Annals of Ecology and Environmental Science
Volume 3, Issue 1, 2019, PP 33-39
ISSN 2637-5338

Radiological Impact due to Atmospheric Releases of the Source Term for F-D, Unit 1, Using HOTSPOT Code

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ABSTRACT

This paper concentrated on the calculation of atmospheric releases of the radioactive materials originating from Fukushima Daiichi Nuclear Power Plant (F-D) accident, unit 1, which were calculated by Tokyo Electric Power Company (TEPCO) and the Egyptian atomic energy authority (EAEA). HOTSPOT Code, Gaussian plume model, was used to calculate the dose rate distribution resulting from the plume air submersion and ground shine of radioactive deposits on the soil surface.

The results showed that the maximum dose rates resulting from air submersion and ground shine are 0.03 and 0.005 Sv/h at distance of 0.27 Km from the reactor. The deposition density for I-131 and Cs-137 in some locations around F-D, NPP were calculated also using HOTSPOT code and the results show good agreement with the measurements of the Japanese Ministry of Education, Culture, Sports, Science and Technology (MEXT). The results also were compared with the deposition calculations of National Oceanic and Atmospheric Administration (NOAA), and Institute for Radiological Protection and Nuclear Safety (IRSN).

INTRODUCTION

The Fukushima Daiichi Nuclear Power Plant (FNPP) accident in Japan resulting from tsunami on 11 March 2011 caused a month-long discharge of radioactive materials into the atmosphere. Several studies have been focused on evaluating the radiological consequences resulting from the Fukushima accident.

The studies used different theoretical models to simulate the radiological release after the accident. In this study, a Gauss-plume model code (HOTSPOT) has been used to simulate and evaluate the radiation dose around the reactor site after the accident (within 80 Km from the reactor).

HOTSPOT code was used the source term calculated by MEXT and EAEA as input data to determine the radiation dose and the radioactive deposits in the soil of the area around the reactor.

Source term was calculated reasonably by EAEA using MCNPX code. The radiation dose evaluation resulting from the radioactive release depends mainly on two parameters; the amount of radioactive materials release and the meteorological conditions during the accidental release.

RELEASE CATEGORIES

The source term used here reconstructs atmospheric releases occurring between March 12th and April13th, 2011. The main release periods are given in Table 1. Two main release heights were considered. A 20 m height (reactor pressure vessel) is taken whenever pressure decreases happen in the unit, and a 120 m height (exhaust stack) is preferred for specific venting actions. For the hydrogen explosions (events 3 and 6), the source was assumed to be diluted by the heat and momentum of the explosion, within 100 m and 300 m on the vertical respectively. After March 15th (events 15-30), releases were detected by on-site monitoring devices, but could not be associated to specific units or events [1, 2].

SOURCE TERM

Tokyo Electric Power Co (Tepco) Source Term Calculations

Determining of radioactive release during Fukushima accident has depended mainly on the measurements of the concentrations of radioactive iodine and cesium in the air around the plant after the accident by Tokyo Electric Power Co. (TEPCO). Then, a reverse method was used to predict the amount of radioactive iodine and cesium released after the accident [3, 4].All studied based on the reverse methods to indicate the atmospheric release of I-131 and Cs-137 by using sets of monitoring data and atmospheric dispersion models, the release began in March12, 2011 and the largest release occurred on March 15, 2011 and during other periods the releases were one or two orders of magnitude smaller than that on March15, 2011 [4, 5, 6]. The release rates for I-131 and Cs-137 with the release time and release duration are tabulated in the following table:

Table1. *Release start time, release duration, release rates of I-131 and Cs-137, I-131/Cs-137 radioactivity ratio, and release height for the period from 05:00 JST on 12 March and 00:00 JST on 1 May 2011[1].*

No.	Start time, JST	Duration (h)	I-131 (Bq/h)	Cs-137 (Bq/h)	I-131/Cs-137	Height (m)
1	3/12/2011 5:00	4.5	3.70E+13	3.70E+12	10	20
2	3/12/2011 9:30	6	1.70E+13	1.70E+12	10	120
3	3/12/2011 15:30	0.5	3.00E+15	3.00E+14	10	100
4	3/12/2011 16:00	31	8.40E+13	8.40E+12	10	120
5	3/13/2011 23:00	12	3.60E+13	3.60E+12	10	120
6	3/14/2011 11:00	0.5	3.00E+15	3.00E+14	10	300
7	3/14/2011 11:30	10	2.30E+13	2.30E+12	10	20
8	3/14/2011 21:30	2.5	1.30E+15	1.30E+14	10	120
9	3/15/2011 0:00	7	3.50E+14	4.00E+13	8.8	120
10	3/15/2011 7:00	3	3.00E+15	3.00E+14	10	20
11	3/15/2011 10:00	3	8.00E+13	8.00E+12	10	20
12	3/15/2011 13:00	4	4.00E+15	4.00E+14	10	20
13	3/15/2011 17:00	37	2.10E+14	3.00E+12	70	20
14	3/17/2011 6:00	57	4.10E+14	1.00E+13	41	20
15	3/19/2011 15:00	36	3.80E+14	3.50E+13	11	20
16	3/21/2011 3:00	18	1.40E+14	1.40E+13	10	20
17	3/21/2011 21:00	26	4.10E+14	4.70E+12	87	20
18	3/22/2011 23:00	25	7.10E+14	8.90E+12	80	20
9	3/24/2011 0:00	24	1.90E+14	2.90E+12	66	20
20	3/25/2011 0:00	35	5.60E+13	1.20E+12	45	20
21	3/26/2011 11:00	47	4.00E+12	1.70E+11	23	20
22	3/28/2011 10:00	35	7.50E+12	4.70E+12	1.6	20
23	3/29/2011 21:00	14	1.50E+13	8.80E+12	1.7	20
24	3/30/2011 11:00	13	1.80E+14	1.40E+14	1.3	20
25	3/31/2011 0:00	22	2.40E+13	4.50E+12	5.3	20
26	3/31/2011 22:00	35	1.80E+12	1.60E+12	1.1	20
27	4/2/2011 9:00	48	1.80E+12	5.80E+11	3.1	20
28	4/4/2011 9:00	80	7.00E+11	1.40E+11	4.9	20
29	4/7/2011 17:00	150	0 7.0E+11	3.50E+11	2	20
30	4/13/2011 23:00	409	0 7.0E+11	1.80E+11	4	20

Eaea Source Term Calculations

EAEA have calculated the inventory of Fukushima using MCNPX considering the knowledge of core composition, dimension, fuel data, core loading patterns, and supplemented by assumptions derived and justified from similar fuel types. The results show a reasonable agreement with the comparisons of JAEA (Japanese atomic energy authority) results as shown in [7]. The total activity in the core is 2.60 E+09 Ci and the specific activity of the homogenous mixture of spent fuel rods is about 8.38 Ci/gm.

The EAEA group used the release fractions depending on the NUREG-1465 relevant for most of the currently licensed light water reactors (LWRs), the characteristics of the radioactive material released from the core into the containment, it is assumed that the releases consist of 100% of the core inventory of noble gases, 50% of the iodine, and 1% of the remaining solid fission products [7].

The atmospheric release was dominated by the volatile isotopes of iodine and cesium. The chemical composition of the fission product release had the direct consequence on the land contamination. The contamination was dominated by the deposition of I-131, Cs-134 and Cs-137 during the first days and weeks of the accident and by Cs-134 and Cs-137 afterwards. Xe-133 is a considerable contributor for the external dose after the accident. As

Cesium forms water soluble compounds, it remains in the environment for several years.

So, the total released radioactive materials of I-131, Cs-134, and Cs-137 depending on EAEA calculations are shown in table 2:

Table2. *Main effective isotopes released to the environment (EAEA).*

Isotope	Core Inventory, Bq	Release Fraction	Release Activity, Bq
Xe-133	2.64E+18	1	2.64E+18
Cs-134	1.93E+17	0.01	1.93E+15
Cs-137	1.64E+17	0.01	1.64E+15
I-131	1.26E+18	0.5	6.30E+17
I-132	1.84E+18	0.5	9.20E+17
I-133	2.63E+18	0.5	1.32E+18
Te-132	1.81E+18	0.01	1.81E+16

The two radionuclides (I-131 and Cs-137) make the largest contribution to the dose received by the population. A large number of other radionuclides would also have been released in the accident and some were measured in the environment; but very few were released in sufficient amounts to contribute significantly to doses. Iodine-131 tended to accumulate in the thyroid gland for a few weeks after the release and delivered a dose primarily to that organ. Caesium-137 was deposited on the ground; it delivers a dose to the whole body over many years following the release.

So, the calculations in this report have focused on estimate the deposition densities for these isotopes by using HotSpot code and comparing the results with the available measurements and verified models. Evaluation of deposition density (Bq/m^2) is very important for determining the ground shine dose especially for Cs-137 (long half-life), and evaluation of time-integrated concentration of I-131 in air ($Bq.s/m^3$) is very important for determining the inhalation dose (internal dose).

Meteorological Data

Since, the windrose or the meteorological data file of the FNPP site during the accident was not available. So, depending on the meteorological data from previous studies, the stability class D was chosen to simulate the meteorological condition around FNPP with wind speed of 3 m/s [2, 5].

Hotspot Code For Dispersion And Deposition Calculations

HOTSPOT Gaussian plume model [9] was used for the simulations.

The HotSpot Health Physics codes were created to provide emergency response personnel and emergency planners with a fast, field-portable set of software tools for evaluating incidents involving radioactive material. The software is also used for safety-analysis of facilities handling nuclear material. HotSpot code is a first-order approximation of the radiation effects associated with the atmospheric release of radioactive materials.

The HotSpot code is designed for short-term (less than a few hours) release durations. HotSpot is a hybrid of the well-established Gaussian plume model, widely used for initial emergency assessment or safety-analysis planning. HotSpot uses the radiation dosimetry methodologies recommended by the International Commission on Radiological Protection (ICRP).

These methodologies are summarized in Federal Guidance Report No. 11 (FGR-11), Federal Guidance Report No. 12 (FGR-12), and Federal Guidance Report No. 13 (FGR-13). FGR-11 provides dose coefficients in the form of 50-year integrated dose equivalents for acute inhalation of radionuclides and is based on the biokinetic and dosimetric models of ICRP Publication 30 (1979, 1980, 1981, 1988). FGR-12 provides dose coefficients in the form of dose per unit time-integrated exposure for external exposure to radionuclides in air, water, or soil. FGR-13 provides dose coefficients using the new ICRP-66 lung model and ICRP series 60/70 methodologies

The Results

Figure 1 shows the calculated dose rate distribution by HotSpot code after the accident resulting from plume air submersion and ground shine dose rate from radioactive deposits on the soil surface assuming that the release of radioactive materials having a constant rate (during March 11 to April 11, 2011) using TEPCO and EAEA data. The maximum dose rates resulting from the air submersion and ground shine are 0.03, and 0.005 Sv/h at distance of 0.27 Km from the plant.

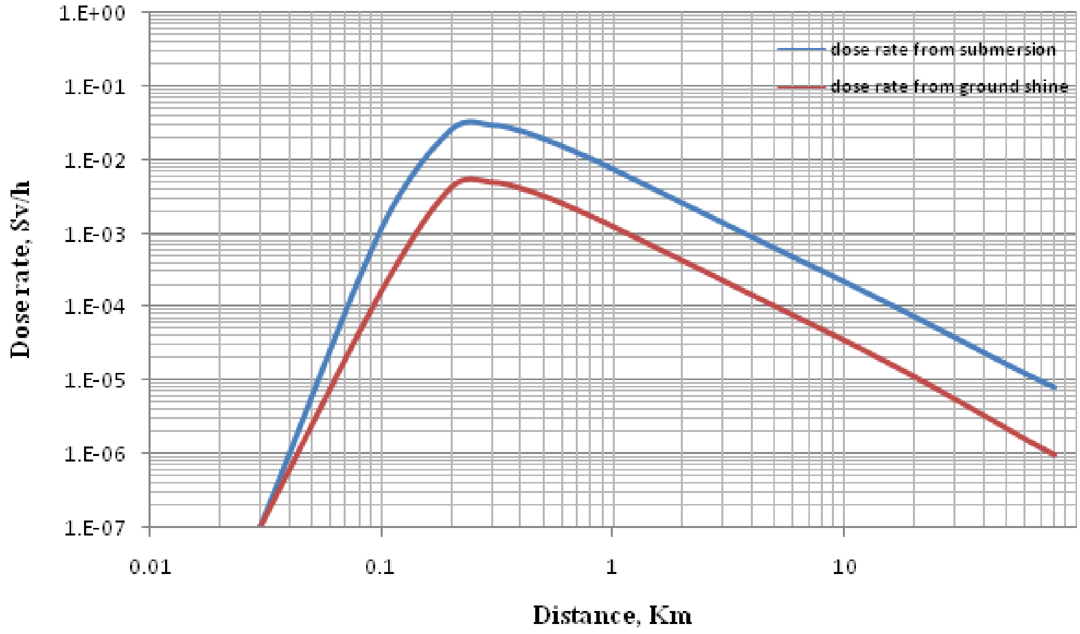

Fig1-1. *dose rate versus distance using TEPCO data.*

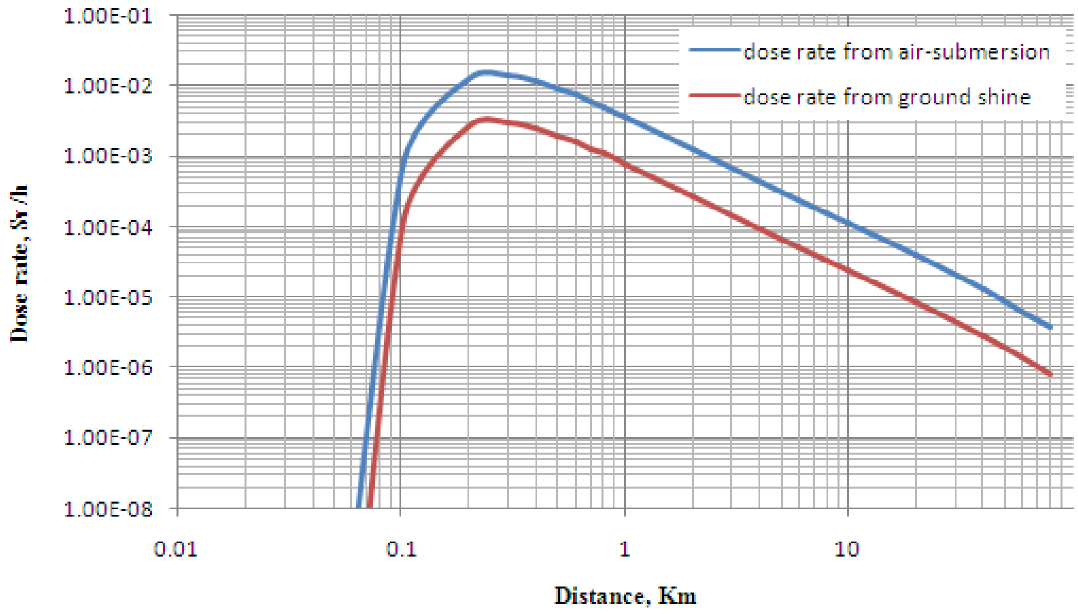

Fig1-2. *dose rate calculations versus distance using EAEA data.*

Figure1. *the dose rate resulting from the atmospheric dispersion of releases from the Fukushima accident.*

Figure 2 shows the calculated deposition density of Cs-137 around FNPP (in the north-west direction) which obtain that inside the 20 km zone (zone of emergency evacuated at the time of the accident), surface activities in Cs-137 vary between 0.02 kBq/m2 and 5.7E4 kBq/m2. The figure includes the Cs-137 deposition depending on TEPCO and EAEA data. Calculations of deposition depending on EAEA data show reasonable values with the calculations depending on TEPCO data.

Comparing with the measured data taken since June 2011, surface activities in caesium-137 measured in the soil samples vary between less than 30 kBq/m2 and 1.5E4 kBq/m2, a difference of a factor of 500 between the extreme values

(MEXT) (the Japanese Ministry of Education, Culture, Sports, Science and Technology).

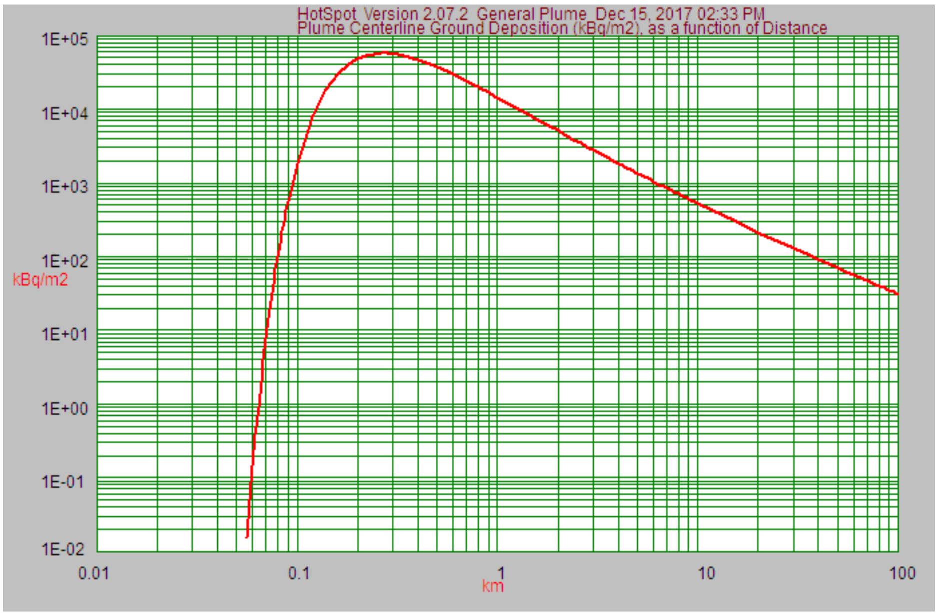

Fig2-1. *Cs-137 deposition for TEPCO data.*

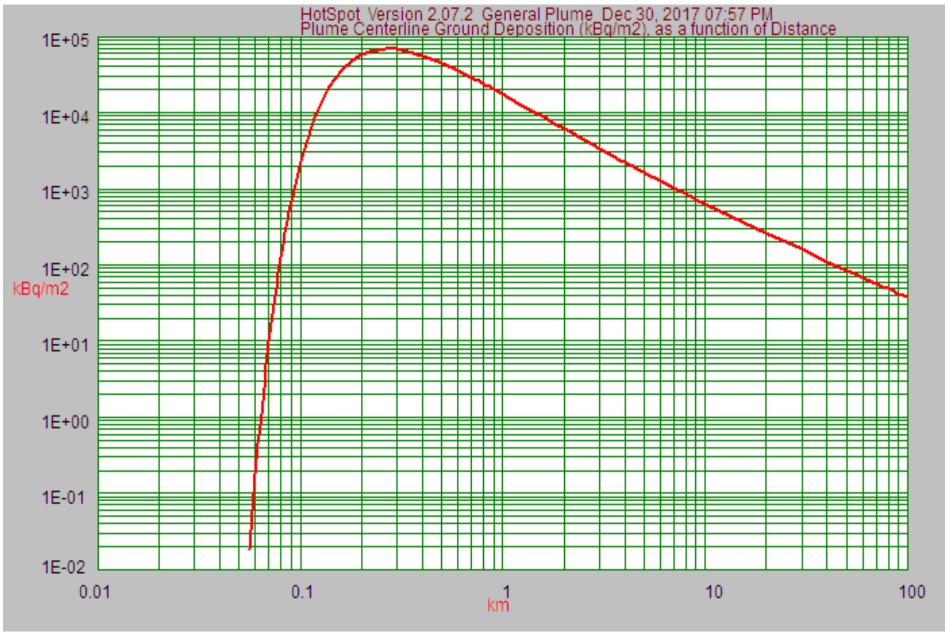

Fig2-2. *Cs-137 deposition for EAEA data.*

Figure2. *Cs-137 calculated deposition density after FNPP accident during March 11 to April 11, 2011.*

HotSpot code was also used to evaluate the deposition density for I-131 and Cs-137 in some locations around the Fukushima nuclear power plant. The HotSpot results were compared with the measurements of MEXT (the Japanese Ministry of Education, Culture, Sports, Science and Technology) [8] and compared also with the verified models of National Oceanic and Atmospheric Administration (NOAA), and Institute for Radiological Protection and Nuclear Safety (IRSN) [10].

The ^{137}Cs deposition pattern computed by HotSpot code was compared with the measured deposition in locations of Kawauchi village, Minami-Soma city, Katsurao, Tamura, and Iwaki city. The HotSpot code estimates for Cs-137 deposition density were within a ratio varied between about 0.36 and 1.25 of MEXT measurements as shown in table 3. The HotSpot code also estimates for I-131 deposition density were within a ratio varied between about 0.7 and 3.6 of MEXT measurements as shown in table

3. The HotSpot code results were considered in a reasonable agreement with the measurements taking the limitations of the code into consideration.

Table3. *Comparisons of the surface density of 137Cs and 131I at some locations estimated by HotSpot code with average MEXT-measurements, March15, 2011.*

Location	MEXT Cs-137 Deposition Density, (Bq/m^2)	HotSpot Code, Cs-137 Deposition Density, (Bq/m^2)	HotSpot/MEXT For Cs-137	MEXT I-131 Deposition Density, (Bq/m^2)	HotSpot Code, I-131 Deposition Density, (Bq/m^2)	HotSpot/MEXT For I-131
Kawauchi Village (20 Km- West-South)	1.01E+05	6.4E4	0.65	1.16E6	1.2E6	1.04
Minami-Soma City (25 km- north)	1.06E+05	4.8E4	0.45	1.2E6	8.4E5	0.7
Katsurao Village (25 km- west-west-north)	2.56E+05	9.2E4	0.36	2.875E6	2.8E6	0.9
Tamura City (35 km -west)	3.78E+04	3.2E4	0.85	4.3E5	1.6E6	3.6
Iwaki City (40 km- south)	2.15E+04	2.7E4	1.25	1.6E6	1.3E6	0.8

The HotSopt code was used also to evaluate the time integrated concentration of I-131 in air and comparing the results with the results obtained by NOAA-GDAS and IRSN-ECMWF. NOAA-GDAS is a source term-meteorology combinations based on reverse modeling of environmental measurements (concentrations in air, deposition densities, dust samples, dose rates). IRSN-ECMWF is a source term-meteorology combinations based on inverse modeling of generally continuous dose-rate measurements from 57 monitoring stations in Japan.

Table4. *Comparison of the time-integrated concentration of 131I in air and deposition density estimated by NOAA, IRSN, and HotSpot code.*

Location	Time period		NOAA		IRSN		HotSpot code	
	from	to	Time-integrated concentration in air (Bq s/m^3)	Deposition density (Bq/m^2)	Time-integrated concentrati on in air (Bq s/m^3)	Deposition density (Bq/m^2)	Time-integrated concentration in air (Bq s/m^3)	Depositio n density (Bq/m^2)
Kawauchi Village (20 Km- West-South)	03-12 2011-11:00	03-16 2011-08:00	3.4×10^7	4.1×10^5	4.0×10^8	2.9×10^6	4.2E+07	1.2E+06
Minamisoma City (25 km- north)	03-11 2011-00:00	03-15 2011-10:00	1.3×10^5	9.3×10^5	2.7×10^8	5.7×10^5	3.0E+07	8.4E+05
Katsurao Village (25 km- west-west-north)	03-11 2011-00:00	03-21 2011-12:00	2.4×10^8	5.5×10^6	2.4×10^8	4.0×10^6	1.0E+08	2.8E+06
Tamura City (35	03-12	03-31	9.4×10^6	3.6×10^5	9.4×10^7	2.5×10^6	5.7E+07	1.6E+06

km -west)	2011- 08:00	2011- 08:00						
Iwaki City (40 km-south)	03-12 2011- 13:00	03-31 2011- 12:00	2.9×10^8	2.5×10^6	1.5×10^8	8.1×10^5	4.5E+07	1.3E+06

CONCLUSION

As shown in table 5, the comparison of HotSpot code results with NOAA estimates for integrated time concentration of I-131 in air were within a ratio varied between about 0.155 and 6 except of an extremely overestimated value of 150.

The comparison of HotSpot code results with IRSN estimates were within a ratio varied between 0.1 and 0.6 which considered a reasonable agreement.

Table5. *the ratios of HotSpot results to NOAA and IRSN estimates (time-integrated concentration of 131I in air).*

HotSpot/NOAA	HotSpot/IRSN
2.23	0.1
150	0.2
0.4	0.42
6	0.6
0.155	0.3

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Citation: *M.K. Shaat, Amr Abdelhady, Rowayda F. Mahmoud (2019).“ Radiological Impact due to Atmospheric Releases of the Source Term for F-D, Unit 1, Using HOTSPOT Code”. Annals of Ecology and Environmental Science 3(1), pp.33-39*