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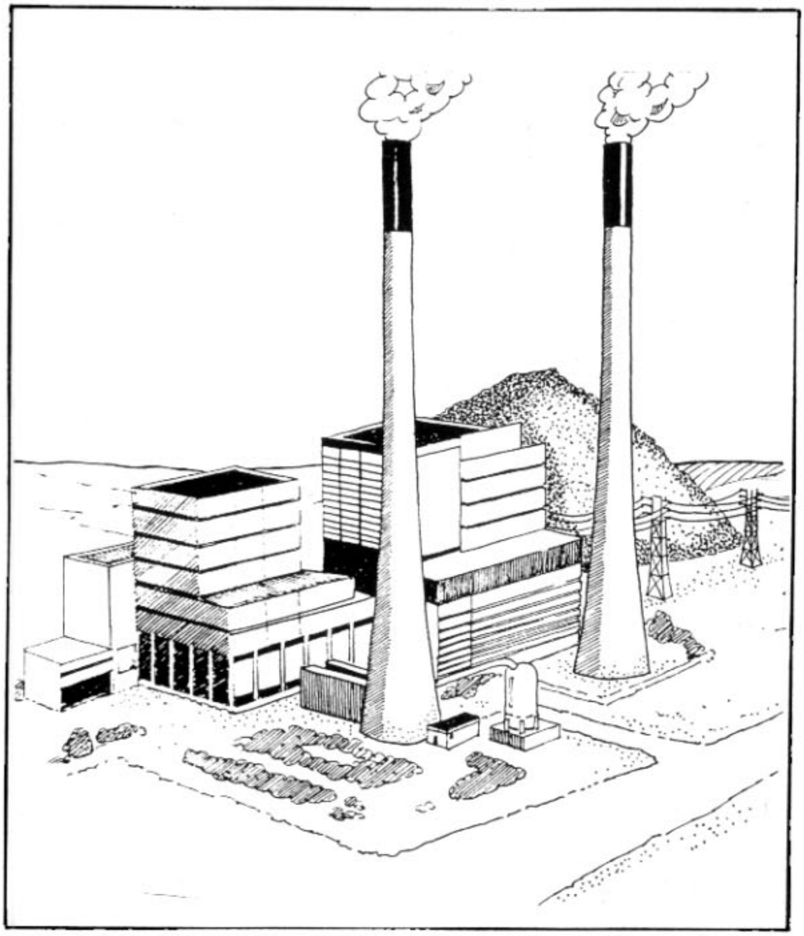

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RADIOLOGICAL IMPLICATIONS OF COAL AND PEAT UTILIZATION IN THE NORDIC COUNTRIES

FINAL REPORT OF NKA PROJECT REK-4

Sven-Olov Ericson
Edsviksvägen 33
Danderyd, Sweden

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The Steering Group for the Radioecology Programme under the Nordic Liaison Committee for Atomic Energy (NKA)

J.O. Snihs (Chairman)	National Institute of Radiation Protection Stockholm, Sweden
U. Grimås	National Swedish Environment Protection Board Uppsala, Sweden
A. Salo	Finnish Centre for Radiation and Nuclear Safety Helsinki, Finland
U. Tveten	Institute for Energy Technology Kjeller, Norway
A. Aarkrog	Risø National Laboratory Roskilde, Denmark
F. Marcus	Nordic Liaison Committee for Atomic Energy (NKA)

P.O. Agnedal (Secretary)	Studsvik Energiteknik AB Nyköping, Sweden

ABSTRACT

Small quantities of radioactive material are released to the environment when burning coal and peat. The resulting doses from plants equipped with modern air cleaning devices are assessed. The doses are comparable to present estimates of those from nuclear power plants. No radiological effects have been found from the use of fly ash in building materials.

KEY WORDS

Building Materials - Coal - Crops - Environmental Impacts - Fly Ash - Fossil-Fuel Power Plants - Peat - Radioactivity - Radiation Doses - Radiation Hazards - Uptake

SUMMARY

Burning coal for electricity and heat production is accompanied by environmental effects which have attracted much attention in the Nordic countries and elsewhere. One aspect which must be regarded as a part of the complete picture is the content of radioactive substances in coal.

Though the activity of naturally radioactive nuclides is quite low, the large quantities of coal used results in relocation of substantial amounts of radioactivity from geological deposits to the surface with possible release into the biosphere. The radiological implications of this have been studied by several researchers during the last decade.

A compilation of the information available from literature led to the conclusion that several questions needed further research.

A critical survey of the dose calculations reported in literature on the radiological consequences of atmospheric releases from coal fired power plants indicate a consensus that the radiation doses are very small. They are of the same order of magnitude as corresponding doses from modern nuclear power stations. The maximum dose received by a person during one year is comparable to the dose received by staying in a normal Swedish dwelling for a few hours, inhaling average concentrations of radon daughters. Inhalation probably is the most important mode of exposure of the population from coal fired plants. There is no consensus between different studies regarding which nuclides are of greatest importance which indicates a considerable uncertainty in quantifying the relation between emission of natural radioactivity from coal fired boilers and resulting dose. The difficulty arises because the contribution from coal fired plants is very small compared to the natural occurrence of the same radionuclides in the environment. Contrary to the situation with emission of artificial radionuclides it is generally not possible to verify assumptions on dispersion and accumulation in food chains by measurements in the environment. Any contribution from burning coal, even in the close vicinity of the plants, is below the accuracy of measurement and natural variations in the back ground.

The radioactivity in coal is concentrated approximately ten times in the ash to give an ash in which the concentration is several times higher than in normal rock, soil and building materials. Independent studies in Denmark, Finland, Norway, and Sweden all indicate that the use of fly ash in concrete results in lower or unchanged levels of radon emanation. There are then no radiological reasons to refrain from using normal coal ash as filling material or substitute for cement in building materials. This conclusion is also supported by recent results obtained in other countries.

One way in which radioactive material can be conveyed from exhaust gases to humans is through a food chain involving the consumption of bread or feeding of live stock with grain. The take up of radioactivity by crops grown on soil with coal or peat ash added has then been investigated. Studies in Denmark where major parts of the soil was replaced by coal ash failed to show any relation between the radioactivity in the soil and in the crop. In Finland work on crop grown on peat soil with addition of peat ash did not indicate any measurable effect on the crop of the added ash.

The accuracy in measurements of radioactivity in fly ash was studied by analysing identical samples in eight laboratories in the Nordic countries. Measurements made by gamma spectrometry showed good accuracy, as a result of previous intercalibrations and general versatility of this technique. Measurements of radionuclides which do not emit gamma radiation often require radiochemical separation and concentration, and spectroscopy of emitted alfa radiation. These measurements carried out in only a few laboratories showed considerable spread in the results. The major difficulty involved in this type of measurements is in leaching quantitatively the radionuclides from the ash sample.

A conclusion of the project is that the radiological implications of any possible effects on health and environment from an increased utilization of coal in modern power plants and district heating plants, can be disregarded as insignificant. The same conclusion is probably valid for peat except for the exceptional deposits with strongly enhanced concentration of uranium.

SAMMANFATTNING

Storskalig användning av kol och torv som bränsle i kraft- och värmeverk medför risker för effekter på hälsa och miljö. Under senare år har stora ansträngningar gjorts att med modern teknik minimera dessa risker. I en fullständig dokumentation av dessa energikällors inverkan på miljön ingår även en beskrivning av naturligt radioaktiva ämnen.

Koncentrationen av naturligt radioaktiva ämnen i kol är i allmännhet mycket låg. Eftersom kol utnyttjas i mycket stora kvantiteter kommer trots detta icke obetydliga mängder av naturligt radioaktiva ämnen att föras upp med kolet från geologiska formationer. Huvuddelen återfinns bundet i olika askfraktioner medan en mindre del kan spridas till biosfären. Radiologiska aspekter på denna spridning har under det senaste årtiondet studerats av ett flertal forskare.

Nordiska kontaktorganets för Atomenergi arbete med naturligt radioaktiva ämnen i kol inleddes med en litteraturstudie. Härvid framkom att kunskapen inom åtskilliga delområden var ofullständig. Det följande arbetet har berört växters förmåga att ta upp radioaktiva ämnen ur aska, mätnoggrannhet, användning av aska i byggnadsmaterial samt en kritisk genomgång av publicerade beräkningar av stråldoser orsakade av koleldning.

Genomgången av publicerade dosberäkningar visade att alla realistiska studier kommit fram till att doserna är mycket små. Till storleksordningen är de jämförbara med stråldoserna från kärnkraftverk. Den högsta dos som årligen erhålles av en person som hela tiden vistas intill ett kraftverk och endast äter livsmedel producerade på denna punkt är jämförbar med den dos man får av att vistas ett par timmar i en normal bostad med för Sverige genomsnittlig koncentration av radon. Troligen erhålls den största delen av dosen genom inandning av askpartiklar. Det föreligger däremot ingen enighet mellan de olika studierna om vilken eller vilka radioaktiva ämnen från kol som ger det största bidraget till stråldoserna. Detta måste ses som en stark indikation på att kvantifieringarna av samband mellan utsläpp och därav följande stråldoser är baserade på ofullständig kunskap och mycket osäkra. Detta förhållande är en naturlig följd av att det är mycket svårt att följa utsläppt aktivitet i miljön. Varje bidrag, även från anläggningar med mycket dålig rening och ovanligt hög aktivitet i kolet, är mycket litet jämfört med den naturliga bakgrundsförekomsten av dessa ämnen. Tillskottet från koleldade anläggningar är alltid mindre än noggrannheten även hos de mest förfinade analyser och lokala naturliga variationer. Antagna spridningsvägar och upptagsfaktorer kan därför, till skillnad från situationen med artificiella nuklider, ej verifieras med mätningar under realistiska betingelser.

Eftersom askhalten i kol är ca 10% kommer koncentrationen av de radioaktiva ämnena att vara tio gånger högre i askan än i kolet. Normal koncentration i aska är därför ett par gånger högre än koncentrationen i normala berg- och jordarter och byggnadsmaterial. Oberoende undersökningar i Danmark,

Finland, Norge och Sverige tyder på att inblandning av kolaska i betong leder till minskad eller oförändrad avgång av radon. Det finns därför ingen anledning att med hänvisning till askans innehåll av naturligt radioaktiva ämnen avstå från att använda den i byggnadsmaterial. Denna slutsats stöds även av motsvarande undersökningar i Nederländerna och USA.

En av de vägar varmed radioaktiva ämnen i kol kan ge stråldoser till människor är via upptag av växter och eventuell anrikning i animaliska livsmedel. Med anledning härav har olika grödor odlats på jord med varierande tillsats av kol- eller torvaska. I Danmark odlades spannmål på jord som blandats med stor andel kolaska. Det var inte möjligt att se något samband mellan andelen aska i jorden och innehållet av radioaktiva ämnen i grödan. I Finland pågår en undersökning där torvaska tillsätts torvjord. Preliminära resultat tyder på att detta ej ger någon mätbar effekt på grödans innehåll av radioaktiva ämnen.

Tillförlitligheten i mätningar av förekomsten av naturligt radioaktiva ämnen i kol och kolaska studerades i projektet genom att identiska prov sändes till olika laboratorier i Norden. Åtta laboratorier sände in resultat. Det visade sig att bestämningar som kan göras med gammaspektroskopi visade god samstämmighet. Detta var väntat eftersom denna analysmetod redan tidigare varit föremål för jämförande mätningar. Bestämningar som kräver radiokemisk separation och anrikning och mätning med alfaspektroskopi utfördes av endast ett fåtal laboratorier och resultaten visade stora avvikelser. Orsaken till detta är att en varierande andel av de radioaktiva ämnena är mycket hårt bundna och svåra att laka ut kvantitativt ur askan.

En sammanfattande slutsats av studierna är att förekomsten av naturligt radioaktiva ämnen i kol som utnyttjas i moderna anläggningar ger stråldoser som är så små att de inte förtjänar vidare uppmärksamhet. Motsvarande slutsats är troligen giltig även för torv med undantag för anläggningar som utnyttjar torv med avvikande hög halt av uran.

LIST OF CONTENTS

1. INTRODUCTION

Coal, like most materials found in nature, contains trace quantities of the naturally occurring primordial radionuclides. Therefore, the mining and utilization of coal results in the release to the environment of some natural radioactivity and re-distribution of that activity from geological formations in the earth to locations where it possibly can increase population radiation exposures. Other primary sources of energy that result in redistribution of natural radioactivity are uranium, natural gas and geothermal wells. In the present context coal includes all varieties as well as lignite and peat.

The radiological implications of coal utilization have been the subject of several research programmes and considerable scientific debate during the last 10 - 15 years. Questions related to this field have been treated in the REK-4 project, one of the projects in radioecology within the Safety Programme 1981-85 of NKA, the Nordic Liasion Committee for Atomic Energy.

The first task within the REK-4 project was a compilation of relevant information available in the open literature and selection of tasks suitable for further research /Ericson

82/. Among the suggested research projects, some were impossible to include as an effect of budget restrictions or limited research capacity. The work within the REK4-project has dealt with the following topics:

- critical survey of dose calculations for atmospheric releases of naturally radioactive nuclides from coal fired power plants.
- studies of the transfer of radioactivity from coal ash added to soil into the crop,
- evaluation of the radiological consequences of using fly ash from coal combustion as a substitute for or as raw material in the manufacture of cement used for building houses, and
- techniques for measuring the activity of the naturally radioactive nuclides in coal ash by intercomparison where 10 laboratories in the Nordic countries made measurements on identical samples of ash.

This report summarises the results of these research efforts put in the context of present knowledge of radiological implications of utilization of coal in modern plants.

2. Radioactivity in coal and peat

The activities of the primordial radionuclides in coal is as a world average a bit lower than the average for those in the earth's crust /UNSCEAR 82/.

UNSCEAR assumed in its 1982 report that the average activity concentrations in coal are 50 Bq/kg of potassium-40 and 20 Bq/kg each of uranium-238 and thorium-232. This corresponds to 1.6 gram uranium and 4.9 gram thorium per ton of coal, (ppm). The available information supports this assumption.

This assumed average activity concentration is not very different from the average activity concentration in soil and building materials in Denmark. It is, however, lower than the average activity concentration in Swedish soils and concrete. As the figures illustrate only representative averages, there are examples of coals with significantly higher and lower activity concentrations.

Thus, there are coals in Greece and Yugoslavia with considerably higher activity concentrations of uranium /Siotis 84/, /Bauman 81/, /Papastefanou 84/.

When prospecting for uranium in western USA uranium concentrations from tens to hundreds of ppm in some coal samples have been reported. This resulted in suggestions that western low sulphur coal contains more uranium than the widely used coal from eastern USA. These samples are not, however, representative for any coal used as energy sources /Cameron 70/. This was verified by samples from 19 operating mines, representing 65% of the production of low suphur coal in western USA, which on an average had only 11 Bq/kg of uranium. This indicates that the activity concentration in the commercial deposits of low sulphur coals in Western USA are in fact lower than the world average /Styron 83/.

The average activity concentrations in peat in Sweden seems to be similar to that of coal. The median of representative sampling in 154 peat bogs was 2 ppm by weight in dry matter each of thorium and uranium. The activity concentration can be much higher in peat bogs located in areas with uraniferous granites. A few bogs with an average uranium concentration of 10 - 40 ppm in the dry matter have ben identified /THM 85/. The uranium is transported to the bogs with moving water, and then adsorbed to peat matter as an effect of redox potential and/or surface adsorption. Thus, very high concentrations can be found on the spots where water enters a bog from surrounding uraniferous granites. In such spots samples with 2.7% by weight of uranium in the ash have been identified /Ehdwall 85/.

3. Combustion of coal

When coal is burned the organic matter is transformed into carbon dioxide and water vapour. The radioactive nuclides are, with the exception of radon isotopes, not volatile and are thus left with other mineral matter as components of the ash. As the ash content of coal is approximately 10% the activity concentration in ash is approximately 10 times that in coal. The proportion of peat ash is lower than coal ash with 6% as a representative figure. This corresponds to a 15-fold concentration of trace elements including radioactive material in the peat ash.

All radon in the coal is released into the atmosphere with the flue gases. As one kilogram of coal gives rise to approximately 10 cubic meters of flue gas, the contribution to radon in the flue gases will be 2 Bq per cubic meter. This is an insignificant contribution not warranting any concern. The average concentration in indoor air in the Swedish housing stock is 50 times higher.

The fate of the radioactive nuclides and their distribution between different types of ash is a function of the combustion technology and the technology used for removing particulates from the flue gases before their release into the atmosphere.

Less prosperous countries still can afford only rather inefficient flue gas cleaning devices. A typical figure for these installations is that 2.5 - 20% of the ash passes through the cleaning device. Similar dust cleaning efficiencies were common in the industrialised countries two or three decades ago. At that time technology was less developed in this area and there was less environmental awareness. Today older plants are often retrofitted with more efficient flue gas cleaning devices, and new installations obtainvery efficient dust cleaning. In Danish coal fired power plants a normal retention of ash today is 99.7%. Electrostatic precipitators are now normally designed to remove > 99.5% of the particulates from the flue gases, and fabric filters often remove 99.9% on a long time average. Flue gas desulphurization also increases the removal of ash particles from the flue gases.

In the combustion process, some of the radionuclides are selectively redistributed to the smaller particles of the ash. This is an effect of partial vaporisation and subsequent condensation on surfaces. The smaller particles having a higher surface-to-mass ratio, thus become enriched in these volatile nuclides, primarily lead-210 and polonium-210. This tendency is most pronounced in wet bottom cyclone furnaces operating at very high temperature (in the range 1600 degrees centigrade). In one investigated boiler of this type 0.3% of the ash passed through the electrostatic precipitator. This fraction, however,was enriched by a factor of approximately 15 in polonium-210 and contained almost 5% of the total amount of this nuclide present in the coal /Jacobi 81/. In normal dry bottom pulverised coal combustion the enrichment was in measured to be a factor of 5. The present development in coal combustion with burners that suppress formation of nitrogen oxides, and with combustion at controlled lower temperatures in various types of fluidised beds certainly will further reduce the selective redistribution of some nuclides to the finer particles.

The importance of this phenomenon, however, should not be exaggerated. It is only the volatile nuclides which can be concentrated on the surfaces of the small particles and they do seem to play a secondary role in both maximum individual and collective dose commitment. The nuclides determining individual and collective dose are not volatile and thus they are separated from the flue gas approximately as efficiently as the ash.

Apart from combustion, both the extraction of coal and handling of its waste products can possibly have radiological implications. Due to the low concentration of radioactivity in coal the miners will not be exposed to increased fields of gamma radiation. The concentration of radon in the air in coal mines is not significantly higher than in dwellings /Roch et al 75/. Thus it can be concluded that mining of coal does not have any significant radiological implications.

4. Radiological consequences of atmospheric releases from coal-fired power plants

The atmospheric release of natural radioactivity from coal combustion can contribute to ambient radiation fields and population radiation exposures via:

- inhalation of activity
- ingestion of contaminated food
- external radiation from the plume
- external radiation from particulates deposited on the ground

Several researchers have presented calculations or estimates of the total individual and collective dose commitments from the atmospheric releases from coal fired power plants. The results are at a substantial variance. The reported maximum individual dose varies over 4 decades from 0.000015 to 0.42 mSv per year. The reported collective dose commitments also range over 4 decades from 0.000018 to 0.65 personSv/PJ of coal /Ericson 83/. There is also substantial disagreement on what exposure pathways are the most important and which nuclides contribute most to calculated doses. These differences can be explained only partially by the differences in composition of various types of coal, in design of the power plant, and in site-specific parameters like population density and climate.

In order to clarify this confusing situation a critical survey of the dose calculations reported in the literature was performed /Tveten 85/.

Tables 1 and 2 present the relevant parameters from a number of studies evaluated by Tveten.

Some results in table 1 stand out as exceptionally high or exceptionally low. These divergent results are possibly the result of:

- too large release assumed by Aigueperse 82
- peculiar and probably faulty assumptions concerning dose relationships and calculations of nutrition dose by Camplin 80, and
- only dose to bone from Ra-226 included in Krieger 78.

After excluding these references Tveten suggests that the presently best estimate of the maximum individual dose in the vicinity of a coal fired power plant is 0.005 mSv/year. It is striking that even after exclusion of the above mentioned references there is no consensus among the remaining ones about critical pathway and critical nuclides. Five references point out inhalation as the critical pathway, while three point out ingestion. Isotopes of U, Th, Ra and Pb are all indicated to be the critical nuclide. This lack of consensus must be regarded as a strong indicator of substantial uncertainty in the quantification. Quantitative information about the radioecology of naturally radioactive nuclides discharged from coal fired power stations is lacking. It can be noted that it is very difficult to follow the contribution from to the activity of these nuclides which are naturally present everywhere, especially as the expected contributions are smaller than the accuracy in analysis.

If the quantification of 0.005 mSv/year is correct, living close to a coal fired-power plant and eating locally produced food is from a radiological point of view equal to living close to a nuclear power station or to spending 35 hours every year in a house with, for Swedish conditions, an average concentration of radon. In Sweden the average retention of ash in power plants will be close to 99.9 % indicating that emissions and doses will be a factor of ten lower than the above estimates. Thus a typical situation in Sweden will be that living in the immediate neighbourhood of a large coal-fired plant for one year results in a dose corresponding to that of spending a few hours inside a normal dwelling.

Reference	retention of ash %	critical pathway	critical nuclide	maximum individual dose mSv/year
Aigueperse 82	?	inhalation	thorium	0.074
Beck 78 new plant	98-99	inhalation		0.0014
old plant	90	inhalation		0.087
Bergström 79	99	inhalation	U-238	0.00013
Camplin 80	99	ingestion	Pb,Po,Pa	0.23
Halbritter 82	99	inhalation	?	0.0005
van Hook 78				
Ilyin 78	78-96	?	?	0.0053
Jacobi 81, lignite	99.7	inhalation	Th	0.0004
cyclone	99.3	inhalation	Th	0.002
Kolb 79	?	ingestion	Ra-226	0.64
McBride77	99	ingestion	?	0.019
Styron 83	?	ingestion	Pb-210	0.0016
UNSCEAR 82	97.5	inhalation	?	0.005

Table1 Maximum individual dose estimates, due to the airborne releases of a 1000 MWe coal-fired power plant

Reference	Retention of ash %	critical pathway	critical nuclides	collective dose, mSv/ GWe,year
Bergström 79	99		Pb-210	5.5
Camplin 80	99	inhalation	Th	180
Halbritter 82	99	ingestion	Pb, Po	3.7
Ilyin 78	78-96			0.15
Jacobi 81, lignite	99.7			0.15 - 0.3
cyclone	99.3			0.8 - 8
McBride 77	99	ingestion	Ra	0.2
UNSCEAR 82	97.5	inhalation	Th	2.8

Table 2 Collective whole body dose commitment personSv per GWe,year

In table 2 the figure given by Camplin 80 is exceptionally high, probably as a result of peculiar and probably faulty assumptions concerning dose relationships and calculations of nutrition doses. After excluding this figure, the remaining references point to a most probable value of about 3 personSv for the collective dose commitment from one year of operation of a 1000-MWe plant. For a plant with flue gas cleaning representative for future installations in the Nordic countries this would be 0.3 personSv/GWe,year.

The carbon dioxide which is released from combustion of fossil fuels does not contain any carbon-14. Thus the use of such fuels will result in an increased amount of carbon dioxide present in the atmosphere and a dilution of carbon-14. This results in lower activity of carbon-14 in living organisms, and thus a reduction in the internal dose from carbon-14. This is referred to as the Suess effect and if this is included in the calculations of collective dose commitment some references indicate that the net effect from coal combustion will be a negative dose commitment. This negative collective dose commitment would be distributed over the global population during several centuries in the future.

5. Transfer of radionuclides from coal- and peat ash into plants

The transfer of radionuclides from ash into growing plants is of interest both when evaluating the ingestion pathway for ash which is released with the flue gases from the stack and when evaluating the radiological implications of using ash as a substitute for dung or lime. Peat ash is alkaline and 0.1 - 0.2 kg per year and square meter added to arable land can compensate for acidifying dung, acid rain, and the alkaline ash removed with the crop. This ash would also supply normal amounts of phosphorus and potassium to the soil. In peat ash these elements can however be less accessible for the crop than normal dung /THM 85/.

In 1982, an experiment was performed at Risø where 2.5 and 10 kg of fly ash from a coal-fired power plant was added per square meter arable land. The amount of added ash corresponded to 1 and 5% of the tilled soil, respectively. The activity concentration of radium in the soil was approximately 23 Bq/kg and in the ash approximately 143 Bq/kg. The effect on the average activity concentration of radium in the soil can thus be calculated to be 4 and 25%, respectively. It was not possible to detect any increase in the activity concentration of Ra-226 or Pb-210 either in straw or grain of barley. There was a slight tendency towards increased activity concentration of Po-210 in grain but not in straw. In 1983, the studies were extended with experimental growing of rye and grass in pots inside a greenhouse. The soil in these experiments was replaced by 0, 25, 50, 75, and 100% fly ash. This rather extreme substratum for growing plants resulted in sharply decreased growth of, in particular, rye. It was not possible to detect any significant correlation with the addition of fly ash to the soil and the activity concentration of Ra-226, Po-210 or Pb-210 in either straw of rye, rye-grain or in grass /Meide 85/.

In a field test started 1983 in northern Finland 2.5 kg/square meter fly ash from peat combustion was added to peat soil. The added ash had an activity concentration of 40 Bq/kg U-238, 87 Bq/kg Ra-226, 321 ±32 Bq/kg Pb-210 and 397± Bq/kg Po-210. During the first two years it has not been possible to detect any effect on the activity concentration in the crop from the addition of fly ash to the soil /Rissanen 85/.

6. Coal ash in building materials

It is always beneficial to find useful applications for industrial waste products. In this way costs and environmental effects of large deposits can be reduced. Fly ash from conventional combustion of pulverised coal can partially substitute portland cement in concrete. In many countries millions of tons of fly ash are used for this purpose. In West Germany, for example, 0.9 Mton out of available 2.5 Mton per year is presently used in cement, concrete and building blocks /Berg 84/.

Ash can be added in several different steps in the production of concrete. It can be mixed with limestone before calcination or with clinker before grinding. It is also possible to substitute some of the portland cement with ash in preparation of concrete.

In Denmark Ulbak /Ulbak 84/ measured the exhalation of radon from samples of concrete where up to 25% of the cement was replaced by fly ash. It was not possible to detect any influence of the fly ash on the exhalation.

The same result was obtained from a corresponding study in Finland. The exhalation from concrete with 0 - 30% of the cement replaced by fly ash was not affected in a detectable way. The exhalation was for all samples 7 - 9 Bq/m2,h /Mustonen 84/.

A study in Norway concluded that substitution of cement with fly ash resulted in a significant reduction of the exhalation with about 33% compared to exhalation from samples of the same concrete without fly ash /Stranden 83/. It was calculated that this decrease in exhalation would reduce the indoor concentration of radon and thus reduce the dose received by the inhabitants. This reduction would outweigh the increase in external radiation which follows from the increase in the activity concentration of radium in the concrete by the addition of ash. Thus, substitution of cement by fly ash in building materials was found to reduce the dose burden to the population.

A corresponding result has been obtained in Sweden where test cubes of concrete with 10% of the cement replaced by fly ash was found to have lower exhalation of radon than reference cubes of conventional concrete /Ericson 83/.

These four Nordic studies were discussed at a seminar arranged in Helsinki by the Nordic Liasion Committee for Atomic Energy. At this seminar the conclusion was drawn that there is no reason from a radiation protection point of view to discourage the use in building materials of conventional fly ash from combustion of normal coal.

The results obtained in these Nordic studies have been confirmed by some other studies. At Lawrence Berkeley Laboratory in California concrete samples in which cement was partially replaced by coal fly ash showed an exhalation rate virtually the same as samples of ordinary concrete /Ingersoll 83/. Recently the results of a study in the Netherlands have been published. There, radon exhalation was measured from 15 cm cubes of conventional concrete and those with 15, 25 and 35% of the cement substituted by three different types of fly ash. The results showed that the radon exhalation from concrete with portland cement has a tendency to decrease when cement is partly substituted by fly ash /Lugt 85/.

One study found that substituting cement with fly ash resulted in an increased exhalation of radon /Siotis 84/. In this study ash from Greek coal was used with specific activities of radium-226 significantly above levels normally found in other countries. The content of moisture in the samples was uncontrolled in this study.

One reason why only a small fraction of the radon produced in fly ash is free to exhale is probably that the radium is trapped in the glass phase of the vitrified slag. If this is so, the emanation could be greater from ash produced in modern and future installations adopting the presently emerging techniques which are developed in order to minimise the formation of nitrogen oxides. In these new techniques the combustion temperature is reduced resulting in the ash not becoming vitrified and the mineral matter not converted from a crystalline to amorphous phase. Similarly, there are some indications that peat ash from fluidised bed combustion has a higher emanating fraction than does peat ash from conventional grate-fired boilers /THM 85/. This could warrant some further studies.

7. Calibration of analyses of radionuclides in coal ash

In order to get an intercomparison of the capability and accuracy of measurements of natural radioactivity in coal and coal ash, samples were distributed to ten laboratories and institutions in the Nordic countries. Each laboratory was free to select which methods to use and what nuclides to measure. Eight laboratories returned results. None measured the activity concentration of all relevant nuclides and only the activity of Ra-226 was measured by all of the participating laboratories.

Results were reported from the folowing laboratories:

Danish National Institute of Radiation Hygiene

Finnish Centre for Radiation and Nuclear Safety
Risø, Department of Health Physics
State Institute of Radiation Hygiene, Norway
Swedish National Environmental Protection Board
Swedish National Institute of Radiation Protection
Swedish University of Agriculture
University of Lund, Department of Radiophysics

The results expressed as Bequerel per kg are summarized in table 3.

Institution	K-40	Th-232	Th-228	Ra-228
1*	560±40	170±20	117±4	95±8
1			160±20	
2	-	-	91±2%	83±1.7%
3	384	91	91±15%	-
4	570±5%	100	100±5%	-
5	-	98	98±12%	-
6	520±20	-	86±4	87±4
7	473±10%	101	101±10%	-
8*	-	11.9±3.1%	90±10	-
8		63±2.3%		
8		90±10		

	U-238	U-234	Th-230	Ra-226	Po-210	Pb-210
1	51±10	53±10	224±20	124±1.1	66±13	2.8±0.6
2	171±6%	-	-	123±0.8%	80±9	62±113
3	57±15%	-	-	57±15%	-	-
4	-	-	-	150±5%	-	-
5	-	-	-	126±12%	-	-
6*	130±20	-	-	128±6	144-170	54±3
6				21		
7	-	-	-	130±10%	-	-
8*	22±1.8%	21±1.8%	15±2.7	18±2	130±10	80±20
8	184±1.3%	182±1.3%	83±2	100±40		

* more than one method was used by this laboratory

Table 3 Compilation of results from intercomparison of methods for analyzing naturally radioactive nuclides in coal ash.

The results were satisfactory for analyses performed with gamma spectrometry, for example radium-226. This was to be expected as the institutions had performed intercalibrations for this type of analysis previously. Analyses requiring radiochemical pretreatment and alpha spectrometry are made by only a few of the institutions and the results varied. This is probably caused by the difficulty of extracting the activity from the glassy ash. Aqua regia often gives only partial extraction and even fusion with alkali yields incomplete and undefined extraction.

8. Conclusions

The radiological implications of coal and peat utilization in modern power plants and district heating plants in the Nordic countries seems to be minor.

This conclusion is believed to be valid though the available quantitative information is lacking or is very limited in some important areas. The dose calculations published for atmospheric releases from power plants indicate lack of scientific knowledge in several steps of the necessary calculations. The results should be regarded as very uncertain as an effect of lacking quantitative information on the radioecology of natural radioactivity in coal and coal ash.

The use of normal fly ash in building materials does not seem to result in increased doses.

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Information Office
National Institute of Radiation Protection
Box 60204
S-104 01 Stockholm
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