EXPERIMENTAL STUDIES ON THE EFFECTS OF MT. SAKURAJIMA VOLCANIC ASHES ON THE RESPIRATORY ORGANS

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Since 1978, the authors have collected ashes from Sakurajima volcanic eruption in Kagoshima City, and the ashes were administered to rats and rabbits through different routes and forms injecting into the trachea in order to see the effect of ashes on the respiratory organs.

The authors experimentally and histopathologically demonstrated bronchitis, pulmonary emphysema, atelectasis lung, degeneration of blood vessel, dust nodes and induction of pneumoconiosis due to dust fibrosis in the study of the effect of volcanic ashes on the respiratory organs.

INTRODUCTION

Mt. Sakurajima, an active volcano located on the east coast of Kagoshima Bay, has often erupted and caused much damage to the daily life and health of the people, to livestock and to agricultural production. Among these hazards, the health effects cannot be ignored.

Wakisaka et al.1-3) made epidemiological studies on acute and chronic health effects of volcanic ash from Mt. Sakurajima and concluded that in the vicinity of the volcano or in areas with high ashfall, 1) asthma was more prevalent among school children, and 2) deaths from bronchitis and emphysema were significantly higher in number than expected deaths. Studies on general pneumoconioses and titan pneumoconiosis (titanosis) by Shirakawa et al.4-13) describe in greater detail the effects of volcanic ash on the respiratory organs. In the present study, the authors made animal experiments on effects on the respiratory organ of Sakurajima ash.

MATERIALS AND METHODS

1. Physical and chemical analysis of the volcanic ash

Volcanic ash which had settled on the roof of the building of the Kagoshima Prefectural Institute of Hygiene was collected from December 1978 to March 1979, with the cooperation of the Institute. The components of the volcanic ash were analyzed at the Shimadzu Scientific Analytic Center by the use of the Shimadzu Inductively Coupled Plasma Quantometer (ICPQ) as shown in Table 1. The ash was fractionated into the following 4 classes; 1) natural ash, 2) ash under 200 mesh, 3) that under 270 mesh and 4) that under 325 mesh. The same samples (Lot Nos. 1 and 2) were analyzed twice and the mean values of the two were taken. X-ray diffraction analysis revealed that volcanic ash, so-called black ash, contained 40% plagioclase, 20% hypersthenite, and 10% quartz and amorphous glass.
Twenty-four Wistar strain male rats (R. No. 1 to No. 24) with average 148.6 g of body weight were used for the intra-tracheal infusion experiment, as described below. For the blank test, 1 ml of 10,000 unit penicillin-added physiological saline was infused into 4 male rats of the same strain (R. No. 25 to No. 28). Twelve male rats (R. No. 29 to No. 40) of the same strain were used without any treatment as controls.

The first group of 8 rats (R. No. 1 to No. 8) was treated with 1 ml of the 50 mg/ml suspension on the first day and retreated with 1 ml of the 250 mg/ml suspension on the 3rd day. Symptoms are shown in Table 2. They survived for 7 to 280 days. Two of them (R. No. 7 and No. 2) died on the 7th and 35th days respectively and the remaining 6 survived until the time of autopsy.

A second group of 8 rats (R. No. 9 to No. 16) was treated with 1 ml of the 250 mg/ml suspension on the 1st and 3rd days. One of them died immediately after the infusion and 4 died on the 4th day. The remaining 3 survived for 278 days until the time of autopsy.

A third group of 8 rats was treated with a single dose of 1 ml of 500 mg/ml suspension. Two of them (R. No. 22 and No. 17) survived for 7 days and 37 days and the other 6 for 354 days until the time of autopsy.

Of the 4 rats used as a blank test, 2 (R. No. 28 and No. 25) survived for 10 days and 25 days and the other 2 for 252 and 385 days until the time of autopsy. Microscopic pictures of the ash are shown in Fig. 2-a (× 25) and Fig. 2-b (× 130) for ash under 270 mesh, Fig. 2-c (× 25) and Fig. 2-d (× 130) under 325 mesh, and Fig. 2-e (× 250) for the mass of the fine particles. Results of electron microscopic examinations by the Electron Prove Microanalyzer, SEM, are shown in Figs. 3-a(Si), 3-b(Fe), 3-c(Ca), 3-d(Mg) and 3-e(Ti). The determination of the diameter and the distribution of the particle size for ash under 270 mesh and 325 mesh are shown in Fig. 4. Particles smaller than 10 μm in diameter were found in 93.25% of ash under 270 mesh (3.74 μm in average) and those smaller than 10 μm in 99.05% of ash under 325 mesh (3.58 μm in average).

2. Animal experiments of intratracheal infusion of ash suspension

The outline of the experiment is shown in Table 2. Volcanic ash under 325 mesh was sterilized by dry heat, and suspended in 1 ml of 10,000 unit penicillin-added physiological saline, so that the suspension would contain the ash of 50 mg/ml, 250 mg/ml or 500 mg/ml.

3. Animal experiments of ash inhalation

For the inhalation experiment, ash under 270 mesh was produced by a dust formation and inhalation apparatus developed by one of the authors, Shirakawa. After being dried in a desiccator the ash was inhaled by 10 Wistar strain male rats (R. No. 41 to No. 50) with average 263.3 g of body weight and 8 male rabbits (K. No. 1 to No. 8) with an average weight of 2,010 g.

The outline of the experiment is shown in Table 3. The inhalation was made by both sets of animals 4 hours a day for 112 days from August 2, 1979 to November 22, 1979, except for R. No. 43 which inhaled the ash samples for 62 days. Rats survived for 420 to 961 days and rabbits for 362 to 730 days until the time of autopsy. The dust levels inhaled were 8.4 to 50.4 mg/m³ (29.4 mg/m³ on average) for rats and 7.3 to 28.8 mg/m³...
(18.1 mg/m³ on average) for rabbits, when measured by a digital dust meter p-5 type of Shibata Scientific Co. Ltd. No particular symptoms developed in the experimental animals during the inhalation period.

For the purpose of histopathological examinations, animals were autopsied and their tissues were fixed in 10% formaline solution, embedded in paraffin before being stained through three dyes; hematoxylin-eosin, Van Gieson and Azan-Mallory.

Chest X-rays of the experimental rabbits (K. No. 1 to No. 8) were taken at 31-39 kV 1.5 mA with a 0.3 second exposure using Softex CBM of Softex KK Apparatus. X-ray pictures of K. No. 4 and
Table 3. Outline of inhalation tests with Mt. Sakurajima ash for rats and rabbits.

<table>
<thead>
<tr>
<th>No. of animals</th>
<th>Dust concentration</th>
<th>Duration of inhalation</th>
<th>Date of death or autopsy</th>
<th>Days of survival</th>
</tr>
</thead>
<tbody>
<tr>
<td>R No. 41</td>
<td>8.4—50.4 mg/m³</td>
<td>112 days</td>
<td>24/IX '80</td>
<td>420 days</td>
</tr>
<tr>
<td>42</td>
<td>(average 29.4)</td>
<td>112</td>
<td>?</td>
<td></td>
</tr>
<tr>
<td>43</td>
<td>62</td>
<td>2/IX '79</td>
<td>62</td>
<td></td>
</tr>
<tr>
<td>44</td>
<td>112</td>
<td>13/XI '80</td>
<td>470</td>
<td></td>
</tr>
<tr>
<td>45</td>
<td>112</td>
<td>?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>46</td>
<td>112</td>
<td>23/II '82</td>
<td>961</td>
<td></td>
</tr>
<tr>
<td>47</td>
<td>112</td>
<td>?</td>
<td></td>
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<tr>
<td>48</td>
<td>112</td>
<td>27/III '81</td>
<td>605</td>
<td></td>
</tr>
<tr>
<td>49</td>
<td>112</td>
<td>30/XII '80</td>
<td>517</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>112</td>
<td>?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>K No. 1</td>
<td>7.3—28.8 mg/m³</td>
<td>112 days</td>
<td>28/VII '80</td>
<td>362</td>
</tr>
<tr>
<td>2</td>
<td>(average 18.1)</td>
<td>112</td>
<td>30/XII '80</td>
<td>517</td>
</tr>
<tr>
<td>3</td>
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<td>4</td>
<td>112</td>
<td>12/VI '81</td>
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<td>5</td>
<td>112</td>
<td>17/IX '80</td>
<td>413</td>
<td></td>
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<td>7</td>
<td>112</td>
<td>21/I '80</td>
<td>530</td>
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<tr>
<td>8</td>
<td>112</td>
<td>24/IX '80</td>
<td>420</td>
<td></td>
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<tr>
<td>K No. 9</td>
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<tr>
<td>10</td>
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</table>

No. 6 are shown in Figs. 6-a and 6-b.

RESULTS

1. Animal experiments of intratracheal infusion of ash suspension

The macroscopic findings at autopsy were general hyperemia in the whole lungs, severe edema and precipitation of the dust on the surface of the lungs. Histological findings are shown in Figs. 7-a to 7-e. Typically, the following characteristics were observed: infiltration of lymphocytes and plasmocytes around the bronchus, intracellular hemorrhage, remarkably localized presence of macrophages, proliferation of the connective tissues around the blood vessels and bronchus, infiltration of polynuclear leukocytes mainly around the bronchus, hemorrhage and edema, accumulation of the dust extensively distributed in the pulmonary parenchyma and hilar lymphnodes, abrasion of the epithelium of the bronchus, a mild degree of bronchitis, localized hemorrhage in the laveolar wall, inflammation within the alveolar septum, chronic bronchitis, hemorrhage and congestion of the pulmonary parenchyma, increase in fibrous components around the bronchus, and proliferation of the collagen fibers.

2. Animal experiments of ash inhalation

The chest X-ray pictures of rabbits K.No. 4 and No. 6 as shown in Figs. 6-a and 6-b revealed a coarse profusion of nodular shadows over the whole pulmonary fields.

Macroscopic examinations of rats and rabbits at autopsy showed congestion and edema in both lobes of the lungs in some cases, but there was neither hydrothorax nor pleural adhesion.

Histopathological findings for rats are shown in Figs. 8-a to 8-h with detailed explanations. The findings can be summarized as follows; congestion and hemorrhage in the pulmonary alveoli, diffuse accumulation of ash in the alveoli, remarkable mass foci of the macrophage containing dust, chronic bronchitis, remarkable proliferation of collagen fibers, remarkable infiltration of lymphocytes into the pulmonary alveoli, inflammation of the alveolar septum and remarkable proliferation of polynuclear giant cells.

The histopathological pictures of rabbits are shown in Figs. 9-a to 9-f, with detailed explanations. The findings were; congestion and hemorrhage in the pulmonary alveoli, remarkable edema and hydrops, atelectasis, remarkable mass foci of macrophage, remarkable accumulation of dust in the pulmonary alveoli and hilar lymph nodes,
proliferation of the connective tissues around the blood vessels and bronchus, remarkable proliferation of collagen fibers, chronic bronchitis and broncho-pneumonia.

When the volcanic ash was analyzed on an electron probe microanalyzer using the stained pathological specimens, infiltration of Si, Fe, Ca, Mg and Ti into the pulmonary parenchyma was conspicuous, as shown in Figs. 10-a to 10-e. The pathological findings and X-rays suggested a high concentration of SiO₂ in the ash. The measurement showed a range of 52.52 to 61.92% of SiO₂ (average 58.08%).

Summarizing these experimental results, all tracheally-infused animals showed a decrease in body weight for several days after the infusion. Some animals died, but most of them recovered body weight and grew normally thenceforth. Pathological examination revealed that the infused ash went deeply into the lungs causing congestion, hemorrhage and edema of the lung, and that the ash may induce chronic bronchitis and fibrosis resulting from a reaction to foreign matters deposited in the pulmonary parenchyma and hilar lymph nodes.

In the rabbits that inhaled dust, the chest X-rays showed nodular shadows in the whole lung fields. Histopathological pictures showed that the volcanic ash reached the deep part of the lung parenchyma and deposited on the surface of the lungs and in the hilar lymph nodes. Chronic bronchitis, bronchopneumonia and fibrotic proliferation were distinctly demonstrated.

As the volcanic ash used in the experiment contained much SiO₂ in a range of 52.52–61.92% (average 58.0%), the ash may cause pulmonary fibrosis after a long time of exposure.

**DISCUSSION AND SUMMARY**

There have been many papers on the effects of volcanic ash, including that of Mt. Sakurajima. Wilcox made extensive studies on effects of volcanic ashfall, with special reference to Alaska, in relation to public health and safety, buildings, utilities, transportation, communication, agriculture and related activities. The health effects of Mt. Sakurajima’s eruptions have been reported by Nishii, Miura and Yano. Wakisaka et al. and Imayoshi et al. gave results of autopsies of victims of the explosion of Mt. St. Helens.

Wilcox mentioned that the odors of acid gases are detectable after such eruptions but usually only temporarily as they soon become diluted with other gases. He considered that all these gases may be harmful only if inhaled insufficient concentration for sufficient length of time.

Horton et al. made observations of air pollution on people, animals, vegetations and other materials on the occasion of the eruption of Irazú Volcano, Costa Rica, stating that 1,248 g of ash/m³ settled on the city in the 1963 eruption. They emphasized the necessity of information on the size distribution, concentration and composition of the ash to assess possible respiratory hazards associated with ashfall.

Murata gave the following analysis of ash samples collected from Irazú Volcano: 55.5% silica (SiO₂), 17.1% aluminum oxide (Al₂O₃), 2.4% iron oxide (FeO₃) and other minor constituents. In regard to the difference in ash components among volcanos, according to MacDonald, 7 volcanos in the world proved to have nearly the same components.

Mitchel observed the size of volcanic ash particles and observed that particles up to 3 μm in diameter are readily retained in the alveoli and those of less than 5 μm are of great physiological significance.

Fruchter et al. reported on chemical, physical, mineralogical and biological properties of Mt. St. Helens ash in the 1980 eruptions. The composition of ash is shown in Table 4. The ash samples were acidic with particle size data of bimodal distribution. All samples contained comparable amounts of particles less than 3.5 μm in diameter (respirable fraction). Mineralogically, the samples ranged from almost totally glassy to almost totally crystalline. All but one of the samples contained free crystalline silica from less than 1% to 3%. In vitro biological tests showed the ash to be nontoxic to alveolar macrophages, which are an important part of the lungs' natural clearance mechanism. Since in vitro toxicity and fibrogenicity of minerals appear to be correlated, it seems unlikely that the ash is highly fibrogenic. On the other hand, their analysis of the ash showed that the major component was silica, which constituted 60–65% of the mineral content. In vitro tests with ash samples demonstrated no notable cytotoxicity toward rabbit macrophages in a test concerning fibrogenicity of minerals.
Fig. 1. Mt. Sakurajima viewed from the west side of Kagoshima City, April 17, 1982.

Fig. 2. Microscopic finding of Mt. Sakurajima ashes. a-d, particles; e, a cluster of particles.

Fig. 3. Mt. Sakurajima ash photographed by electron probe microanalyzer. a, Si; b, Fe; c, Ca; d, Mg; e, Ti.
Fig. 4. Particle size distribution of Mt. Sakurajima ash collected at the roof of the building of Kagoshima Prefectural Institute of Hygiene, July 15, 1977.
Fig. 5. The instrument of dust inhalation for rats and rabbits.

Fig. 6. Radiographs of rabbits experimentally exposed to Mt. Sakurajima ash showing nodular shadows of the lungs of rabbits K.No.4 (a) and K.No. 6 (b).
Fig. 7-a. Rat No. 1. Histological findings (hematoxylin-eosin) of the lung, 174 days after intra-tracheally injection of the ash of 50 mg on the 1st day, added by 250 mg on the 3rd day. Marked bronchitis is shown with many dust cells and monocytes filled in the alveoli. A small amount of polynuclear leukocytes and erythrocytes are present with dust deposition in the alveolar wall. The alveoli are emphysematous in the subpleural region with epithelial cells in some part.

Fig. 7-b. Rat No. 9. Histological finding (hematoxylin-eosin) of the lung, 278 days after intra-tracheally injection of the ashes of 500 mg on the 1st day, added by the same dose on the 3rd day. Many dust cells are found with monocytes and leukocytes. Exudate is considerably absorbed or aggregated, as stained lightly with eosin dye.

Fig. 7-c. Rat No. 17. Histological findings (Azan-Mallory) of the lung, 37 days after intra-tracheally injection of a single dose of 500 mg volcanic ash. The alveoli are congested, including hemorrhage in some part. Dust cells and giant cells containing foreign bodies are recognized, with vacuoles in some cells. Marked deposition of collagen is seen on some alveolar walls. Fiber cells and monocytes are also found in the alveolar tissues.

Fig. 7-d. Rat No. 18. Histological findings (Van Gieson) of the lung, 176 days after intra-tracheal injection of a single dose of 500 mg of the ash. Much exudate is seen in the alveoli around the veins with dust cells. Radial extension of fibers is also found in various sizes from the walls of the veins.

Fig. 8-a. R. No. 41. Histological findings (hematoxylin and eosin) of the lung, 420 days after the 112-day inhalation of the volcanic ash. Dust cells in the alveoli are enclosed. Nuclei, and the cell membrane are not clear. Dust particles are shown as black, gray, or bright dotted small matters. Infiltration of fibers and small round cells is shown. Thickened collagenous substance is deposited on the surrounding tissues.

Fig. 8-b. R. No. 44. Azan-Mallory-stained lung, 470 days after the 112-day inhalation of the volcanic ash. Infiltration of small round cells around the bronchi is shown. Scattered dust cells are shown in the alveoli at the peripheral part. Fine fibrous collagen is seen at the site of deposition of the dust cells.

Fig. 8-c. R. No. 44. Van Gieson-stained lung shows dust cells densely gathering around the blood vessels. Remarkable infiltration of small round cells is found around the dust cells. Increase in the fine collagen fibers is shown in the infiltrated part of the small round cells within the dust cells and in the wall of alveoli. A slight vacuole is seen in the dust cells. Network formation of collagen fiber is shown around the dust cells.

Fig. 8-d. R. No. 46. Hematoxylin-eosin-stained lung, 961 days after the 112-day inhalation of the volcanic ash. Dust cells densely gather in alveoli to form nodules. Dust cells are slightly seen in hydatiform centering in the crystals showing vacuole, and contain bright fine dusts. Nodules are surrounded by fibers partially infiltrated by small round cells. Solidified exudate is shown in the alveoli in the peripheral region.

Fig. 8-e. R. No. 46. Van Gieson-stained lung reveals dust cells are densely accumulated and the alveoli are united to form large nodules of dust cells. Many dust cells and fiber cells are present at the center of the nodules. Infiltration of small round cells is found around the nodules, and the outer part of the infiltration is covered with fiber cells. Collagen fiber and fine fibers infiltrate into the nodules. Dust cells have slight vacuole formation. Hyaline degeneration of capillary vessels is found around the nodules.

Fig. 8-f. R. No. 46. Azan-Mallory-stained lung contain dust nodules. Dusts stained as pale blue are scattered within the nodules. Fine collagen fibers form network. Many fibers and small round cells are present in the nodules, particularly in the outer part of the nodules.

Fig. 8-g. R. No. 49. Azan-Mallory-stained lung, 517 days after the 112-day inhalation of the volcanic ash. Deposition of dust is less in the dust cells and the cells look as bright material. Pale bluish vacuoles are included in the peripheral dust cells, and slight-degree of the degenerative vacuoles is recognized. Alveolar capillary vessels have marked deposition of collagen fibers showing giant fibrous state.
Fig. 8-h. R. No. 49. Van Gieson-stained lung includes lightly stained dust cells and brightly stained dusts. Infiltration of small round cells to the peripheral portion is seen. Fine collagen fibers or thick collagen fibers are found inside and around the dust cells.

Fig. 9-a. R. No. 1. Van Gieson-stained lung, 362 days after the 112-day inhalation of the volcanic ash. Some alveoli contain many dust cells. Ducts in the dust cell look like dots in size of 2-3 μm. Their shapes are irregular oval, triangular or comma, with black to grayish glossy of hyalinous materials. Around the dense part of the dust cells, infiltration of small round cells and the increase in the fiber cells are seen. Increase in the collagen fibers is also found in the dust cells at the dense part.

Fig. 9-b. R. No. 1. Azan-Mallory-stained lung shows deposition of dust cells around the bronchi. The surrounding part is covered with fibers. Fiber cells are found between dust cells and fine collagen, forming fiber networks.

Fig. 9-c. R. No. 1. Hematoxylin-eosin-stained lung reveals congestion, hemorrhage and exudate in the pulmonary tissues. Dense dust cells are seen in the alveoli. The infiltration of many small round cells situated closely to the alveoli is recognized. Many fibers are shown in the small round cells and in dense part of the dust cells.

Fig. 9-d. K. No. 2. Hematoxylin-eosin-stained lung, 517 days after the 112-day inhalation of the volcanic ash. Many cells are present in the neighboring cells, and some of them develop necrosis, with unclear cellular borders. Small round cells are seen on the alveolar walls together with fiber cells, and the thickening of the capillary vessels in the alveolar walls looks notable. Fibers are present clearly in the dense part of the dust cells.

Fig. 9-e. K. No. 3. Azan-Mallory-stained lung, 730 days after the 112-day inhalation of the volcanic ash. Infiltration of small round cells is seen at the scattered part of the dust cells in the alveoli. Thick collagen fibers are generally seen in the surrounding area of the capillary vessels on the alveolar walls, particularly on the walls of capillary vessels. Networks of collagen fibers are seen in dust cells extending from the proliferated fiber cells and from the alveolar wall.

Fig. 9-f. K. No. 4. Hematoxylin-eosin-stained lung, 682 days after the 112-day inhalation of the volcanic ash. Proliferation of small round cells and the presence of fiber cells are seen in the wall of capillary vessels on the alveolar walls. Dust cells are densely accumulated with thickened walls.

Fig. 9-g. K. No. 5. Van Gieson-stained lung, 413 days after the 112-day inhalation of the volcanic ash. Dust cells densely gather in the connective tissues around the artery. Some of the dust cells have necrosis. Collagen fibers cover the dense part of the dust cells and the partial infiltration of small round cells is shown.

Fig. 9-h. K. No. 5. Azan-Mallory-stained lung shows vacuole formation in part of dust cells yielding necrotic state. Fiber cells are present with fine collagen fibers, and collagenic fibers around the alveolar walls. Fine dusts are deposited in some of such cells. The capsular body of the dust cells is stained as bluish color, and the infiltration of fine fiber cells into the intercellular space is seen.

Fig. 9-i. K. No. 6. Hematoxylin-eosin-stained lung, 730 days after the 112-day inhalation of the volcanic ash. Dense part of the dust cells is seen in the connective tissues surrounding the bronchi. Fibers cover the dense part of the dust cells. Small round cells and fiber cells are present outside of the capsules. Most dust cells contain vacuoles with unclear nucleus and some have necrosis in them. Many fibers infiltrate from the fiber cells like capsules into the dust cells to form networks. Collagen fibers are also seen.

Fig. 9-j. K. No. 8. Azan-Mallory-stained lung, 420 days after the 112-day inhalation of the volcanic ash. Dust cells are seen in the lymph gland around the artery. They are surrounded by fibers and collagen fibers. The presence of fiber cells and collagen fibers is seen in the dust cells.

Fig. 10. Volcanic ash photographed by electron microanalyzer on the specimens of the lung tissues of rabbits which were experimentally exposed to the Mt. Sakurajima ash. a, Si; b, Fe; c, Ca; d, Mg; e, Ti.
Baxter et al.34) touched on ash characteristics in their report on the Mt. St. Helens eruptions. More than 90% of the particles were within the respirable range of less than 10 μm. Peak levels of total suspended particulates (TSP) in the ambient air were recorded in excess of 30,000 μg/m³. They assumed that these levels provoke acute respiratory illness in exposed, susceptible people. The Environmental Protection Agency's current emergency TSP level for significant harm, as quoted by Baxter, is regarded as 1,000 μg/m³, 24 hour average exposure. The levels of crystalline free silica were found in the range of 3% to 7% with no fibrous minerals. They concluded that emergency workers and the state patrols with no protective measures may face the risk of silicosis, if they should have high exposure for many years.

Green et al.35) examined mutagenicity, fibrogenicity and cytotoxicity of the volcanic ash of Mt. St. Helens and its likely effects on immunological antiviral, and antibacterial defence mechanisms. In their experiments on rats intratracheally exposed to volcanic ash, an acute pulmonary inflammation response was recognized, followed by granulomatous and fibrotic reactions which persisted until the end of the 6-months period. They also examined the lungs of two heavily exposed persons and found lesions formed as a reaction to volcanic ash. Their conclusion was that although non-quartz silicates by themselves should cause high exposure for many years, further work is required to determine which ash component(s) exert the fibrogenic effect.

In the present authors' examinations, as already stated, particles less than 10 μm in diameter were found in 99.05% of the ash under 270 mesh and in 93.25% under 325 mesh.

Table 4. Major element composition of Mt. St. Helens ash. Values are percentages. Samples were analyzed by plasma emission spectroscopy:

<table>
<thead>
<tr>
<th>Element (as oxide)</th>
<th>Tieton (98 km)*</th>
<th>Ahtanum (125 km)</th>
<th>Yakima (137 km)</th>
<th>Richland (224 km)</th>
<th>Moses Lake (240 km)</th>
<th>Spokane (378 km)</th>
<th>Rosalia (385 km)</th>
<th>Pullman (388 km)</th>
<th>Missoula (644 km)</th>
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<tr>
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<td>68.2</td>
<td>66.9</td>
<td>68.2</td>
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<td>0.88</td>
<td>1.25</td>
<td>1.56</td>
<td>1.55</td>
<td>1.60</td>
<td>1.75</td>
<td>1.60</td>
<td>1.69</td>
<td>1.47 ± 0.28</td>
<td>1.4</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.70</td>
<td>0.88</td>
<td>0.83</td>
<td>0.85</td>
<td>0.68</td>
<td>0.63</td>
<td>0.53</td>
<td>0.55</td>
<td>0.58</td>
<td>0.69 ± 0.13</td>
<td>0.60</td>
</tr>
<tr>
<td>P₂O₅†</td>
<td>0.23</td>
<td>(0.37)</td>
<td>0.33</td>
<td>0.46</td>
<td>0.32</td>
<td>(0.37)</td>
<td>0.39</td>
<td>0.48</td>
<td>(0.37)</td>
<td>0.37 ± 0.09</td>
<td>0.2</td>
</tr>
<tr>
<td>MnO</td>
<td>0.093</td>
<td>0.12</td>
<td>0.092</td>
<td>0.087</td>
<td>0.077</td>
<td>0.067</td>
<td>0.063</td>
<td>0.063</td>
<td>0.064</td>
<td>0.077 ± 0.020</td>
<td>0.076</td>
</tr>
<tr>
<td>Weight loss ignition‡</td>
<td>0.51</td>
<td>(0.56)</td>
<td>0.62</td>
<td>(0.56)</td>
<td>0.35</td>
<td>(0.56)</td>
<td>0.55</td>
<td>(0.56)</td>
<td>0.78</td>
<td>0.56 ± 0.16</td>
<td>0.56</td>
</tr>
</tbody>
</table>

Total | 103.1 | 101.3 | 100.4 | 99.0 | 103.1 | 103.7 | 100.1 | 101.1 | 100.8 | 101.6 | 99.5 |

* Distance from Mount St. Helens. † Data are from Nockolds (l). ‡ Numbers in parentheses are taken from average of other samples.

Wakisaka et al.1) observed that the prevalence of bronchial asthma was higher in the areas within 20 km of Mt. Sakurajima, where the recorded levels of ash were much higher than in more remote areas. Monthly levels of volcanic ash were also much higher than at the recorded levels of March 1980. Wakisaka et al. observed that the prevalence of bronchial asthma was higher in the areas within about 20 km of Mt. Sakurajima, where the recorded levels of ash were much higher than in more remote areas. Monthly levels of volcanic ash were also much higher than at the recorded levels of March 1980. Wakisaka et al. observed that the prevalence of bronchial asthma was higher in the areas within about 20 km of Mt. Sakurajima, where the recorded levels of ash were much higher than in more remote areas. Monthly levels of volcanic ash were also much higher than at the recorded levels of March 1980.
formed giant cells. 3) large dust particles would liberate more cells from the tissue and 4) larger foci consisting of the dust-included cells were formed to induce fibrosis. He added that larger dust particles tend to be more toxic and to be more easily recognized as foreign matters, and those exceeding 10 μm in diameter would cause bronchiolitis.

Wakisaka et al.29 made 3 series of observations on ashfall effects of Mt. Sakurajima based on standard mortality rate and expected death rate of several respiratory diseases, in relation to the distance from the mountain, the amount of ashfall and the annual number of eruptions from 1971 to 1979 (364 in 1974 at the highest). They suggested that there was a high probability of the ashfall affecting the health of the people, although the correlation was not always consistent.

CONCLUSION

The ash of Mt. Sakurajima volcanic eruptions collected in 1978 and 1979 were administered through intra-tracheal infusion and inhalation to rats and rabbits to investigate their effects on the respiratory organs. The ash was composed of 58% of SiO₂, followed by aluminum oxide, ferric oxide, calcium oxide, titanium oxide, manganese oxide, phosphorous pentoxide and magnesium oxide. These components suggest the possibility of inducing pneumoconiosis, as chest X-rays of rabbits in this study revealed nodular shadows of ash. Distribution of particle sizes of the ash was: particles smaller than 10 μm in diameter in 93.25% of the ashes under 270 mesh, 99.05% of those under 325 mesh. It was confirmed that such fine dust particles reach the pulmonary alveoli either by direct infusion or by inhalation, causing marked disturbances in the respiratory organs. The dust particles deposited in the alveoli, and some of them settled around the blood vessels and bronchi through lymphatic routes. The particles were enclosed in phagocytes to form dust cells whose accumulation produced dust nodules. Cell reactions such fibrosis and small round cells appeared as a result of necrosis and vacuole-formation of the dust nodules. At the same time, hyaline degeneration progressed in the alveolar walls and the collagenic materials deposited there. Such cell responses induced cell proliferation and the collagen fibers were recognized in the form of networks. Thus dust nodules came to appear.

These experimental studies demonstrate the histopathological occurrence of pneumoconiosis with such findings as bronchitis, emphysema, atelectasis, the degeneration of blood vessels, dust nodules and fibrotic dust foci.

The hazardous nature of the inhalation of volcanic ash should be thoroughly understood, and, as far as possible, preventive measures should be developed and implemented.

Acknowledgments. The authors would like to thank Dr. Tetsuya Masuda and Dr. Yoshihisa Omori, Analytical Application Laboratory, Shimadzu Corporation in Kyoto, for these doctors' analysis of Mt. Sakurajima ash using inductively coupled plasma quantometer, Dr. Nobuo Watanabe, Chief of Chemical Division, Miyazaki Industrial Laboratory, for his analysis of the ash using X-ray diffraction, and Dr. Yusuke Inoue, The Institute of Scientific Technology, Fukuoka Dental College, for his analysis of the ash on electron probe microanalyzer. Furthermore, the authors wish to express their gratitude to Dr. Tadatoshi Miyazaki, pathologist and former Vice President, Mitsui Institute of Industrial Medicine, to Professor Tadashi Kôno, Department of Pathology of Miyazaki Medical College, for their pathological examinations and advices, and also to Professor Hirotoshi Okutani, Department of Public Health of Nagoya City University School of Medicine for his courtesy help.

REFERENCES

6) Shirakawa, M., Okuno, C. and Hattori, M.: Experimental studies on the effects of inhalation of

和文要旨
著者らは1978年以降、鹿児島の爆発により、鹿児島市内に落下した火山灰を採取し、ラットおよび家児を用いての動物実験により、火山灰粉塵の気管内注人ならびに、

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