SAFETY AND HEALTH CONTROL OF URANIUM FACTORY

Takashi Kitabatake, Yoji Mizutani and Shunzo Okajima

Department of Radiology, Nagoya University School of Medicine
(Director: Prof. Shinji Takahashi)

The industrial use of uranium metal has increased recently. Sumitomo refinery factory in Nagoya City started operation of milling of uranium two years ago and we have been assigned the health supervision of the workers in this factory. In this paper our experience on this will be described in detail.

MONITORING AND SAMPLING

The factory has been working on trial arc-melting, tempering, heat-treatment, or finishing-manufacture of uranium ingot.

The building of this uranium factory was designed by us with the object of diminishing uranium injures. The space of the building equipped with an air-ventilator capable of exchanging the room air in 11 minutes, occupied 135 square-meters. The corners of the walls and floor were cleanable by water. Waste water was conducted to a concrete tank of about $5 \times 8 \times 15$ m in size. An exhaust system works for removing dusts in air by a compulsive drawing blower (30 m^3/min., 10 hP). Dusts in the venturiscrubber (1.26 T/h in quantity of water) are separated from the contaminated air by a cycron of moist type (0.75 T/h in quantity of water). Air passed through the venturiscrubber is filtered by a filter of 24 sheets of glass-wool, and then is released outdoors. The dust-mixed water is conducted to the tank.

Workers in this factory wear special working-dress, cap, gloves, and dust-mask. They wear also a film-badge and pocket-chamber on their right chest. When working is over, the clothings with accessaries are checked for contamination. Fig. 1 shows a worker's costume during working time.

An environment study to determine the exposure dose was conducted as follows:

External Irradiation Radiation dose of beta- and gamma-rays emitted from the uranium ingot was counted by the dose-rate meter of ionization chamber type made in Japan. The radiations of beta- and gamma-rays were measured by the probe of the mica-window (2–3 mg/cm^2), while that of gamma-ray by the probe of the bakelite plate window, which cut off the beta-rays. As shown in Fig. 2 our results indicated that exposure to gamma-rays is less significant when it was an external radiation, except in case of contact radiation of uranium ingot. The dose measured by the film-badge and pocket-chamber was approximately negligible.

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FIG. 1. Costume of uranium workers during operation.

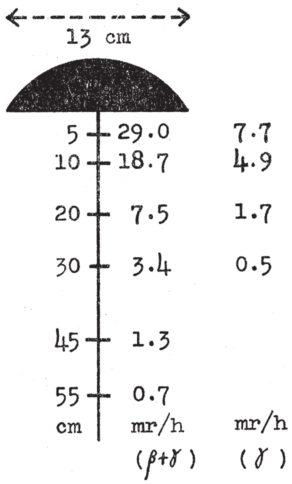

FIG. 2. External radiation dose from the uranium ingot measured by the dose-rate meter of ionization chamber type.

Contamination of Air A dust-monitor made in our country (type MDS-2) was used for measuring uranium concentration in air. For quantitative measurement, air was drawn compulsively through the filter-paper, and the amount of radioactivity of the filter-paper was measured. The beta- and gamma-rays were counted by a GM counter and alpha-radiation by the scintillation counter, which worked by automatographic system.

The drawer was capable of drawing 300 l/min. The lower limit of counting of the dust-monitor for alpha-ray was near 5×10^{-12} micro-c/ccm/cps under the following working conditions: filter efficiency of filter-paper, 60%; collecting area of dust, 3×9.8 cm^2; linear velocity of air flow, 300 l/min; effective window size of detector, 12 cm^2; and efficiency of detector, 25% of the entire disintegration; As for the beta and gamma-rays the lower limits of detection ability lie at the level of 6×10^{-12} micro-c/ccm/cps under the condition of 80% filter efficiency, 3×9.8 cm^2 of dust-collecting area, 5.7 cm^2 of effective window size of the detector, and 30% of detector efficiency of the entire disintegration.

The counting values obtained by the dust-monitor during operation are shown in Table 1. The value measured in the area in contact with the worker's mouth are shown in Table 2. Based on average counts of the back-ground radiation, measured at no-working time, the natural radioactivity originating from the alpha-emitters in air was estimated to be 6.5×10^{12} micro-c/ccm, while that from the beta- and gamma-emitters 7.3×10^{-11} micro-c/ccm. During working time the level of alpha-emitter in air rose to about 2×10^{-12} micro-c/ccm, which was, nevertheless, about one-tenth the maximum permissible concentration in air. On the other hand the beta- and gamma-emitters in air did not increase, and remained at the same level as the back-ground radiation.

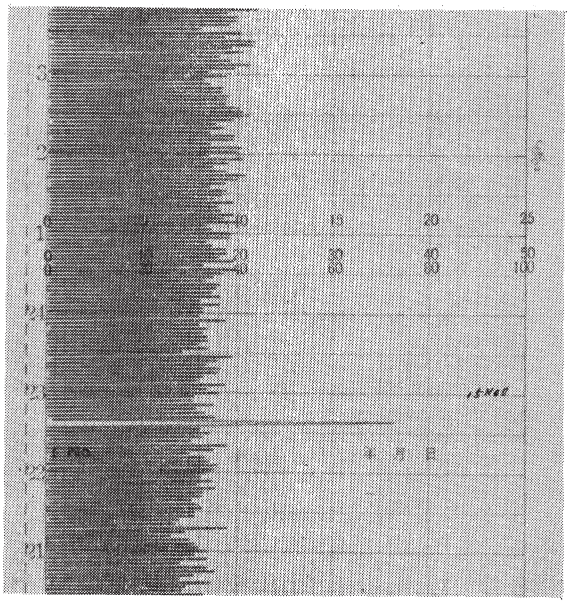

FIG. 3. Automatograph of radioactive count from beta- and gamma-radiation in air of the factory measured by the GM-counter.

TABLE 1. Counting Number in the Factory Measured by the Dust-monitor (Back-ground Counts)

Date of measurement	Place measured	Counting values (cps)	
		Alpha-ray	Beta- and gamma-ray
10. Dec. 1958	Out of room		7.2
11. Dec. 1958	Out of room		6.6
12. Dec. 1958	Out of room		8.4
13. Dec. 1958	Out of room		5.1
14. Dec. 1958	Out of room		9.0
18. Dec. 1958	In the room		33.0
19. Dec. 1958	Out of room		15.0
20. Dec. 1958	Out of room		11.0
22. Dec. 1958	Out of room		6.3
24. Dec. 1958	Out of room		4.2
27. Dec. 1958	Out of room	0.3	6.0
15. Jan. 1959	In the room	3.0	5.0
21. Jan. 1959	In the room	1.8	40.0
23. Jan. 1959	In the room	1.3	13.8
30. Jan. 1959	Out of room	0.6	4.0
31. Jan. 1959	Out of room	0.1	2.0
3. Feb. 1959	Out of room	0.6	8.0
4. Feb. 1959	In the room	1.6	16.0
11. Feb. 1959	In the room	0.1	12.0
13. Feb. 1959	In the room	2.0	20.0
14. Feb. 1959	In the room	2.4	24.0
16. Feb. 1959	In the room	1.2	12.0
18. Feb. 1959	In the room	1.0	10.0
19. Feb. 1959	In the room	1.5	15.0
Average		1.3 (cps)	12.2 (cps)

TABLE 2. Counting Number Near the Worker's Mouth Measured by the Dust-monitor During Operation

Date of measurement	Types of uranium working	Counting values (cps)	
		Alpha-ray	Beta- and gamma-ray
3. Dec. 1958	Arc-manufacturing of uranium ingot		10.8
4. Dec. 1958	Arc-manufacturing of uranium ingot		8.4
5. Dec. 1958	Arc-manufacturing and lathe-working		22.0
8. Dec. 1958	Heat-treatment		20.4
9. Dec. 1958	Heat-treatment		7.4
17. Dec. 1958	Cutting of uranium metal		13.0
25. Dec. 1958	Lathe-manufacturing	1.3	12.9
17. Jan. 1959	Electrolysis	5.4	6.0
20. Jan. 1959	Electrolysis	0.6	7.2
22. Jan. 1959	Lathe-manufacturing	1.8	12.0
24. Jan. 1959	Lathe-manufacturing	1.2	16.0
26. Jan. 1959	Measurement of hardness	1.2	8.0
27. Jan. 1959	Pressing of uranium metal	0.4	4.0
	Average	1.7	11.4 (cps)

For determining the type of radioactive material collected by the dust-monitor, the radiation decrement curve was drawn as shown in Fig. 4. The initial part of this decrement curve shows a linear and steep slope. The half-life calculated from this was about 50–60 minutes. This indicated the presence of radon and/or its daughters.

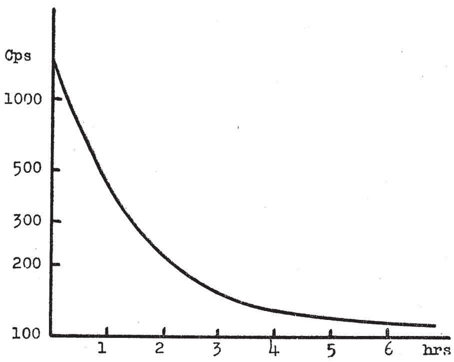

FIG. 4. Radiation decrement curve of natural radioactive materials collected by the dust-monitor at no-working time in the factory.

Uranium Concentration in Waste Water The concentration of uranium in waste water was measured by means of the colorimetric analysis because this method was considered to be more accurate when used for low specific radioactivity such as, uranium. The maximum value of uranium concentration in the waste water was about 3 000 gamma per liter (10^{-6} microcuries per ccm), and the mean concentration was near the level of 300 gamma per liter (10^{-7} microcuries per ccm). It was much bleow the maximum permissible concentration in water.

MEDICAL EXAMINATION

Thirty-seven uranium workers were examined. They were all adult Japanese males without any histories of professional radiation exposure. Four persons, however, have worked in the environments of dust idustry. Most workers were not in full service, but had an additional post engaged in the treatment of the other types of non-radioactive metals. Based on the duration of working-time they were divided into three groups, as shown in Table 3. Medical examinations were performed every half-year since the start of uranium operation. General physical examination, chest X-ray study, liver function test, urinalysis, blood sedimentation-rate test, blood pressure test, body weight, inspection of the skin, mucous menbrane, hands and fingers, and hematologic study were made.

TABLE 3. Classification of Uranium Workers After Their Working time in the Uranium Factory

	Number of workers	Average working time (hrs/w)
Group A	5	5 to 6 hours/w
Group B	7	2 hours/w
Group C	25	Under 30 minutes
Total	37	1 hour in average

Physical Examination Over a two years period variation of the body weight was within ±2 kg in all cases. None showed acceleration of the blood sedimentation-rate to over 12 mm per hour or 30 mm per 2 hours. The blood pressure was within normal limits. There were three cases of systolic heart murmur, and the liver was palpable in 10 cases. However, they had no complaints nor other physical signs. The kidney of two workers was palpable with negative urinalysis. Urinalysis included a qualitive test for urobilinogen, sugar and protein. In the urinary tests, positive urobilinogen was found in 3 cases, but sugar and protein tests were negative. No abnormalities were seen in the head hair, cilia, supercilia, skin of the face, trunk and extremities, mucous membrane of the oral cavity, tongue, and tonsils, hands and fingers, and nails.

X-Ray Examination In the routine chest film, one case of hilar calcification, 1 case of parenchymal calcification, 1 case of pleural thickening, 2 cases of old tuberculous lesion, and 1 case of rib anomaly were found. These remained unchanged, the same until the end of our examination period. In one case with systolic heart murmur and a soft palpable liver, the increased pulmonary markings rather improved than before the employment.

In three cases moderate pneumoconiotic change was seen, which was, however, not exaggerated when compared with that before the commencement of uranium work.

Liver Function The liver function test was conducted on 5 persons of Group A. The examination, including the bromsulphalein test, Takata reaction test, CCF test, cobalt test and a qualitative test for urobilinogen in urine, was

TABLE 4. Liver Function Test of Group A Performed in December 1958 (cf. Text)

Patient No.	Urobilinogen in urine	BSP		Takata R.	CCF		Cobalt R.
		30 min.	45 min.		24 hr	48 hr	
6	+	Under 5%	0	+	−	++	$R_3(5)$
13	±	0	0	−	−	+	$R_4(6)$
15	+	0	0	−	−	−	$R_4(6)$
20	±	0	0	−	−	−	$R_3(5)$
30	±	Under 5%	Under 5%	−	−	+	$R_3(5)$

TABLE 5. Hematological Data of Uranium Workers. Values Followed by the Legend ± Indicate the Confidence Limits at 5% Level. All Values are Within Normal Limits

	Date	Dec. 1957	Mar. 1958	Dec. 1958	June 1959
Group A	Red cells	499± 39	461± 102	477± 68	555± 81
	White cells	6775±2188	6100±4787	6240±1747	6800±1921
	Colour index	0.97± 0.08	1.05±0.15	1.06± 0.08	0.95± 0.16
	Basophils	0.25± 1.15		0.2 ± 0.2	1.5 ± 1.4
	Eosinophils	2.75± 1.58	(not examined)	1.6 ± 2.6	3.5 ± 2.0
	Staff cells	3.5 ± 3.6		6.6 ± 3.0	7.5 ± 4.2
	Segmented	58.0 ±10.8		52.0 ±13.3	53.2 ±16.0
	Lymphocytes	31.5 ± 9.6		36.8 ±19.5	28.5 ±21.0
	Monocytes	4.3 ± 1.2		3.8 ± 3.8	5.7 ± 4.6
Group B	Red cells	497± 63	494± 53	467± 52	491± 62
	White cells	6400±1713	8250±2838	6950±1853	5980±1690
	Colour index	1.04± 0.09	1.07±0.15	1.12± 0.16	1.00± 0.15
	Basophils	0.25± 0.50		0.14± 0.3	0.3 ± 0.14
	Eosinophils	4.0 ± 1.76	(not examined)	1.3 ± 1.1	3.0 ± 1.12
	Staff cells	5.3 ± 3.3		5.7 ± 2.2	7.5 ± 3.8
	Segmented	43.3 ± 9.2		50.8 ± 6.7	53.5 ±11.0
	Lymphocytes	41.2 ±14.3		38.1 ±16.9	30.5 ± 8.60
	Monocytes	3.4 ± 1.6		6.1 ± 1.2	6.5 ± 1.9
Group C	Red cells	499± 21	474± 17	484± 20	474± 31
	White cells	6810±1540	7643±1649	6792±1597	5590±1420
	Colour index	1.07± 0.04	1.07±0.06	1.02± 0.06	1.09± 0.09
	Basophils	0.16± 0.20		0.12± 0.20	0.2 ± 0.2
	Eosinophils	3.3 ± 1.0	(not examined)	2.2 ± 1.49	2.4 ± 1.1
	Staff cells	5.5 ± 1.5		6.64± 1.62	7.9 ± 2.9
	Segmented	55.3 ±13.6		47.3 ±13.0	54.8 ±14.8
	Lymphocytes	32.4 ±13.0		39.1 ±11.2	23.2 ±10.0
	Monocytes	4.1 ± 1.7		5.8 ± 1.6	6.4 ± 2.1
Normal	Red cells	480± 58			
	White cells	7600±1100			
	Colour index	1.00±0.10			

(The normal data were cited in reference 15.)

carried out in December 1958 and in July 1959. As shown in Table 4, the results were approximately within normal limits. One person (Patient No. 6), who had suffered from sequelae of liver disease (with moderate jaundice) a few years ago, was positive to the Takata reaction test.

Hematological Study Hematological examinations were made four times. RBC counts in Group A were as follows: $(499 \pm 39) \times 10^4$ at the first study, $(461 \pm 102) \times 10^4$ at the second, $(477 \pm 68) \times 10^4$ at the third, and $(555 \pm 81) \times 10^4$ at the fourth examination. The values are followed by the sign of $\pm$representing the confidence limits. No significant variation was recognized in these values when compared with normal Japanese data.[15] The other data of this study are described in detail in Table 5.

DISCUSSION

Regarding uranium injury, the lungs and kidneys are regarded to be the critical organs.[12][13] Many authors support this opinion.[1][6][9][13][16] Eisenbud reported two autopsy cases of uranium workers, where only a little amount of uranium was demonstrated in the lungs[3]. The medical examination and environment survey of the Ningyo-toge uranium mine in Japan were reported by Inoue and his co-workers.[7][8] It was worthy of note that there were found many cases of leukopenia among the pit-workers, and high concentrations of radon in the mine gap, up to 1 000 times the maximum permissible level. Harris reported that about $0.1\text{–}1.5 \times 10^{-11}$ c/l of uranium concentration in the air was found in a mine in New York state.[5]

In an uranium factory such as we surveyed, internal irradiation due to inhaled radioactive dusts may be one of the most marked problems because external irradiation is considered negligible. Therefore air-clarification by a satisfactory exhaust system and periodical medical examination are most useful as safety control. Monitoring of radioactivity in air by means of the filter-paper method is generally easy to manupulate and adaptable for relatively small amounts of radioactivity in air. However, it is very difficult to determine precisely the filter efficiency of filter-paper because the dusts in air are generally too small in size (probably under 0.01 microns). Therefore the filtration rate of the filter for dusts is very variable and is from 2–3 per cent to 99 per cent according to different authors.[2][10] The filtrating ability of the filter used in this study is regarded as about 60 to 80 per cent efficient.[2] As uranium dusts produced in the factory were approximately about 0.5 microns in diameter,[9] this grade of the filter efficiency may be suitable. However, many other factors such as rate of self-absorption of the filter, variation of counting efficiency due to the type of radiation, increase of radiation counts caused by the back-scattering etc., may influence the results of measurement, although this type of dust-monitor would be of suitable for determining roughly the radiation dose in air.

Medical examination revealed nothing positive resembling uranium injury. This could be due to the low radiation level and relatively short duration of exposure. However, if uranium operation becomes prolonged, even at the level of working-time as at present, subacute or chronic uranium injury may or may not be provoked, and hence it will be necessary to conduct medical examinations at least twice a year. In our study chest X-ray films and urinalysis were considered to be of great importance. However other examinations, such as general physical examination, liver function test, hematological study, etc., also seem to be valuable, since uranium poisoning is composed of radiation injury, chemical toxicity and pneumoconiogenic factor.

On the other hand no blackening of the badge-films was recorded in all the two-weeks-period of the last two years, which may indicate that external irradiation is practically negligible for uranium workers and the film-badge method may be of poorer significance, if the sensitivity of badge-film remains the same as at present.

SUMMARY AND CONCLUSIONS

1. Health and safety control of a certain uranium milling factory in Nagoya City, Japan was conducted for the past two years.

2. External irradiation from the uranium ingot was approximately negligible.

3. Concentration of uranium in air was a little increased in the operating room, though variation of radioactivity lay nearly within the range of maximum permissible concentration.

4. Uranium concentration in the waste water of the factory was below the maximum permissible dose.

5. Medical examination, including general physical examination, revealed no new abnormalities as the result of uranium exposure.

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