EFFECT OF THE FOODCHAIN IN RADIOACTIVITIES RELEASED FROM THERMAL POWER PLANTS

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INTRODUCTION AND SUMMARY

The radiological impact of fossil fuel burning (effect of radioactive impurities) has been investigated since the first paper by Eisenbud and Petrow (1), but no attempt has been made about the effect of the foodchain. Among many radioactivities released from fossil fuel burning ^{210}Pb and ^{210}Po are especially important, because they are very volatile and are released at higher rates than others, and also because they are concentrated very strongly in marine organisms (2,3). This is very important in Japan, because most power plants in Japan are built near the seacoast and the seawater contamination due to these radioactivities is likely. ^{210}Pb and ^{210}Po also contaminate leafy vegetables by fallout. Since Japanese eat vegetables and seafoods very often, this foodchain is important.

The dose due to this foodchain is estimated. It is found to be two to three orders of magnitude higher than the dose calculated previously (4) without considering this foodchain. The average individual dose of Japanese is of the order of several tens of μSv (several mrem)/y. Although much smaller than the natural background, it is comparable to the dose of the *total* fuel cycle of *full scale* nuclear electricity generation (1 kW per person), and so its social implication cannot be overlooked. The same argument applies to other countries where the seafood consumption rate is high.

IMPORTANCE OF ^{210}Pb AND ^{210}Po

Recent coal-fired power plants have excellent dust removal devices, the efficiency of which reaches 99% or higher. However, this removal efficiency is referred to the *weight* of particulates. Small particulates, which can pass through the dust removal device, have a large surface-to-volume ratio, and volatile substances such as ^{210}Pb or ^{210}Po are adsorbed on the surface of these small particulates. Such small particulates are especially dangerous, because they spread to much further distances than larger ones do, are not washed away by rain easily, and when inhaled, reach the deepest part of lungs.

In addition there could be a gaseous emission. The dust removal efficiency is referred to *solid* particulates, and so if the gaseous emission is included, the release rates of volatile substances could be much higher than is usually believed.

One might argue that ^{210}Pb and ^{210}Po produced from ^{222}Rn emanated from the ground is still much larger than those produced from coal burning, but this argument overlooks an important point. Radon daughters are usually adsorbed by atmospheric aerosols, the residence time of which is 10–20 days at most. This is too short for the longlived radioactivities such as ^{210}Pb (20 y) or ^{210}Po (138 d) to reach equilibrium with their parents, and hence the atmospheric contents of ^{210}Pb and ^{210}Po are many orders of magnitude lower than ^{222}Rn.

On the contrary, all radioactivities in fossil fuels have completely reached their radioactive equilibrium while the fossil fuels have been underground for hundreds of millions of years. When the fossil fuels are burnt, these radioactivities are released *keeping their equilibrium*. Thus the ratio of ^{210}Pb or ^{210}Po to ^{222}Rn is *one*. Therefore as far as the air contamination due to ^{210}Pb or ^{210}Po is concerned, coal burning is relatively more effective than radon emanation from the ground by several orders of magnitude.

This point is important also when comparison is made with nuclear energy. Radon emanation from uranium tailings is essentially the same as that from the ground, and so the same argument as above can apply. For instance, one 1000 MW coal-fired power plant releases about 1 Ci of ^{222}Rn every year, which in the effect of ^{210}Pb and ^{210}Po is comparable to the release of 7000 Ci from tailings of the Ranger uranium mine in Australia, which can provide 6000 tonnes of U_3O_8 annually.

CONTAMINATION OF LEAFY VEGETABLES AND SEAFOODS

^{210}Pb and ^{210}Po are taken up by plants both through root uptake and direct absorption from the leaves. Although which of the two pathways is more important is somewhat controversial, the argument claiming direct absorption appears more persuasive, especially in the case of leafy vegetables. Therefore in this paper it is assumed that ^{210}Pb and ^{210}Po in leafy vegetables are completely due to direct absorption from fallout.

The ratio of ^{210}Pb or ^{210}Po produced from coal burning to natural ones is denoted as R_a in air and R_w in water. R_a is estimated to be 0.03 ~ 0.1 (5). However, this is the average over Japan. Leafy vegetables are usually grown near cities to be supplied in a fresh form, and R_a in air of urban areas is probably higher than 0.1.

The intake of ^{210}Pb from leafy vegetables is about 3 pCi/d (6). The data on the ^{210}Po intake from leafy vegetables is not available, but can be estimated as follows. The average of ^{210}Po content in leafy vegetables in Japan is 0.35 pCi/100g (7). Since the daily consumption of vegetables by Japanese is about 300 g/d, the ^{210}Po intake is about 1 pCi/d. Therefore contributions from coal burning are 0.3 and 0.1 pCi/d for ^{210}Pb and ^{210}Po, respectively, assuming $R_a = 0.1$.

Contamination of seafoods is much more difficult to estimate, because R_w is very uncertain. However a tentative estimate is $0.001 < R_w < 0.05$ (5). The ^{210}Pb intake from seafoods by Japanese is about 12 pCi/d (6). The data on ^{210}Po is not available, but is estimated to be about 40 pCi/d (5). Then contributions from coal burning are 0.012 ~ 0.6 pCi/d for ^{210}Pb and 0.04 ~ 2 pCi/d for ^{210}Po.

DOSE DUE TO COAL BURNING

The individual dose can be calculated using the model of UNSCEAR 1977 and the data of Parfenov (3). The results are shown in Table 1.

TABLE 1. Individual dose due to contamination of leafy vegetables and seafoods by coal burning in Japan (mrem/y).

Organ	Leafy vegetables	Seafoods[a)]	Total[b)]
skeleton	3.7	0.15 ~ 7.5	3.9 ~ 11.2
gonads	0.7	0.1 ~ 3.9	0.8 ~ 4.6
breasts	0.2	0.03 ~ 1.3	0.3 ~ 1.5
lungs	0.6	0.07 ~ 3.4	0.7 ~ 4.0
thyroid gland	0.6	0.07 ~ 3.5	0.7 ~ 4.1
liver	1.9	0.2 ~ 10.4	2.1 ~ 12.2
kidney	1.6	0.2 ~ 8.8	1.8 ~ 10.4
lymph nodes	1.2	0.1 ~ 6.7	1.3 ~ 7.9
pancrea	0.4	0.04 ~ 2.2	0.4 ~ 2.6
spleen	0.4	0.04 ~ 2.1	0.4 ~ 2.4
whole body	0.9	0.1 ~ 4.9	1.0 ~ 5.8

a) Upper and lower values correspond to upper and lower values of R_w in the text.
b) For countries other than Japan the values are roughly 1/10.

The population dose is calculated by multiplying the whole body dose by the Japanese population of 116 millions. This corresponds to coal burning of 80 ~ 90 million tonnes/y, which is equivalent to 35-40 1000 MW coal-fired power plant. Thus the above value is divided by 40 to give the collective dose per 1000 MW power plant.

However fossil fuel burning releases CO_2 which lacks ^{14}C, and as a result the atmospheric ^{14}C is diluted (Suess effect). This gives rise to a *decrease* of internal dose due to ^{14}C. The collective dose commitment of ^{14}C integrated over the world population and up to 100 years is given as 40 man-rem/Ci of ^{14}C (average of three values) (8). Operation of one 1000 MW coal-fired power plant can be regarded as a *negative* emission of ^{14}C of 11.4 Ci/y (5) which corresponds to a *decrease* of the collective dose of about 460 man-rem/y.

Since comparison with nuclear energy is important from the sociological viewpoint, the relevant data of nuclear energy are also shown in Table 2 together with the data of coal.

TABLE 2. Collective dose of coal burning in Japan[a)] and its comparison with nuclear energy. (All in man-rem/y except for the Harrisburg accident.)

	Coal	Nuclear energy
Japanese population dose		
	$1.2 \sim 6.7 \times 10^5$	1.7×10^4 [b)]
Per 1000 MW power plant		
(A)	$18 \sim 23$ [c)]	13[e)]
(B)	$2.9 \times 10^3 \sim 1.7 \times 10^4$ [d)]	$5.2 \sim 8.2 \times 10^3$ [f)]
Suess effect	-4.6×10^2	Harrisburg nuclear accident
		3.3×10^3 man-rem

a) In the case of other countries the dose due to coal burning is about 1/10 of Japan.

b) Dose due to all nuclear facilities all over the world (mainly from ^{3}H and ^{85}Kr) in 2000 (9).
c) Values neglecting the foodchain (4).
d) Values including the foodchain.
e) Routine operation only (4).
f) Total fuel cycle (UNSCEAR 1977).

As can be seen from the table, the collective dose of coal burning including this foodchain is 100 to 1000 times larger than that excluding it, clearly showing its importance. The Suess effect is much too small to cancel it. Compared with nuclear energy the dose due to coal burning is comparable to or even greater than that of nuclear energy. Thus its social implication cannot be overlooked.

OIL AND NATURAL GAS

These are usually believed to be much cleaner than coal. As a crude estimate the dose due to oil burning is assumed to be about 1/100 of that of coal, namely about 30 ~ 170 man-rem/y per 1000 MW power plant, which can be cancelled by the Suess effect (-280 man-rem/y for oil). The same is probably true for natural gas also.

However it must be pointed out that natural gas contains a large amount of radon and presumably its daughters including ^{210}Pb and ^{210}Po, which could alter the above estimate significantly. The same can be said for oil as well. This point must await further investigation.

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