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BERYLLIUM: TOXICOLOGY, CLINICAL ASPECTS OF DISEASES,  
LABOR HYGIENE  
by V. M. Kozlov and V. D. Turovskiy  
- USSR -

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BERYLLIUM: TOXICOLOGY, CLINICAL ASPECTS OF DISEASES,  
LABOR HYGIENE

- USSR -

Following is a translation of parts of the Russian-language book by Valentin Mikhaylovich Kozlov and Valentin Dmitriyevich Turovskiy Berilliy: toksikologiya, klinika porazheniy, gigiyena truda (Beryllium: Toxicology, Clinical Aspects of Diseases, Labor Hygiene), State Publishing House for Literature in the field of Atomic Science and Technology, Moscow, 1962, 120 pages. Complete bibliographic information accompanies each article.

NOTE: All names in the text are approximations as transliterated from the Cyrillic.

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#### EXPERIMENTAL TOXICOLOGY OF BERYLLIUM AND ITS COMPOUNDS

Following is a translation of Chapter 3 of a book by Valentin Mikhaylovich Kozlov and Valentin Dmitriyevich Turovskiy Berilliy: Toksikologiya, Klinika Porazheniy, Gigiyena Truda (Beryllium: Toxicology, Clinical Aspects of Diseases, Labor Hygiene), State Publishing House for Literature in the Field of Atomic Science and Technology, Moscow, 1962, pages 19-31.<sup>7</sup>

The toxic properties of beryllium were first investigated by the German scientist I. Blek in 1882. He asserted that beryllium in its biological action is not toxic but is similar in this respect to such metals as aluminum and iron.

Sayyema (1886) and Komar (1935) arrived at a completely different conclusion. They established the existence of toxic properties for beryllium when its dissolved salts were introduced internally into experimental animals.

While studying the effect of fluorine-beryllium compounds, when inhaled, on the organism of test animals, A. N. Magnitskiy, E. M. Zamakhovskaya, (31) and others came to the conclusion that the main active element is fluorine. At the same time the authors indicate that beryllium, in a highly dispersed condition, also has a toxic action which, however, is weaker.

Some scientists (Hislop, Talmanis, Alford, Monaco, and Fei ergol) (32) who in 1943 were investigating the toxicity of beryllium and its compounds denied the presence of toxic qualities for beryllium, contending that the detected pathological changes which had occurred during the use of beryllium salts on test animals were the result of the action of acid radicals and the hydrolysis of these salts in the organism of the animals and were not the result of the action of beryllium itself.

Through the work of Soviet and foreign researchers it was established that beryllium has a high toxicity which depends on the degree of dispersion of the compounds which are used, their solubility in water, and also the methods of introducing the

beryllium salts into the organism of the experimental animals.

In studying the action of beryllium on protein and on very simple organisms, S. V. Vol'ter (33) noted that solutions of beryllium oxyfluoride and beryllium chloride in acting on 10% solutions of egg white and mare's whey cause an opalescing of the solution from the very beginning of the reaction and the appearance of a precipitate after standing, which indicates the disruption of the molecular structure of the protein as a result of the action of beryllium.

Compounds of beryllium in concentrations of 1:10, 1:100, 1:1,000, and 1:10,000 depress the activity of Infusoria Paramecium; their movement is slowed; the body changes from an elongated to a spherical shape; the protoplasm becomes cloudy, sometimes disintegrating into separate parts.

The toxic action of an aqueous solution of  $\text{BeCl}_2$  on Daphnia crabs was exhibited in a lowering of their life span in comparison with that of control specimens. (34)

On the basis of research conducted by S. V. Vol'ter and G. D. Lebedeva, it was established that beryllium oxychloride and beryllium chloride act similarly to the salts of heavy metals. They precipitate protein in vitro, depress the activity of unicellular and simple organisms and denature the protoplasm of cells.

#### The Toxicity of Beryllium when Introduced Subcutaneously or Intra-Abdominally

In the case of subcutaneous or intra-abdominal injection of beryllium in mammals there is a sharp local inflammation of the tissue which becomes chronic. Histochemical research indicates that beryllium in the form of free ions is fixed by the tissue at the site of injection, firmly linking with the tissue protein. The death of the animals in this case comes only after the introduction of very large doses of beryllium.

V. N. Aldridge, J. H. Barnes, and F. A. Denz, (32) in studying the action of beryllium sulfate, beryllium chloride and beryllium lactate when introduced subcutaneously and intra-abdominally into mice and rabbits, established that a dose of 5 milligrams per kilogram of weight of the animal does not kill mice. Only beryllium oxyfluoride is lethal in these concentrations; however, death occurs because of fluorine poisoning. The sodium-beryllium tartrate proved to be more toxic in subcutaneous injection than beryllium lactate or beryllium sulfate.

The research conducted by S. V. Vol'ter (33) established the fatal doses of beryllium oxyfluoride and beryllium chloride for white rats when introduced subcutaneously. In order to kill a rat in three days it is necessary to use not less than 36 milligrams of beryllium chloride per kilogram of weight of the animal or 9 milligrams of beryllium oxyfluoride.

S. P. Voskresenskiy (35), on the basis of experimental work, established the fatal doses of beryllium oxide for subcutaneous injection in white rats as 10 milligrams per kilogram of weight of the animal and in rabbits as 20 milligrams per kilogram.

Some authors surmise that in the subcutaneous introduction of beryllium, stable compounds are formed with the tissue protein. However, the work of A. Vorvald and A. Revis (36), who conducted tests in vitro, established the fact that beryllium does not form complexes with the proteins of serum, but rather produces insoluble precipitates consisting of beryllium hydroxide and phosphates.

F. A. Dutra (32) made an attempt to obtain the formation of granulated skin in experimental animals, using for this purified compounds of beryllium and metallic beryllium. During the experiment the organism reacted differently to the metal, beryllium oxide, and various fluorescent powders containing beryllium oxide.

The reaction to the introduction of the powder into the subcutaneous cellular tissue through an incision in the skin was observed chiefly in the subcutaneous fat layer, directly under the epidermis, and was characterized by a sharp inflammation with proliferation of fibroblasts and activity of the mononuclear phagocytes. The fibrosis and phagocytosis of particles of fine powder in a short time became dominant, and already in 5 (or more) days the reaction was of the nature of a chronic inflammation.

Powdered metallic beryllium and beryllium oxide caused the formation of giant cells and led to a granulomatous inflammation of a non-specific type. In the skin and in the subcutaneous fat tissue there appeared bundled masses of large mononuclear cells and giant cells containing powdery particles which had been absorbed. Small quantities of lymphocytes were often scattered throughout these granulomas. After several months the granulomatous afflictions became less and consisted almost solely of mononuclear phagocytes filled with powder and of giant cells within the fibrous tissue.

The fluorescent powders caused the formation of granulomatous nodules consisting of rings of freely organized collagenous tissue in which there were very many mononuclear phagocytes and giant cells and numerous lymphocytes.

### The Toxicity of Beryllium When Introduced Internally

When beryllium is introduced internally, its toxic action is more notable and does not depend on the acidity of the solution or the properties of its anions. Soluble beryllium compounds proved to be the most toxic, causing death in test animals when used in small concentrations. Beryllium salts, when introduced into the bloodstream, very quickly enter the tissue of various organs.

Within 24 hours after its introduction, according to the data of V. H. Aldridge, J. H. Barnes, and F. A. Denz (32), beryllium is detected in the following organs (as a percentage of the total amount of beryllium introduced into the organism);

liver. . . . .	27.5
spleen . . . . .	2.6
kidneys. . . . .	0.8
lungs. . . . .	0.7
intestines . . . . .	2.8

Beryllium is not detected in the heart muscle, brain, skin, or skeletal musculature. It is absent in the skeleton throughout the first 24 hours; however, it is identifiable at later times in quantities not exceeding 10% of the amount originally introduced. Thus, in internal introduction the greatest quantity of beryllium is detected in the liver.

After the internal introduction of an average lethal dose of beryllium, the animals became sluggish and indifferent to their surroundings and refused food. They remained in such a state until the advent of death. Rabbits before dying often experienced convulsions. Rats which lived more than 3 days became jaundiced.

During a pathoanatomical examination of the dead animals one finds that disease of the liver is sharply indicated. When the animals die early, the liver is hemorrhagic and has a red color. If death occurs later, the liver acquires a yellow color and a soft consistency. The normal pattern of the liver disappears; a solid mass of swollen cells which acquire a hexagonal shape appears. After 24 hours following the introduction of beryllium, the animals acquire beginning affections of the liver with separate groups of necrotic parenchymatous cells. The cytoplasm of these cells becomes pale and vacuous; the borders of the cells wear away; the nuclei disassociate. Necrosis of the cells appears around small focal accumulations of beryllium. After 48 hours the focal sites of the disease of the liver are fully developed and encompass the middle zone of the lobes. After 72 hours the liver is diseased to a considerable amount.

Changes in the kidneys are detected after 24 hours following the introduction of beryllium. Some small proximate winding canaliculi are afflicted; their epithelium loses its similarity of pigments; the outlines become uneven; the lumens of the canaliculi contain cytoplasmic and nuclear fragments. Later cylinders are formed in the canaliculi. Changes are not observed in the glomeruli and the straight canaliculi.

In the spleen of the test animals, small focal points of disease develop around the sinuses, and groups of cells undergo autolysis. The white pulp consisting of cells presents a sharp contrast to the structureless red pulp which is filled with erythrocytes and is free of lymphocytes. J. Scott in introducing beryllium sulfate into animals observed an oozing of liquid into the serous cavities, an increase of the spleen of 2 to 3 times, and the development of jaundice. The author did not note any pathological changes in the brain, heart muscle, lungs, intestines, transverso-striated musculature, or the thyroid, parathyroid, pancreas, thymic and lymph glands.

A histochemical test of the tissue did not reveal any beryllium content in these organs (V. N. Aldridge, J. H. Barnes, F. A. Denz). (35)

Fatal doses of beryllium oxide when introduced internally are as follows:

for rats -- 11.2 milligrams per kilogram according to the data of S. P. Voskresenskiy (7.2 milligrams per kilogram using beryllium sulfate according to the data of J. Scott);

for rabbits -- 1 to 2 milligrams per kilogram (S. P. Voskresenskiy and M. G. Petrovnik);

for dogs -- from 5 to 20 milligrams per kilogram (Ye. M. Kedrova).

F. P. Dutra and E. Largent in the intravenous introduction of a 1% suspension of beryllium oxide in a physiological solution observed the formation of osteosarcoma in 6 of 9 test rabbits. The earliest period for the appearance of tumors was 11.5 months from the beginning of the tests. In 4 rabbits the initial tumors were located correspondingly at the right clavicle, at the top of the right femur, at the lumbar vertebra and at the distal end of the right femur. Metastasis of the lungs was detected in these 4 animals. Two other rabbits had multiple initial tumors.

The microscopic structure of all tumors was typical of osteosarcoma. The sections showed that the large tumors contained necrosis and areas of hemorrhage. In all animals in the red bone marrow there were numerous white spots which under microscopic examination proved to be accumulations of beryllium oxide which had been absorbed by phagocytic cells. Beryllium was also detected in other organs. A large part of it was contained in the reticulo-endothelial cells of the bone marrow of long bones which did not have tumors.

#### The Toxicity of Beryllium When Inhaled

A. N. Magnitskiy, E. M. Zamakhovskaya, and others (31), in testing animals with vapors and gases formed by liquefying beryllium fluoride compounds in concentrations of from 5.0 to 54.0 milligrams per cubic meter for fluorine and from 2.48 to 5.78 milligrams per cubic meter for beryllium, observed shortness of breath, coughing, nasal drip, fine tremors, twitching of the skin of the back and extremities, and, in some cases, vomiting in the animals. After the cessation of the tests the animals showed higher temperatures and a drop in body weight. In succeeding days they became sluggish, lost appetite, had difficulty in breathing, and experienced hoarseness, coughing, and periods of vomiting. The reserve alkalinity of the blood dropped and remained at a low level until death. The reaction on the bilirubin was negative. There was an increase of the hemoglobin and of erythrocytes. Leucocytosis with a neutrophilic shift to the left, lymphopenia, and eosinopenia appeared.

With pathoanatomical tests it was discovered that the respiratory organs were primarily afflicted: the lungs were edematous and in a number of cases there was a suppurative exudate. Focal emphysema and pneumonia of a catarrhal or fibrous-necrotic type were observed. Necrotic endobronchitis and inflammatory infiltration of the peribronchial spaces (peribronchitis) were also noted. Sometimes to these occurrences were added suppurative or fibrinous suppurative pleurisy. Granular growth was observed in the kidneys and myocardium. In the parenchyma of the liver scattered tiny necrotic sectors were encountered. The spleen was usually enlarged as a consequence of the hyperplasia of the cells of the pulp.

In the case of giving animals beryllium oxide in lower concentrations than in the above-mentioned experiments, the animals experienced only insignificant changes. The body temperature increased in only one of 8 dogs which were being tested. With respect to blood, except for monocytosis there were no deviations discovered. In one dog edema of the lungs was noted;

and in four others there was slight edema of the lungs and moderate plethora. There were punctate hemorrhages in the parenchymatous organs and in the spleen capsule.

G. Stockinger, S. A. Stroud, and M. T. Rochester (32), in studying hematological changes in connection with the inhaling of beryllium fluoride in concentrations which do not cause other toxic symptoms, observed the development of anemia in animals. Rabbits were exposed to beryllium fluoride vapor in concentrations of  $2.2 \pm 0.25$  milligrams per cubic meter. The experiment lasted 23 weeks.

The results of the experiment showed that the average number of red blood cells by 16 to 20 weeks was lowered from 5.5 to 3.8 million per cubic millimeter. The hemoglobin content fell at the beginning of the experiment but in 12 weeks reached a norm. The average hemoglobin concentration in erythrocytes was at a norm of  $33 \pm 1.7\%$ . No changes were observed in the number of white blood cells or in the hemogram. At the same time the average size of the erythrocytes increased progressively and by the 16th week had reached a maximum of 100 microns in contrast to the norm of 72 microns.

In the case of the action of beryllium oxide on rabbits, a similar hematological reaction was observed. The tests showed that anemia develops differently in different types of animals. In dogs the number of erythrocytes, their average size, and the hemoglobin change in a fashion typical of normochromastic macrocytic anemia. In rabbits there was a less-defined tendency toward a lowering of the concentration of the hemoglobin of whole blood. In rats, with a normal hemoglobin content, two other hematological indicators change as in macrocytic anemia. Animals react differently to the introduction of hemopoietic stimulators (lextron, folic acid, and vitamin B<sub>12</sub>). Lextron and folic acid not only did not have a favorable effect on the course of the anemia in dogs but even hastened the death of the animals. In rats, however, folic acid prevented the development of anemia and eased the severity of the poisoning. Recovery from anemia occurred spontaneously in 3.5 to 4 months.

G. Stockinger, R. Hall, and others (32), in studying the action of beryllium sulfate when inhaled in 11 species of animals, established that 6 hours of exposure to the action of beryllium in concentrations of 1, 10, 50, and 100 milligrams per cubic meter is absolutely fatal for most of the species of test animals when the concentration is 50 milligrams per cubic meter. For concentrations of 10 milligrams per cubic meter there was a low mortality rate for all species of animals except the white rats. In the case of 100 day

exposure to beryllium sulfate in concentrations of one milligram per cubic meter there were no fatalities in any of the species being tested.

The authors indicate the existence of two forms of acute beryllium poisoning: an acute toxic form in which the most susceptible representatives of a given species perish -- in these cases death comes with small histological changes; a prolonged form in which expressed pathological changes develop, sometimes leading to the death of the animals 7 to 10 weeks after the beginning of the experiment.

In the case of the action of beryllium sulfate in concentrations of one milligram per cubic meter, the following pathological reactions of the organism are observed: acute inflammatory phenomena in the lungs, anemia, changes of some lipids of the red blood cells, changes in the amount of protein in the serum, disruption of the nitrogen exchange, and changes in the oxygen content of the arterial blood.

In the case of the inhalation of beryllium, the greatest amount of it is found in the lungs and the lymph nodes. Besides this, beryllium is found in lesser quantities in the liver, kidneys, spleen, bones, and teeth.

In the case of the inhalatory action of beryllium sulfate in concentrations of 10 milligrams per cubic meter over the course of 95 days, the quantity of beryllium in the lungs of white rats, guinea pigs and dogs reached 4 to 11.6 milligrams per gram of tissue. In the case of the action of beryllium sulfate in concentrations of one milligram per cubic meter for the same duration of the experiment, the content of beryllium in the lungs was 0.6 to 1.6 milligrams per gram of tissue.

A general reaction of an organism to beryllium is the loss of weight in animals. The greater is the concentration of beryllium, the greater is the loss of weight. As a rule, the loss of weight is accompanied by a lessening of the appetite. However, it was noted that dogs which were being subjected to the action of small concentrations of beryllium, while eating all their food, often lost weight the same as animals which refused their food.

In small concentrations beryllium sulfate after 3 to 8 weeks of use causes anemia in dogs with a decrease in the number of erythrocytes (to 1.5 to 2 million per cubic millimeter) and in the hemoglobin (from 1 to 2 grams per 100 grams of blood) and also an increase in the size of the erythrocytes from 98 to 110 microns. In rats and rabbits anemia was observed upon the action of beryllium

in high concentrations (47 to 100 milligrams per cubic meter). Besides changes in the red blood in dogs, rats, and rabbits, high concentrations of beryllium cause leucocytosis up to 40,000 in a cubic millimeter (rats) and thrombocytosis (rabbits and rats) up to 800,000 in a cubic millimeter. For doses of 50 milligrams per cubic meter, 50% of the test animals had albumin in the urine. This did not occur in rabbits. In the blood there appeared hypoalbuminemia with a tendency to hyperglobulinemia. There were some changes in the amount of protein in the serum.

The reaction of lung tissue to the action of beryllium sulfate has an inflammatory character with the occurrence of interstitial and intralveolar edema. This edema along with atelectasis and emphysema of the lungs causes considerable changes in the lung structure. The structure of the alveoli is destroyed in many places, because of the appearance of accumulations of lymphocytes, monocytes and sometimes plasmatic cells with a relatively small number of neutrophilic leucocytes. The exudate within the alveoli contains a large quantity of phagocytes, the cytoplasm of which is filled with a granular substance, probably fragments of cellular nuclei. Affliction of the bronchial and bronchiolitic epithelium, its defurcation, and hyperplasia with thickening of the walls of the alveoli are observed.

In the case of the action of high concentrations of beryllium (47 to 100 milligrams per cubic meter), in 2 to 3 weeks from the beginning of the experiment rabbits show sharply defined lung ailments in the form of edema, hemorrhage, and focal necrosis of the tissue.

Similar results were obtained by J. Scott (32) who conducted tests with white rats, mice, guinea pigs, hamsters, rabbits, and dogs using beryllium sulfate in a concentration of 88 milligrams per cubic meter with particle sizes on the order of 4.5 microns.

Lung damage appeared in the form of intra-alveolar edema of various degrees accompanied by hyperstitial edema and thickening of the alveolar septa. At a later period there was an exudation of neutrophils and phagocytic cells to the terminal bronchi and to the alveoli surrounding them. There also developed necrosis of the liver cells and of the epithelium of the kidney canaliculi in rabbits and white rats.

G. F. Sprague, Ch. Lobell, and others (32), in the inhalatory introduction of beryllium sulfate in concentrations of 4.5 milligrams per cubic meter for 2 weeks of daily 6-hour exposure, observed a loss of weight in the animals. Rabbits and dogs lost up to 5% of their weight and hamsters and rats lost up to 11%.

During the second week of the experiment the content of residual nitrogen in the blood increased to 78 milligrams and toward the end of the experiment it was at the level of 70 milligrams per 100 cubic centimeters. An increase in the quantity of albumin in the urine of rabbits was discovered on the 6th day of the experiment. By the 10th day the albumin content had grown to 350 milligrams per 100 cubic centimeters. Toward the end of the experiment it had dropped again to 80 milligrams per 100 cubic centimeters.

V. V. Mel'nikov (37, 38) studied the action of beryllium acetate using inhalatory introduction in a special chamber on rats, mice, and rabbits. He established that for a single two-hour exposure, beryllium acetate in a concentration of 70 milligrams per cubic meter causes the death of 50% of the animals while in a concentration of 8 milligrams per cubic meter it is endured by all animals.

Acute poisoning by beryllium acetate has three stages. In the first stage there is motor stimulation which lasts for 35 to 50 minutes with coughing and sneezing. Then there is a period of depression in which the animals lie on their sides and some of them go to sleep. During this period there is acute shortage of breath and cyanosis. The depression stage passes into an agony stage and the animals die.

V. V. Mel'nikov studied in rats the toxic effect of beryllium acetate in concentrations of 0.03, 3, 0.3, and 30 milligrams per cubic meter for a two-hour exposure a day over the course of 40 days. He found that for a concentration of 30 milligrams per cubic meter the animals experience a considerable loss of weight. For lesser concentrations there is a slow increase in weight; however, it is always less than the weight gain of the control animals. The pathomorphological picture of the dead animals that underwent acute intoxication is characterized by extensive edema of the lung tissue and the presence in some cases of catarrhal desquamative pneumonia. Severe degenerative changes with the presence of proliferative phenomena are observed in the liver, kidneys, and spleen.

In the case of the use of concentrations of 0.03 and 0.3 milligrams per cubic meter, 30 days after the end of the experiment there were comparatively small changes which could be observed in the form of a productive intermediate process. In using a concentration of 3 milligrams per cubic meter a more expressed productive process is observed in the lungs of the animals; in a number of cases characteristic single miliary granulomas are formed. In some animals catarrhal desquamative bronchitis and catarrhal pneumonia were detected. In giving animals a concentration of 30 milligrams per cubic meter, catarrhal and catarrhal suppurative bronchitis,

desquamative and fibrinous pneumonia, and fibrinous suppurative pleurisy are observed. Simultaneously with affliction of the lungs there are also degenerative changes in the liver, kidneys, spleen, and heart muscle.

In order to determine the fatal concentrations of beryllium acetate, V. V. Mel'nikov used the conditioned reflex method. For white rats he developed a conditioned motor reflex to a sound and light stimulant on the basis of a non-conditioned food reflex. Then the animals were subjected to the action of the vapors from the distillation of beryllium acetate in small concentrations for short single exposures. After this they checked the previously developed conditioned reflexes.

On the basis of the results which were obtained it was established that beryllium acetate in concentrations of one milligram per cubic meter for a single hour exposure causes a lowering of the reaction to a sound stimulant and then a prolapse of different conditioned reflexes both to sound and light stimulants. The use of beryllium acetate in concentrations of 0.08 milligrams per cubic meter causes in all animals a disruption of the inhibiting process, and in a number of cases there is a prolapse of individual conditioned reflexes. Only in concentrations of 0.02 milligrams per cubic meter does beryllium acetate for one-time use not have any influence on the higher nervous activity of the animals. The same dose when used for 60 days causes changes in the conditioned reflex activity of animals and morphological changes in the cerebral cortex (deformation of the dendrites, their uneven thickening, the disappearance of the spine-shaped appendages which are normal to the structure of the dendrites). However, these changes disappear after the cessation of the experiments.

For the study of the action of insoluble compounds of beryllium, R. Hall, J. Scott, and others (32), using inhalation, introduced four types of beryllium oxide which differed in particle size into cats, dogs, guinea pigs, rabbits, rats, and monkeys.

As a result it was established that fireproof forms of beryllium oxide having relatively large dust particles (5 to 12.7 microns) do not cause even the symptoms of disease. Pathological changes in the organism of control animals were noted only for finely-dispersed beryllium oxide of a particle size of from 0.38 to 0.47 microns. There was a loss of appetite, lower arterial oxygen pressure, hyperglobulinemia and hypoalbuminemia, higher alkali phosphatase of the serum of the blood with subsequent falling and occurrence of anemia. In pathoanatomical sections of the lungs an inflammatory reaction was found which was characterized by hyperalveolar and interstitial edema with fagocytic infiltration

and the presence of lymphocytes and granulocytes. The granulocytes consisted chiefly of polymorphonuclear neutrophils, but there were also eosinophils and myeloid forms. There was also defurfuration of the bronchial epithelium and hyperplasia of it and also thickening of the walls of the alveoli.

These works showed that the toxicity of beryllium oxide depends completely on its degree of dispersion. As the dispersion increases, so do the toxic properties of beryllium oxide and also the other insoluble compounds of this metal. The tests by V. V. Mel'nikov in 1957 and 1958 confirm these conclusions.

#### The Toxicity of Beryllium When Introduced into the Gastro-Intestinal Tract

The introduction of beryllium into the gastro-intestinal tract of experimental animals also causes a series of pathological changes. E. Hayward, V. Downs, and G. Hodge (32), who mixed beryllium sulfate and beryllium acetate, metallic beryllium, and beryllium oxide in the food of white rats, observed the influence of beryllium on the growth and food consumption of the test animals. They also discovered a considerable increase in the metaphysis area of the proximal ends of the tibia.

F. Clemperrer, J. Miller, and K. Hill (32), citing a number of authors, note that a diet with an excessive beryllium content causes rickets in animals. The development of beryllium rickets was explained by the authors as a sharp hypophosphatemia which occurred as a result of the depositing of beryllium phosphate in the intestines and the lessening of its suction from the gastro-intestinal tract. However, T. F. Aino and A. B. Goodman established that beryllium has a harmful influence on the local factor in the calcification of cartilage.

Tests which were conducted with B-glycerophosphate as the only source of phosphorous in concentrations of 10 milligram percents of phosphorous in the absence of beryllium and with it in concentrations of  $10^{-3}$ ,  $10^{-4}$ ,  $10^{-5}$ , and  $10^{-6}$  M showed that beryllium in concentrations of  $10^{-5}$  M and higher completely blocked the calcification of cartilage in vitro and in concentrations of  $10^{-6}$  M caused a noticeable inhibiting effect.

Because the role of phosphatase in the formation of bony tissue is very great, it was assumed that the disruption of the normal formation of bone depends on disrupting the activity of this enzyme with beryllium. In the tests the authors used solutions on enzymes prepared from defatted and dehydrated swine kidney powder to which was added beryllium sulfate in concentrations up to  $10^{-5}$  M.

Beryllium caused an inhibition of alkaline phosphatase of up to 60.4%. F. Grayer, M. Hood, and M. Hogeland (32) tested the action of various concentrations of beryllium on the activity of alkaline phosphatase for extracts of bone, kidney and intestine from rats. They also used extracts from the serum of a person with high phosphatase activity and from a sarcoma of a rat. The solutions of beryllium for these tests were prepared from beryllium sulfate. The results of the experiments showed that beryllium in small concentrations on the order of  $10^{-7}$  M inhibits the activity of alkaline phosphatase. With a maximum beryllium concentration of  $10^{-4}$  M, extracts of bone, kidney, human serum, and rat osteogenous sarcoma show approximately the same degree of inhibition, 40%. Extracts of intestinal phosphatase are inhibited by 60 to 70%. Similar results indicating the suppression of the activity of alkaline phosphatase under the influence of small concentrations of beryllium have been obtained by other authors.

#### Maximum Permissible Concentrations of Beryllium

Numerous experimental works by both foreign and Soviet authors have shown that beryllium is a highly toxic substance which causes pathological changes even in small concentrations.

The clinical and pathologico-anatomical picture of afflictions from beryllium and its compounds depends on the method by which it is introduced into the organism of experimental animals, on the solubility of its salts, and also on the degree of dispersion of metallic beryllium and its insoluble compounds. The most toxic are the soluble salts of beryllium; almost as toxic are the insoluble finely-dispersed compounds with particles less than one micron in size. Insoluble compounds of beryllium with particles of greater size are less toxic.

The introduction of beryllium into the organism of animals in toxic doses leads to the development of a local reaction with inflammation and edema, changes of the protoplasm of the cells and necrosis of the tissue, damage to the liver, kidneys, and spleen, hematological changes (macrocytic anemia and leucocytosis), disruption of the biological processes of the organism, lowering of the activity of the alkaline phosphatase and disruption of the calcification of the bony tissue, and the development of malignant tumors (osteosarcoma, etc.).

Thus beryllium is a general toxic poison which causes the development of profound irreversible processes in the organism of animals. The size of a fatal dose depends on the method of introduction, the physical-chemical properties of the beryllium compounds which are taken, and the type of experimental animal.

In the case of the inhalation of beryllium and its compounds the most prominent effect is affliction of the respiratory organs, occurring as inflammatory processes with the occurrence of inter-alveolar and hyperstitial edema and the development of bronchitis and pneumonia. At the same time other organs and systems are also afflicted. The inhalatory method of having beryllium enter the organism of man is of greatest danger because the recorded cases of people becoming ill under the conditions of beryllium production have chiefly involved the entry of beryllium and its compounds into the respiratory organs.

The determination of harmless concentrations of beryllium in air which is inhaled is one of the most vital tasks in preventing work-connected ailments in beryllium production. In order to solve this problem experiments have been undertaken involving the study of the toxicology of beryllium and its compounds as have clinical observations over the state of health of production workers and also the local population in the area of beryllium enterprises.

The American Industrial Hygiene Association established a maximum permissible concentration of beryllium in the air of production facilities for an 8 hour working day of 0.002 milligrams per cubic meter and of up to 0.025 milligrams per cubic meter for short periods (less than 30 minutes). For the outside air in the vicinity of plants which process beryllium, the permissible average monthly concentration is 0.00001 milligrams per cubic meter. (36)

V. V. Mel'nikov recommends as a maximum permissible concentration for beryllium acetate (soluble salt) in the air at production facilities for a 6 hour working day a value of 0.001 to 0.002 milligrams per cubic meter and of 0.01 to 0.02 milligrams per cubic meter for finely dispersed beryllium oxide (insoluble salt). (37-39)

In the Soviet Union the hygienic regulations have established the maximum permissible concentration of beryllium in the air at production facilities as 0.001 milligrams per cubic meter.

For open reservoirs G. D. Lebedeva (34) proposes that 0.01 milligrams per liter be considered a harmless concentration for beryllium chloride. A. F. Zaytseva and Ye. G. Repina (40), on the basis of tests on the influence of beryllium on the sanitary state of a reservoir, recommend that the maximum permissible concentration of beryllium for reservoirs be 0.05 milligrams per liter.

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## LABOR HYGIENE IN WORKING WITH BERYLLIUM

Following is a translation of parts of Chapter 5 of a book by Valentin Mikhaylovich Kozlov and Valentin Dmitriyevich Turovskiy entitled: Berilliy: Toksikologiya, Klinika Porazheniy, Gigiena Truda (Beryllium: Toxicology, Clinical Aspects of Diseases, Labor Hygiene), State Publishing House for Literature in the Field of Atomic Science and Technology, Moscow, 1962, pages 84-93.

### Means of Individual Protection

In the production of beryllium means of individual protection are employed which protect the human organism from the harmful action of toxic substances (68-70).

The means of individual protection include coveralls which are employed under production conditions for the protection of the worker from mechanical, thermal and chemical action, glasses which protect the eyes from radiant energy and also from mechanical, thermal and chemical action, respirators of various types and industrial gas masks for protecting the respiratory organs against the entry of toxic substances, and antinoise devices which lower the harmful effect of noise on the human organism.

In the production of beryllium special clothing is used with which it is possible to completely cover the worker in a sanitary slipover outfit. The set of special clothing for personnel working on the basic technological processes of producing beryllium includes: cotton underwear, socks or leggings, suits, berets or kerchiefs, boots or rubbers, cotton and rubber gloves, plastic aprons, and sleeveguards.

In some operations such as when working with concentrated mineral acids or in smelting departments, suits are used which are made of coarse wool cloth which is more resistant to acids and high temperatures.

Synthetic materials have been widely used in recent years for making various cloths.

The All-Union Research Institute for Labor Protection of the All-Union Central Council of Trade Unions together with the Central Institute of the Wool Industry and the Central Institute of the Cotton Industry (69) developed a new cloth -- a cotton moleskin with a special acid-resistant impregnated compound (moleskin "553-KP"), which has good protective properties for working with small concentrations of acids (not over 15%).

These institutes, from a mixture of coarse wool and perchlorovinyl fiber, made ShKhV-30 cloth which is highly resistant to acids. The wearing period for suits made of the acid-protective cloth is 2 to 2.5 times higher than the wearing period for special clothing made from ordinary coarse wool cloth. However, the ShKhV-30 cloth does not have sufficient thermal resistance; at temperatures above 70 degrees Centigrade the perchlorovinyl cloth softens and when later cooled becomes hard and brittle.

New synthetic fibers have been developed and are being produced by industry using polymers: vinitron, lavsan, nitron, and ftorlon Fluorlon. S. M. Gorodinskiy (71) and his co-workers conducted tests of new fibers and established that cloth made from lavsan is resistant to acid, has low hygroscopic qualities, is thermal resistant (softening temperature of 250 to 265 degrees Centigrade), and has good mechanical durability.

The scientific research institutes for silk and wool together with other institutes created the following cloths: lavsan-silk type 21529; lavsan-wool (in a ratio of 1:1) type 350; and staple lavsan type 773.

The laboratory and production tests of the special clothing made of lavsan-silk showed that in practice this cloth does not lose its durability under the action of concentrated hydrochloric and sulfuric acids and of concentrated bases. Under the action of 70% nitric acid it retains up to 50-70% of its strength. The chemical resistance of lavsan-wool cloth has also been established as being sufficiently high.

The permeability to air of lavsan cloth varies widely depending on its structure. The functional condition of the human organism when working in lavsan special clothing is within the permissible physiological limits.

Cotton and wool special clothing wears out quickly and is replaced three or four times a year. The lavsan clothing, however,

at the end of a year does not lose its mechanical durability and even its external appearance does not change. In comparison with special clothing made of natural fiber, the lavsan special clothing is considerably easier to wash off and eliminate any soil which can be handled by the washing agent while not losing its strength or sanitary properties.

On the basis of the results which have been obtained, it is possible to recommend the use of cloths made of lavsan for special clothing for workers involved in the production of beryllium.

The special clothing for workers in beryllium production should have the smallest possible number of cuts so that dust containing beryllium will not get under the special clothing. This requirement is met by a special type of coveralls with a system of vents and with sealed openings.

In order to protect the skin of his hands from the action of salts of beryllium, acids, and bases, the worker should put on rubber gloves. In order to prevent maceration of the skin which could lead to the development of beryllium dermatitis, cotton gloves should be worn under the rubber gloves. Caps or kerchiefs, which are an essential part of the complex of special clothing for workers in beryllium production, protect the top of the head from contamination. Plastic aprons and sleeveguards are worn on top of the special clothing.

There must be strict controls over the degree of soiling of the special clothing and over the frequency of its change and repair. The washing of special clothing soiled with beryllium should be conducted in plant laundries separately from the special clothing from other production shops not involved in the production of beryllium. The washing of special clothing which has been soiled with beryllium is not permitted at home.

In order to protect the respiratory organs from the entry into them of beryllium and its compounds, respirators, gas masks, pneumatic masks, pneumatic suits are employed. The F-45, F-46, PRB, and other respirators which are used at most enterprises did not find wide employment in the production of beryllium. Good hygienic results under the conditions of beryllium production were obtained when using ShB-1 "Lepestok" respirators (72, 73).

The ShB-1 "Lepestok" respirator (Figure 24) is intended to protect the respiratory organs from toxic and other dust when the content of harmful substances in the inhaled air does not exceed 200 maximum permissible concentrations.

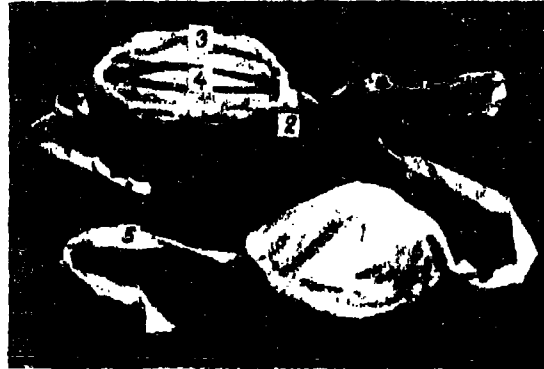


Figure 24. ShB-1 "Lepestok" respirator.  
 1 -- body; 2 -- rubber lace; 3 -- plate;  
 4 -- supports; 5 -- straps

Filtering materials FFM-15 and FFP-15 which have an effectiveness of 99.9% for the most penetrating aerosols are used in the ShB-1 "Lepestok" respirator. The weight of the respirator is about 10 grams; the filtering surface is 250 square centimeters; the resistance to breathing is 3 millimeters of a water column. A properly worn respirator lies tightly against the skin of the face (Figure 25).



Figure 25. A properly worn ShB-1 "Lepestok" respirator.

In conducting repair work connected with the opening of apparatus and communications when there are considerable increases in the permissible concentrations of beryllium and other toxic substances, one should use the pneumatic suits or pneumatic helmets which were developed by A. A. Letavet and S. M. Gorodinskiy.

The "LG-2" pneumatic suit (Figure 26) is worn over the special clothing and completely isolates the body and respiratory organs of the worker from the surrounding environment. The suit has a glass viewer made of organic glass. The suit is made with a polyvinylchloride layer. The feeding of pure air into the pneumatic suit is conducted using special air lines.

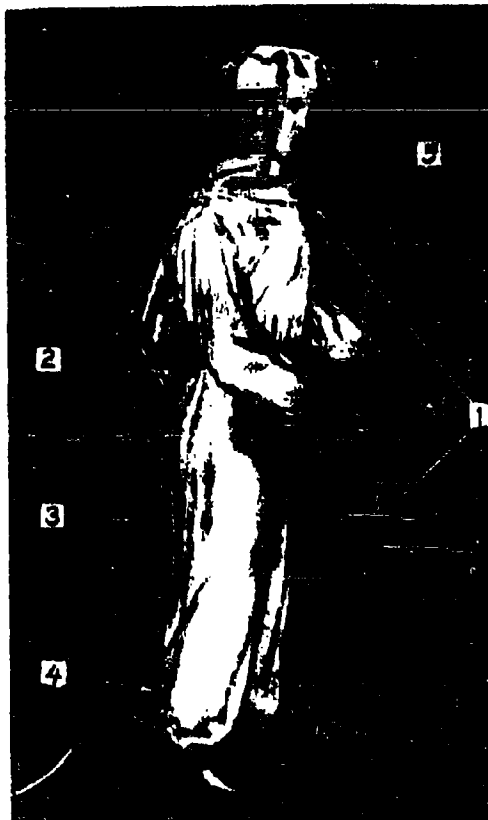


Figure 26. LG-2 Pneumatic Suit  
1 -- plastic coveralls; 2 -- folded aperture; 3 -- hose;  
4 -- exhaust valve; 5 -- glass viewer.

When the conditions do not require the complete isolation of the worker from the surrounding environment, the LI2-1 pneumatic helmet (Figure 27) is employed to protect the respiratory organs. It is made of a thickened polyvinylchloride layer and has a glass viewer of organic glass. Air is fed into the pneumatic helmet by the same method as for the pneumatic suit.



a

b

Figure 27. LI2-1 Pneumatic Helmet  
a -- side view; b -- front view

#### Preventative and Periodic Medical Examinations

All citizens entering beryllium production undergo a medical examination. The cadre departments of enterprises cannot permit personnel to work with beryllium without a positive medical report. The examination is conducted by a doctors' commission at polyclinics of medico-sanitary units or of territorial public health organs.

In conducting the medical examination, special attention is paid to the condition of the respiratory organs, liver, and skin; the vital capacity of the lungs is always determined (spirometry); an X-ray is made of the chest; and a general clinical analysis of the blood and urine is performed.

Diseases which are considered to bar the entry of a worker into beryllium production include the following:

- 1) tuberculosis of the lungs in any form (the presence of petrificates does not serve as a counter-indication);
- 2) tuberculosis outside of the lungs (of the glands, testicles, bones, etc.);
- 3) diseases of the upper respiratory tracts and bronchi; deviation of the nasal bridge which hampers nasal respiration; atrophic rhino-pharyngeal laryngitis; ozena; syccosis of the nose; chronic inflammatory processes of the supplementary cavities of the nose; new growth of the upper respiratory tracts which hampers respiration; chronic bronchitis; bronchial asthma; broncho-ectatic illness;
- 4) pneumosclerosis and emphysema of the lungs;
- 5) organic ailments of the cardiovascular system (defects of the heart, hypertonic illness, expressed arteriosclerosis);
- 6) ailments of the liver and of the bile tracts;
- 7) nephrosis, nephritis, and nephrosclerosis;
- 8) all ailments of the blood and of the blood-producing organs; secondary anemia;
- 9) organic ailments of the central nervous system;
- 10) expressed endocrino-vegetative ailments;
- 11) skin ailments; and
- 12) chronic ailments of the eyelids, conjunctiva, cornea, and tear ducts.

For workers entering an enterprise, the doctors' commission fills out the form for the entering medical examination and the conclusion of the commission. A chest X-ray is attached to the entering medical examination form. All these documents are sent to the shop doctor under whose observation the new worker will be located.

All personnel working with beryllium and its compounds must undergo a medical checkup once every six months. The basic purpose of the checkups is to detect the earliest signs of the action of

beryllium and other production factors on the organism of the workers. The detection of the initial symptoms of such ailments makes it possible, on the one hand, to implement timely medical-prophylactic measures designed to prevent the development of severe irreversible forms of beryllium intoxication and, on the other hand, it helps to determine the most unfavorable working areas where it is necessary to take concrete prophylactic measures to improve working conditions.

In addition, during the medical checkups ailments are discovered which are not connected with causes arising from the work but which do require certain treatment and also ailments are discovered which prevent further work under the conditions of beryllium production.

Periodic medical checkups of the workers are organized and conducted according to plan by the medical-prophylactic elements which service beryllium production with the direct participation of the shop doctor-therapist and the industrial sanitation doctor. An annual operational plan for conducting periodic medical checkups is compiled. The plan covers the number of personnel to receive checkups, their professions, the dates of the checkups, the medical staff to be assembled to conduct the checkups, and also the number and types of laboratory, X-ray and other examinations. The responsible person for conducting the periodic medical checkups is the chief physician (or his deputy for medical affairs) of the medical-prophylactic office (medical unit). Lists of personnel to undergo the medical checkup are presented by the administration of the enterprise. The plan for conducting a periodic medical checkup is coordinated with the trade union organization and the administration of the enterprise. The administration of the enterprise is responsible for prompt appearance of the personnel at the medical examinations in accordance with the approved plan; the medical office is responsible for the quality of the examination.

In conducting periodic medical checkups of personnel working with beryllium and its compounds, it is necessary to have the following medical specialists: therapist, otolaryngologist, dermatologists, neuropathologist, and radiologist. The required laboratory and other diagnostic tests include the following: X-ray of the chest, spirometer, and general analysis of the blood and urine. Besides these, it is necessary to test the urine for its content of beryllium. (74) (See Appendix IV) The results of the checkup are entered in the medical booklet of periodic medical checkups which is maintained for each engineer-technician from the time he starts work; it is kept in a special file by the shop doctor. The results of succeeding medical checkups are entered in the same medical booklet. This makes it possible to provide continuing observation of the state of health of the worker and

simplifies the checking of the indicated medical-prophylactic measures. As a result of conducting a medical checkup it is possible to uncover: ill persons with obvious symptoms of beryllium poisoning; cases of suspected work-connected ailments which require further tests or observation; individuals suffering from a disease which bars them from working with beryllium and its compounds; persons with ailments which require bed or ambulatory treatment; etc.

Upon the completion of the medical checkup of the personnel working in a given shop of an enterprise, a complete analysis is made of the results of the examinations. Depending on the nature and degree of the pathological changes uncovered during the examinations, appropriate medical-prophylactic measures are designated, including the following: systematic dispensary observation; admission for bed treatment or testing; admission to a prophylacticorium, rest home, or sanatorium; provision of a special diet; vacation; temporary removal from the conditions of beryllium production; permanent removal from the conditions of beryllium production; sending the person to a resort; etc.

Sanitary-hygienic measures to improve the working conditions are being developed in these production areas where instances of work-connected ailments are uncovered. These measures are included in a single complex plan of sanitary improvements or in the collective agreement on labor protection, equipment safety, and industrial sanitation at the enterprise.

The medical booklets for periodic medical checkups of workers who have contacted work-connected ailments and of workers who are suspected of having work-connected pathological changes are marked accordingly and are kept in a separate card file under "work-connected sick" and "suspected sick." Control cards are filled out for individuals with general ailments requiring dispensary observation.

The diagnosis of an acute work-connected ailment is established on the basis of tests of the ill person, his prophylactic anamnesis and prophylactic course, and the nature of the working conditions immediately prior to the outbreak of the illness.

The diagnosis of a chronic work-connected ailment is established by a doctors' consultative commission after confinement and testing on the basis of clinical data which has been confirmed by the appropriate laboratory, X-ray and other tests.

Each case of an acute work-connected ailment with loss of capacity for work and all cases of chronic work-connected ailments

with or without loss of capacity for work are to be investigated in accordance with the "Regulation on the notification and registration of work-connected poisoning and work-connected ailments" and the "Instructions on conducting the registration, follow-up, and records on work-connected poisoning and work-connected ailments," as approved by the People's Commissariat for Public Health of the USSR on 16 February 1939. On the basis of the materials from the investigation, the industrial-sanitary physician together with the shop doctors each quarter conducts a detailed analysis of the work-connected disease rate and indicates sanitary measures to be implemented. The data on the work-connected disease rate and the list of sanitary measures are discussed at a meeting with the chief engineer of the plant which is attended by the chiefs of the shops and representatives of the trade union organization.

The struggle against the temporary loss of capacity for work is of great importance in the activities of a medical-prophylactic office and the industrial-sanitary service of a sanitary-epidemiological station which serve the personnel of an enterprise, including those involved in the production of beryllium and its salts.

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PROTECTION OF THE EXTERNAL ENVIRONMENT  
FROM BERYLLIUM CONTAMINATION

Following is a translation of Chapter 6 of a book by Valentin Mikhailovich Kozlov and Valentin Dmitriyevich Turovskiy Berilliy: Toksikologiya, Klinika Porazheniy, Gigiyena Truda (Beryllium: Toxicology, Clinical Aspects of Diseases, Labor Hygiene), State Publishing House for Literature in the Field of Atomic Science and Technology, Moscow, 1962, pages 94-98.

Besides the basic component elements (oxygen -- 49.5%, silicon -- 25.7%, aluminum -- 7.5%, iron -- 4.7%, calcium -- 2.4%, sodium -- 2.6%, etc.) all the elements entering into Mendeleev's System are contained in dispersed form in small quantities under natural conditions in the surrounding external environment (atmosphere, hydrosphere, and lithosphere). (6)

The elements as a result of the constant exchange of substances enter plants and animal organisms.

In the composition of living organisms, besides the 11 macroelements (hydrogen, oxygen, carbon, nitrogen, sodium, magnesium, phosphorus, sulfur, chlorine, potassium, and calcium), which are contained in concentrations of from whole number to hundredth percentages, there are 39 microelements, including beryllium. Many of these microelements are of great importance in the biological processes as mineral catalysts entering into the composition of biological substrata. The content of beryllium in animal organisms is 0.000001%, and in plants it is 0.001%. The quantity of beryllium in the human organism and in animals depends on its content in the external environment.

The importance of beryllium as a microelement has not been studied sufficiently. However, it is known that increased concentrations of it in an organism cause a series of pathological changes. According to the data of N. M. Tomson (6), an excess of beryllium along with simultaneous insufficiency of calcium in an organism leads to beryllium rickets in animals.

The development of the industrial production of beryllium in recent years has led to its spread in the external environment to considerable distances, chiefly as a result of production discharges into the atmosphere. (75, 76) The contamination by beryllium of the surrounding environment in the area of a plant which is receiving and processing beryllium considerably exceeds the concentrations of beryllium which are encountered under natural conditions, even in areas which are rich in beryllium and other minerals containing beryllium. The beryllium which is in the atmosphere near the enterprises enters the organism of people living in the area of the enterprise and in a number of cases causes pathological changes which lead to the development of beryllosis. J. Sterner and M. Eisenbad (32) recorded ten cases of affliction with beryllosis among people who had lived for ten years in the vicinity of beryllium production. M. Eisenbad (10), indicating the high toxicity of beryllium, describes a case of acute disease of the lungs caused by beryllium; this was recorded for a person living in the vicinity of a plant for the extraction of beryllium from ore in Donora, Pennsylvania, USA; however, this acute case was the only one among instances of chronic affliction.

Among persons living at a distance of 1,200 meters from this plant, there were 16 recorded cases of beryllosis, 5 of which ended in death. A test of the contamination of the air by beryllium in the vicinity of the plant during a period of normal operation showed that the concentration of beryllium at a distance of 1,200 meters from the plant varied between 0.00001 to 0.0001 milligrams per cubic meter. At a distance of 400 meters from the plant where the concentration of beryllium in the air was 0.001 milligrams per cubic meter, the frequency of cases of beryllosis among inhabitants not involved in the production of beryllium was about 1%.

G. V. Chamberlain (36) points to 21 cases of beryllosis which developed among persons living near a place of beryllium production but who did not have working contact with beryllium. In addition, he states that in the spectroscopic examination of lung tissue of 13 inhabitants of this area who had died of various causes but did not have clinical symptoms of beryllium disease, in 12 persons there was beryllium. In one of these cases beryllium was found in the lung tissue of a three year old baby who had lived 16 kilometers from the plant.

I. H. Wardi (36) reports of 20 cases of beryllosis of non-work-connected origin among persons living near enterprises using beryllium and among members of the families of workers at these enterprises who brought home clothing which was contaminated with beryllium. Of this total, 6 cases ended in death.

According to the data of M. Eisenbad (10), in the vicinity of a beryllium plant at a distance of 100 meters from the waste stack which was 10.5 meters high, the concentration of beryllium in the air was approximately 0.0002 milligrams per cubic meter for a total discharge of 2,268 grams of beryllium per day or 68 kilograms of beryllium per month. The main sources of the entry of beryllium into the atmosphere were the operations at the subliming and pyrolysis furnaces, the section for receiving and loading the hydroxide, the point for packing the prepared product, and the drier units. Besides these, the air of the air-circulation system which had become contaminated when repairs were being performed while the apparatus was open could be a source of beryllium contamination of the atmosphere.

In order to lower the concentrations of beryllium in the discharge air, they employ sleeve filters and wet scrubbers; however, with this method the necessary cleanliness of the discharged air is not achieved.

For cleaning air with high concentrations of dust and with dust particles greater than one micron in size it is proper to use sleeve filters. Such dust is formed during the processes of crushing and pulverizing the beryllium concentrate and sodium fluosilicate and also during the operations of preparing a charge.

The cleaning of the air in places where gases and aerosols are formed is best performed using foam apparatus. Foam apparatus are scrubbers in which aerosols of beryllium are attracted by the spraying compound in the counter current of air. In order to increase the contact surface, nozzles are employed on which there forms a layer of foam which gives greater effectiveness in trapping the aerosols. Such a type of cleaning device can be recommended for the preliminary cleaning of air which has been expelled by local pumps from the equipment, at operations of roasting a charge, in drying units, in subliming and pyrolysis furnaces, in decomposing furnaces, and in other production sectors where considerable quantities of dust or gas are formed.

Besides the foam apparatus, for preliminary cleaning it is possible to use centrifugal rotating cleaning it is possible to use centrifugal rotating dust removers (77) and fiber filters with a fiber diameter of 500 to 10 microns. Fiber filters retain up to 98% of the beryllium aerosols. When using fiberglass, special attention should be devoted to the even distribution of the filter layer, otherwise the air streams can create spaces between the fibers through which the aerosols can pass freely through the filter.

Air from the local pumps and technological blowers which has been preliminarily cleaned of the main mass of dust must go to the exhaust ventilating center for further cleaning by the two-step method. For the first step of cleaning the aerosols it is possible to use granular tower filters in which charcoal turnings and teflon and rubber grains are used as the filler. The filtration in granular filters is based on the presence in the air of aerosols of condensation origin. The effectiveness of these filters reaches 99%.

Besides the tower granular filters, it is also possible to use fiber filters as the first stage in cleaning air of aerosols at the exhaust ventilation center.

A higher degree of cleaning the air while trapping finely dispersed aerosols (less than one micron) is provided by the second step of cleaning using frame filters of FFP-15 fabric.

FFP-15 fabric carries an electric charge. The trapping of the aerosols is accomplished both by the electrostatic precipitation of charged particles and between the fibers of the fabric, the thickness of which is less than one micron. The effectiveness of cleaning using frame filters of FFP-15 fabric reaches 99.99%. The air after the final cleaning through the frame filters of FFP-15 fabric can be discharged into the atmosphere through a pipe, the height of which has been calculated.

The air of the general ventilation system which is evacuated from the zone of the equipment and the repair-transport areas also should be cleaned by the equipment of the exhaust ventilation center.

The question of the location of enterprises involved in the production of beryllium is of great importance in protecting the health of the surrounding population because the toxicity of beryllium exceeds the toxicity of all compounds previously used in industry and because there is no information on the influence of small concentrations of beryllium on the organism of man throughout the course of his life. In building plants for obtaining and using beryllium, it is necessary to envisage a sanitary-protective zone with a radius of not less than 2 to 3 kilometers.

Along with the gas and aerosol discharges, there are also liquid and solid wastes which have an unfavorable influence on the extent of contamination of the external environment. (78,79) Solid wastes in the form of dismantled equipment, building rubble formed during reconstruction work, and the waste pulp and residue which contains residual amounts of beryllium can be secondary sources of beryllium contamination of the air and soil. Therefore, all dismantled equipment, contaminated gear and other parts should be

carefully washed in special premises and only afterwards should they be taken out of the shop for further transporting or repair. Building rubble and other solid wastes which are not to be used any more should be buried in a special area on the plant grounds. Wastes which are to be burned should be burned in special furnaces which are equipped with a system for trapping aerosols from exhaust gases.

Production wastes in the form of pulp, cakes, and gravel should be cast into a waste reservoir by a hydraulic conveyor system. The purified water of the waste reservoir should be reused primarily in the hydraulic conveyor system.

The waste reservoir should be separated from any living quarters, public buildings, and rest areas of the workers. Around the waste reservoir there should be a sanitary-protective zone with a radius of not less than one kilometer.

In order to eliminate the possibility of forming dust and spreading it from the surface of the waste reservoir, the waste should be covered with fresh dirt as the various sections start to fill up.

The industrial waste water from beryllium production can contaminate open water reservoirs with beryllium.

The works of A. F. Zaytseva and Ye. G. Repina (40) indicate that a beryllium content in the water of 0.05 milligrams per liter does not have a retarding effect on the biochemical processes of the consumption of oxygen. Concentrations of beryllium in the water of 0.5 to 1 milligram per liter cause a retardation of the oxidation of glucose (BPK-8 was 52 to 58%); for a beryllium content of 3 milligrams per liter the consumption of oxygen was sharply retarded (BPK-8 was 27%); and for 5 milligrams per liter it stopped completely.

This data makes it possible to establish the fact that the retarding of the processes of the biochemical consumption of oxygen begins with concentrations of beryllium in water of greater than 0.5 milligrams per liter. The latter can have a negative effect on the operation of equipment designed to accomplish the biological purification of waste water and can also disrupt the processes of self-purification of the reservoir from organic substances of ordinary waste.

Waste water from beryllium production should be cleaned thoroughly and after this should be returned to the technological process.

Then the water of open reservoirs will remain pure.

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