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Research Article

Comparison between Cancer risk resulting from Chernobyl and Fukushima accidents using near field air dispersion model

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Abstract

Nuclear accidents are normally accompanied by radioactive releases, which can follow different radiation exposure pathways: air and water dispersion pathway. In this work the cancer risk resulting from radionuclides released to the atmosphere was estimated and compared for both Fukushima and Chernobyl accidents. A screening method using near field air dispersion pathway was used .The simulation was carried out using ^{131}I, ^{134}Cs, ^{137}Cs and ^{85}Kr. The analysis of the results showed that the cancer risk resulting from ^{131}I, ^{137}Cs, ^{134}Cs and ^{85}Kr at Chernobyl accident is higher than at Fukushima accident for different stability classes and downwind distances . Also at the same downwind distance the cancer risk for ^{131}I is higher than for ^{137}Cs, ^{134}Cs and ^{85}Kr . Therefore, it is necessary to consider atmospheric stability class characteristics in developing emergency preparedness and response strategies.

Keywords: *Chernobyl accident; fukushima accident; atmospheric Dispersion model ; risk Coefficient, exposure factor .*

Introduction

Nuclear accidents have major environmental consequences, where effluents discharged into the atmosphere are transported and diluted as a function of the atmospheric conditions in the local environment, the topography of the region, and the characteristics of the effluents (R.G. 1.21,2009) . The public can be exposed to direct radiation in the downwind direction and also to radioactivity deposited on the ground and vegetation resulting in exposure through different pathways (Ararkrog, 1995) and IAEA (1982) . In this study an analyses was made for the cancer risk resulting from atmosphere exposure pathway for Chernobyl and Fukushima accidents.

The Chernobyl accident

The Chernobyl nuclear reactor accident occurred on 26 April IAEA (1986) .The Chernobyl reactor is a pressurized water reactor using light water as a coolant and graphite as a moderator. Detailed information about what is currently known about the accident and the accident sequence has been reported, notably in 1992 by the International Atomic Energy Agency IAEA (1992), in 1994 in a report of the Massachusetts Institute of Technology (Sich *et al*.,1994), in 1995 by the Ukrainian Academy of Sciences (Purvis,1995), and in 1991- 1996 by the Kurchatov Institute (Cherkasov *et al*., 1996;Kiselev,1994;Kiselev *et al*, 1994;Surin *et al*,1994;Velikhov *et al*,1991). Nuclear accidents release both gaseous and particulate radioisotopes (Lelieveld etal.,2012). Although only a small fraction of the radionuclides from the Chernobyl accident was released as ^{137}Cs ($T_{1/2}$= 30.07 yr), it is used to map the deposition because it is straightforward to measure and is radiologically important on a long time scale (Smith *et al*,2005 ; IAEA 2006) . ^{131}I ($T_{1/2}$= 8.02 days), is also important; especially in the first weeks after an accident, as it is released in relatively large quantities, leading to high doses, because it rapidly enters the food chain and is concentrated in the thyroid (IAEA 2006; WHO,2006; Christodouleas *et al*, 2011).The radioactive release data for Chernobyl accident which were used in our model is shown in table 2 (Sich *et al* ,1994; Belyaev *et al*,1991; Begichev *et al* ,1990; Buzulukov *et al*,1993;. Dreicer *et al*, 1996; Kruger el at,1996; OECD, Paris, 1995)

The Fukushima accident

On 11 March 2011 an earthquake occurred off the Pacific coast of Tohoku, which triggered a powerful tsunami. The tsunami damaged the Fukushima Dai-ichi nuclear power plant complex, followed by a series of major accidents, giving rise to three INES (International Nuclear Event Scale) level 7 events. This caused the release of large amounts of radionuclides to the atmosphere (Butler ,2011; Chino *et al* ,2011; Stohl *et al*,2012) . In particular the isotopes of iodine and caesium adversely affect human health through the large-scale contamination of air, water, soils and agricultural products (Anspaugh *et al* ,1988). The Fukushima radioactive release data which were used in our model are shown in table 2 (Hiroya Shiraki,2012).

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The objective of the present study is to calculate and compare between cancer risks resulting from near field air dispersion model for Chernobyl and Fukushima accidents for different stability classes and downwind distances.

Methodology and Theoretical Background

For purposes of estimating concentrations of radionuclides, a straight-line Gaussian plume model of atmospheric transport is assumed (Miller,1984). This type of model has been used in screening models developed by the National Council on Radiation Protection (NCRP,1996) and the International Atomic Energy Agency (IAEA,2001). In applying the model, it is assumed that all releases occurred at ground level and that there was no depletion of radionuclides in the plume by radioactive decay or deposition onto the ground surface during transport to the receptor location .Based on the assumptions described above, the concentration of a radionuclide in air, X(Bq/m^3), at an assumed receptor location due to a given release *Q*(Bq/s) is given by

$$X = (2.032\, f\, Q / x\, u\, \sigma_z) \quad (1)$$

For this purpose, an average wind speed (*u*) of 2 m/s, is assumed; this value has been used in screening models developed by the NCRP (1996) and IAEA (2001). The assumed wind speed is substantially lower than the average wind speed at INEL (DOE 1991). An assumption of a lower-than-expected wind speed results in an overestimate of X/Q , since X/Q varies inversely with wind speed. With this assumption, the atmospheric dispersion factor is given by David , 2005.

$$X/Q = (1.016\, f / x\, \sigma_z) \quad (2)$$

Where

X/Q is the atmospheric dispersion factor,

f is the fraction of the time the wind direction is toward the receptor location during a release ,and assumed to be 1.0 (NCRP,1996;SENES,2002) .

x is the downwind distance to the receptor location in meters (m),

σ_z is the standard deviation of a Gaussian (normal) distribution of air concentration in the vertical (*z*) direction in meters (Miller,1984)

The vertical plume spread (σ_z) is calculated using the following equation:-

$$\sigma_z(\mathrm{x}) = \beta\, \mathrm{x}^{\mathrm{n}} + \tau \quad (3)$$

Where,

β , η, τ are Coefficients derived by Eimutis *et al*,1972 ,which are function of stability class and distance values as shown in Table 1.

x is downwind distance, m

Table 1 Values used to calculate Vertical Diffusion Coefficients

Pasquil Category (Stability Class)	Valid Range(m) ,x >1000 m		
	β	η	τ
A	0.00024	2.094	-9.6
B	0.055	1.098	2.0
C	0.113	0.911	0.0
D	1.26	0.516	-13
E	6.73	0.305	-34
F	18.05	0.18	-48.6

Results and Discussion

The cancer risk due to a given activity of a radionuclide released to the atmosphere was estimated using the following simple model.

{ Risk = Release (Bq/s) * Atmospheric dispersion factor (Bq/m^3 per Bq/s) *
Exposure factor (Sv per Bq/m^3) * Risk coefficient (risk per Sv) }

The application of the equation is based on the assumed risk coefficient of 0.1 Sv^{-1}(18) and exposure factors of ^{131}I , ^{137}Cs , ^{134}Cs and ^{85}Kr : 1.5* 10^{-1} ,1.8* 10^{-1} , 1.9* 10^{-1} and 7.9*10^{-9} (Sv.m^3/Bq) respectively IAEA (2001) . A FORTRAN computer program has been designed to facilitate the calculation of cancer risk for different stability classes and distances and it was based on mathematical models only used in accident case. The simulation has been carried out on four radioisotopes: ^{131}I , ^{137}Cs , ^{134}Cs and ^{85}Kr and these isotopes lie into two groups ; 1st group of short half-life time (^{131}I of $t_{1/2}$= 8.02 days) and 2nd group of long half –life time (^{137}Cs , ^{134}Cs and ^{85}Kr of $t_{1/2}$ = 30.07 , 2.03 and 10.7 years , respectively). The results of simulation of cancer risk at different distances and stability classes are represented in Table 2 and graphically in Figs; 1(a,b),2(a,b),3 (a,b).

Table 2 illustrates the values of Cancer risk in Chernobyl accident (A) and Fukushima accident (B) at different distances and stability classes for the four radioisotopes in concern.

For Chernobyl accident , the results show that the cancer risk of ^{131}I is higher than ^{137}Cs , ^{134}Cs and ^{85}Kr for different conditions of stability class and distances ,which reached about 2.01E-06 , 1.14E-07 , 6.37E-08 and 1.95E-19 for unstable condition & 1.25E-05 , 7.08E-07, 3.96E-07 and 1.21E-18 for neutral condition & 2.58E-05, 1.46E-06 , 8.16E-07 and 2.5E-18 for stable condition respectively at 5 km . These results correlate with Andreev et.al,2000 and Jongtae Jeong et.al, 2001 .The cancer risk decreased with increasing distances as shown in figs, 1(a),2(a),3 (a) , which may be attributed to atmospheric dispersion factor.

For Fukushima accident , the analysis of results showed that the cancer risk of ^{131}I higher than ^{137}Cs, ^{134}Cs and ^{85}Kr for different conditions of stability class and distance , which reached about 5.59E-07 , 1.34E-08,1 .42E-08 and 1.50 E-20 for unstable condition & 3.47 E-06, 8.33 E-08 , 8.8 E-08 and 9.33 E-20 for neutral

Table 2 Variation of Cancer Risk with stability class and distances in case Chernobyl (A) and Fukushima accidents (B)

Stability Class	Isotopes	Released amount (10^{15}Bq) in Chernobyl accident (A) (s)	Released amount (10^{15}Bq) in Fukushima accident (B) (s)	Cancer Risk in Chernobyl accident (A)				Cancer Risk in Fukushima accident (B)			
				Distances (m)				Distances (m)			
				3000	5000	7000	10000	3000	5000	7000	10000
Unstable	^{131}I	1800	500	5.56E-06	2.01E-06	1.03E-06	5.12E-07	1.54E-06	5.59E-07	2.87E-07	1.42E-07
	^{137}Cs	85	10	3.15E-07	1.14E-07	5.86E-08	2.90E-08	3.70E-08	1.34E-08	6.90E-09	3.42E-09
	^{134}Cs	45	10	1.76E-07	6.37E-08	3.28E-08	1.62E-08	3.91E-08	1.42E-08	7.28E-09	3.61E-09
	^{85}Kr	6500	500	5.39E-19	1.95E-19	1.00E-19	4.97E-20	4.14E-20	1.50E-20	7.72E-21	3.82E-21
Neutral	^{131}I	1800	500	2.84E-05	1.25E-05	7.36E-06	4.19E-06	7.88E-06	3.47E-06	2.05E-06	1.16E-06
	^{137}Cs	85	10	1.61E-06	7.08E-07	4.17E-07	2.37E-07	1.89E-07	8.33E-08	4.91E-08	2.79E-08
	^{134}Cs	45	10	8.98E-07	3.96E-07	2.33E-07	1.33E-07	1.99E-07	8.80E-08	5.18E-08	2.95E-08
	^{85}Kr	6500	500	2.75E-18	1.21E-18	7.14E-19	4.06E-19	2.11E-19	9.33E-20	5.50E-20	3.12E-20
Stable	^{131}I	1800	500	5.49E-05	2.58E-05	1.59E-05	9.62E-06	1.52E-05	7.16E-06	4.42E-06	2.67E-06
	^{137}Cs	85	10	3.11E-06	1.46E-06	9.01E-07	5.45E-07	3.65E-07	1.72E-07	1.06E-07	6.41E-08
	^{134}Cs	45	10	1.73E-06	8.16E-07	5.04E-07	3.05E-07	3.86E-07	1.81E-07	1.12E-07	6.77E-08
	^{85}Kr	6500	500	5.32E-18	2.50E-18	1.54E-18	9.33E-19	4.09E-19	1.92E-19	1.19E-19	7.18E-20

condition & 7.16 E-06, 1.72 E-07, 1.81 E-07 and 1.92 E-19 for stable condition respectively at 5 km . This results correlate with Andreev et.al,2000 and Jongtae Jeong et.al, 2001. The cancer risk decreases with increasing distance as shown in figs,1(b),2(b),3 (b).

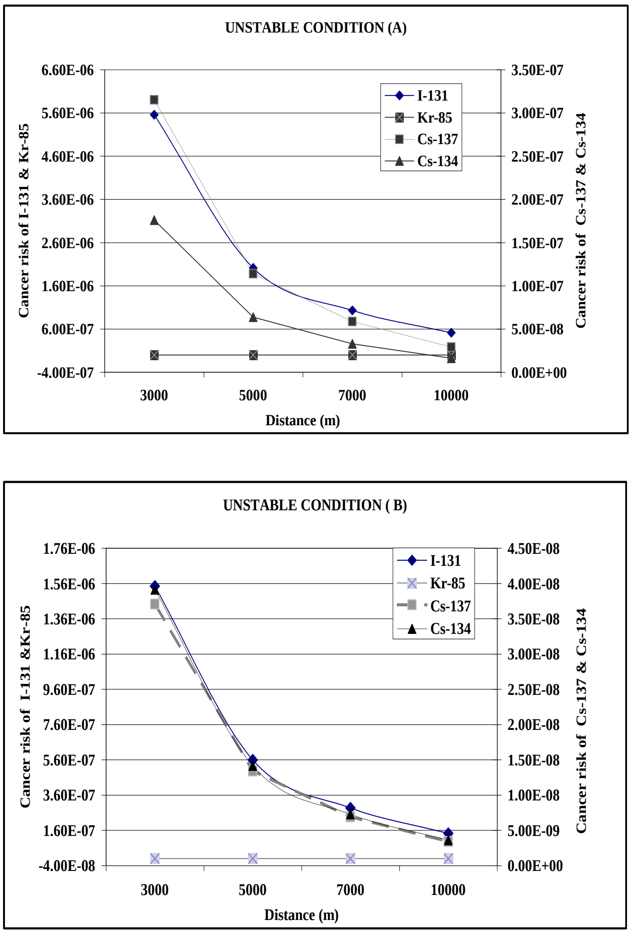


Fig.1 Cancer Risk as function of distance under unstable condition

A- Chernobyl accident B- Fukushima accident

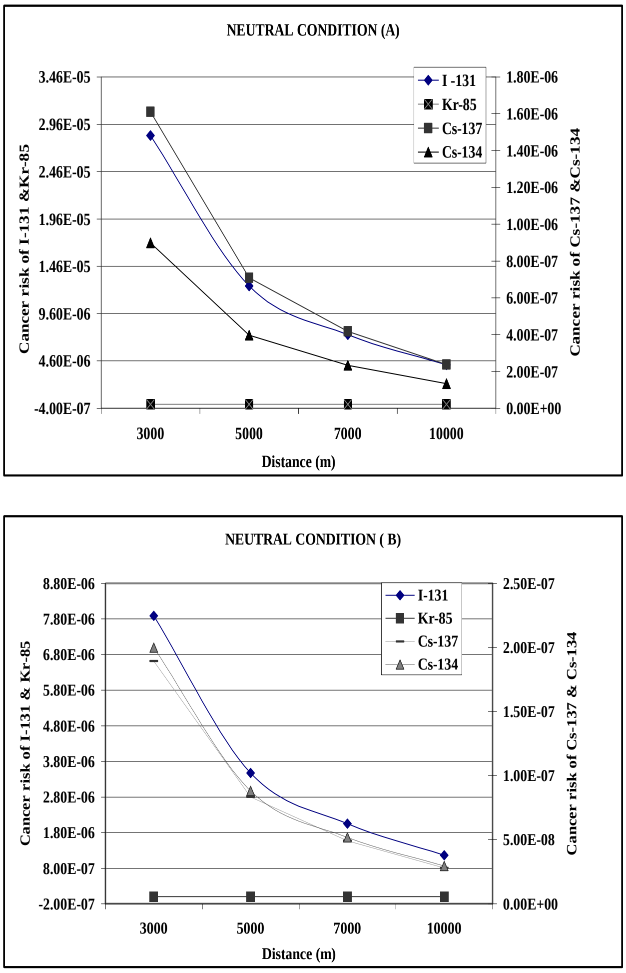
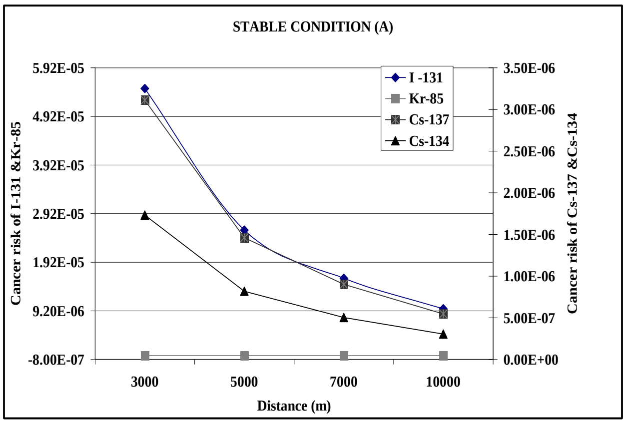


Fig. 2 Cancer Risk as function of distance under neutral condition

A- Chernobyl accident B- Fukushima accident



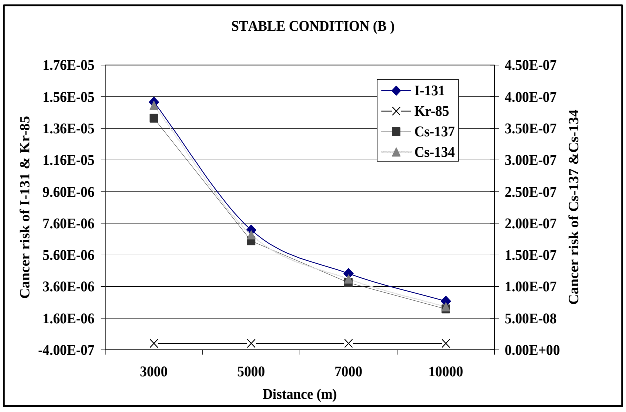
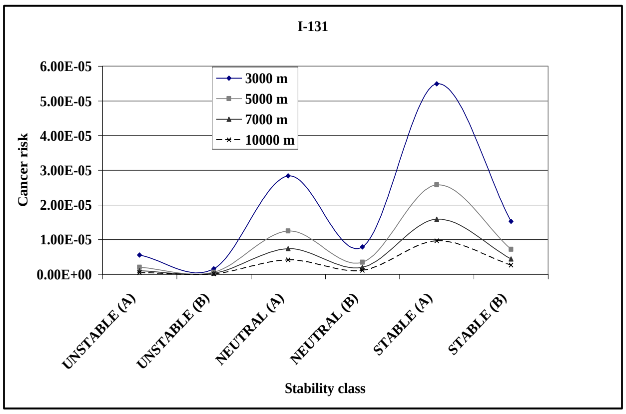
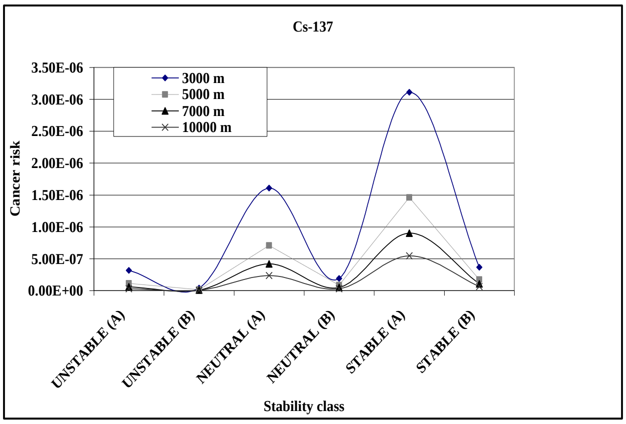
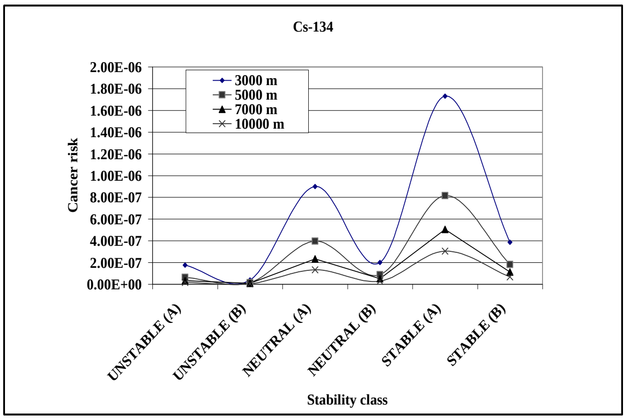


Fig.3 Cancer Risk as function of distance under stable condition.

A- Chernobyl accident B- Fukushima accident







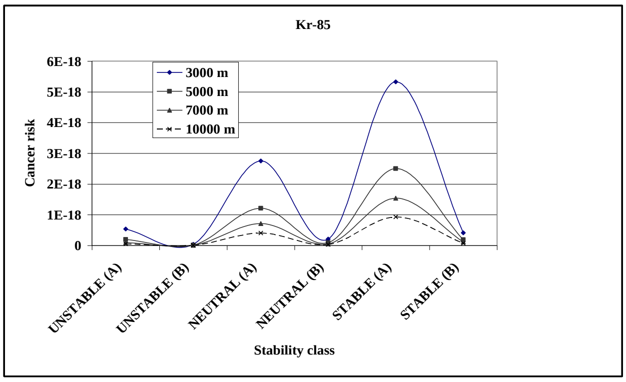


Fig.4 Comparison between cancer risk as function of degree of stability class at different distances.

A- Chernobyl accident B- Fukushima accident

Fig.4 illustrates the relation of cancer risk and stability class for Chernobyl and Fukushima accident, the results show that the cancer risk in two accident is high for stable condition than other conditions, which may be due to different source term of the two accidents.

Conclusion

The increase of the nuclear activities has radiological impacts. To simulate the cancer risk resulting from an accident, it is necessary to estimate atmospheric dispersion factor, exposure factor and risk coefficient. In this study the cancer risk of ^{131}I , ^{137} Cs ,^{134}Cs and ^{85} Kr is calculated for Chernobyl and Fukushima accident and the analysis of the results showed that .

- The variation of cancer risk versus distance shows that the cancer risk decreases as the distance from the site increases.
- Cancer risk is higher for Chernobyl accident compared to Fukushima accident
- At the same distances, the cancer risk from ^{131}I is higher than from ^{137} Cs ,^{134}Cs and ^{85} Kr.
- The cancer risk in stable condition was found to be higher compared with other stability classes.

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