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# Assessment of the radiological health damage costs of the Yeniköy and Kemerköy lignite-fired power plants in Muğla

*The health impacts and corresponding damage costs of radioactive emissions of Yeniköy and Kemerköy lignite-fired power plants in Muğla have been assessed by using the simplified impact pathway approach. Radiation dose and risk calculations have been carried out by the code CAP88-PC around the power plants. Specific isotopes, $^{226}Ra$, $^{232}Th$, $^{40}K$ and $^{238}U$ in the flying ash samples are considered as radioactive sources. The estimated total collective doses around Yeniköy and Kemerköy power plants are $3.15 \times 10^{-4}$ man Sv/year and $3.77 \times 10^{-4}$ man Sv/year. Health effects and the corresponding damage costs around the power plants due to radioactive emissions from the power plants are negligible.*

***Beurteilung der Kosten radiologischer Gesundheitsschäden durch die Yeniköy und Kemerköy Braunkohle-Kraftwerke in Muğla.*** *Die gesundheitlichen Auswirkungen und die entsprechenden Kosten der Schäden der radioaktiven Emissionen der Yeniköy und Kemerköy Braunkohle-Kraftwerke in Muğla wurden mit Hilfe des vereinfachten Wirkungspfadansatzes geprüft. Strahlendosis und Risiko-Berechnungen wurden mit Hilfe des Codes CAP88-PC rund um die Kraftwerke durchgeführt. Bestimmte Isotope $^{226}Ra$, $^{232}Th$, $^{40}K$ und $^{238}U$ in Flugascheproben wurden als radioaktive Quellen berücksichtigt. Die geschätzten Kollektivdosen rund um die Yeniköy und Kemerköy Kraftwerke liegen bei $3.15 \times 10^{-4}$ man Sv/year und $3.77 \times 10^{-4}$ man Sv/year. Gesundheitliche Auswirkungen und entsprechenden Schadenskosten aufgrund der radioaktiven Emissionen aus den Kraftwerken sind vernachlässigbar.*

## 1 Introduction

Lignite-fired power plants used to generate electricity convert the coal into useful heat energy, but they are also the cause of great environmental impact and health problems because they emit considerable amounts of hazardous emissions into the atmosphere [1]. Those emissions are separate in two type namely non-radioactive and radioactive emissions.

The negative impact of lignite-fired power plants operation has been underestimated or even ignored for the sake of socioeconomic improvement that these power plants created. As energy demand grows, we can no more ignore the adverse effects of non-radioactive and also radioactive emissions to our health.

It is therefore about time to find a balance between the positive and the negative effects of lignite-fired power plants operation. No one alleges that lignite-fired power plants should suspend their operation but there are several factors to be evaluated as to how they should operate. Because of non-radioactive and radioactive emissions from lignite-fired power plants operation has also global effects and it is important to consider sustainability issues and the future of the generations to come [2].

The lignite-fired power plants were mostly constructed in western Turkey which is close to tourism regions. Moreover, those regions are the most forested areas of Turkey. In particular, two lignite-fired power plants in Muğla and its districts, namely Yeniköy (2 × 210 MW) and Kemerköy (3 × 210 MW) have caused important controversies in the media for a long time. In addition, there are many archaeological sites in this region [3]. Lignite in Muğla and Yeniköy and Kemerköy power plants specifications are presented in Table 1 [4–6]. Particulate control system has been employed in power plants when these power plants started to operate.

Lignite in Muğla province contains some uranium as all lignite does. Lignite in uranium passes to ash with a higher concentration during the firing process in furnace chamber at 1000 °C. While well-burned ash goes to the plant chimney, the others are not burned perfectly which are called slag ashen drops the furnace chamber floor. The radioactive in flying ash is released to the atmosphere, depending on the efficiency of the plant's particulate control system.

*Table 1. Lignite and power plants specifications*

| Specification | Yeniköy | Kemerköy |
|---|---|---|
| Age of the power plant | 25 | 18 |
| Fuel consumption (Mtonnes/year) | 3.75 | 5.90 |
| Calorific value of lignite (kcal/kg) | 1,750 | 1,750 |
| Sulphur content of lignite (%) | 4.0 | 3.2 |
| Ash content of lignite (%) | 29 | 29 |
| Moisture content of lignite (%) | 33 | 32 |
| Stack height (m) | 207 | 320 |
| Stack diameter (m) | 7.82 | *20.5* |
| Exhaust velocity (m/s) | 17.2 | *22.5* |
| Exhaust gas temperature (°C) | 160 | 160 |
| Load factor (%) | 46.1 | 47.2 |

The major potential pathway which might result in increased radiation doses to people are inhalation of flying ash, ingestion of food grown in contaminated soil or direct radiation exposure from the increased deposited radioactivity when flying ash are released from the plant chimney.

The methodology for assessing the health impacts of energy production has undergone a major evolution in recent years, and the impact pathway approach (IPA) has established itself as the most logical method for valuing environmental externalities. IPA has been used in a series of studies in several countries [7–9] in recent years. But those studies generally for non-radioactive emissions from lignite-fired power plants.

In environmental and health respects, the effects of non-radioactive emissions from lignite-fired power plants are much higher than the effects of radioactive emissions from lignite-fired power plants. Since the radioactivity of the lignite used in power plants is natural.

In this study, the health impacts and corresponding damage costs of radioactive emissions of the Yeniköy and Kemerköy lignite-fired power plants have been assessed by using the simplified impact pathway approach [2, 10]. The radiation dose calculations have been carried out by the code Clean Air Act Assessment Package (CAP88-PC) [11] for the population living within 80-km radius of each power plant by using the specific isotopes $^{226}$Ra, $^{232}$Th, $^{40}$K and $^{238}$U in the flying ash samples as radioactive sources. Based on the dose calculations, the stochastic health effects have been estimated by using the risk factors, as recommended by the International Commission of Radiation Protection (ICRP) [12]. Then the predicted health effects have been monetized by using the methodology given in NucPacts model [10]. The assessment was carried out for the year 2012.

## 2 Method

For airborne radioactive air pollution, from power plants, the model utilises a simplified version of IPA, also known as the Damage Function Approach (DFA). The main evaluation step of this approach is illustrated in Fig. 1.

CAP88-PC computer code uses a modified Gaussian plume equation to estimate the average dispersion of radioisotopes released from up to six emitting sources for a circular grid of distances and directions for a radius of up to 80 kilometres around the facility. The sources may be either elevated stacks, such as a smokestack, or uniform area sources, such as a pile of uranium mill tailings. Plume rise can be calculated assuming either a momentum or buoyant-driven plume. The plume centerline remains at effective stack height unless gravitational settling of particulates produces a downward tilt, or until meteorological conditions change. Radioisotopes are depleted from the plume by precipitation scavenging, dry deposition and radioactive decay. The stored depletion fractions were calculated numerically with a Simpson's rule.

Ground surface and soil concentrations are calculated for those isotopes subject to deposition due to dry deposition and precipitation scavenging. Agricultural arrays of milk cattle, beef cattle and agricultural crop area are generated automatically, requiring the user to supply only the agricultural productivity values. Only 7 organs are valid for the effective dose equivalent. They are Gonads 25 %, Breast 15 %, Red marrow 12 %, Lungs 12 %, Thyroid 3 %, Endost 3 % and Remainder 30 %.

Risks are estimated for these cancers: leukemia, bone, thyroid, breast, lung, stomach, bowel, liver, pancreas and urinary. Doses and risks can be further tabulated as a function of radioisotope, pathway, location and organ. Dose and risk factors are provided for the pathways of ingestion and inhalation intake, ground level air immersion and ground surface irradiation. Particle size, clearance class and gut-to-blood transfer factors of the released isotope type further break down factors. These factors are stored in a database for use by the program. Dose and risk estimates from the code are applicable only to low-level chronic exposures, since the health effects are based on low-level chronic intakes.

The meteorological data and population distribution file around the power plants for 16 wind directions must be inputted to the code. Maximum 20 distances of each wind direction is available for the population distribution file.

The occurrence of each of the main stochastic health effects (i. e. fatal and non-fatal cancers and severe hereditary effects) arising as a result of routine atmospheric emission from a power plant is calculated as [10]:

$$N_h = HR_h \tag{1}$$

Where $N_h$ is the total occurrence of health effect, $h$ (cases/year), $H$ is the total collective dose occurring via all pathways (man.Sv/year), $R_h$ is the risk factor for health effect $h$ (cases.-man/Sv).

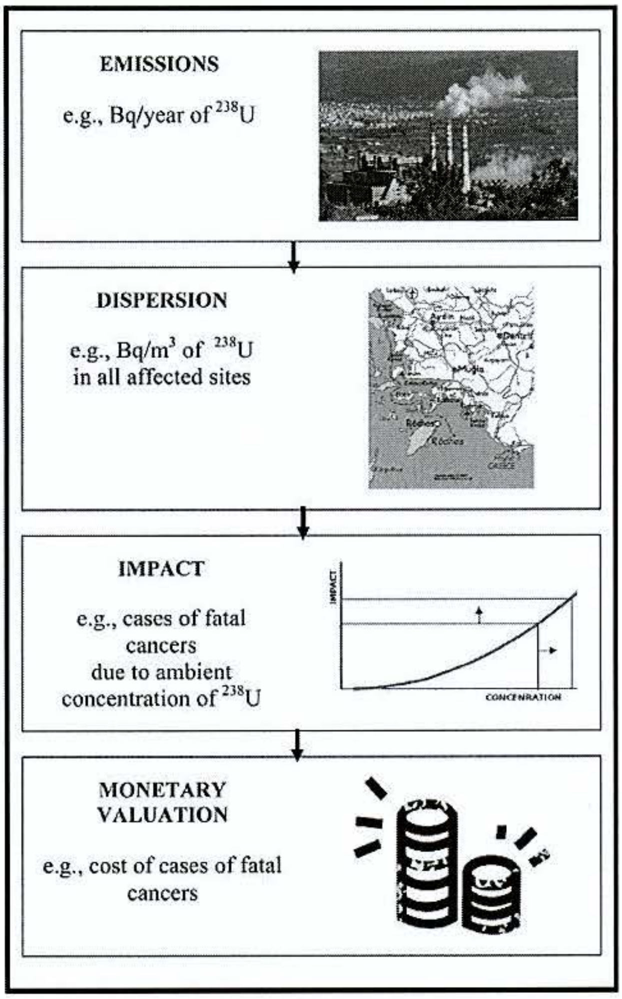

*Fig. 1. Calculation step of IPA*

The monetary damage of various health impacts have been estimated by using a simplified benefit transfer methodology. This method involves translating the costs in other economies to Turkish costs by scaling down the use of the real gross national product per capita in purchasing power parity terms [13]. This assumes that someone's willingness to pay for better air quality is likely to be lower in a low-income economy. This type of method of transferring values from one economy to another economy assumes that the two risk groups are sufficiently alike with respect to their personal preferences and attitudes towards improving air quality standards.

If the damage cost for the country $X$ is available ($D_X$), the damage cost for the country $Y$ can be estimated as follows [14]:

$$D_Y = D_X \left( PPPGNP_Y / PPPGNP_X \right)^E \qquad (2)$$

Where $PPPGNP_Y$ is the real gross national product per capita in purchasing power parity terms for country Y, $PPPGNP_X$ is the real gross national product per capita in purchasing power parity terms for country X and $E$ is the elasticity of income. This relation also assumes that the elasticity of willingness to pay (WTP) with respect to real income is one.

## 3 Calculation step of impact pathway approach

### 3.1 *Input data for CAP88-PC analysis*

Plume rise is calculated by using the momentum plume model since ash emission velocity at the chimney exit is known. An average lid for the assessment area is provided as part of the input data. The agricultural data like beef cattle density, milk cattle density and land fraction cultivated for vegetable crop and others for the region are inputted to the code in order to estimate of emitted isotopes into the food chain.

The meteorological data which obtained from Turkish State Meteorological Service [15] are processed to find out the stability array file for 16 directions. The atmospheric dispersion of the radionuclide's from the stack of a power plant are strongly depends on the meteorological conditions where the power plant is located. Therefore the meteorological data are annually averaged within hourly time step for the each year of the period 1975–2012. The stability array files consist of 4 different wind frequencies, one for each of the 16 wind directions and 6 Pasquill stability categories (A–F). 16 records are entered for each Pasquill stability category and wind frequencies. Pasquill stability classes used in the code are A: extremely unstable, B: unstable, C: slightly unstable, D: neutral, E: slightly stable, and F: stable. Once stability array files have been prepared, and these are converted to wind files for input to the CAP88-PC code which is namely YENIKOY.WND and KEMERKOY.WND.

Population distribution in the 30-km radius of the each plant is prepared for 20 distances. Each distance covers 16 wind directions. And the total populations in the 30-km radius are 113599 and 41914 persons around the Yeniköy and Kemerköy power plants respectively [16]. Once population distribution files has been prepared these population files for input to the CAP88-PC code which are namely YENIKOY.POP and KEMERKOY.POP respectively. Input parameters required for CAP88-PC analysis are presented in Table 3 [3, 6, 15–18].

The estimate of radioactivity released annually in the environment by the power plants have been carried out for $^{226}$Ra, $^{232}$Th, $^{40}$K and $^{238}$U isotopes that according to the measured maximum radioactivities in the flying ash samples [17]. Annual isotope release rate for the isotope type $i$ [$Q_i$: Bq/year] is calculated from the relation given by:

$$Q_i = \dot{m} A_i L \qquad (3)$$

Where $\dot{m}$ is the ash emission rate at maximum power of the power plants [18] same as the $PM_{10}$ emission (see Table 3) from the plant chimney (kg/year), $A_i$ is the measured maximum isotope radioactivity type $i$ (see Table 3) in flying ash (Bq/kg) and $L$ is the plant loading factor [4, 6]. The power generating at maximum power of the each power plant strongly depends on the operational problems of the power plants. Therefore loading factors of the power plants change year to year. In this study the loading factors for the power plants are averaged for the period 2002–2012 to consider a long time period for loading factors (see Table 1).

Total estimated collective effective dose equivalent rate values including all isotopes and pathways effect around the each power plant by CAP88-PC code are presented Table 4.

### 3.2 *Risk calculation*

Risks factors have been used in the calculation are presented in Table 2 [12] and the total collective dose occurring via all

*Table 2. Risk factors for main stochastic health effects for whole population (cases/man Sv)*

| Health effect category | Risk factor |
|---|---|
| Fatal cancer | $5.0 \times 10^{-2}$ |
| Non fatal cancer | $1.0 \times 10^{-2}$ |
| Severe hereditary effects | $1.3 \times 10^{-2}$ |

*Table 3. Input parameters required for CAP88-PC analysis*

| Plant data | Yeniköy | Kemerköy |
|---|---|---|
| Annual precipitation (cm/year) | 55.90 | 53.02 |
| Annual ambient temperature (°C) | 18.1 | 18.7 |
| Annual average wind speed (m/s) | 1.1 | 1.4 |
| Height of lid (m) | 352 | 448 |
| $PM_{10}$ emission rate (kg/h) | 0.50 | 0.83 |
| Measured activity in flying ashes<br>$^{226}$Ra (Bq/kg)<br>$^{232}$Th (Bq/kg)<br>$^{40}$K (Bq/kg)<br>$^{238}$U (Bq/kg) | <br>509<br>29<br>283<br>399 | <br>995<br>44<br>498<br>1017 |
| Human inhalation rate, (cm$^3$/h) | $9.17 \times 10^5$ | $9.17 \times 10^5$ |
| Land fraction cultivated for vegetable crops | $5.50 \times 10^{-2}$ | $5.50 \times 10^{-2}$ |
| Beef cattle density (number/km$^2$) | 3.89 | 3.89 |
| Milk cattle density (number/km$^2$) | 1.13 | 1.13 |
| Meat ingestion per person, (kg/year) | 15 | 15 |
| Cereals ingestion per person (kg/year) | 228 | 228 |
| Milk ingestion per person (L/year) | 33 | 33 |

pathways are calculated by the code CAP88-PC for each power plant.

The total stochastic health effects around the each power plant are calculated from Eq. (1) by using the risk factors (see Table 2) and the total estimated effective dose equivalent rate (see Table 4). The estimated total stochastic health effects for the power plants are presented in Table 5.

### 3.3 The monetary value of the predicted health effects

In this study, the economic unit values for Turkey are estimated by using Canadian economic unit values of radiological health impacts since the Canada is the country that the recent economic unit values of radiological health impacts are available [10]. $PPPGNP_{Turkey}$ and $PPPGNP_{Canada}$ 8,600 US$ and 27,630 US$ respectively, in 2000 [19]. Economic unit values of radiological health impacts for Canada and estimated values for Turkey are given in Table 6 [10, 19].

Based on the economic unit values of radiological health impacts (see Table 6), the valuation of the predicted health effects of the power plants are calculated from Eq. (2). The estimated damage costs of the radiological health effects of the power plants are given in Table 7.

## 4 Conclusions

The IPA has been widely used for decision aid in the fields of energy production and consumption, transport and environmental protection. In spite of the large uncertainties exist; however will be more and more reduced due to ongoing research.

In this study, the radiation dose calculations have been carried out by the code CAP88-PC for the population living within 30-km radius of the Yeniköy and Kemerköy coal-fired power plants. The measured maximum specific isotopes $^{226}$Ra, $^{232}$Th, $^{40}$K and $^{238}$U in the flying ash samples are considered as radioactive sources. Based on the dose calculations, the stochastic health effects and predicted health effects have been estimated.

It is seen that the total health impacts for the Yeniköy and Kemerköy power plants were $2.31 \cdot 10^{-5}$ cases/year, $2.76 \cdot 10^{-5}$ cases/year respectively. Those values are lower than recommended by the ICRP and it does not pose any risk for public health.

*Table 4. Total estimated collective effective dose equivalent rate around the power plants (man Sv/year)*

| Plant name | Collective dose |
|---|---|
| Yeniköy | $3.15 \times 10^{-4}$ |
| Kemerköy | $3.77 \times 10^{-4}$ |

*Table 5. The total stochastic health effects for the power plants (cases/year)*

| Plant name | Fatal cancer | Non Fatal cancer | Severe hereditary effects |
|---|---|---|---|
| Yeniköy | $1.58 \times 10^{-5}$ | $3.15 \times 10^{-6}$ | $4.10 \times 10^{-6}$ |
| Kemerköy | $1.89 \times 10^{-5}$ | $3.77 \times 10^{-6}$ | $4.90 \times 10^{-6}$ |

*Table 6. Economic unit values of radiological health impacts (US $2000/case)*

| Health effect category | Canada | Turkey |
|---|---|---|
| Fatal cancer VOSL[a] | $1.73 \times 10^{6}$ | $5.38 \times 10^{5}$ |
| Fatal cancer VLYL[b] | $7.73 \times 10^{5}$ | $2.41 \times 10^{5}$ |
| Non-fatal cancer | $5.77 \times 10^{5}$ | $1.80 \times 10^{5}$ |
| Severe hereditary effect | $1.73 \times 10^{6}$ | $5.38 \times 10^{5}$ |

[a] (VOSL): Value of Statistical Life
[b] (VLYL): Value of Life Year Lost

*Table 7. The monetary value of the predicted health effects (US $2000/year)*

| Plant name | Fatal cancer (VOSL) | Fatal cancer (VLYL) | Non fatal cancer | Severe hereditary effects |
|---|---|---|---|---|
| Yeniköy | 8.50 | 3.81 | 0.57 | 2.21 |
| Kemerköy | 10.17 | 4.55 | 0.68 | 2.64 |

The total health damage cost assessed for the Yeniköy and Kemerköy power plants were 15.09 US$2000/year and 18.04 US$2000/year respectively. The results indicate that the predicted damage costs due to health effects are negligible in comparison to the economic values of the each power plant.

The speculations on the radionuclide emissions from the lignite-fired plants in Muğla and their health effects have continued since 1993. Against the speculations there is restricted literature [20] on the stochastic health effects and the cost of the predicted health effects from the Yeniköy and Kemerköy power plants [21]. Therefore, the results of this study are very useful for ending up the speculations on the health effects and the costs of those effects.

(Received on 30 October 2013)

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**Bibliography**
DOI 10.3139/124.110395
KERNTECHNIK
79 (2014) 1; page 1–5

ISSN 0932-3902

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Correction:

Reference 12 will replace with document given below:

"Annals of the ICRP: The 2007 recommendations of the international commission on radiological protection. Publication. 103, The International Commission on Radiological Protection, Elsevier, UK."