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Application of extreme value analysis of radioactivity concentration in environmental matrices and dose to members of public around Madras atomic power station, Kalpakkam

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ABSTRACT

Extreme value analysis is a statistical method applied to study the extremes and to forecast the same over a period of time. Generally, statisticians have used this analysis in meteorological data, in construction and design of structures. This paper presents the extreme value analysis of radiological parameters measured in environmental matrices for a period of 20 years in 1.6 to 5 km zone of Kalpakkam. Extreme value analysis is used to quantify activity concentration of Cs-137, Sr-90, I-131, H-3 in sea water, H-3 in fresh water and air moisture and external dose due to Ar-41 during 1989-2008. This study revealed that H-3 concentration in sea water alone followed the Fisher-Tippett Type-I extreme value distribution and in the rest such as Cs-137, Sr-90, I-131 in seawater, H-3 in freshwater and air moisture and external dose due to Ar-41 followed Fisher-Tippett Type-II extreme value distribution. Various distribution parameters for each variable were determined using which the activity concentration and total dose to the members of public for return periods of 5, 10, 15, 20, 25 and 50 years were derived. It was observed that based on the extreme values these dose levels were lower than the limits prescribed by AERB.

KEYWORDS

Extreme value analysis;
Fisher-Tippett type distribution;
Environmental matrices;
Total dose and predicted dose;
Cs-137;
Sr-90;
I-131;
Ar-41;
Statistical method.

INTRODUCTION

Kalpakkam situated on the coast of Bay of Bengal in Tamil Nadu, India consists of many nuclear installations such as Madras Atomic Power Station, MAPS (two units of PHWR type reactors commissioned during 1984 and 1985), Fast Breeder Test Reactor (FBTR), Kalpakkam Reprocessing Plant (KARP), Centralised Waste Management Facility (CWMF). These facilities discharge radioactive effluents to environment in a controlled manner during normal operation. Low level treated liquid effluents are released into the Bay of Bengal and gaseous effluents through 100m high stacks. These discharges are governed by the limits set by AERB[1]. Environmental Survey Laboratory (ESL), Kalpakkam has been carrying out a detailed monitoring programme from 1974 onwards to study the impact of these releases on the environment and assess the dose received by the members of public.

Extreme value analysis method is a statistical method of analysis applied to the observed measurements and predicting further extremes by way of interpreting data of different parameters. In general, extreme value has been successfully used by many meteorological stations to the problems pertaining to predicting the approximate chance of exceeding an event of given size. In view of this fact extreme value theory can be applied for variation in activity concentration of environmental matrices and exposure incurred therein with time.

In this paper an attempt has been made to apply the extreme value analysis on the data collected for the past 20 years (1989-2008) during normal operation. Gross beta and H-3 are discharged through liquid route and H-3 and Ar-41 were released to the atmosphere through stack well within technical specification limit.

For extreme value analysis, activity concentration of Cs-137, Sr-90, I-131 and H-3 in sea water, H-3 in fresh water, H-3 in air moisture and external dose due to Ar^{41} collected over a period of 20 years (1989-2008) are used.

METHODOLOGY

The parameters chosen for this study are activity concentration of Cs-137, Sr-90, I-131 and H-3 in sea water, H-3 in fresh water, H-3 in air moisture and external dose due to Ar-41 collected over a period of 20 years (1989-2008). These values are arranged in ascending order and each data point is assigned a rank 'm'. If 'M' is the total number of data points then the probability of non-exceedance of a particular magnitude x of the data point of rank m is obtained as,

$$P(x) = m/(M+1) \quad (1)$$

To analyse the data sets for Fisher and Tippet type distribution the data sets were plotted for linear fit between data points and probability of non-exceedance with P(x.) on the x-axis. Correlation coefficient was obtained for both x versus P(x) and ln(x) versus P(x) to choose the best straight line fit and assign the function type to the variable x. Figure 1 to 7 shows the best fit for extreme value analysis of all the parameters.

Equation for the straight line fit between x versus P(x) can be written as[2],

$$x = \alpha + \beta_1 Y_p \quad (2)$$

Similarly the equation for the straight line fit between ln(x) versus P(x) can be written as,

$$\ln(x) = \ln(\beta_2) + (1/\gamma) Y_p \quad (3)$$

where Y_p is the reduced variate corresponding to P(x) given by,

$$Y_p = -\ln\{-\ln[P(x)]\} \quad (3)$$

Equations (2) and (3) can be transformed into the widely used Fisher and Tippet extreme value distribution functions.

In case of Fisher-Tippet Type-I distribution P(x) can be written as,

$$P(x) = \exp\{-\exp[-(x-\alpha)/\beta_1]\} \quad (5)$$

In case of Fisher-Tippet Type-II distribution P(x) can be written as,

$$P(x) = \exp\{-(x/\beta_2)^{-\gamma}\} \quad (6)$$

In equations (5) and (6) α, β_1 are the location and

TABLE 1 : Extreme value analysis data

Year	Maximum Activity						
	Cs-137 in SW	Sr-90 In SW	I-131 In SW	H-3 in FW	H-3 in SW	H-3 in Air	Ar-41 Dose
	(mBq/l)			Bq/l		Bq/m^3	uSv
1989	15	17	5.0	97	123	169.0	27.8
1990	17	24	8.8	201	387	29.7	61.0
1991	30	19	9.0	72	251	71.1	55.2
1992	30	21	5.0	118	340	7.6	57.4
1993	22	15	10.2	179	242	1.5	20.6
1994	35	22	5.0	113	291	66.6	44.0
1995	17	13	9.5	245	422	24.3	14.1
1996	20	14	8.7	226	481	140.0	23.5
1997	20	20	10.3	213	297	5.7	24.2
1998	160	32	5.0	136	333	9.1	22.1
1999	34	30	5.0	148	363	11.7	21.7
2000	234	457	8.0	74	114	7.3	16.4
2001	79	427	20.0	117	117	10.5	20.1
2002	53	58	44.0	98	268	5.7	6.6
2003	113	159	16.0	107	104	3.2	8.8
2004	135	302	33.0	42	46	8.6	7.0
2005	158	212	50.0	74	45	11.8	9.3
2006	54	48	25.0	49	27	11.7	18.0
2007	45	6	40.0	53	21	6.8	12.7
2008	10	6.5	14.0	54	54	10.3	10.3

TABLE 2 : Extreme value analysis of radiological parameters

Radiological parameters	R1	R2	Observed variant form used	Funtion type	α	β-1	β-2	γ
Max. Cs-137 activity in sea water (mBq/l)	0.874	0.982	Ln (r)	FT-II	-	-	27.597	0.773
Max. Sr-90 activity in sea water (mBq/l)	0.780	0.947	Ln (r)	FT-II	-	-	20.463	0.844
Max. I-131 activity in sea water (mBq/l)	0.882	0.970	Ln (r)	FT-II	-	-	8.497	1.438
Max. H-3 activity in fresh water (Bq/l)	0.969	0.992	Ln (r)	FT-II	-	-	82.541	2.101
Max. H-3 activity in sea water (Bq/l)	0.986	0.954	Linear	FT-I	148.100	130.260	-	-
Max. H-3 activity in air (Bq/m^3)	0.737	0.935	Ln (r)	FT-II	-	-	7.823	0.920
Max. Ar-41 dose (μSv)	0.903	0.980	Ln (r)	FT-II	-	-	14.133	1.66

TABLE 3 : Probability of non exceedance of activity concentration for predicted return periods

Return period (years)	P(x)	Cs-137 in SW (mBq/l)	Sr-90 in SW (mBq/l)	I-131 in SW (mBq/l)	H-3 in FW (Bq/l)	H-3 in SW (Bq/l)	H-3 in Air (Bq/m^3)
5	0.80	95	122	24	169	344	40
10	0.90	177	294	41	240	441	90
15	0.93	241	458	53	288	490	136
20	0.95	321	691	67	339	535	198
25	0.96	388	905	79	378	565	253
50	0.98	692	2083	128	528	656	544

TABLE 4 : Probability of non exceedance of dose

Return period (years)	P(x)	Dose to public in 1.6 to 5 km zone (μSv/y)		
		Internal(H-3)	External(Ar-41)	Total
5	0.80	18	35	53
10	0.90	37	55	92
15	0.93	55	71	126
20	0.95	78	85	163
25	0.96	98	97	195
50	0.98	206	148	354

scale parameters of Type-I distribution function and and β_2, γ are the scale and shape parameters of Type-II distribution function. α and β_1 can be obtained from the slope and intercept of the straight line obtained in the plot x versus Y_p and β_2 and γ from the slope and intercept of the straight line obtained in the plot ln(x) versus Y_p. TABLE-2 gives the values for the distribution parameters. Using these parameters, P(x) that is the probability of non-exceedance can be calculated for any value irrespective of whether the value lies within the observed range or not.

The time interval for not exceeding a certain probability defined as Mean Recurrence Interval (MRI) or return period is related P(x) by[5],

$$MRI = 1/\{1-P(x)\} \text{ years} \quad (7)$$

Vice versa the probability of not exceeding a particular value for a given period can be calculated as,

$$P(x) = 1 - 1/(MRI) \quad (8)$$

In case of Fisher-Tippet Type-I distribution equations (5) and (8) are used to arrive at extreme values for a given return period say 5, 10, 15, 20, 25 and 50 years. Similarly for Fisher-Tippet Type-II distribution equations (6) and (8) are used to arrive at the extreme values.

For calculating the total dose to the members of public H-3 and Ar-41 are considered since activity concentration of Cs-137, Sr-90 and I-131 are in the global fallout levels. The internal dose due to H-3 is calculated based on the maximum tritium concentration in air and water. For calculating ingestion dose due to tritium, daily water intake by the local public was taken as 2.9 litre and for the computation of dose due to inhalation and injection a breathing rate of 27.4m^3/day of air was used. External dose estimates were computed using site specific meteorological data i.e. Atmospheric dilution factor X/Q (sec/m^3), Joint Frequency Distribution of Wind Speed and Wind Direction and annual Ar^{41} stack release data. The maximum external dose due to Ar-41 received by the public is taken for extreme value analysis.

RESULTS AND DISCUSSION

For extreme value analysis the data collected over a period of 20 years (1989-2008) is used which is

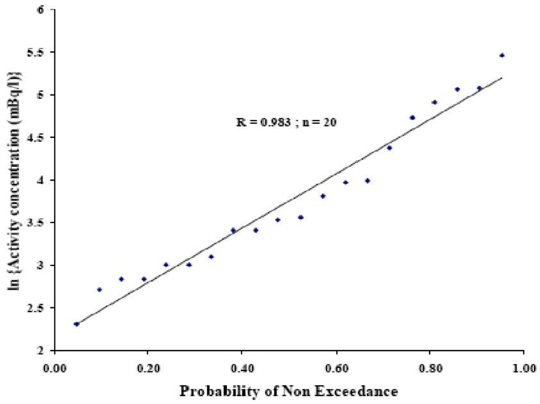

Figure 1 : Extreme value analysis of Cs-137 in sea water

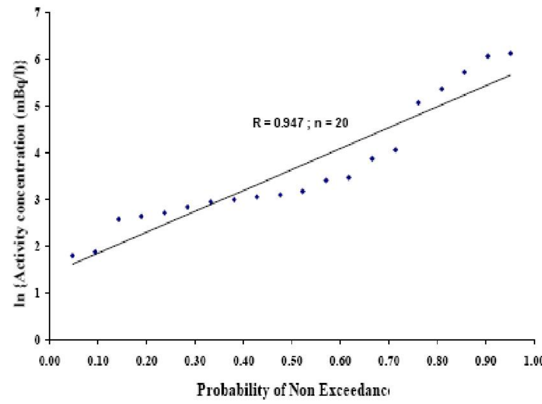

Figure 2 : Extreme value analysis of Sr-90 in sea water

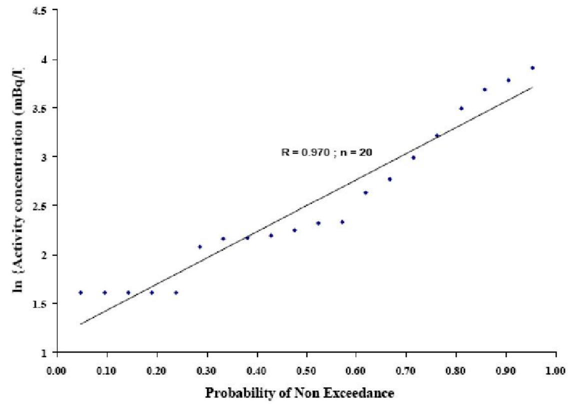

Figure 3 : Extreme value analysis of I-131 in sea water

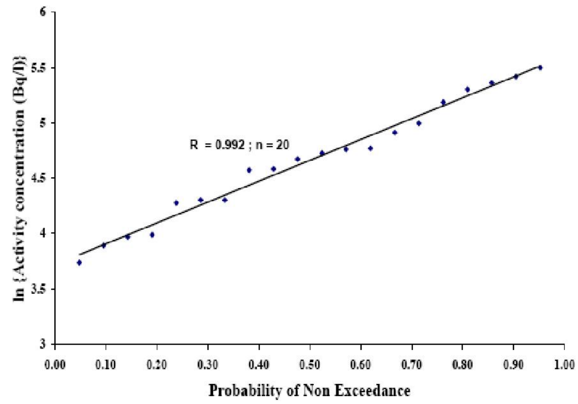

Figure 4 : Extreme value analysis of H-3 in fresh water

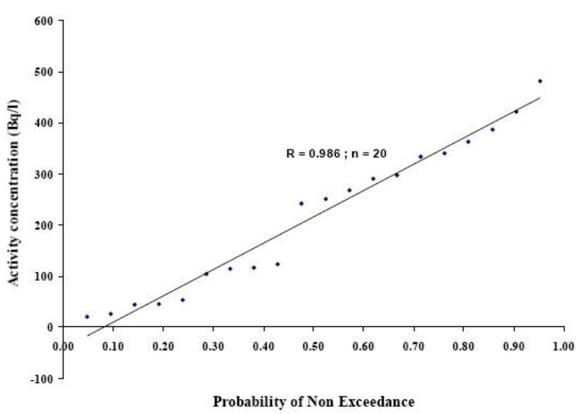

Figure 5 : Extreme value analysis of H-3 in sea water

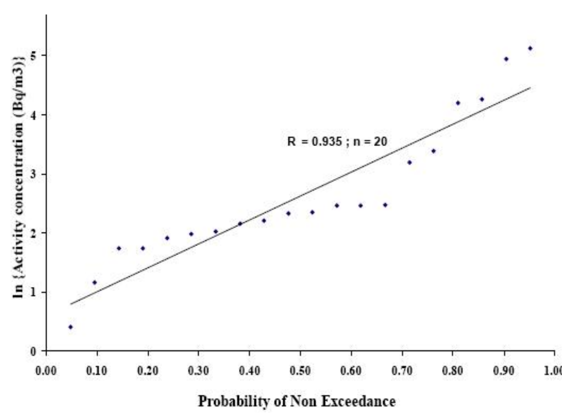

Figure 6 : Extreme value analysis of H-3 in air

shown in TABLE 1.The parameter values describing the distribution functions of extreme value analysis is given in TABLE 2. The correlation coefficients R1[x Vs P(x)] and R2 [ln(x) Vs P(x)] is used to determine the function type. R2 is greater than R1 for all the parameters except H-3 in seawater. Hence activity concentration of Cs-137, Sr-90, I-131 in seawater, H-3 in fresh water, H-3 in air and external dose due to Ar^{41} follow the Fisher-Tippet Type-II[4] extreme value distribution. R1 is greater than R2 for activity concentration of H-3 in seawater and hence this variable follows Fisher-Tippet Type-I distribution.

The extreme values of the radiological parameters derived for return periods of 5, 10, 15, 20, 25 and 50 years are given in TABLE 3. For a return period of 50 years it is observed that the probability of exceeding 0.692 Bq/l of Cs-137 concentration in seawater, 2.083 Bq/l of Sr-90 in seawater, 0.128 Bq/l of I-131 concentration in seawater, 528 Bq/l of H-3 in fresh water, 656 Bq/l of H-3 in sea water, and 544 Bq/m^3 H-3 in air

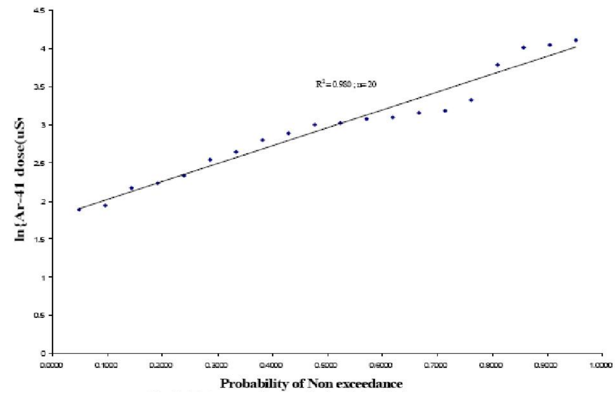

Figure 7 : Extreme value analysis of Ar-41 dose

is 0.98. The activity levels of Cs^{137}, Sr^{90} & I^{131} are in the same range as those of global fall-out levels. Therefore the ingestion doses due to these radio nuclides are not taken into account in the dose computation since they are not related to the Station operations. In view of this, only internal dose due to ingestion, inhalation and skin absorption of tritium in different zones are calculated along with external dose due to Ar^{41}.

The values of H-3 in air and fresh water for the given return periods were used to calculate the internal dose to members of public living in the 1.6-5km zone. The derived extreme values of internal dose due to tritium and extreme values of external dose due to Ar-41 is given in TABLE 4. It can be observed that for a return period of 50 years the predicted dose is 35 % of the AERB dose limit (1mSv/y) in case of extreme values also.

CONCLUSION

The extreme activity concentration for return periods of 5, 10, 15, 20, 25 and 50 years were derived for activity concentration of Cs-137 in seawater, Sr-90 in seawater, I-131 in sea water, H-3 in seawater, H-3 in fresh water, H-3 in air and external dose due to Ar-41. The doses calculated for the extreme values of H-3(internal) and Ar-41(external) for 5, 10, 15, 20, 25 and 50 years were 53, 92, 126, 163,195 and 354μSv/y respectively which are well below the dose limits prescribed by AERB which is 1000μSv/y. Extreme value analysis for 50 years taking into account the actual release and the resultant dose (354μSv/y) received by a hypothetical man staying in 1.6-5km zone does not exceed 35% of the AERB dose limit.

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