Thus every exposed person was given 50 g of carbon daily for an average of one week.

5. What is thought to have happened

Harmonics, the exceptional connection positions of the network, and possibly also the hot weather - which had lasted for a long period - blew a number of fuses in the capacitors. The imbalance relay was not operational, and the over-current relay, due to its high setting, does not yet operate in a case like this; therefore one of the units "exploded".

The explosion caused the impedances of the network to move closer to resonance condition, and the harmonics caused the voltage to increase. This situation led to the destruction of other units when the capacitors went into resonance condition. A total of eleven units were destroyed by pressure, two units were destroyed by external electric arc, and two more units were destroyed mechanically. It is estimated that altogether about 100 litres of PCB leaked out from the destroyed units. The over-current relays tripped the capacitors from the network two seconds after the electric arc.

6. Initiation of investigations

Some three to four hours after the explosion, the Labor Protection Manager was asked to come to the mill. He called an industrial hygienic expert from the Lappeenranta District Occupational Health Center to test the concentrations of gas. MD P. Vuojolahti was alerted at about 4:00 AM to organize the required medical measures. At 7:00 AM a conference was held at the Kaukopää mill in which he explained the toxicity of PCB and the possibility of the presence of the even more dangerous pyrosynthetic derivatives. We decided to call in specialists to carry out investigations, first from the Industrial Insurance Company and a representative of Oy Nokia Ab. The first samples of soot dust were flown to the Department of Chemistry of the University of Helsinki in the afternoon of 3 August 1982. That same evening we were informed that the samples analyzed contained furan. Thus, that day the Industrial Insurance Company immediately contacted specialist institutions in Europe to collate the information available from reports on similar accidents or investigations on PCB derivatives. products.

On 4 August 1982 Prof. Lindberg from the University of Helsinki arrived at the scene of the accident. At his instructions, the systematic collection of floor samples was started in the mill departments thought to have been polluted.

On 5 August Dr. Reggiani from Hoffman La Roche in Basel, Switzerland arrived at the mill. He was known to have extensive experience in the investigation of PCB derivatives and the clearing up of polluted areas.

The Institute of Occupational Health participated in the investigations during the initial stages by measuring the concentrations of PCB in the air and, later, in dust samples. The University of Helsinki concentrated on the collection of samples of PCB disintegra- derivatives and the analysis of the results of soot dust tests.

7. Effects of the explosion

The explosion took place in the board mill capacitor bank behind the 10 kV contactor station. The pressure wave, accompanied by clouds of soot and gas, went mostly through an open doorway into the 10 kV contactor station and further into the adjacent 3 kV contactor station.

The filter and control rooms of the storage department are located directly above capacitor room and the neighboring room. The cloud of soot and gas entered these rooms through openings in the floor; the openings include three uncovered cable holes, one of which led underneath the floor level of the instrument cross-connection room situated under the control room.

The pollued area at the floor level of the storage department was limited to the surroundings of the control room and the end of the floor.

Some traces of PCB were also discovered on the story below the floor level of the storage department; these were, however, considerably lower than the concentrations detected at the floor level.

The gases and soot were not able to penetrate into the board and paper machine halls.

Once the electric power had been cut off, it was no longer possible to run the three board machines and two paper machines, the outer pulper station, and the Kamyr pick-up machine.

After the pulp storage tanks had been filled, the pulp production line also had to be stopped.

8. Cleaning and other follow-up measures

8.1. General

Depending on the concentration of PCB, the cleaners used different kinds of protective clothing: VSS suits and compressed air respirators; disposable protective clothing with filter mask; or disposable clothing that included gloves and head protection. The vacuum cleaners used were all fitted with microfilters.

Once collected all the waste was packed in metal containers or specially made plywood cases.

8.2. Control room and cross-connection rooms

The control room and cross-connection rooms were vacuum cleaned several times with microfilter-equipped vacuum cleaners and wiped several times with methylene chloride and methyl alcohol.

8.3. Switching station and adjacent rooms

The switching station and the adjacent rooms were vacuum cleaned as above, wiped with methyl alcohol, and high-pressure washed with warm water. The walls and the ceiling were painted twice over with epoxide pitch, and the floors received a coating of epoxide.

8.4. Room of the explosion

The floor, an area of approx. 30 m^2, was pick dressed and the plaster was removed from the walls. It was vacuum cleaned several times (as in 8.1.) and wiped several times with methyl alcohol. The floor and walls were ground. The floor underwent the following treatment: moisture insulation, new concrete, and epoxide paint. The walls and ceiling received double coatings of epoxide pitch.

8.5. Mill area

The storage department was vacuum cleaned and washed with water two or three times. The Ka 4 beater department was vacuum cleaned, washed with water, and partly wiped with methyl alcohol. The room adjacent to the control room was vacuum cleaned and washed with water several times. The surroundings of the bobbin machine were vacuum cleaned and partly wet-wiped.

8.6. Electrical and other appliances in the various rooms

These were vacuum cleaned with microfilter-equipped vacuum cleaners several times and wet-wiped with methylene chloride and methyl alcohol several times.

8.7. Special equipment and supplies for these operations

The following list of items was used:
3,300 respirators
4,900 overalls of non-woven material
1,200 protective hoods
4,100 shoe covers
2,800 disposable gloves
40 ordinary overalls
45 pairs of rubber boots
35 raincoats and hats
600 glass jars
120 kg of seaming foam
4,000 kg of ABSOL absorption agent
93 VSS suits, in circulation (350 washes)
compressed air à 4 l x 200 BAR:
    1,087 units at 3.8 - 12.8
    1,195 units at 13.8 - 18.1
c. 2,000 litres of paint

8.8. Cleaning waste

All cleaning waste, a total of about 100 tons, was first packed in closed casks or boxes which were stored in the vicinity of the mill, either in bundles or in containers. The waste materials were later sent to be destroyed in England.

9. Results of the measurements at Kaukopää Mills

9.1. Concentrations of PCB measured in air samples

The first measurements for the levels of PCB in the air were carried out about five and a half hours after the explosion, at a place close to pillar B 2 in the storage department. An open cable channel leads to this site from the condenser room. The concentration of PCB in the air at this site was 16,000 µg/m³. A similar test was done in the capacitor room itself; the result was 8,000 µg/m³. (This latter figure can hardly be a correct reading.) A sample was taken in the control room of the storage department only at 4:00 PM on the day of the explosion; the finding was 77 µg/m³. By this time the level of PCB in the air close to pillar B 2 had gone down to 80 µg/m³. Further tests were carried out in the capacitor room only on 12 August 1982, and the reading was still high, 1,600 µg/m³. The electricity department was later fitted with special ventilation, for which suction fans equipped with activated carbon filters were used.

By 6 August 1982 the level of PCB was below the critical value of 10 µg/m³ in areas other than the electric power areas (i.e., the capacitor room, the 10 kV and 3 kV contactor stations, and at point B 4 on the second floor). By 18 August 1982 the concentration in the 3 kV contactor station had dropped below the critical level. On 29 September 1982 the concentrations recorded in the capacitor room and the 10 kV contactor station still exceeded the critical level. Only on 12 November 1982 was the concentration in the capacitor room below the critical level; at that time PCB levels of 4.9 - 6 µg/m³ were measured.

Mechanical ventilation had been arranged for the electric power areas by the use of temporary pipe constructions. The ventilation system was fitted with activated carbon filters; these reduced the level of PCB by 80 - 90 %.

9.2. Determination of PCB and pyrosynthetic products on surface samples

At the time of the accident it was not possible to measure the concentrations of PCB on dust samples in Finland. The Department of Chemistry of the University of Helsinki carried out tests to determine the contents of furan from 3 August 1982 onwards. Samples taken from the 10 kV contactor station on the day of the accident contained 10,000 ng/m² of furan. On 4 August 1982 samples were collected from the storage department; the lowest findings were about 10 ng/m², the highest 1,500 - 3,600 ng/m². In the electric power area, in the 3 kV contactor station, the levels detected were 508 - 630 ng/m². Tests were carried out in the capacitor room on 11 August, when the concentration on the floor varied from 11,600 to 25,900 ng/m² and on the walls from 209 to 576 ng/m².

Dust samples were also sent for analysis to Sweden, to Prof. Rabbe of the Department of Organic Chemistry of the University of Umeå. These analyses showed concentrations of furans at varying degrees of chlorination, biphenyls and concentrations of tetra- and pentachlordibenzodioxins about tenfold less than the levels of furans.

After the explosion at Kaukopää, the Institute of Occupational Health in Helsinki began to develop methods to determine the levels of PCB and its pyrosynthetics in dust and soot samples. However, such analyses were done on dust samples taken on 24 August only, by which time a fair amount of cleaning had already taken place. Analysis of soot samples taken in the capacitor room after the explosion showed that some dibenzofurans at various degrees of chlorination had been created in the explosion. Sample No. 1 contained about 20 µg/g of tetrachloride benzofurans, and isomers 2, 3, 7, 8 2 µg/g. .Soot sample No. 2 contained about 90 µg/g tetrachloride benzofurans, and 6,5 µg/g isomers 2, 3, 7, 8. . Traces of polychlorinated pyrenes and polychlorinated biphenyls were detected in the soot samples. No dioxin was found in the samples; in this respect the results of the analyses carried out by the Institute of Occupational Health differed from those reported by Prof. Rabbe.

9.3. Concentrations in mill products

The concentrations of PCB in mill products were also measured. The tests proved that the content of PCB in paperboards did not exceed the critical value. The levels of PCB in clean washing water and used washing water were also recorded.

II. EXAMINATIONS OF PERSONS EXPOSED TO PCB AND ITS PYROSYNTHETICS

1. Composition of the group and data on their symptoms

This report deals with the examinations of the people who comprise group A, i.e., those with the heaviest exposure. The group contains the storage department attendants and supervisors on duty at the time of the accident, members of the fire brigade, and labor protection personnel, a total of 16 persons thought on the basis of of the interviews to have been the most heavily exposed. The group contains only men.

Of the acute symptoms, 63 % had headache, 63 % experienced smarting of the eyes, and 50 % reported irritation of the throat and respiratory tract. Nausea, dizziness, increased sweating, and irritation of the skin were markedly less common. The acute symptoms of all the exposed persons disappeared within 24 to 48 hours.

Table 4 presents the results of seven months of follow-up with regard to diagnosed diseases or changes in health status among the exposed group. The more unusual conditions observed include ridges in the nails of two persons and reduced immunity to infections among two persons. The acne of an exposed person worsened visibly and required a dermatologist's treatment. Nine had lesser skin symptoms such as flaking of the face skin, redness, itching, and pimples. One of them also had increased pigmentation of the neck skin. Immediately after the explosion one person had an allergic-type, itchy rash on the upper part of his body that lasted for five days and disappeared by itself; this does not fit the picture of chlorine-induced acne. There was not one case of chlorine-induced acne. The association of these mild skin symptoms with PCB is questionable. The exposed were requested to check for any possible skin changes, and the reporting of milder changes can merely be the result of close, active observation.

2. Measurements of PCB levels

2.1. Blood and its subfractions

Some of the blood samples taken on the day of the explosion were sent for analysis to Sweden, to Prof. Rabbe of the Department of Organic Chemistry of the University of Umeå. On 16 August 1982 we were informed by telephone that no PCDF could be detected or that the concentrations were below the detection limit of 0.15 ppt = 0.15 pg/g. No dioxins were found, either.

2.2. Adipose tissue

Biopsies of adipose tissue have been taken from some of the most heavily exposed. These samples also await analysis by the Institute of Occupational Health.

2.3. Urine

Urine samples have been collected from the group with the heaviest exposure. The samples are now being stored at the Institute of Occupational Health in the event of future analyses.

3. Measurements to reveal effects

3.1. Hematologic measurements

Samples have been taken to analyze the levels of enzyme activities in the red blood cells. These determinations have not yet been done.

Typical blood tests (for La, Hb, Hkr, MCHC, and leuk) and differential counts of the leukocytes were followed for a period of six months. Patient No. 3 has continually had elevated La levels that range between 26 and 37; the reason is rheumatic arthritis. Patient No. 6 has also had moderately elevated La levels (between 12 and 22), with no clear reason for the elevation. Other have had mild fluctuations above the La level considered normal (i.e., 10), but these increases do not appear to be a result of exposure.

For the differential counts of the leukocytes, an unusual finding was that the proportion of lymphocytes exceeded 40 % in 43 of the 86 analyzed samples, i.e., in half the samples. Fifteen of the sixteen studied had at least one elevated level of lymphocytes. A similar finding of elevated lymphocyte levels has been reported in Japan for patients with Yusho disease. No clear anemic trend was observed. A slightly increased percentual distribution of eosinophiles was found in 18 of the 86 samples; these increases are probably not connected with the exposure.

The blood samples were analyzed at the company health service center in Vuoksenniska.

3.2. Biochemical analyses

Liver functions were followed by analyses of enzymes (Gamma-Gt, AFOS, ALAT, and ASAT) over a period of six months. The determinations were made by the Institute of Occupational Health in Helsinki. The reference values were: 40 U/l for Gamma-Gt; 35 U/l for S-ASAT and S-ALAT; and 60 - 270 U/l for AFOS. The following values in excess of the reference values were found: Gamma-GT, 35 of 95 values; ASAT, 7 of 95 values; ALAT, 22 of 95 values; and AFOS, 10 of 95 values. Pathological enzyme levels were detected at least once for twelve of the exposed, and four persons had completely normal enzyme levels at each examination. Figures 1 - 4 show the changes in enzymes activities for the individuals as a function of time.

As seen in the figure, about two weeks after the explosion, there was a slighlty rising trend in the activities of Gamma-Gt, ASAT, and ALAT enzymes at group level. Nô similar trend was detected for the entire group at later stages; rather, variations probably had other causes. In some cases alcohol may have been a factor confounding the initial group trend of increased liver enzyme activities. An ASAT/ALAT ratio greater than 1 is highly indicative of increased liver enzyme activity caused by alcohol. Of the eleven in the group for whom samples were analyzed for enzyme activities after two weeks of follow-up, seven had an ASAT/ALAT ratio under 1 and four had a ratio over 1. The latter had consumed slight amounts of alcohol a couple of days before the samples were collected; the liver enzyme activities of two of them did not exceed the normal limits. Thus the slight increase in liver enzyme activities detected at group level can at least in part be interpreted as an effect of exposure to PCB and its pyrosynthetics. No essential change was noted in the levels of AFOS.

Serum proteins and their electrophoreisis were also followed. The reference values for proteins were 65 - 80 g/l. The determinations were done by United (Yhtyneet) Laboratories. Protein levels above the reference values were found in 20 of 98 samples. The increases were only slight and most likely due to slight dehydration caused by fasting. Ten of 98 electrophoreisic values deviated from the reference values. No specific changes were discovered. Hypoalbuminemia was not detected at all. Thus the levels of exposure in question did not bring about noticeable effects in serum proteins.

To follow the fatty metabolism the levels of cholesterol, trigyl-cerides, and the electrophoreisis of lipoproteins were measured from the serum. A clear increasing tendency was noted for triglicerides in the serum. For many of the exposed, the peak was reached a week after exposure; the peak was reached two weeks after exposure for the remainder. Four weeks after exposure the baseline values were attained again. The baseline value for the ten exposed persons from whom all four samples were collected was 1.39 mmol/l. For this group the mean peak level of triglycerides was 2.14 mmol/l; their mean level at four weeks was 1.13 mmol/l. At group level a 54 % increase was found (Figure 5).

A clear decreasing tendency in the level of cholesterol was observed for the same group. The lowest levels were attained, again, at either one or two weeks after exposure. The mean baseline value was 6.25 mmol/l, the mean of the lowest values was 4.62 mmol/l, and four weeks after exposure it was 5.69 mmol/l. Compared with its baseline value, a mean drop of 26 % occurred in the level of cholesterol (Figure 6).

The electrophoreisis of the lipoproteins was followed. Electro-phoreisic measurements of the samples collected the first few days after the explosion could not be done because the samples had been stored in deep freeze. The first electrophoreisic analyses were carried out for the samples taken two weeks after the explosion, at a time when the peak values for trigylcerides had already passed. In electrophoreisis triglicerides are transported in pre-β-fractions.

Increased levels of pre-β-fractions were detected as follows:

2 weeks	3/12	18-19 weeks	4/16
4-5 weeks	1/15	26 weeks	5/16
12 weeks	3/16		

Otherwise the electrophoreisis of the lipoproteins was normal. The results for these samples do not allow any conclusions to be drawn. Electrophoreisic analyses at earlier stages after exposure would probably have provided more information.

At least some of the changes detected in the fatty metabolism were an effect of the exposure. Alcohol may be a confounding factor that accounts for some of the changes.

3.3 Cytogenic determinations

It is known that chlorinated dibenzodioxins and dibenzofurans are mutagenic. Therefore chromosomal aberrations and sister chromatid exchanges were studied in the lymphocytes of ten persons in the group with the heaviest exposure. A reference group was composed that contained a group of workers with similar smoking habits from the Tainionkoski factories. Chromosomal aberrations reflect damage that can lead to the rise of somatic chromosomal mutations. The analysis of sister chromatid exchanges reveals changes in the organization of the chromosomes within the DNA strands. Many substances known to be mutagenic cause increased frequencies of sister chromatid exchanges in cell cultures. The results should be examined at the group level only, as the meaning of intraindividual variations is not yet clear.

Compared with the reference group, the exposed did not have statistically significantly more chromosomal aberrations. Smokers in these groups did not have more chromosomal aberrations than nonsmokers. The frequencies of sister chromatid exchanges among the exposed were not higher than the frequencies among the referents. The frequencies were somewhat higher among the smokers, but the difference from the nonsmokers was not statistically significant. The findings indicate that the exposure to mutagenic agents was not heavy enough to induce an increase in chromosomal damage. Appendix 8 presents the data in detail.

3.4. Immunologic tests

3.4.1. Immunoglobins and complements

The levels of immunoelectrophoreisis and complements [C_4, C_3, and CI-INH (Hane method)] were followed in the exposed. The determinations were made at the Clinical Immunological Laboratories. The samples were taken one month (ten persons) and six months (sixteen persons) after exposure. The immunoelectrophoreisic values were normal except for one sample taken six months after exposure; in this sample a polyclonal increase was detected in IGM. Five of the samples contained amounts of complements that deviated from the normal values. The deviations were usually values above the normal range. No sign of deficiencies was detected in the complements. It can thus be concluded that the exposure did not alter either the complement system or the immunoglobins.

3.4.2. Cell immunologic tests

These were done at the Transplantation Laboratory of the University of Helsinki, by Drs. E. Taskinen (D. Med. Sc.) and R. Renkonen (D. Med. Sc.). The mononuclear cells were isolated by the method of Ficoll-Isopaque (FIP). In addition to overall and differential cell counts, the staphylococcus technique and monoclonal antibodies were used to study the following subclasses of T-lymphocytes: T cells (OKT-11); T-helper cells (OKT-4); and T-suppressor cells (OKT-8). Surface and/or intracytoplasmic immunoglobin-positive tests were used to study B cells. Furthermore, the following mitogens were used for stimulation tests of the lymphocyt s:

phytohemagglutin (PHA); concanavall A (ConA); and pokeweed mitogen (PWM).

Samples were taken from ten persons five weeks after the explosion. Since the results contained many pathologic findings, control samples were taken from six persons twelve weeks after the explosion and, again, from five persons six months after the explosion.

Results

The FIP isolation method yielded a range in the number of cells from 9×10^6 to 58×10^6; the means were 33.8×10^6 five weeks after the explosion and 24×10^6 twelve weeks after the explosion. The differential cell count revealed that three of the ten samples had more than 10 % large granular lymphocytes (LGL cells).

In all of the samples studied (8/8), the level of T cells was low (< 35 %) five weeks after the explosion. Four of the samples taken seven weeks later had normal T cell levels. The ratio of T-helper cells to T-suppressor cells was low (< 1.4) in six of seven samples taken five weeks after the explosion. The ratio was still low in two of the samples taken six months after the explosion.

No decisive conclusions could be made with respect to the percentages of B cells.

The results of the stimulation tests varied according to the mitogen and the time of the test (see the table below).

TABLE. Frequencies of reduced mitogenic responses of the mononuclear cells in the blood (< 66 % of normal control values) among persons exposed to PCB.

Duration after the explosion	PHA	ConA	PWM
five weeks	4/10	3/10	5/9
twelve weeks	1/6	5/6	2/4
six months	0/5	1/5	0/5

Thus the responses that reflect the functions of T cells were reduced for nearly half of the exposed, and, except for PHA, the reduction was still observed twelve weeks after the exposure. Only one of the exposed had reduced ConA responses six months after the explosion.

Summary

Reduced percentages of T cells, a reduced ratio of T-helper/T-suppressor cells, and reduced responses of T cell functions in stimulation tests were found in the blood samples taken from persons exposed to PCB five weeks after exposure. Seven weeks later these changes had levelled off to some extent, and the percentages of T cells had become normal. Six months after exposure only two of the ten had a reduced ratio of T-helper/T-suppressor cells.The results of the stimulation tests indicated that T cell functions had normalized. The findings suggest that some temporary damage occurred in the number and functions of T cells.

3.5. Neurophysiological examinations

The nerve conduction velocities were measured for the first time on 1 October 1982 and for the second time on 9 February 1983. The motor conduction velocities (MCV) were measured from the median, the ulnar, and the peroneal nerves. The distal sensory conduction velocities (dSCV) were measured from the median and the ulnar nerves, and the sensory conduction velocities (SCV) were measured from the sural nerve in the area of the calf. The table below presents the group means and standard deviations (SD).

Nerve	Under 40 years old		Over 40 years old	
	Mean	SD	Mean	SD
Median, MCV, m/s	57.0	0.8	58.2	4.8
Median, dSCV, m/s	47.5	3.1	45.8	3.2
Ulnar, MCV, m/s	59.6	4.0	57.7	5.5
Ulnar, dSCV, m/s	43.8	4.8	41.0	4.8
Peroneal, MCV, m/s	47.2	5.2	50.9	6.1
Sural, SCV, m/s	36.0	3.3	38.2	4.0

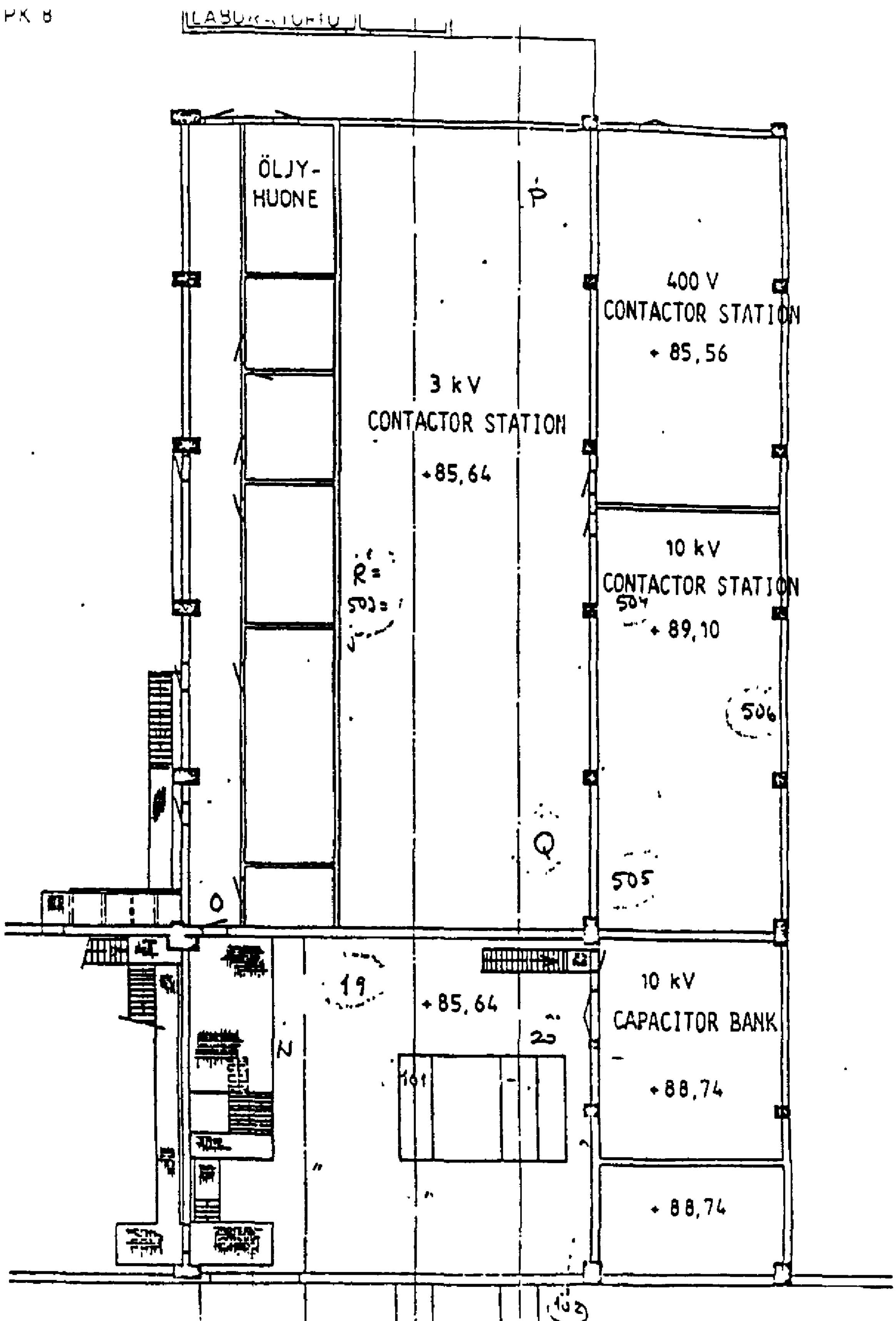
The means were somewhat lower than the mean conduction velocities of referents. At group level significantly slower sensory conduction velocities were measured for the ulnar and sural nerves, and significantly slower motor conduction velocities were measured for the peroneal nerve. These findings are indicative of damage to nerve axons.

The measurments were repeated about six months after the explosion for the 16 exposed. The following table shows the results of these latter measurements.

Nerve	Under 40 years old		Over 40 years old	
	Mean	SD	Mean	SD
Median, MCV, m/s	60.1	5.3	57.	4.9
Median, dSCV, m/s	54.2	9.4	50.0	4.9
Ulnar, MCV, m/s	58.9	3.4	59.7	4.8
Ulnar, dSCV, m/s	45.9	3.0	44.3	4.2
Peroneal, MCV, m/s	-51.0	6.1	54.5	5.8
Sural, SCV, m/s	39.3	2.6	40.1	3.3

The means for the latter measurements were higher than those for the previous measurements and were now on the same level with the means for referents. The mean amplitudes of the sénsory nerve potentials were also higher than for the previous measurments. Furthermore, all of the conduction velocity measurements fell in the normal range of variation. The measurements were taken by Docent Seppalăinen from the Institute of Occupational Health, in in whose opinion the findings indicated temporary, mild neuropathy of the sansory distal nerves in particular.

1. PK 8



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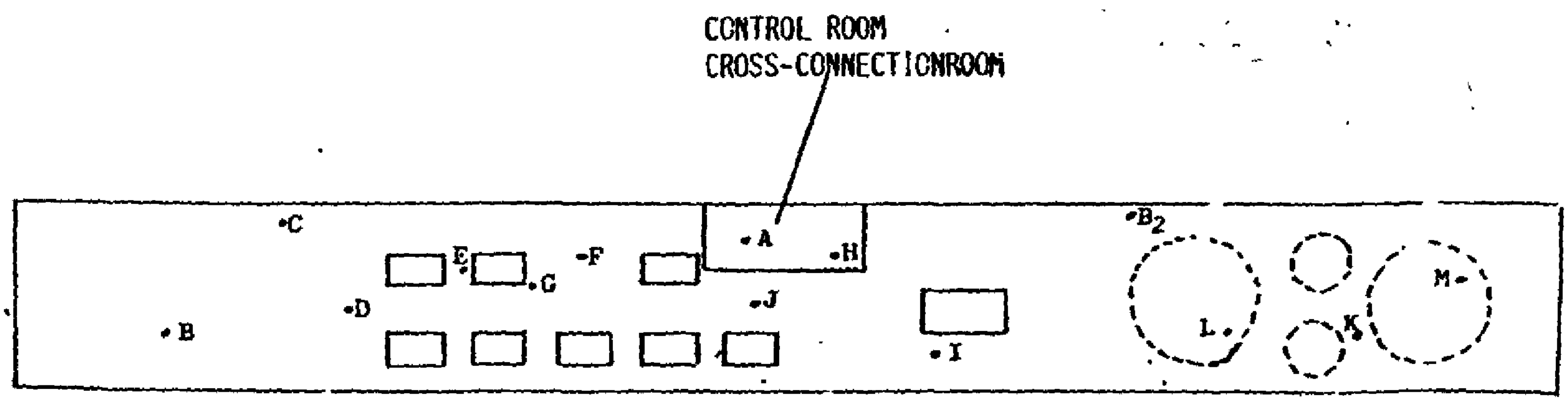

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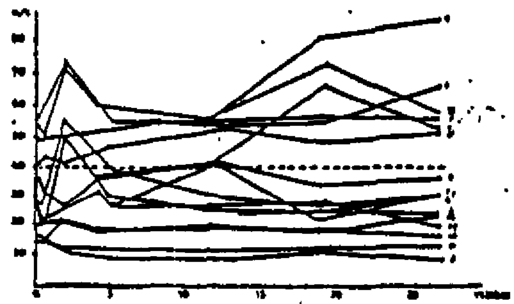
MONS 214000

TABLE 1. Diagnosed diseases and findings during the seven-month follow-up (3 August 1982-3 March 1983)

Patient's number	Diseases, signs, symptoms
1	Barber's itch. Some pimples on the face. Aching joints.
2	Acne worsened. Repeated sinus infections (treated four times with antibiotics). One respiratory infection. Ridges in the nails.
3	One respiratory infection. Gastroenteritis once.
4	Redness in the nasal area two weeks after exposure. One respiratory infection. Ridges in the nails. Erysipelas.
5	One respiratory infection.
6	One respiratory infection. Flaking, itching rash on the face.
7	Itching rash on the arms two months after exposure.
8	One respiratory infection. Pimples on the face, temporarily.
9	Nonspecific urethritis.
10	---
11	One respiratory infection. Slightly increased pigmentation of the skin on the neck.
12	Pharyngitis once. One respiratory infection. One attack of gout.
13	Four or five aphthae in the mouth. Dry skin.
14	---
15	Itching, allergic-type rash on the upper body between 4 August and 9 August 1982.
16	One respiratory infection. Cold sores twice.

Figures 1-6



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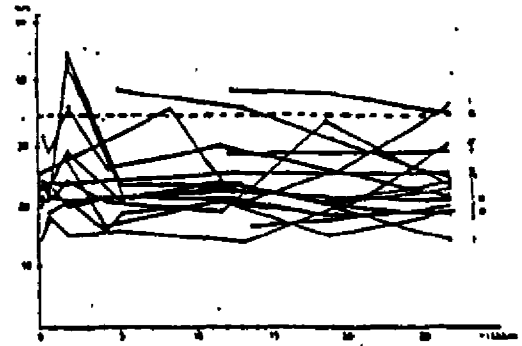

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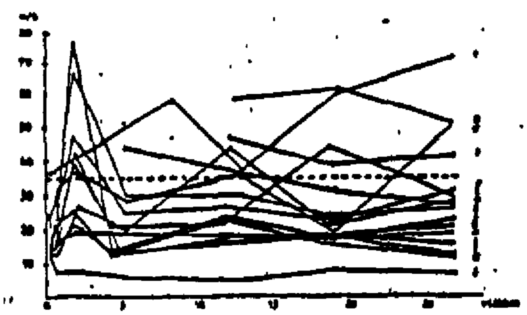

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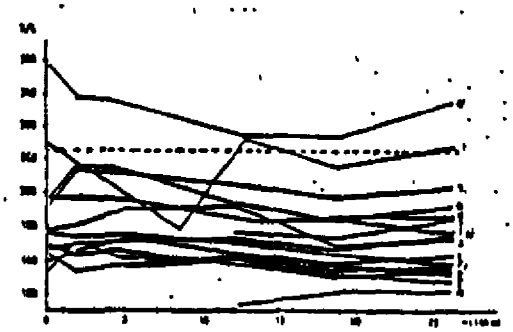

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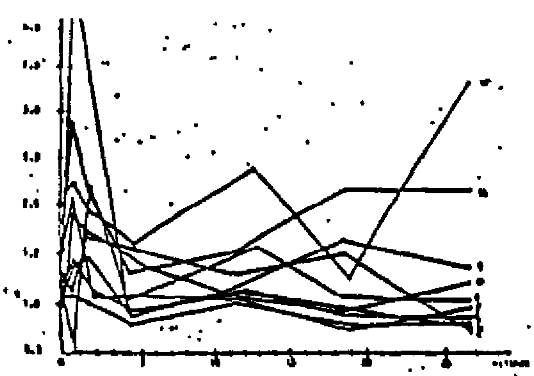

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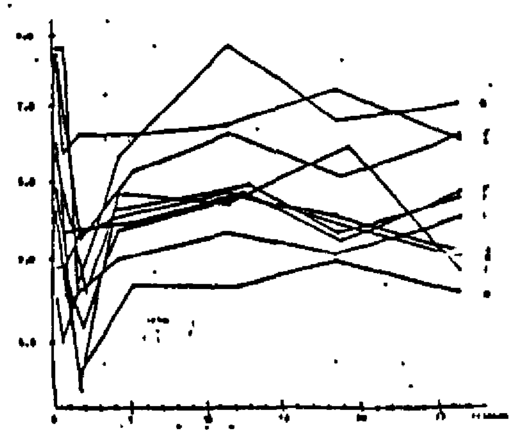

n:o 6 S-Cholesterols

MONS 214002

TABLE 3 THE RELATION BETWEEN PCB-LEVELS AND OTHER FINDINGS

	P C B		GammaGT ↑	AFOS ↑	ALAT ↑	ASAT ↑	Kolest ↓	Trigly ↑	Cell. Immun. Test ↓	Nerve Conduction Velocity ↓
	3.8.	6.8.								
1	3,5	0	-	-	+	-	-	-	0	+
2	4,1	20,3	-	-	+	+	+	+	-	+
3	0	20,6	-	-	-	-	-	+	-	-
4	11,2	25,5	+	+	+	+	+	+	-	-
5	5,2	19,0	+	-	+	+(-)	+	-	+	-
6	19,9	31,9	+	+	+	+	+	+	+	-
7	48,3	13,4	+-	+	-	-	-	+	+	-
8	33,4	11,2	-	-	+	+-	+	-	+	+
9	0	0	0	0	0	0	0	+?	0	+
10	10,0	7,7	-	+-	-	-	+	+	0	-
11	0	0	0	0	0	0	0	0	0	+
12	0	0	0	0	0	0	0	0	0	-
13	36,9	7,1	+	+	+	+H	-	+	+	+
14	6,9	0	0	0	0	0	+	+	0	-
15	4,5	5,0	-	-	+	-	+-	-	-	-
16	19,8	6,3	-	-	+H	-	+	+	+	-