ESTIMATION OF RADIOLOGICAL DOSES OVER TURKEY BY USING ATMOSPHERIC DISPERSION MODEL AFTER FUKUSHIMA NUCLEAR POWER PLANT ACCIDENT

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FUKUSHIMA NÜKLEER SANTRALI KAZASI SONRASI TÜRKIYE IÇIN RADYOLOJIK DOZLARIN ATMOSFERIK DAĞILIM MODELI KULLANARAK DEĞERLENDIRILMESI

Abstract

The effects of Fukushima Nuclear Power Plant accident over Anatolian Peninsula were investigated by using an atmospheric dispersion model with three different source terms. Air concentration amounts for ^{131}I particles over Turkey were found between 0.1 mBqm^{-3} and 0.5 mBqm^{-3}, for ^{137}Cs between 0.01 mBq m^{-3} and 0.05 mBqm^{-3}, and for ^{131}I gas between 1 mBqm^{-3} and 10 mBqm^{-3}. Results were compared with the measured values. The radiological doses were calculated over Anatolian Peninsula by using air concentration values simulated by atmospheric model. In addition the effective doses were found around nSv which shows that Fukushima Nuclear Power Plant accident has limited effects compared to Chernobyl Power Plant accident.

Özet

Fukushima Nükleer santral Kazasının Anadolu Yarımadası üzerindeki etkileri üç farklı kaynak terim ile atmosferik dağılım modeli kullanılarak araştırılmıştır.. 131I parçacıklarının haca konsantrasyon değerleri 0.1 mBqm-3 ile 0.5 mBqm-3, 137Cs değerleri 0.01 mBq m-3 ile 0.05 mBqm-3, for 131I gaz değerleri 1 mBqm-3 ile 10 mBqm-3arasındadır. Bulunan değerler ölçüm değerleriyle kıyaslanmış ve bu değerler kullanılarak Anadolu Yarımadası için radyolojik doz değerleri hesaplanmıştır. Bulunan efektif doz değerleri Fukushima Nükleer Güç Santrali Kazasının etkilerinin Çernobil Nükleer Güç Santrali ile kıyaslandığında oldukça sınırlı olduğunu göstermektedir.

Keywords: Fukushima,Radiological dose,Atmospheric dispersion,HYSPLIT

Anahtar kelimeler: Fukushima,Radiolojik doz, Atmosferik dağılım, HYSPLIT

1. Introduction

Fukushima Daiichi Nuclear Power Plant (FNPP) located around the towns called Okuma and Futaba of Japan had a big damage after the earthquake and tsunami which occurred on March 2011. The reason of the damage was the hydrogen explosions occurred in the Unit 1 and 3 reactors on March 12 and 14, and in the Units 4 and 2 on March 15 (Thakur, Ballard and Nelson, 2013). Explosions resulted release of large amount of radioactive particles into the atmosphere (Chino, et al. 2011). The radioactive gases and particles released in the accident were dispersed over entire northern hemisphere and also measured in the southern Hemisphere (Thakur, Ballard & Nelson, 2013).

After a nuclear power plant accident, the technical expression 'source term' is used to have information about releases to the environment. The source term is defined as the magnitude, composition, form (physical and chemical) and mode of release (puff, intermittent or continuous) of radioactive elements (fission and/or activation products) released during a reactor accident (IAEA SRS 53, 2008). Many studies have been done to estimate the FNPP accident source term. In general it is estimated that the amount of ^{131}I released from Fukushima (150 PBq) was less than 10% of the amount released from Chernobyl Nuclear Power Plant (CNPP) accident (~1760 PBq). ^{137}Cs, the next most important fission product, released from Fukushima (12 PBq) was less than 15% of the CNPP accident (85 PBq) (Steinhauser, Brandl and Johnson, 2014). Even though the released radionuclides after FNPP accident were less than CNPP accident, there are many studies reporting measurement of radionuclides at different locations around the world. These measurement studies reported the results of different techniques including air, water, food sampling, mostly for the ^{137}Cs, ^{134}Cs and ^{131}I radionuclides. ^{131}I and ^{137}Cs are the most important radionuclides responsible for the public to receive doses as they can travel long distances and their impacts on human health.

People, animals and environment were exposed to ionizing radiation due to the released radioactive gases and particles. With the release of a mixture of short and long-lived radionuclides to the atmosphere after an accident like in Chernobyl or Fukushima, stochastic health effects over a wide area and deterministic health effects in the region close to the accident are probable (IAEA SRS 53,2008). Also as a stochastic effect, the cancer risk to the population can be assessed several years later through the cancer registration system of Japan after FNPP accident (Evangeliou, Balkanskia, Cozica & Møller, 2014).

In this study, the air concentration amounts of ^{137}Cs and ^{131}I (both gas and particle) of FNPP accident over Anatolian Peninsula were investigated by using an atmospheric dispersion model. The HYSPLIT-online model for the FNPP accident was used for this purpose. The results for Istanbul were compared with the measurement results of the study performed by Gungor, Gungor, Yuksel, Bag and Orhan (2014) and radiological doses were calculated over Anatolian Peninsula.

2. Materials And Methods

2.1 HYSPLIT

The HYSPLIT (Hybrid Single-Particle Lagrangian Integrated Trajectory (http://www.arl.noaa.gov/HYSPLIT_info.php), model from NOAA-ARL's (National Oceanic and Atmospheric Administration Air Re- sources Laboratory) is a complete system for computing simple air parcel trajectories to complex dispersion and deposition simulations using either puff or particle approaches (Draxler, Stunder, Rolph, Stein and Taylor, 2009). The model can be run either interactively on the Web through the READY system or the code on a PC. In this study, HYSPLIT-online model was used which meteorological data provided and has pre-defined source terms to calculate the air concentration amounts of ^{137}Cs and ^{131}I (gas and particle) occurred over Turkey after the Fukushima nuclear reactor accident. The advantage of using HYSPLIT model in this study was that radioactive decay of a radionuclide was taken into account in the model (Draxler and Hess, 1997). The decay constant for radioactive processes (λ_{rad}) is defined by the half-life $T_{1/2}$,

$$\lambda_{rad} = \ln2 \, / \, T_{1/2} \tag{1}$$

hand the radioactive mass of a pollutant ($m_{t+\Delta t}$) after a time interval Δt, either in the air or deposited at the soil, becomes,

$$m_{t+\Delta t} = m_t \exp\left(-\lambda_{rad}\,\Delta t\right) \tag{2}$$

In HYSPLIT online model for reported emissions of ^{131}I and ^{137}Cs from the Fukushima Daiichi Nuclear Power Plant are used to demonstrate the system. It is possible to demonstrate four generic species with or without calculating the deposition parameters (https://ready.arl.noaa.gov/READY_fdnpp.php). The reported emissions which HYSPLIT online for Fukushima are the studies of Chino et al., (2011), Terada, Katata, Chino and Nagai (2012) and Katata, et al. (2014). Figure 1 shows the graph of these three different source terms for [131]I (particle and gas) and ^{137}Cs radionuclides. As we discussed meteorological conditions 6 hours before the accident were chosen at these simulations
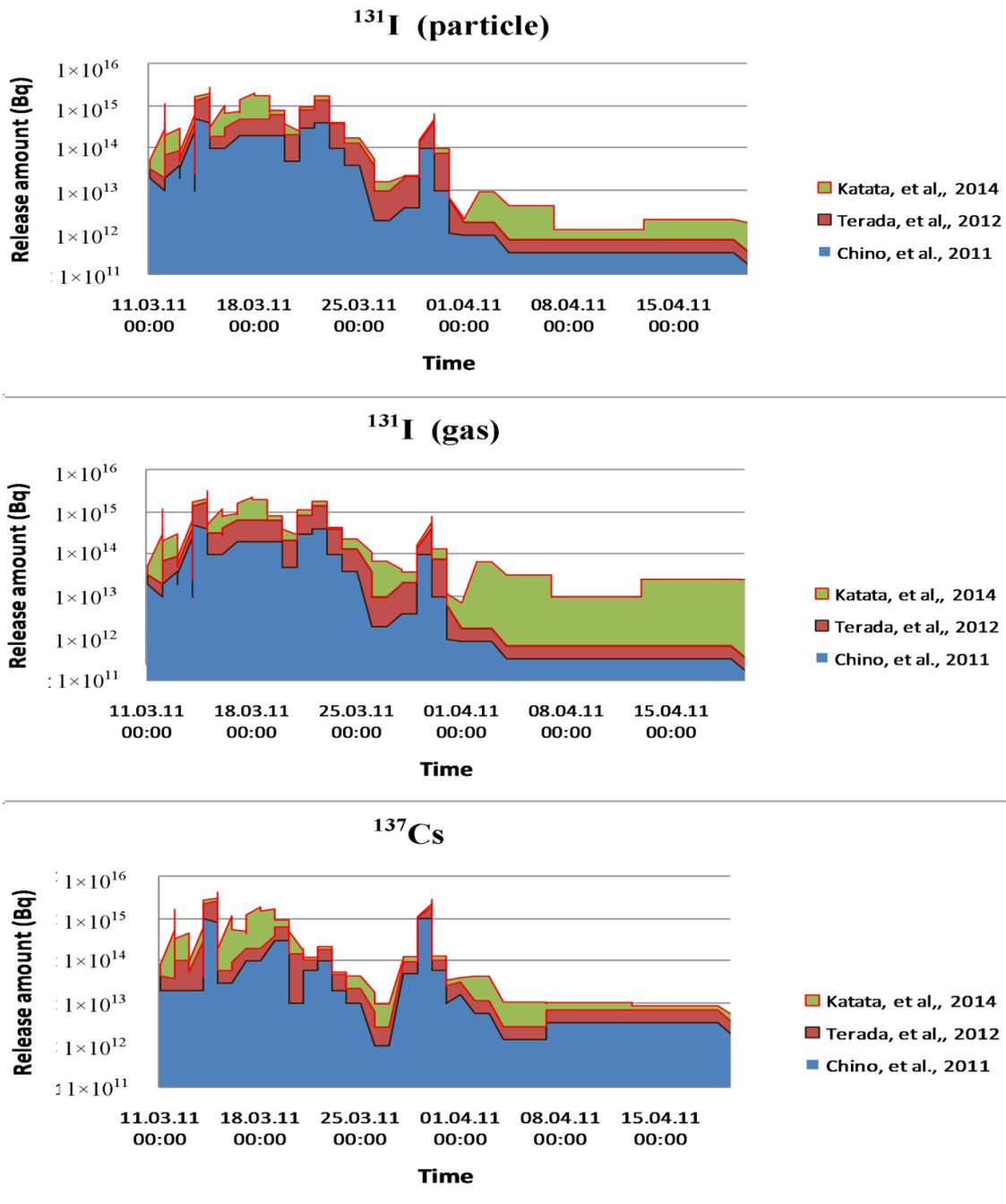

Figure 1. Release amounts of the radionuclides [131]I (gas and particle) and ^{137}Cs according to the three studies. (Chino, et al., 2011), (Terada, Katata, Chino and Nagai H, 2012) and (Katata, et al., 2014).

2.2 Radiological dose calculations

It is possible to define main exposure pathways to radioactive material are: a) external effective dose from cloud gamma (Dc); b) internal effective dose from inhalation (Da) during radioactive cloud passage; c) external effective dose from radionuclides deposited on soil and other surfaces d) internal effective dose from the consumption of contaminated food and water (IAEA RARS 1239, 2006). Only the a and b processes were progressed in this study since we obtained air concentration amounts by our simulations. Dose calculations were performed according to the UNSCEAR 1988 report (United Nations Scientific Committee on the Effects of Atomic Radiation) (Radiological Toolbox Eckerman and Sjoreen, 2006) developed for the U.S. Nuclear Regulatory Commission (NRC), a tool for dose calculation, was used to obtain dose coefficients cloud gamma and dose calculation due to inhalation. This tool uses public inhalation dose coefficients taken from International Commission on Radiological Protection report ICRP Publication 72: Age-dependent Doses to the Members of the Public from Intake of Radionuclides (ICRP 72., 1995) and external dose coefficients for cloud gamma doses coefficients taken from FGR 12 (Federal Guidance Report no. 12) (Eckerman and Ryman, Federal guidance report no. 12, 1993).

2.2.1. Cloud gamma doses

Whereas γ radiation from airborne radionuclides is the main exposure pathway of dose from external exposure, some radionuclides give rise to β radiation, which can lead to exposure to the skin. Cloud gamma doses were calculated by the formula;

$$D_c = C_a \times S_a \times M_o + C_a \times S_a \times M_i \times B_a \tag{3}$$

Where C_a is the air concentration value (Bqm^{-3}) simulated by HYSPLIT, S_a is the external cloud gamma coefficient. In formulas 3.3 and 3.4, the values for M_o is the outdoor occupancy factor, M_i is the indoor occupancy factor, and B_a is the building shielding factor and these are 0.2, 0.8 and 0.2 (UNSCEAR., 1988), respectively.

2.2.2. Inhalation doses

Public inhalation effective dose (Da) was calculated using the coefficients from the report No. 72 of the International Commission on Radiological Protection report (ICRP 72., 1995);

$$D_a = C_a \times I_a \times M_o \times R + C_a \times I_a \times M_i \times B_r \times R \tag{4}$$

where Ca is the air concentration value $(Bq\ m^{-3})$ simulated by HYSPLIT, I_a is the public inhalation effective dose coefficient, R is the breathing rate $(m^3\ h^{-1})$, and B_r is the indoor air reduction factor (0.3) (UNSCEAR., 1988). Breathing rates were 19.2 $m^3\ day^{-1}$ for an adult, 14.4 $m^3\ day^{-1}$ for 10 years old child and 4.8 $m^3\ day^{-1}$ for 1 year old infants (Robinson, 1996).

3. Results And Discussion

3.1. Air concentration values

The effect of FNPP accident was simulated by using HYSPLIT model online which Air Resources Laboratory configured previously by using three different source terms as named in website of ARL; Source Term 1 (NOAA-6h) (Chino, 2011), Source Term 3 (JAEA-Terada-6h) Terada, et al., 2012, and Source Term 5 (JAEA-Katata-6h) (http://www.arl.noaa.gov/HYSPLIT_info.php.) These are the source terms which 6 h meteorological data are provided, and the results were obtained for every 6 hours. HYSPLIT simulations show us that radioactive gases and particles released in the accident were dispersed over entire world as mentioned by the study of Thakur et al., 2013 carried out after accident.

Figure 2 shows the global distribution and distribution over Turkey of integrated ^{131}I particle air concentration simulated by HYSPLIT online for the source term of the study done by Katata et al. (2014) between March 11, 2011 and April 21, 2011. In global scale the integrated values of ^{131}I particles were found to be between 1.2×10^{-18} mBqm^{-3} (generally around southern hemisphere) and over 10000 mBqm^{-3} (around Japan) reaching up to 1.7E+04 Bqm^{-3}. Between March 11, 2011 and April 21, 2011 integrated values of ^{131}I particles over Turkey because of the FNPP accident release were found between 0.1 mBqm^{-3} and 0.5 mBqm^{-3} for ^{137}Cs, between 0.01 mBq m^{-3} and 0.05 mBqm^{-3} for ^{131}I gas and between 1 mBqm^{-3} and 10 mBqm^{-3} for all three simulations.
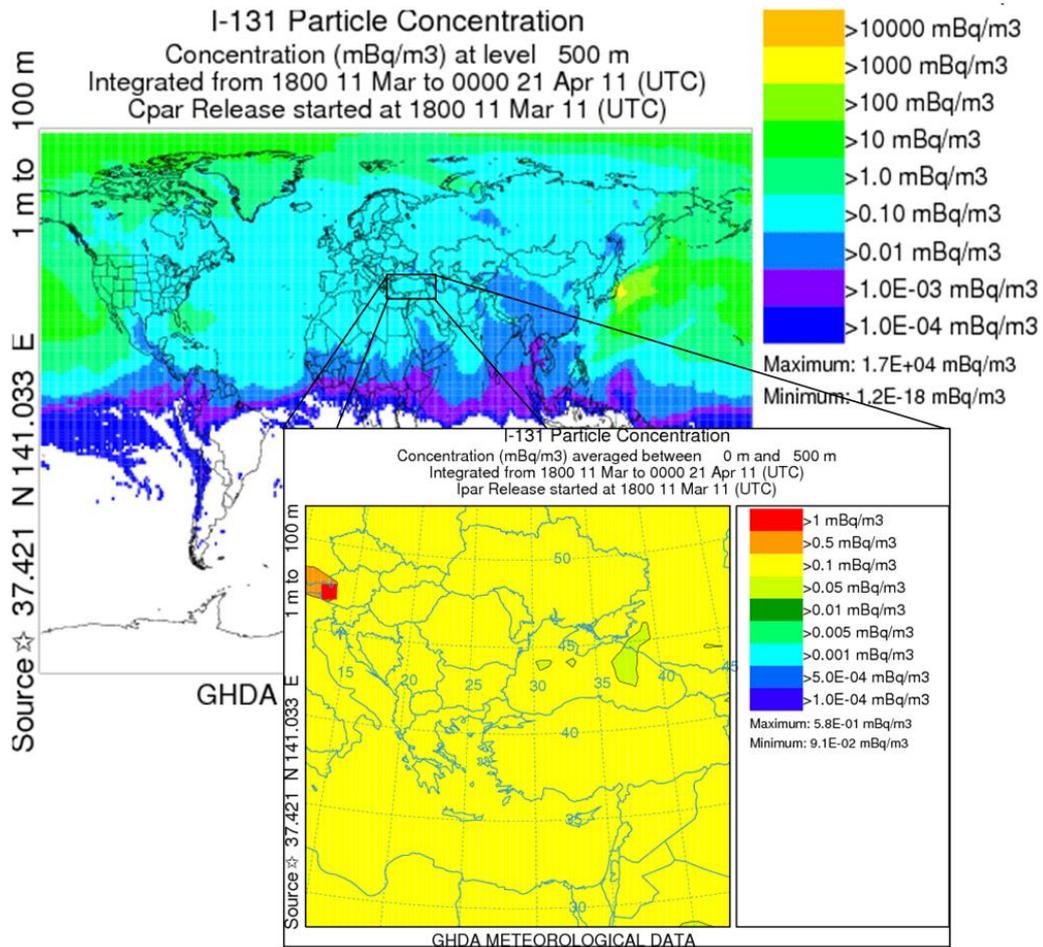

Figure 2. ^{131}I particle concentration values after FNPP accident.

The obtained air concentration amounts were compared with the study of Gungor et al., 2014. They collected airborne particle samples daily on air filters and radio assayed with a high purity germanium detector at Cekmece Nuclear Research and Training Center located at Istanbul. The sampling coordinates are 41.023056 N and 28.759444 E, which were also chosen sampling point for this study. The daily mean values of the each measurement were used for comparison as some of them are integrated values for more than one day. Simulated and measured (Gungor E., Gungor N., Yuksel A., Bag G., and Orhan N., 2014) air concentration values for ^{131}I (particle and gas) and ^{137}Cs are shown in Figure 3. The behavior of simulated air concentration values with three simulations for ^{131}I particle and ^{137}Cs are similar with measurement values as seen in Figure 3. As the study of Gungor et al., 2014 includes technique

of measuring air concentration of particles, it is not possible to make comparison for the ^{131}I gas. Since same meteorological data was used for all radionuclides, it is possible to use ^{131}I gas air concentration amounts for the calculation of radiological doses. The agreement between the simulated air concentration values and the measured values at some points can be well but generally higher than the measured ones. This can be due to several reasons. The simulation results are averaged air concentration values between 0 and 500 m. On the other hand, the measured values are at ground surface. This can make a big difference as the transport of the particles occur in higher altitudes and an important factor which affects the deposition (wet and dry) of particles at ground surface. Also the objects on the surface such as buildings, trees etc. affect the distribution of measured air concentration values due to the measuring location. Another important factor which caused the difference is that the measured values are not given per day for all dates. At this point, the results are affected as ^{131}I has short half life. Figure 3 shows the air concentration results of our simulations and measured values by Gungor, Gungor, Yuksel, Bag and Orhan (2014) (daily mean values calculated) for the radionuclides ^{137}Cs and ^{131}I particle and simulation results for ^{131}I gas.
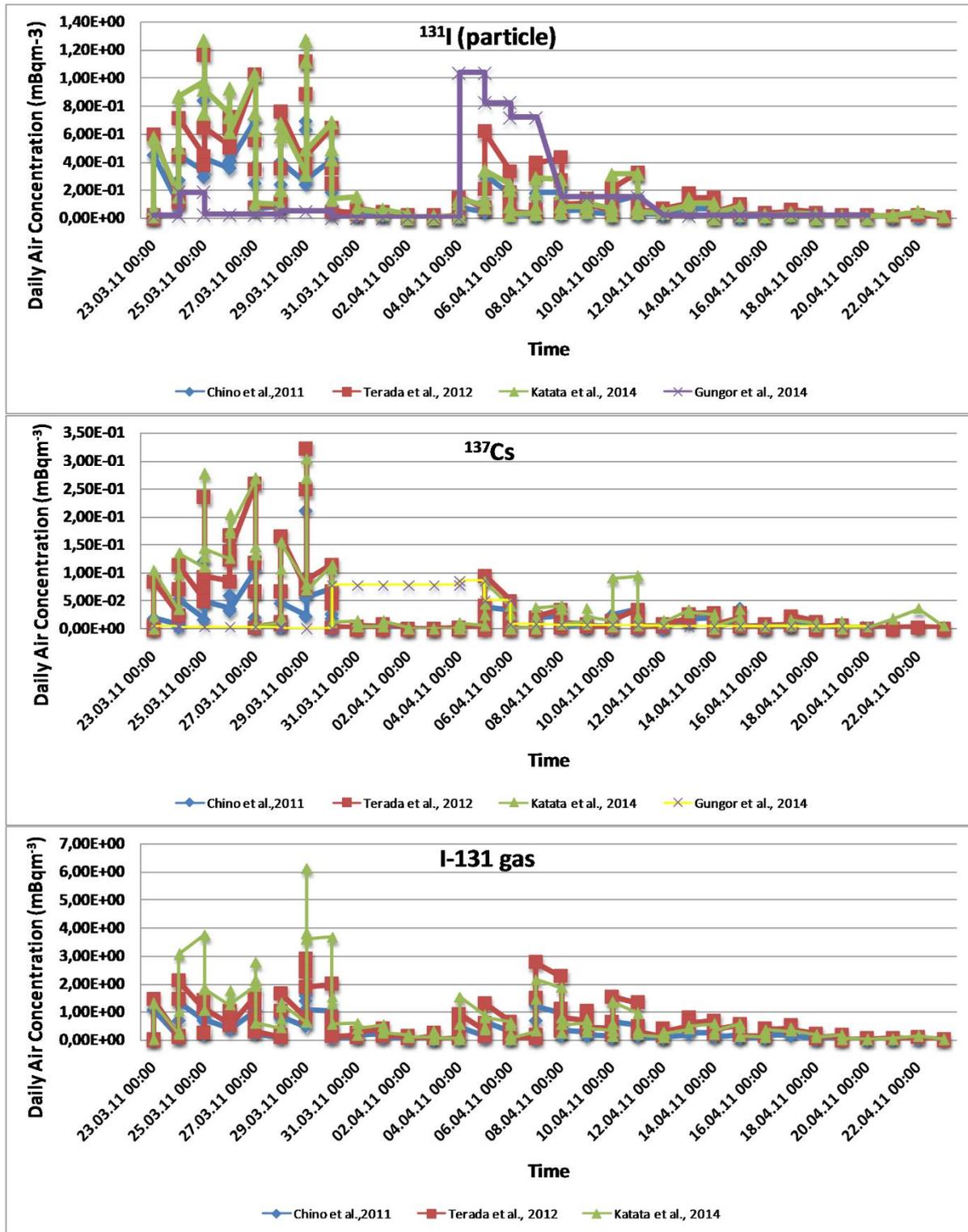
Figure 3. Simulated and measured (Gungor E., Gungor N., Yuksel A., Bag G., and Orhan N., 2014) daily air concentration values for ^{131}I and ^{137}Cs.

Maximum simulated air concentration value was found for the date March 29, 2011 for the ^{131}I (particle+gas) with a value 7.395 mBq/m^3 by using the source term described by (Katata, et al., 2014), Where the measured values reached up for ^{131}I (particle) on April 4, 2011. For ^{137}Cs maximum simulated value reached up to 3.22E-01 mBq/m^3 for the March 29, 2011 with the source term (Katata, et al., 2014).

3.2. Radiological dose values

Radiological effective doses were calculated over Turkey after FNPP accident. Dose calculations were done using three simulations and for the days ^{131}I and ^{137}Cs radionuclides air concentration measurement data consists at the study of Gungor, Gungor, Yuksel, Bag and Orhan, 2014. Figure 4 shows the calculated total effective radiological doses with three simulations.
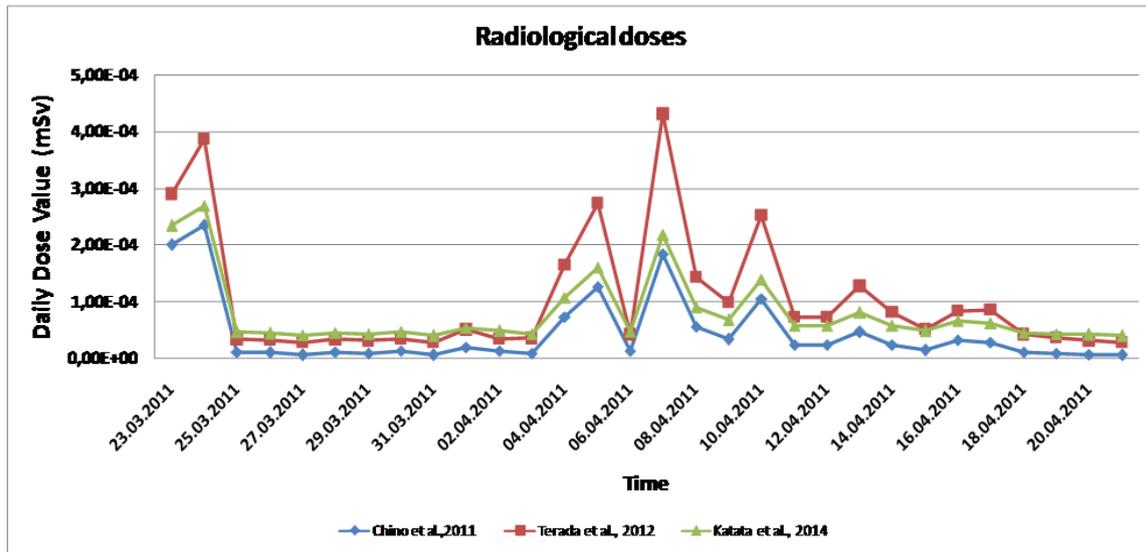

Figure 4. Calculated effective doses by three simulations

Calculated daily maximum effective doses due to ^{131}I radionuclide are 2.29×10^{-4} mSv, 4.03×10^{-4} mSv, 4.99×10^{-4} mSv for the source terms (Chino et al., 2011), (Terada, Katata, Chino and Nagai, 2012) and (Katata, et al., 2014) respectively. For all source terms calculated minimum effective doses are around 1.30×10^{-7} mSv. For the ^{137}Cs radionuclide 1.88×10^{-5} mSv, 3.77×10^{-5} mSv, and 4.46×10^{-5} mSv was calculated for the same source terms. The effect of ^{131}I radionuclide on the doses is in the order of 10 reaching 100 which makes the ^{131}I main radionuclide contributing doses over Turkey. Total effective doses are 1.38×10^{-3} mSv, 3.16×10^{-3} mSv, and 3.19×10^{-3} mSv for the source terms (Chino, et al., 2012) and (Katata, et al., 2014) respectively. The calculated dose values are for the sampling coordinates are 41.023056 N and 28.759444 E. These values are also the same for all Turkey as the simulation results show us that the air concentration values are in the same range as seen in Figure 2. Since all Turkey was interested by the CNPP radioactive cloud, and adult effective doses due to only ^{137}Cs radionuclide reach values up to 0.15 mSv/year in North Eastern Turkey (Simsek, Pozzoli , Unal, Kindap and Karaca, 2014), it is possible to say that FNPP accident has limited effect on Turkey.

4. Conclusions

Estimation of radiological doses after FNPP accident was done by using HYSPLIT-online model. Air concentration values were simulated by the HYSPLIT-online model. Simulated air concentration values were compared and found in the same order with measured air concentration values. March 29, 2011 is the date where simulated maximum air concentration values were found for both ^{131}I and ^{137}Cs radionuclides. Radiological doses are found in 1.38×10^{-3} mSv, 3.16×10^{-3} mSv, and 3.19×10^{-3} for three simulations. This dose amount is around daily background dose as mentioned by Gungor, Gungor, Yuksel, Bag and Orhan, (2014) and very low compared to doses due to Chernobyl accident over Turkey.

5. Acknowledgements

6. References

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