HYGIENIC CONTROL OF BERYLLIUM

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1. Characteristics and Major Applications of Beryllium

Beryllium (abbreviated to Be) is a relatively rare metal present in the amount of 6-9 ppm in the earth's crust. The major beryllium ores have been beryl, phenacite, chrysoberyl, etc.; at present, only beryl is of industrial importance. Beryl is characterized by pale blue-green columnar crystals, its specific gravity is 2.6-2.8, and its hardness is 7.5-8.0.

Emerald is a precious form of green beryl, aquamarine is blue-green beryl, and chrysoberyl is known as alexandrite. Major mines are found in India, Brazil, Argentina, Africa, etc., but Brazilian production is largest. Recently, beryllium has been called a "wonderful metal" because of its specific characteristics as well as the characteristics of its compounds. The major fields of application of beryllium are shown in Table 1. As is apparent from the table, beryllium has a wide range of useful applications as one of the leading elements in modern industry.

2. Health Disorders Caused by Beryllium

1) Types of health disorders

The health disorders caused by beryllium may be classified as acute and chronic. The acute disorders include conjunctivitis, contact skin inflammations, skin ulcers, and a series of acute respiratory system disorders (upper respiratory tract inflammation, trachea inflammation, bronchitis, acute pneumonia, etc.). With regard to chronic beryllium-

Table 1. Characteristics and major fields of application of beryllium.

Material	Application state: Application form	Characteristics of beryllium used	Current major fields of application
Metal beryllium	Plates	Less-X-ray absorption, light and strong, good heat sink properties	X-ray tube windows, airplane structural materials Thermal sink plates for space exploration
	Tubes	Less absorption of hot neutrons, strong at medium temp., and corrosion resistant	Fuel cladding for natural uranium power reactors
Beryllium oxide	Moldings, various shapes	Good neutron decelerating capacity, heat resistant Dielectric material and good thermal conductor	Decelerating material for hot neutron reactors Thermocouple protective tubes, chemical and scientific experimental devices
		High heat resistance, strongly resistant to thermal stress, and chemically stable	Crucibles, expensive refractory material
Beryllium-copper alloys	Plates or wires	Nonmagnetic, extremely good spring properties	Spring material, diaphragms, bellows
	Rods, castings	Hard, good electroconductivity Good thermal conductivity and strong No impact flash, hard	Welding electrodes, switching parts Various molding tools Safety tools
Aluminum-beryllium-(magnesium) alloys	Mother alloy	Improve antioxidizing properties, prevent burning of magnesium	4/1,000% addition to 10% hydrosodium, 3/1,000% addition to magnesium alloy castings, 0.01% addition to magnox alloys

Table 1. (Continued).

Material	Application form	Characteristics of beryllium used	Current major fields of application
Magnesium-beryllium alloys	Extruded rods	Improve antioxidizing properties, less absorption of hot neutrons	Cladding for fuel used for carbon dioxide cooled power reactors
Nickel-beryllium alloys	Plates, castings	Strong Strong	Special spring materials Drill bits, pump parts
Zinc-beryllium alloys	Plates	Ductility not found in other zinc alloys	Deep-contracted electric parts
Beryllium-iron alloys	Plates, various worked materials	Strong and anti-corrosive	Corrosion-resistant spring hangers, wear resistant parts

(Header spanning Material and Application form: "Application state")

[Source: Beryllium Kondankai (Beryllium Discussion Group)]

related disorders, beryllium lung (berylliosis) which is a pulmonary granuloma and skin granuloma caused by penetration of Be compounds inside the skin are known.

On the other hand, in addition to these human health disorders, lung cancer, malignant tumors such as osteosarcomas, etc., rachitic disorders and osteosclerosis have been induced by Be compounds in animal experiments; however, the occurrence of these disorders in humans has not been reported to date.

Fig. 1. Contact skin inflammation.

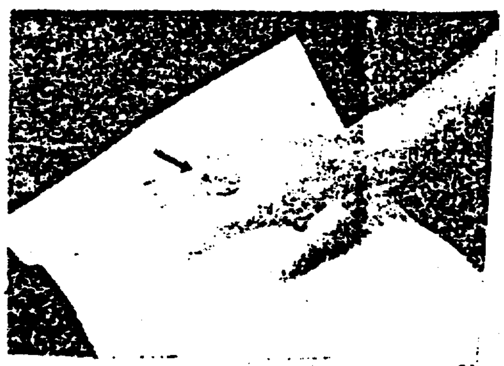

Fig. 2. Skin ulcer.

2) Clinical reports of beryllium disorders

a) Acute Be disorders

Contact skin inflammation (Figure 1) is most often observed among workers handling beryllium; small grains and reddened papules are seen, primarily on the exposed portions of the body such as the face, neck, forearms, legs, etc., although, initially, these symptoms are limited to the contact areas. The itching sensation is strong, and the affected area gradually expands. In serious cases, erosive and bullar exanthema of the entire body, similar to that of measles, occurs, but these symptoms disappear within one month, and the prognosis is generally good. A similar evolution is also observed in the case of conjunctivitis. Skin ulcers (Figure 2) generally do not occur on healthy skin, but they often occur where cuts or burns are present. At first glance, the ulcers appear to be "corns", but they cause a dull pain if pressed. If left alone, the ulcers do not expand; however, healing does not occur unless a small portion of the skin is excised.

Most of the respiratory disorders are thought to be caused by local irritation by Be compounds when their fumes, gases or powders are inhaled. The most serious clinical cases are those of acute pneumonia (Figure 3); death due to beryllium-induced pneumonia has been reported in foreign countries. The characteristics of this disorder include the absence of inflammation, even though it is referred to as pneumonitis. The disorder is characteristically limited to occurrence within three months after exposure to beryllium. The initial symptoms are a sensation of malaise throughout the entire body, poor appetite, a heavy feeling in the chest, a hacking cough, and slight difficulty in breathing; within a few days, the symptoms worsen. Clinically, the most serious period occurs about 15 to 20 days after onset; subsequently, the symptoms are suddenly reduced, and complete recovery occurs around the 30th to 40th day. However, in cases which are diagnosed and treated promptly, the symptoms are completely eliminated within 7 to 10 days in most cases. Prognostic investigation of 26 cases for 4-13 years showed no abnormalities; no symptoms indicative of chronic disorders were found. The occurrence of acute beryllium-related disorders at a beryllium refinery is summarized in Table 2.

Table 2. Frequency of occurrence of acute beryllium-related disorders (1958-1970).

Disease \ Year / No. of workers	'58	'59	'60	'61	'62	'63	'64	'65	'66	'67	'68	'69	'70	Total
No. of workers	28	46	78	100	147	242	247	284	281	302	325	326	370	2.834
Acute Be pneumonitis	6 (15.8)	2 (4.3)	7 (9.0)	2 (1.8)	3 (2.0)	2 (0.8)	1 (0.4)	1 (0.4)	1 (0.4)	0	1 (0.4)	0	0	26 (0.9)
Trachea inflammation, bronchitis	11 (2.9)	2 (4.4)	10 (12.8)	0	3 (2.1)	1 (0.4)	0	1 (0.4)	3 (2.2)	7 (2.3)	5 (1.5)	2 (0.6)	0	45 (1.6)
Contact skin inflammation	21 (55.3)	5 (11.0)	19 (24.4)	25 (22.8)	26 (17.7)	24 (9.9)	15 (6.1)	5 (1.4)	4 (1.4)	23 (7.6)	2 (0.6)	5 (1.4)	8 (2.1)	181 (6.4)
Conjunctivitis	5 (13.2)	1 (2.2)	10 (12.8)	12 (10.9)	8 (5.4)	6 (2.5)	4 (1.6)	0	4 (1.4)	1 (0.3)	0	0	0	51 (1.8)
Other	5 (13.2)	2 (4.3)	5 (6.4)	0	2 (0.8)	1 (0.4)	0	1 (0.4)	6 (2.1)	1 (0.3)	0	0	0	23 (0.8)

(percent, inside parentheses)

b) Chronic Be disorders

Be lung (berylliosis) (Figure 4) is caused by the long-term inhalation of the fumes, gases or powders of BeO, Be silicate or Be phosphate. The occurrence of so-called pneumoconiosis is suspected among workers handling beryl, metallic Be, mother alloys with Cu, Al, Ni, Fe, Mg, etc., which are water-insoluble substances similar to those compounds described above, but the occurrence of berylliosis is said to be rare. The subjective symptoms of this disorder include gradually progressing difficulty in breathing, coughing, often accompanied by expectoration, chest pain, weight loss, and a sensation of malaise in the entire body. These symptoms, however, are weak at the beginning; they often occur without being recognized.

For the early diagnosis of this disorder, it is most important to look for diffuse, nodal and pneumoconiosis-like findings in the lung field by direct X-ray examination of the chest; the subjective symptoms often occur several months to several years after the X-ray evidence. Be is often detected in the patients' lung tissue samples, urine, blood, etc., but there is no constant relationship of the amount and frequency of Be detected to the severity of the chronic disorders. According to the data for the cumulative number of deaths from chronic Be-related disorders in the United States for the past 25 years, the mortality was 264 (35%) among 475 workers, and it was 31 among 60 patients of a general public nature (explained in detail, later). These patients were exposed to a high dose of Be prior to 1956; these diseases have barely been observed among beryllium workers since then because the work environment has been significantly improved (Hardy, 1966) [1]. In the United States, 21 cases of acute pneumonitis and subsequent chronic disorders have been reported. But the Be exposure status and the amount of Be exposure, etc., are not known; it is difficult to conclude that the chronic disease is derived from the acute disease. Among those cases studied by the author, no such transition was observed.

c) Treatment

The first step in the treatment of Be disorders is to immediately remove the patient from the Be-exposure environment. In the case of acute pneumonitis, rest, general maintenance, symptomatic therapy, prevention of complications, oxygen inhalation if necessary, etc., may be carried out, and administration of adrenocortical hormones is also effective. The treatment is strongly affected by the concentration of the Be exposure; but equally important are the stage at which the disease was diagnosed, the resting period (removal of the patient from the Be environment), and the previous therapy, etc. On the other hand, at present, there is no decisive treatment method for the chronic disease. During a certain period in the past, the administration of ATA (aurin tricarboxylic acid) and ACTH was said to be effective; recently, it has been reported that the mortality rate of the chronic disease was reduced by the administration of adrenocortical hormone.

3) Workplaces with frequent Be disorders

The sites where the acute disorders are often observed are those involving the Be refining process, especially the sites where the baking and sintering operations of Be compounds, pulverization operations using crushers or electric or arc furnace related operations are carried out; in contrast, the disorders almost never occur at sites involving ore crushing, molding and processing of mother alloys, extraction, etc. On the other hand, those workplaces which are liable to be overlooked are those places where small-scale testing furnaces are constructed, and research projects or analytical tasks are carried out; cleaning of the floor, etc., of the workplaces where Be exposure is possible has to be carried out carefully. According to the United States data on the chronic disease, cases are observed in fluorescent-lamp production (52.4%), Be refining operations (6.4%), atomic-power related industries (8.2%), neon gas production (4.8%) and the ceramic industries (4.4%); most of these cases are due to exposure to water-insoluble beryllium compounds.

Fig. 3. Acute beryllium pneumonitis.

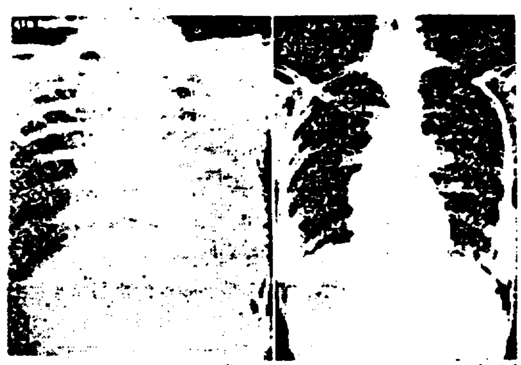

Fig. 4. Chronic beryllium lung (berylliosis).

4) Be exposure concentration and occurrence of disorders

The guideline for the allowable amount of Be is 2 μg/m^3 (transient limit of 25 μg/m^3 in plant environments and 0.01 μg/m^3 outdoors) (U. S. AEC environmental standard) [2]. Among the acute disorders, inflammation of the skin is often observed as a result of direct contact with soluble

Be salts; however, the respiratory disorders are caused by direct penetration of Be compounds into the respiratory system.

If the amount of Be inhaled is greater than 100 $\mu g/m^3$, many cases of respiratory disorder occur as a result of local irritation and intoxication, even without involvement of allergic reactions to Be [3]. In the acute pneumonitis cases observed by the author, the onset of the disease was observed within three months after the workers started to work at Be exposures of 25-70 $\mu g/m^3$. In the case of bronchitis, the Be concentration range is wider than the above range. However, if the working environment concentration is lower than 2 $\mu g/m^3$, disorders almost never occur.

On the other hand, in the case of chronic disorders, the beryllium exposure concentration is as high as 10-50 mg/m^3 in the American cases. Many reports have shown that the extent of Be exposure in the United States before 1956, including the above example, was remarkably high. In those cases studied by the author, a small number of the workers who were involved for ten or more years in Be-related operations, exhibited slight pneumoconiosis-like findings; however, the Be exposure was 2.15 $\mu g/m^3$ (10.85-0.07 $\mu g/m^3$) for the immediate past five years and 11.51 $\mu g/m^3$ (70.5-0.98 $\mu g/m^3$) for the five-year period before that. Therefore, if the continuous Be exposure is less than 2 $\mu g/m^3$, the period before the chronic disorder is observed is long, and the progress of the disease is slow [4].

3. Management for the Prevention of Beryllium-related Disorders

1) Characteristics and problems of environmental management

In order to prevent beryllium-related disorders, it is necessary, first of all, to change the Be exposure environment. Furthermore, in order to maintain the strict environmental standards described above, efforts have to be made not only in the field of public health but also in the fields of environmental engineering and economics. In this context, it is rather irrational to carry out centralized environmental management of complex production sites. It is desirable to carry out careful and smooth environment control considering and emphasizing the actual occurrence of beryllium-related disorders.

Among the various work processes which involve handling Be and its compounds, the steps which are especially important for the prevention of beryllium-related disorders are as follows:

(a) In the processes for the production of industrial BeO, purification of crude BeO, and production of beryllia porcelain, operations such as pulverization, mixing, calcination, baking, furnace charging and discharging, transport, weighing, hopper operation, loading-unloading of containers, etc., of Be compounds, Be alloys, and their mixtures with other substances.

(b) In the processes for the production of Be-Cu mother alloys, operations such as fusion, degassing, forging, mixing, drying, transportation, weighing, hopper operation, charging-discharging from containers, etc., of Be-containing raw materials.

(c) In the processes for the production of Be-containing products, operations such as weighing, mixing, drying, reaction, fusing, electrolysis, pulverization, fractionation, molding, transportation, weighing, hopper operation, charging-discharging of containers, etc., of Be-containing raw materials.

It is necessary to consider complete ventilation, local gas collection, local dust collection, isolation of the sites for the operations described above, as well as sealing off of small portions of the processes, automation, etc.

One example of the environmental improvement in a company is described below. The beryllium sintering operation is one of the procedures which is liable to cause acute disorders. At the beginning, the sintering operation included the manual procedures of charging and discharging burned products directly from the sheathings. Therefore, various attempts at environmental improvement were carried out such as isolating the manual operation site by means of an air curtain so that the operators did not inhale Be directly, recovering burned products from their sheathings by suction utilizing vacuum cleaners (Figure 5), and further improving the above procedures to pile up bottomless sheathings, recover the burned products by suction from the top and transfer them to a hopper by forced air transportation (Figure 6, left). Recently, the section was automated, the sheathings having a risk of breakage or secondary contamination were completely eliminated, and the extent of the operations in which the operators had to come into contact with Be-containing substances was reduced as much as possible to cope with the problems (Figure 6, right).

Fig. 5. Improvement in sheath removing of beryllium compound (I).

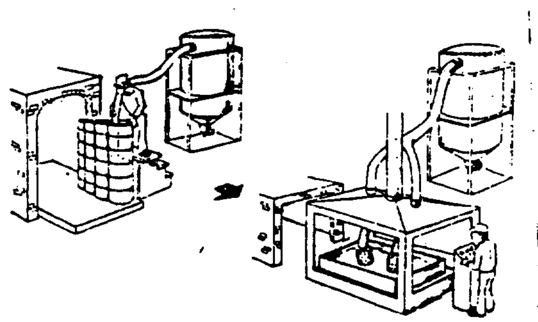

Fig. 6. Improvement in sheath removing of beryllium compound (II).

It is delightful to find that various efforts have been made to control Be contamination in the environment in other processes, although the nature of the measures taken varies considerably. One point to emphasize is that it is premature to think that the prevention of Be-related disorders has been completely finished when the macroscopic improvement in the environment has been completed.

Although automation and sealing has been carried out extensively, there are always some operations which still require the presence of operators, and it is not unusual to find unexpected application problems at the operation sites. For example, the operation of dismantling arc furnaces is such a case; there are many other examples such as handling the containers used for compounding operations, disposal of the sheathings used for sintering operations, contamination of work clothing and protective tools, etc.

Furthermore, the environmental improvement goals are generally established in the context of a regular production schedule; therefore, if the demand is increased and the delivery dates become too pressing, the balance of maintaining such environmental standards is broken without much notice, and unexpected environmental contamination may be generated. In contrast with the macroscopic problems, these microlevel problems cannot be solved without the understanding and cooperation of the individual workers; it is important that these problems must be solved with the cooperation of labor and management, from the viewpoint that the health of the workers is always to be given first priority.

2) Characteristics and problems of health management

There are two important viewpoints for the health management of Be workers. One is the prevention of acute disorders, and the other is the problem of chronic disorders. The disease mode of the Be disorders is extremely diverse, and, in general, there is no linear relationship beween the acute and chronic disorders in the form of acute → semiacute → chronic. In addition, the acute disorders include sensitization reactions (Be acts as an antigen in a living body which, in turn, produces an antibody inducing the antigen-antibody reaction, and if this reaction is advantageous to the body, it is called immunity, but if it is a disadvantageous phenomenon as in the case of Be, it is called allergy); this involvement of sensitization renders the problems for prevention of acute disorders more complex. Furthermore, the chronic disorders can occur under the influence of exposure to a rather small amount of beryllium for a long period of time and the prognosis is poor. Therefore, it is necessary to approach the health maintenance management of Be workers from these two sides; the main point is to establish a control system effectively satisfying both the acute and the chronic aspects.

a) Health examination (Figure 7)

The figure shows an actual health maintenance system utilized by the author in one company. In outline, the system is comprised of health examination at the time of hiring, periodic health examinations, job-change control, and monitoring of retired employees. Figure 8 shows acute-disorder preventive measures developed by one author; these measures have been carried out to date. The health examination is carried out every month for three months after hiring since the author's experience shows that the acute disorders often occur during this period (Figure 9). This process is also effective in increasing the interest of the individual workers in their health and providing them with information related to the prevention of Be disorders while they are in direct touch with the physician involved in health management.

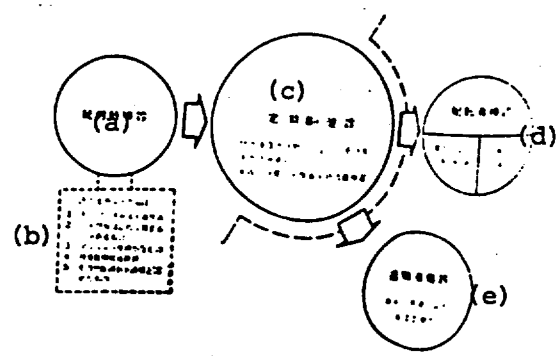

Fig. 7. Health control for beryllium plant workers.

KEY: (a) hiring time health examination; (b) major items to be checked: 1. illegible patch test illegible; 2. illegible; 3. allergic reaction; 4. illegible; 5. illegible; (c) periodic Be health examination. Every month for 3 months after hiring, subsequently, every 3 months. Body weight, subjective symptoms, illegible; (d) job-change control illegible and (e) retired employee monitoring. Once a year.

The direct chest X-ray examination is one of the most important measures in the health examination for the prevention of chronic beryllium-related disorders. In addition, it is necessary to carry out tests to determine the pulmonary ventilation function as well as examinations to detect alveolar expansion disorders. Furthermore, the examination contents must contain tests to detect increases in the hematocrit, increases in the serum protein, γ-globulin number increases, high blood calcium levels, poor liver function, right-heart load, etc. Nevertheless, it is very difficult to develop a generalized and effective system to satisfy all of these requirements; however, one daring preliminary plan is shown in Table 3.

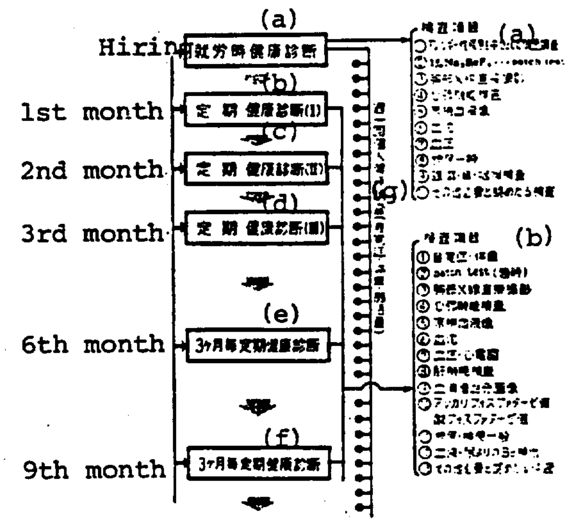

Fig. 8. Health examination at the time of hiring and at regular intervals.

KEY: (a) health examination at the time of hiring; (b) regular health examination (I); (c) regular health examination (II); (d) regular health examination (III); (e) regular health examination, every 3 months; (f) regular health examination, every 3 months; and (g) individual health examination (subjective symptoms, body weight, and vital capacity) once a week.

<u>Test items (a)</u>

(1) health history emphasizing allergic reactions
(2) 1% Na_2BeF_4 patch test
(3) direct chest x-ray
(4) cardiopulmonary function testing
(5) peripheral blood picture
(6) blood sedimentation
(7) blood pressure
(8) general urine examination
(9) eye, ear, nose and throat examination
(10) other necessary tests

<u>Test items (b)</u>

(1) subjective symptoms, body weight
(2) patch test (suitable time)
(3) direct chest x-ray
(4) cardiopulmonary function testing
(5) peripheral blood picture
(6) blood sedimentation
(7) blood pressure, electrocardiogram
(8) liver function testing
(9) serum protein fraction picture
(10) alkali phosphatase value, acid phosphatase value
(11) general urine and stool testing
(12) detection of Be in blood and urine
(13) other necessary tests

Table 3. Health examination contents for the prevention of acute and chronic beryllium-related disorders.

Health examination at the time of hiring	Periodic health examinations	Detailed health examination (reference items)
1. Work history investigation 2. Current and previous disease check a) Allergic respiratory diseases such as bronchial asthma, etc. b) Occlusive respiratory diseases such as chronic bronchitis, pulmonary emphysema c) Skin and eye diseases 3. Direct chest X-ray examination a) Pneumoconiosis, pulmonary fibrosis, bronchiectasis b) Tuberculous and non-tuberculous pulmonary disorders c) Abnormal cardiac shadow 4. Subjective symptoms Malaise of the whole body, poor appetite, weight loss, pharynx unusual sensation, pharynx pain, uneasy chest feeling, chest pain, coughing, sputum, short breath, palpitation, breathing difficulty sensation, skin itching sensation 5. Vital activity 6. 1% Na_2BeF_4 patch test (excluding natural positive)	1. Be exposure status a. type of Be handled b. work and operation c. Be handling period 2. Investigation of past diseases to date from the time of hiring (or the last health exam.) 3. Body weight measurement 4. Skin, eye and throat exam 5. Chest physical testing 6. Subjective symptoms Malaise of the whole body, poor appetite, pharynx unusual sensation, pharynx pain, uneasy chest feeling, chest pain, coughing, sputum, short breath, palpitation, breathing difficulty sensation, skin itching feeling 7. Direct chest X-ray examination Especially, acute pneumonitis and pneumoconiosis 8. Pulmonary ventilation function exam. Vital activity, 1% vital capacity, 1 second amount, 1 second rate, motion index, ventilation reserve rate * Health exam. carried out 3 months after hiring and 3-6 months thereafter.	1. Detailed chest X-ray examination 2. Blood tests a. hematocrit value, acidophilic leukocyte proportion b. serum total protein, A/G γ-globulin 3. Electrocardiogram 4. Pulmonary expansion function 5. Liver function 6. Quantitative determination of Be in the blood and urine 7. 1% Na_2BeF_4 patch test 8. Erythrocyte sedimentation 9. Tuberculin reaction (distinguish from sarcoidosis) 10. Pathohistological examination by biopsy

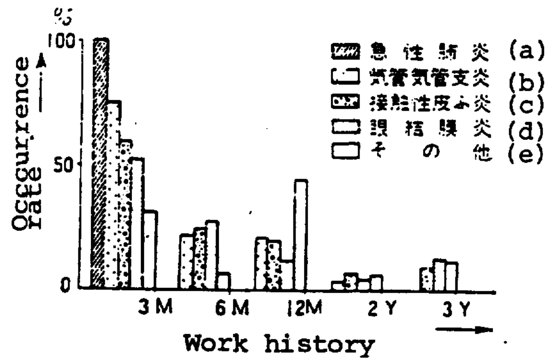

Fig. 9. Acute beryllium-related disorder occurrence period.

KEY: (a) acute pneumonitis; (b) trachea inflammation and bronchitis; (c) contact skin inflammation; (d) conjunctivitis and (e) others.

b) 1% Na_2BeF_4 skin patch test

The Be skin patch test is useful for determining whether the body has become sensitized by Be.

The skin patch test using 1% Na_2BeF_4 is a method developed by the author. Lint cloth with a disc (1-cm diameter and about 0.5 cm thick) of testing material containing 1% Na_2BeF_4 (hydrophylic ointment base) and a control cloth (hydrophylic ointment) are patched inside the upper arm, fixed and sealed. After 48 hours, examination for reddening and papules is carried out. If the site shows reddening + papules (small grain size) or papules, the result of the test is positive (Figure 10). If the reaction is only reddening or unclear papule formation with 2-3 papules, the result is reexamined after a day or two, or the testing is carried out again. After the testing, the site is sufficiently cleaned, and an antihistamine or an ointment containing adrenocortical hormone is applied. If the test has to be repeated, it is necessary to avoid the same site.

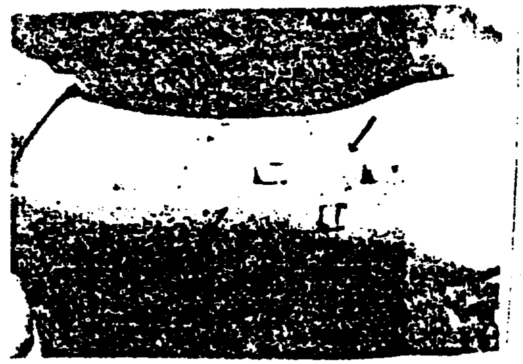

Fig. 10. 1% Na_2BeF_4 skin patch test positive reaction.
* left --- control (hydrophylic ointment)

The acute disorders, especially skin inflammation, create a positive result of this test by themselves, and if the test is carried out for these cases, a severe local reaction (wide-range reddening, swelling, papules or bulla formation in some cases) is often observed. If the reaction is significant, the site often shows a thin deposit of a dark brown pigment, but it disappears completely sooner or later, and there have been no problems after this skin patch test. Incidentally, the percentage of natural positive reactions is 3.7% (13/355) for males and 4.6% (3/65) for females; **if these naturally-positive persons are allowed to take jobs which** involve handling beryllium, various acute **disorders occur at an early stage,** usually with severe symptoms, according **to the author's experience.**

The significance of a positive skin patch test according to the author's previous studies may be summarized as follows.

(a) In the case of an individual who has no history of exposure to beryllium, it is possible to determine whether this individual has natural hypersensitivity.

(b) If the Be exposure is 2 $\mu g/m^3$ or more, more than 80% of the workers exhibit positive results to this skin patch test within 6-12 months. However, these results cannot be connected directly to Be-related disorders.

(c) If the Be exposure is less than 0.03 $\mu g/m^3$, the reaction to this test may not change from negative to positive. The result indicates that the Be sensitization is unsuccessful, but it does not mean that no Be has penetrated into the body.

(d) Once the reaction is positive, it rarely reverts to negative.

(e) Patients with acute Be-induced disorders exhibit positive test results. The intensity of the reaction is stronger than that of healthy persons, and the time required for the reaction to appear is shortened.

(f) A small percentage of workers exposed to Be for a long period of time continue to exhibit negative results to this skin patch test.

(g) This skin patch test is useful for distinguishing Be-related disorders from other similar diseases. However, if the patients have previously been exposed to beryllium, there is only little diagnostic significance [5].

c) Detection of Be in the urine of beryllium workers

With respect to the amount of Be excreted in the urine by beryllium workers, the tendency is that the longer the duration of the exposure to beryllium, the higher the level of beryllium in the urine; however, if individual urine levels are considered, there is often no constant relationship between the duration of the exposure and the amount of beryllium excreted in the urine.

The amount of Be excreted in the urine depends to a major extent on the type of beryllium to which the worker has been exposed, i.e., water-soluble or insoluble beryllium; thus, evaluation of the urine levels requires consideration of the type of beryllium and the exposure situation.

Furthermore, subjects whose exposure to beryllium has been interrupted still show the presence of Be in their urine samples; in some cases, excretion of trace amounts of beryllium can continue for an extremely long period of time (maximum of 11 years according to the cases studied by the author). However, no specific abnormalities have been observed with respect to these results to date; however, studies are currently being carried out on this problem regarding the effect of trace amounts of Be on the physiological level.

If the Be is detected in the urine of beryllium workers, it indicates the fact that the workers have been exposed; however, at present, the problems of Be-related disorders cannot be related to the detection of urinary beryllium excretion [4].

d) Management of protective equipment and work clothing

Depending on the requirements, workers use required work clothing, various dustproof masks, airline masks, gloves, aprons, aluminum heat-proofing clothing, protective glasses, etc. The problem is how these protective tools and work clothing are managed. This management is important since it is related not only to the problems of the individual health of the workers but also to the possibility of these materials becoming sources of secondary contamination. Inspection before working and arrangement after working is desirably carried out efficiently in an organized control process system rather than by individual control at the production sites.

Figure 11 shows an actual example at a company. The workers come to the plant wearing their own clothing, they change into the required work clothing in the locker room prior to work, they bathe after work, and in this case, the work clothing is tossed into a chute connected to a required container in the adjacent laundry room. After bathing, the workers change back to their own clothing to go home. The contaminated clothing and protective equipment are collected by workers exclusively assigned to this task, and the collected materials are stored in specific boxes. Incidentally, stockings or socks are washed by the individuals and stored by them.

[Japanese communal-style] bathing seems to be useful for avoiding Be contamination; however, if the bath water is not continuously changed, the Be concentration in the bath water is significantly increased, and as a result, this bathing process becomes meaningless. Therefore, the bath water has to be changed sufficiently, and a sufficient amount of hot water before entering the bath tub and after coming out from it has to be used, or a shower may be taken.

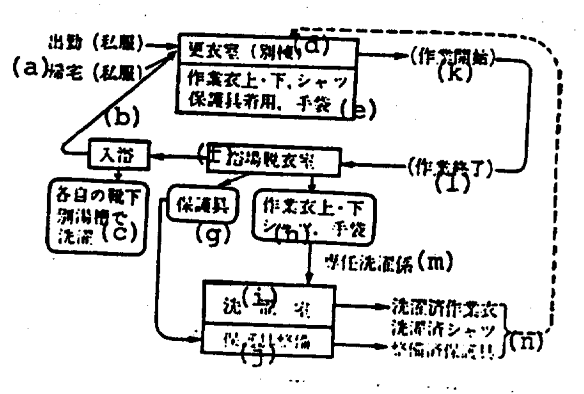

Fig. 11. Management of protective equipment and work clothing for Be workers.

KEY: (a) coming to work (own clothing), going home (own clothing); (b) bathing; (c) wash socks and stockings using a special tub; (d) locker room (different building); (e) work clothing, shorts, protective gear, gloves, etc.; (f) bathroom locker; (g) protective tools; (h) work clothing, shirt, gloves; (i) laundry; (j) protective gear maintenance; (k) start work; (l) finish work; (m) washing workers and (n) washed work clothing, washed shirts, maintained gear.

e) Health control organization and health education

No single system can be used as a health control organization system, but in order to promote occupational health control, the system must be rooted at this stage, or no significant effect can be expected.

In one company, a Be-related disorder measures committee has been established based on the labor contract between management and workers (Table 4); in order to make the system practical, an exclusive Be committee is established comprising representatives from management, the physician staff, health management department, related departments, and the labor union. This committee provides an occupational safety and health group at each site. Although this type of system often tends to become a formal operation without any substance, in the present case the participants' interest in the subject is strong, and the meetings of the committee have been carried out smoothly and effectively.

With respect to health education, it is very important that top management recognize the need for this activity. The physician has discussed with top management the current situation, problems, specific plans for control, etc. However, all of the information related to health management is available to the labor union side, and ideas have been exchanged with respect to specific Be control management.

With respect to the Be workers, an effective shortcut is to let them have all of the available information related to Be such as the current state of Be disorders, characteristics of prevention management, daily advice and reminders, etc. New employee education and health re-education after working for a certain period are carried out in groups according to the type of operations; it is important to maintain contact with the workers by setting up a suggestion/question box, carrying out individual interviews, etc.

f) Health management in subcontractors and related businesses

The health control management of subcontractors handling Be tends to be ignored. In one company, Be environmental measurement, environmental improvement guidance, employee health examination, etc., have been carried out with mutual understanding and cooperation between the two.

Furthermore, in the case of temporary employees from outside of the company, health examination is carried out and attempts are made to let them understand the problems of Be-related disorders as much as possible.

Table 4. Management-labor contract related to beryllium-induced disorders (extract).

Article 1 (Objective)

This contract is to be signed to promote the prevention of beryllium-related disorders, health control management, and medical treatment measures.

Article 2 (Beryllium-related disorder measurements committee)

In order to accomplish the objectives described in the previous article, a beryllium-related disorder measures committee (referred to as the Committee, below) comprising members from both management and the labor union is established; the Committee will decide upon specific items for the promotion of the objectives. The Committee is operated in accordance with the "Beryllium-related disorder measures committee, by-laws" set up separately.

Article 3 (Health eduction)

Health education measures are periodically carried out by the company in order that workers involved in beryllium-handling jobs can understand and receive the information required for the prevention of beryllium-related disorders.

Table 4. (Continued).

Article 4 (Observing and respecting related regulations)

Workers involved in beryllium-handling jobs are to observe and respect the regulations established by the company including company rule EC-22 "Beryllium health control regulations", in order to prevent beryllium-related disorders.

Article 5 (Beryllium handling jobs)

The beryllium handling jobs are those of production-processing, research-analysis and handling of beryllium, its alloys and its compounds; the specific range of jobs is determined by the committee.

Article 6 (Installation)

The company will provide devices to prevent the dissemination of beryllium and will install hygienically-required facilities in the beryllium job sites.

Article 7 (Protective tools)

The company will provide protective tools and equipment to prevent beryllium-related disorders. The job sites where these tools and equipment are applicable will be decided by the committee.

Article 8 (Females and minors)

The company will employ neither females nor minors in beryllium operations.

Article 9 (Health examination)

1. The company will provide health examinations for newly hired employees involved in beryllium jobs and subsequently after the

Table 4. (Continued).

hiring based on company rule CE-22 "Beryllium health control regulations".

2. Among the newly hired employees, only those who are judged suitable for beryllium jobs by the health examination are allowed to work on the beryllium jobs.

Article 10 and Article 11 (omitted)

Article 12 (Job change)

1. The company will change the jobs of beryllium-handling workers based on instructions from the company-employed physician.

2. Workers who have to change their jobs in accordance with the previous section will receive job-change allowances corresponding to 10 days average wage. If the situation is, however, based on pneumoconiosis control, the amount is 30 days average wage.

3. For workers who are prevented from overtime work as a result of job change, the company will provide compensation every month corresponding to one hour of overtime wage for every overtime hour worked by the worker's department (more than 50% of the department's work force have to perform overtime work).

4. Workers who were required to change jobs will not be allowed to return to beryllium-handling jobs.

Article 13 (Rest and treatment)

The company will order workers to take a leave of absence for rest and treatment based on instructions given by the physician; this situation is handled as follows.

Table 4. (Continued).

(1) The company will provide 100% of the daily average wage including the holiday compensation provided by law and long-term sickness-injury wages until the individual reaches his retirement age.

(2) If the problem is suspected to be due to the occupational problem, the situation is handled as a special vacation according to the procedures provided for occupational accidents. Once the problem has been determined to be occupational, the treatment defined in the above section is carried out retroactively to the beginning.

(3) If the above special vacation period becomes long and subsequently, it is officially recognized that the disorder is other than an occupational disorder, it will be handled as a private ailment from the day of official recognition.

Article 14 (Special vacation)

The company will decide to give special vacations to those who have been recognized to have occupational disorders according to items (1) and (2) of the previous article and who have spent five years after the rest-treatment period has started, until the individual reaches his retirement age. During the special vacation period, there will be no wage increases or bonuses.

Article 15 (Retirement allowance)

The retirement allowance of those who have special vacation is computed five years after the rest-treatment period has started; the allowance is paid at the time of retirement.

Table 4. (Continued).

Article 16 (Mandatory retirement age)

The company will annul the employment contract on the day the individual in the rest-treatment period reaches 55 years of age. However, if the rest-treatment period is less than five years, a lump sum of daily average wage with the legal holiday compensation and long-term sickness-injury wage deducted will be paid for the remaining period.

Article 17 (Sympathy payment)

The company will pay the following sympathy payments to those who are in the long-term rest-treatment period.

(1) Hospitalization compensation money 10,000 yen

(2) Sympathy gift 1,000 yen/month

Article 18 and Article 19 (omitted)

Article 20 (Survivor's compensation)

If an individual in the long-term rest-treatment period dies because of the beryllium-related disorder as the major cause of death, the survivor's compensation for the family will be discussed by the Committee

Articles 21-23 (omitted)

January 21, 1966

4. Quantitative Determination of Beryllium

Various quantitative determination methods of Be are absolutely necessary for the evaluation of environmental contamination as well as for health control. The Be quantitative determination methods may

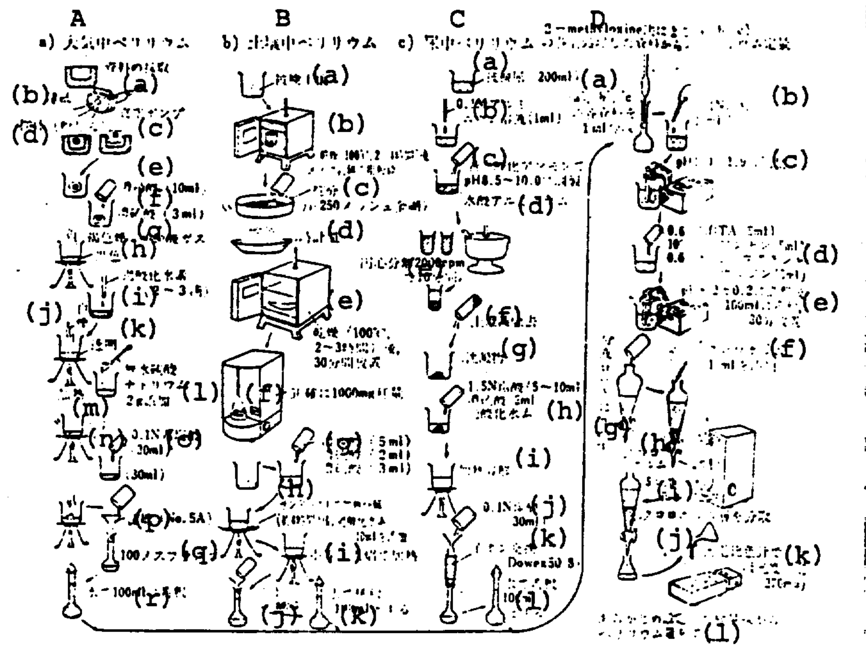

Fig. 12. Quantitative determination of beryllium in air, soil and urine (2-methyloxine method).,

KEY:

A: a)beryllium in air; (a) sample collection; (b) filter paper; (c) vacuum pump; (d) sample (powder); (e) conc. nitric acid (10 ml); (f) conc. sulfuric acid (3 ml); (g) brown smoke (sulfurous acid gas); (h) black; (i) hydrogen peroxide (2-3 drops); (j) white smoke; (k) transparent; (l) addition of 2 g of anhydrous sodium sulfate; (m) heating; (n) dissolution; (o) 0.1 N dilute hydrochloric acid solution (30 ml); (p) filter paper (No. 5A); (q) 100-ml volumetric flask; (r) dilute to make up 100 ml with water

B: b)berylliun in soil; (a) sample soil; (b) drying (100°C, 2-4 hrs.) and subsequent pulverization in an agate mortar; (c)sifting (250 mesh wire mesh); (d) watch glass; (e) drying (100°C, 2-3 hours) and subsequently allowed to stand for 30 minutes; (f) accurately weighing 1,000 mg; (g) conc. hydrochloric acid (5 ml), conc. sulfuric acid (2 ml), conc. nitric acid (3 ml); (h) heating-decomposition (about 4 hours) on a sand bath, and subsequent addition of 10 ml of hydrogen peroxide; (i) heating with a medium flame; (j) filtration (Toyo Roshi No. 5); (k) make up to 100 ml with water

Fig. 12. (Continuation of KEY).

C: c)beryllium in urine; (a) urine sample (200 ml); (b) 0.1 M aluminum solution (1 ml), (c) adjust to pH 8.5-10.0 using dilute ammonium hydroxide solution; (d) aluminum hydroxide; (e) centrifugation at 2,000 rpm for 10 minutes; (f) decantation; (g) sediment; (h) 1.5 N hydrochloric acid solution (5-10 ml), conc. sulfuric acid (2 ml) hydrogen peroxide; (i) heating and dissolution; (j) 0.1 N hydrochloric acid solution (30 ml); (k) ion-exchange resin (Dowex 50-8); (l) make up to 100 ml with water

D: quantitative determination of beryllium in samples pretreated by (a), (b) and (c) by the 2-methyloxine method; (a) 1 ml of sample pretreated by (a), (b) or (c); (b) addition of 10 ml of 0,1 N hydorchloric acid solution; (c) adjust pH to 1.0-1.9; (d) 0.6% EDTA (5 ml), 10% ammonium chloride (5 ml), 0.6% 8-hydroxyquinaldine (5 ml); (e) after adjusting to pH 8.2 ± 0.2, dilution to 100 ml and allowed to stand for 30 minutes; (f) addition of 10 ml of chloroform; (g) transfer into a separation funnel; (h) chloroform; (i) shaking for 5 minutes; (j) fractionation of the chloroform layer; (k) absorbance measurement (270 mμ) using a colorimeter; (l) compute the amount of beryllium from the working curve prepared in advance.

be classified into analytical chemical methods and instrumental analyses. A colorimetric method using the 2-methyloxine method which is suitable for handling a relatively small number of samples is discussed here with a drawing (Figure 12). This method [6] is known as one of the quickest and most reproducible methods since Be forms an extremely stable chelating compound $Be(C_{10}H_8NO)_2$ with 8-hydroxyquinaldine.

The quantitative determination of Be in air, soil or urine is carried out by a pretreatment as a first stage, and subsequently, the 2-methyloxine method as shown in the figure (refer to the figure for details) is carried out. One problem in this method is that it is inefficient if the number of samples is large; in this case, methods utilizing various analytical instruments are required.

5. Beryllium and Pollution

In the United States, where the Be industry is advanced, the problems of Be-related disorders are no longer in-plant problems but problems occurring outside the plants. Specifically, air pollution caused by Be is the concern.

In the United States, 535 cases of chronic beryllium-related disorders have been observed; among these cases, 60 involve people living near beryllium plants. Among these patients, 31 persons died. If the situation is analyzed from the Be exposure state, 27 cases of clothing contamination, 17 cases of air contamination, 17 cases of both, and 4 cases of unknown causes are found. The onset of the disease was caused as a result of secondary clothing contamination from Be workers, and this fact indicates the importance of the work clothing management discussed above.

When considering the pollution problems associated with Be, it is most important to consider the risk of respiratory damage caused by the air pollution, in relation to the past history and current situation with regard to beryllium-related disorders; water pollution can also be a factor. However, water pollution is a problem of relatively limited area, whereas air pollution may be found not only in the Be refining processes but also in fusing and other secondary processing of Be mother alloys. In addition, the Be upper limit outside plants is 0.01 $\mu g/m^3$ which is extremely low, and as a result, handling and air pollution control measures have to be carried out carefully.

Figure 13 shows the yearly transition of the Be concentration in the air near the plant of one company. The results were obtained since

1965 by carrying out periodic measurement at 25, 50, 100, 300 and 500 m from the plant, which were concentric points with the plant at the center. According to the results shown in the figure, no Be was detected at the points beyond 300 m from the plant. (Incidentally, the site within 50 m is the plant site; the locations beyond 300 m are beyond the company property). The measured values at each point within 300 m show a decreasing tendency, indicating that the results are closely related to the results of these efforts to improve the work environments. The wind direction during measurement was also considered; the Be concentration in the air beyond 1 km was measured, but no Be was detected. Furthermore, there was no seasonal variation.

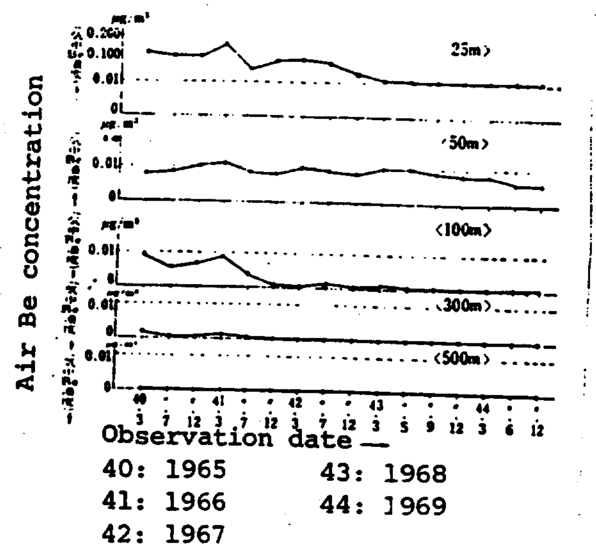

Fig. 13. Transition in beryllium concentration (average) in the air near beryllium refining plants.

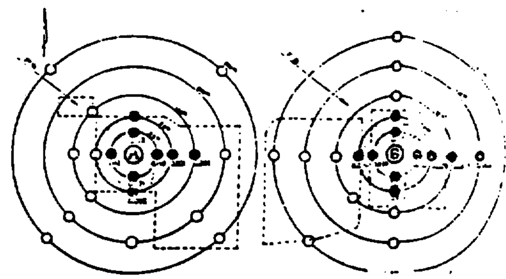

Fig. 14. Examination of the amount of beryllium in the soil near beryllium plants (A and B plants).

KEY: (a) Be plant sites and (b) company property.

As another method of evaluating Be contamination near the plants, the amount of Be in the soil at various points near the plants was measured. As shown in Figure 14, Be was detected in the soil within 100 m from the plants, and the concentration of the sites within 50 m, which is the direct activity range of the Be workers, is significantly high. In order to examine the possibility of a wide range of contamination, the entire city area was examined by carrying out measurement at various concentric points (Figure 15), but no Be was detected. From the results obtained, it may be concluded that there is no effect of Be contamination near the surrounding area of the Be plants at least to date. However, this problem has been continuously studied and will be studied in the future as a responsibility of business to society.

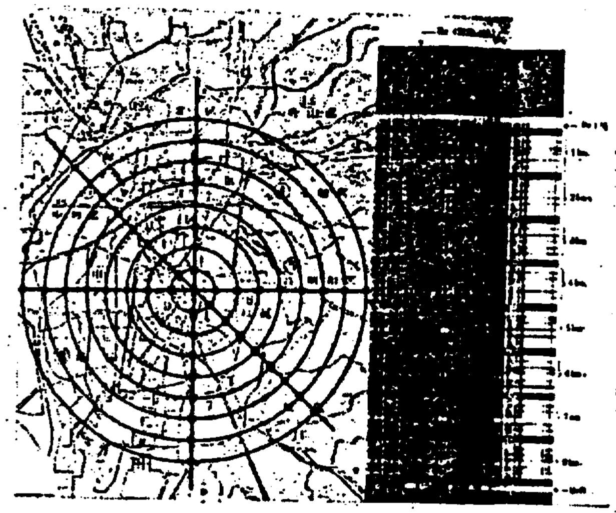

Fig. 15. Be levels at various urban cites.

6. Last Words

The health control management with respect to Be and the current problems have been briefly discussed based on the author's experience over the past ten years.

Fortunately, Be does not have any disorder patterns such as blood poisoning, nerve poisoning, etc., as is the case of some heavy metals. The major problems associated with beryllium are respiratory disorders; furthermore, in the conventionally used forms of metal Be or mother alloys themselves, Be disorders are hardly caused.

The author emphasized an effective and concentrated management in the text because of the reason described above. Therefore, in order to prevent Be-related disorders, health control emphasizing the main points is required to obtain effective results. The problem has to be considered within the range of extremely trace amounts of Be exposure; thus the attitude toward the prevention management has to be nothing but careful.

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