THE RADIOLOGICAL IMPACT OF COAL-FIRED POWER STATIONS IN ITALY

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1. ABSTRACT

In this work a first indication of the radiological impact on Italian population from coal-fired electricity generation is presented. The estimate of collective dose is based on a simplified model (1) and some data relative to Italian power plants.

2. INTRODUCTION

A working group involving Regional and National Environmental Protection Agencies is estimating the radiological impact on the environment of industrial activities with materials containing enhanced concentrations of natural radionuclides (2). Among the relevant industries the first to be addressed was the energy production by coal firing, that in Italy covers about 13% of the total electrical energy production.

Coal contains low levels of natural radionuclides, but the ashes resulting from the combustion process are enriched in radionuclides and reused as inert material in building materials. The radiological impact on population of this non-nuclear industry depends then on the ash fraction and the gaseous radionuclides released in the environment and on the amount of ash used in building materials..

The exposure pathways considered in this work are inhalation of radionuclides in the plume, and the external and internal irradiation of radionuclides deposited on the ground. The collective effective doses committed to Italian population from this industry are estimated by means of a simplified model suggested by UNSCEAR (1), on the basis of the radioactivity released from the stack. Site specific data introduced in the calculation are plant production and district population density; for coal and ash activity concentration average values measured in Italy were used.

In Italy there are currently 13 power stations operated by ENEL company, representing the 98% of the overall electrical energy generated from coal. Data relative to the energy produced by each plant were available for the operation in 1999, when only 9 plants were active. The estimate reported here is then referred to 1999 electricity production.

3. COAL AND ASH RADIOLOGICAL CHARACTERISTICS

Radionuclide content of coal depends mainly on the material origin. ARPA Liguria has measured the activity concentration of numerous coal samples and a few ash samples, burnt in the plants of Genova, La Spezia and Vado Ligure from 1998 to 2000. The results of the analysis relative to coal from different countries are presented in Table 1 for ^{238}U, ^{232}Th and ^{40}K; the number of samples and activity range are already reported elsewhere (2). The average value is in good agreement with the values reported in USCEAR 1982, that are 20 Bq/kg for both ^{238}U and ^{232}Th, and 50 Bq/kg for ^{40}K.

Table 1. Measured concentrations of radionuclides in coal with different origin

Coal origin	average coal activity concentration (Bq/kg)		
	^{238}U	^{232}Th	^{40}K
USA	16	11	69
Colombia	6	3	36
South Africa	30	26	28
Indonesia	6	7	49
Poland	23	14	73
Venezuela	5	4	44
China	31	37	27
Russia	10	9	62
average	16	14	48

The two natural chains are assumed to be in secular equilibrium (1), then the activity concentration of the decay products is the same of the parent before burning. After the combustion process the radioactivity of coal is concentrated in ashes, and moreover some enrichment is observed in radon long-lived daughters concentration.
The activity concentration in fly ashes is shown in Table 2.

Table 2. Measured concentrations of radionuclides in fly ashes of three plants

Plant site	average ash activity concentration (Bq/kg)		
	^{238}U	^{232}Th	^{40}K
Genova	118	92	452
La Spezia	123	104	445
Vado Ligure	137	96	478
average	126	97	458

On the basis of the values reported here the following activities were assumed for fly ashes: 130 Bq/kg for the ^{238}U series, 100 Bq/kg for the ^{232}Th series, and 400 Bq/kg for ^{210}Pb and ^{210}Po, that corresponds to an enrichment factor of

about 3. These values are lower than the ones assumed by UNSCEAR 1982, that are 200 Bq/kg for both ^{238}U and ^{232}Th, and 600 Bq/kg for ^{210}Pb and ^{210}Po. The ratio between activity concentration in coal and ash is about 0.14 for ^{238}U and ^{232}Th, that is coherent with the average percentage of ash contained in coal, usually in the range from 10% to 20% (1, 3).
The production of electricity from coal in Italy was about 2.5 GWa in 1999, corresponding to the combustion of 8.4 10^6 tonnes of fuel. The total amount of fly ashes produced resulted 839 10^3 tonnes, corresponding to a fraction of 10%. The fraction discharged into the atmosphere was taken 0.5%, as the efficiency of filtering devices was not known for all plants. According to these figures, approximately 4.2 10^3 tonnes of ash were released to the atmosphere in 1999, to which the activity concentrations derived from Table 2 was attributed.
The amount of radon gas released is assumed to correspond to the activity of the coal burnt; for the 9 plants considered in this work an activity of 134 GBq was calculated.

4. MODEL

The collective dose committed to population living in the surroundings of the plant is due to three main exposure pathways, that are inhalation of radionuclides during the passage of the cloud, internal and external irradiation resulting from the activity deposited on the ground. The dose assessment was carried out by using the simplified model presented in UNSCEAR 1982, in which the absorbed dose coefficients were replaced by the effective dose ones.

4.1 INHALATION OF THE RADIONUCLIDES IN THE CLOUD

By assuming that there is no decay during the atmospheric transport, the committed effective collective dose due to the inhalation of a radionuclide *r* in the plume can be estimated by:

$$M^{r}_{Inh} = \frac{A_o}{v_d} \delta N B \frac{D_r}{I_{ih}} \qquad (1)$$

where A_o (Bq) is the released activity due to the radionuclide *r*, which will eventually be deposited on a surface S at the velocity v_d (m/s); δN (m^{-2}) is the population density on S, *B* (m^3/s) is the individual breathing rate for adults and D_r/I_{ih} (Sv/Bq) is the committed effective dose per unity of activity inhaled due to the radionuclide *r*. The values of v_d and *B* were assumed to be constant and equal to 10^{-2} m/s and 2.3 10^{-4} m^3/s, respectively.
As deposition surface, we considered the surface of the administrative district (corresponding to the Italian "Comune") in which the power plant is located. The extension of the district surface and the corresponding population density, δN, are reported in Table 3 for each considered plant.
The released activity, A_O, is given by the product of fly ash activity concentration (from Table 2) multiplied by the amount of the ash released from each power plant. This quantity was estimated by multiplying the total amount of the fly ash, as reported previously, by the percentage of the burnt coal in each power plant

and by assuming a filtering efficiency equal to 99.5%. The values of D_r/I_{ih} used here are those for adults reported in ICRP 72 (4). The absorption type was assumed M for all the radionuclides under consideration, apart from Thorium, for which absorption type S was considered.
The particular case of the inhalation of ^{222}Rn was treated by modifying formula (1); v_d was replaced by the ratio of the average emanation rate of ^{222}Rn (0.02 Bq m^{-2} s^{-1}) and its average outdoor equilibrium concentration (1.8 Bq/m^3) and the product $B\ D_r/I_{ih}$ was instead replaced by the ^{222}Rn dose coefficient 5.5 10^{-5} Sv/y per Bq/m^3 (5). Since radon is not collected by particulate control devices, the radon activity contained in the burnt coal was assumed to be entirely discharged in the atmosphere.

Table 3. Geographic and demographic characteristics of coal-fired plants

Plant site	District	Surface (km^2)	Population Density (km^{-2})
Bastardo	Gualdo Cattaneo	97	62
Brindisi Sud	Brindisi	329	288
Fusina	Venezia	458	648
Genova	Genova	244	2683
La Spezia	La Spezia	52	1899
Monfalcone	Monfalcone	21	1303
Porto Marghera	Venezia	458	648
Sulcis	Portoscuso	40	144
Vado Ligure	Vado Ligure	24	351

4.2 INTERNAL AND EXTERNAL IRRADIATION DUE TO DEPOSITED RADIONUCLIDES

The assessment of the collective dose due to internal and external irradiation of the radionuclide r deposited on the ground can be roughly evaluated by comparing the dose rate due to the natural activity of the soil with that due to the released radionuclide:

$$M^r_{Int+ext} = \frac{A_o \dot{D}_r}{hC} \delta N\, \tau \qquad (2)$$

where A_0 and δN are, respectively, the released activity and the population density, C (Bq/kg) is the natural activity concentration of the radionuclide r in the soil, h (kg/m^2) is the interested layer of the ground, τ is the mean time after which the deposited activity becomes unavailable to the vegetation and $\dot{D}_r$ (Sv/y) is the natural effective dose rate due to the considered radionuclide. In the case of external irradiation, $\dot{D}_r$ represents the natural effective dose rate due to the whole series of ^{238}U or ^{232}Th. h and τ were assumed to be constant and equal to 500 kg/m^2 and 100 years, respectively. The natural soil activity concentration was considered the same for all the radionuclides belonging to the same series. An activity of 35 Bq/kg for ^{238}U series and 30 Bq/kg for ^{232}Th series was assumed (6). The values of natural dose rate estimated from reference concentration in the body are reported in UNSCEAR (6). In the case of radon emanated from deposited Radium, $\dot{D}_r$ was estimated from the natural dose rate due to 100% outdoor exposure. By using data reported in UNSCEAR (6) $\dot{D}_r$ = 473 μSv/y for ^{222}Rn and $\dot{D}_r$ = 35 μSv/y for ^{220}Rn were obtained.

5. RESULTS

The committed effective collective dose per unity energy generated evaluated from Eq. (1) and (2) is shown in Table 4 for a power station with an average population density, taken as 10^{-3} (m^{-2}).

The contribution to the dose due to the different radionuclides strongly depends on the exposure pathway; if compared with UNSCEAR results, the differences are due to the change in dose coefficients and the higher value for the population density used. The main contribution to the effective dose committed to Italian population is due to the ingestion of ^{210}Pb and ^{210}Po deposited on the ground and the inhalation of ^{222}Rn emanated from ^{226}Ra deposited on the ground. Regarding the passage of the cloud, only Thorium isotopes contribute significantly to the total dose.

Table 4. Estimates of radionuclide collective effective dose committed per unit energy generated (10^{-3} man Sv per GWa) for a plant surrounded by a population density of 10^{-3} (m^{-2})

radionuclide	Cloud inhalation	Deposited radionuclides internal irradiation	Deposited radionuclides external irradiation	total
^{238}U	14	8	155	176
^{234}U	17	8		25
^{230}Th	62	7		69
^{226}Ra	16	8		23
^{222}Rn	8	522		530
^{210}Pb	15	265		280
^{210}Po	44	265		309
^{232}Th	85	4	156	246
^{228}Ra	9	18		27
^{228}Th	137	18		155
^{224}Ra	10	18		28
^{220}Rn		35		35
total	416	1174	311	1901

Table 5. Collective and individual doses per coal-fired power plant

Plant site	Collective dose (10^{-3} man Sv)	Individual dose (µSv/y)
Bastardo	15	2,5
Brindisi Sud	369	3,9
Fusina	584	2,0
Genova	1392	2,1
La Spezia	1212	12,4
Monfalcone	594	22,2
Porto Marghera	135	0,5
Sulcis	37	6,6
Vado Ligure	302	36,8

The plant specific collective and individual doses estimates are reported in Table 5. Individual doses are in the range 1-37 µSv/y; the collective dose resulting from a typical power station, normalised to 1 GWa of electricity produced, is about 2 man Sv per year.

6. CONCLUSIONS

Italian legislation implementing the BSS EU Directive 96/29/Euratom does not include coal-fired power stations among the work activities under control and the results of this preliminary study confirm that in Italy this industry has a low radiological impact on population.
However, the collective and individual doses estimated in this work resulted quite high if compared with those from other studies (1, 3, 7). In fact the values reported here must be considered highly conservative, because of the crude approximation in the population interested by atmospheric releases of the plant and in the amount of radionuclides deposited transferred in food chain. Moreover, the radon emanation rate of fly ashes might be an order of magnitude lower than that of normal soil (8), and the dose deriving from inhalation of the gas would be accordingly reduced.

7. REFERENCES

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