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Assessment of the Dose Produced from Nuclear Reactor

By

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ABSTRACT

The dose assessment due to release of radioactivity from nuclear reactor during its normal operation was determined. The experimental data was obtained by a radiometric survey of the environmental components around the reactor site. The accumulated radioactivity in soil, air, water and plants samples at different distances and periods were measured. Gamma activity was determined using a high purity germanium detector, while beta and alpha activities were assessed using a low background detector. The obtained experimental data, beside the published data concerning meteorology, geology, hydrology ...etc., were used to perform a computer program to determine the dose produced and to define the safety requirements for the site selection, as well as the design and the operation of the nuclear installation in the site.

INTRODUCTION

During the normal operation of nuclear reactors, radioactive isotopes are released and despaired according to the meteorological conditions. Thus, radioactive dose absorbed to human body should be assessed. It is necessary to make assumptions concerning the relationship between average and maximum doses. Meanwhile, various radioactive elements are detected in the environment, some of these radionuclides may find their ways to soil, water, plant ...etc., inducing varying implications with respect to the resulting radiation exposure of aquatic environments. Direct exposure from the atmosphere can occur either externally; due to a person being immersed in it or internally; as a result of inhalation [1], or metabolism foodstuffs. Nuclides, which have been considered as sources of direct exposure from the atmosphere, including tritium, krypton and particularly iodine^{131} [2] alpha, beta and gamma were detected.

The present work illustrates the measurements of Inchas site, determines the radionuclides content in environmental samples and also calculates the radiation dose rate and surface contamination in the vicinity of the reactor site in Inchas. A computer program, including the obtained results and those published concerning meteorology, hydrology, geology ...etc was established, to assess the dose received from both the disposal waste site and other nuclear installations in the surrounding environment.

EXPERIMENTAL WORK

Different environmental samples namely water, soil, plant and air were collected and prepared to count the radioactivity for the studied area, beginning from the reactor zone site till 5 Km away in all directions.

The high Purity Germanium detector was used for the gamma assessment, while the automatic Low Background counting alpha, beta and gamma was utilized for the alpha beta and gamma assessment The used air sampler is an instrument designed for the detection and measurement of beta emitting particulate matter. A second detector was provided for subtraction of gamma background. The portable dose rate meter was utilized for the measurement of dose equivalent and dose equivalent rate from the beta and gamma radiation, through which the apparatus was calibrated.

RESULTS

1- Obtained Data :

Radiometric alpha, beta and gamma survey of the reactor site was performed to determine the background radiation level. The studied area is located at the eastern direction of the Atomic Energy Authority and extended to the northern direction for about 2 km Fig.(1), Detailed radiometric surveys were carried out in many areas around some facilities, handling radioactive isotopes. No alpha, beta or gamma activities were detected at this site. The background and the radioactive survey of the studied area were found to be within the permissible dose.

2- Activity Air Samples :

The variation of gamma, alpha and beta activities in air, for different time intervals, is given in Fig (2), Fig (3) and Fig (4). The air was passed through a filter paper fixed on an air sampler during one year. The maximum activity was obtained during the normal operation of the reactor. The observed activities were found to correspond to I^{131}, Kr^{85} and Sr^{89}.

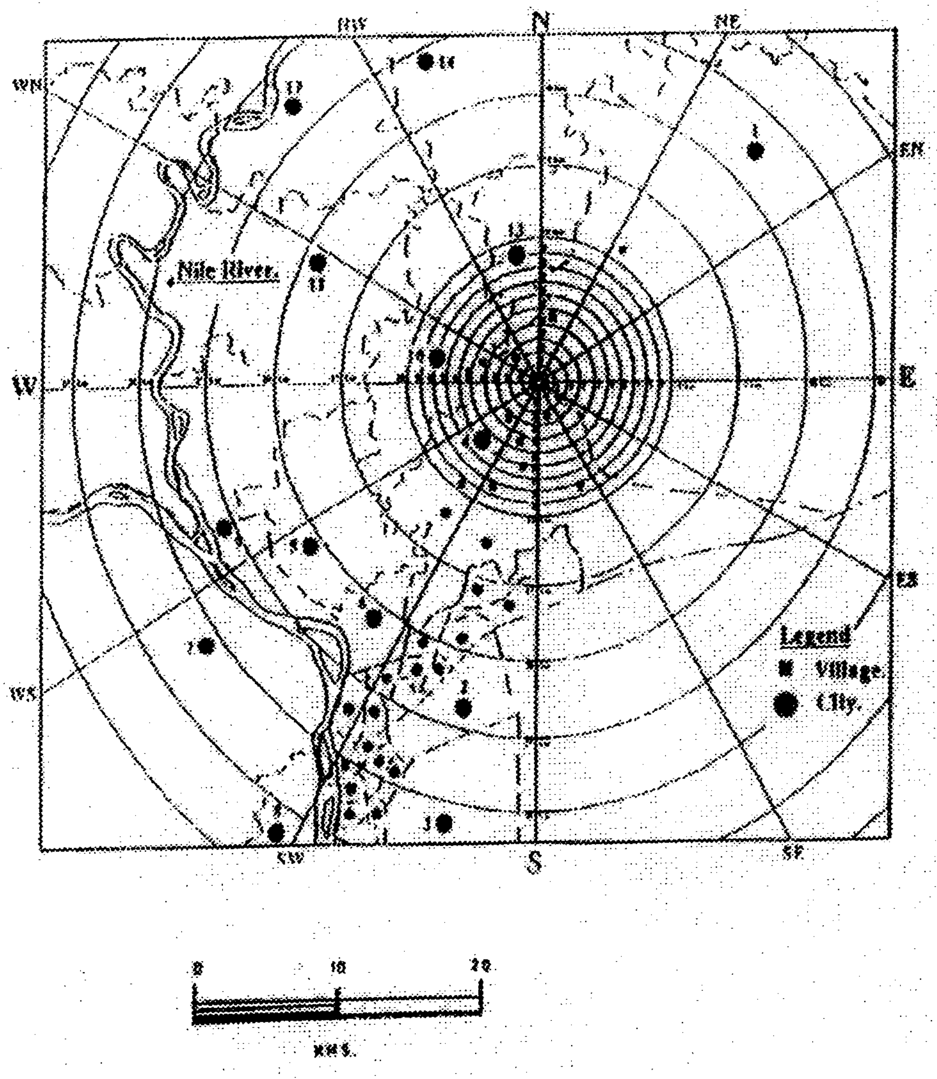

Fig. (1) Location map

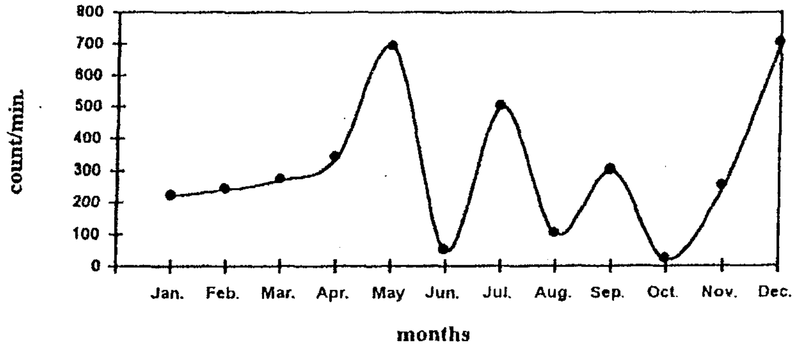

Fig. 2 : Varition of the gamma activity in air with time during year 1997

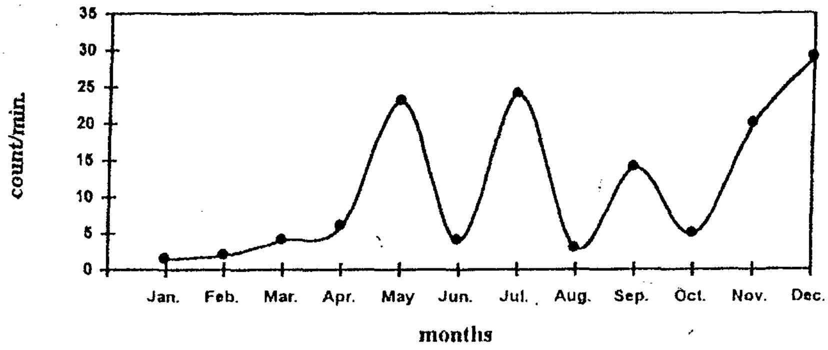

Fig. 3 : Varition of the alpha activity in air with time during year 1997

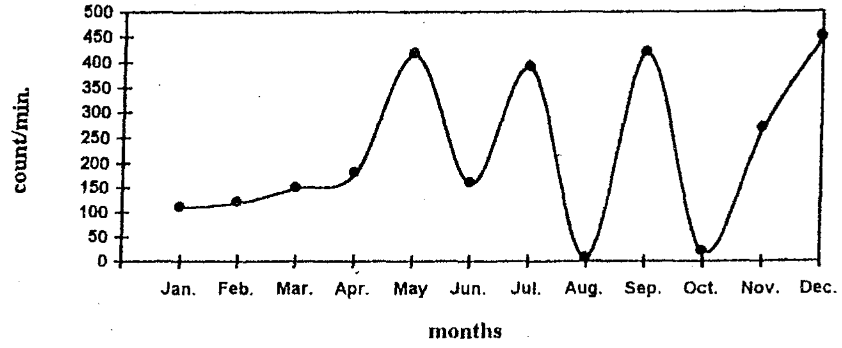

Fig. 4: Varition of the beta activity in air with time during year 1997

For the determination of gamma activity in soil, air, water and plant, the high purity germanium detector was used. Table (1) shows the peaks at 63.3, 84.2, 92.6, 185.7, 238.6, 295.2, 338.5, 351.9, 583.1, 609.3, 911.1, 968.9, 1460 and 1764.5 KeV. These energy peaks correspond to Th^{234}, Th^{231}, Th^{234}, U^{235}, Pb^{212}, Pb^{214}, Ac^{228}, Pb^{214}, Tl^{208}, Bi^{214}, Ac^{228}, Ac^{228} and Bi^{214}, respectively [4]. The radiometric measurements were repeated after 15 days. The gamma, beta and alpha activities were decayed, indicating and confirming that, the measured radionuclides had short half-life time.

The distribution of population density around the site was established, from a proposed place to 40 km in all directions, except from the north - northeast to south – southeast, where the number of the populations is negligible [3]. As can be seen, Cairo in which 15,000,000 (15 millions) persons, is located at 35 km from the site, for accommodation of the workers.

Geophysical studies namely, magnetic and electrical investigations showed that, two basaltic layers are found, the first layer is located at 20 m depth, and the second basaltic layer is located at 60 m depth. In the studied area, the groundwater occurrs after the second basaltic layer.

Meteorological studies exhibited that the relative humidity is high in general. The distribution of temperature over the area under consideration during the year shows large variations. January is the coldest month and July is the hottest one.

The percentage frequency of surface winds blowing between the northwest (NW) and northeast (NE) directions are in general during the summer. In the winter, winds are blowing from south and west directions.

3- Mathematical treatment :

In order to establish the mathematical equations for dose assessment of the upper limit of the reactor site and the radioactive waste disposal site, one should analyze the results in case of accidents and malfunctions of both reactor and the radioactive waste disposal sites. Another part of the problem is concerned with the long-term average exposures, which result from the "routine" releases to the environment of small quantities of radioactive materials. An understanding of the result of such releases is of importance in establishing the compatible site and design criteria. The proposed procedure consists of calculating the dose due to atmospheric dispersion of radioactive materials from the stack of the reactor and the radiation dose from radioactive waste disposal site.

Two mathematical models were used for determining the dispersion of fission products. Sutton's equations were utilized for neutral and unstable atmospheric

Table (1): Radiometric measurements of energy, activity and the corresponding isotopes using HPGe detector of background, soil, air, water and plant samples taken from the studied site.

γ- ray	Soil, Air, Water and Plant samples									correspondng
Energy	B.G	S		A		W*		P		onding
(KeV)	C/Sec	Net C/Sec	Act. (Bq/Kg)	Net C/Sec	Act. (Bq/Kg)	Net C/Sec	Act. (Bq/Kg)	Net C/Sec	Act. (Bq/Kg)	Isotope
63.3	0.007	---	---	---	---	---	---	---	---	Th^{234}
84.2	0.003	---	---	---	---	---	---	---	---	Th^{231}
92.6	0.009	0.007	6.250	---	---	---	---	---	---	Th^{234}
185.7	0.004	0.003	0.139	0.001	61.71	---	---	0.001	1.157	U^{235}
238.6	0.002	0.020	3.104	---	---	0.001	0.233	0.001	3.880	Pb^{212}
295.2	0.001	0.006	2.377	---	---	---	---	---	---	Pb^{214}
338.5	0.001	0.002	1.301	---	---	---	---	---	---	Ac^{228}
351.9	0.004	0.006	1.426	---	---	---	---	---	---	Pb^{214}
583.1	0.001	0.005	2.110	---	---	---	---	---	---	Tl^{208}
609.3	0.001	0.008	2.540	0.001	74.01	---	---	---	---	Bi^{214}
911.1	0.001	0.003	2.009	---	---	---	---	---	---	Ac^{228}
968.9	0.001	---	---	---	---	---	---	---	---	Ac^{228}
1460.0	0.007	0.015	36.36	---	---	---	---	0.003	136.4	K^{40}
1764.5	0.001	---	---	---	---	---	---	---	---	Bi^{214}
Total Act. (Bq/kg)			57.62		135.72		0.233		141.4	

conditions (lapse conditions) and the modified diffusion equations were used for stable atmospheric conditions (temperature inversions).

In stable atmosphere, the time-integrated concentration (E) at ground level, according to the mathematical equations proposed by Watson [5] is as follows:

$$E = \frac{q}{\pi \sigma_Y \sigma_Z \bar{u}_h} \exp\left[-\frac{1}{2}\left(\frac{y^2}{\sigma_Y^2} + \frac{h^2}{\sigma_Z^2}\right)\right] \tag{1}$$

Also Sutton's equation, utilized for neutral and unstable atmospheres is:

$$E = \frac{2q}{\pi C_Y C_Z \bar{u}_h x^{2-n}} \exp\left[-\frac{1}{x^{2-n}}\left(\frac{y^2}{C^2_Y} + \frac{h^2}{C^2_Z}\right)\right] \tag{2}$$

For both equations, the symbols are defined as:

E = time-integrated concentration at ground level ($\{\mu Bq/s\}/cm^3$),

q = apparent quantity emitted as measured by an observer at downwind distance x (Bq),

σ^2_Y $= \alpha x^{1.6}$ (m^2),

α = 0.016 for emission of short (~ 10 min) duration,

α = 0.040 for emission of longer (~ 1 h) duration,

x = down-wind distance (m),

σ^2_z $= a\,[1-\exp(-k^2 t^2_x)] + b t_x$ (m^2).

a, b and k^2 are functions of the degree of stability. Their values for two conditions of stability are shown in Table (2),

C_y, C_z and n are Sutton's parameters and the values used in this analysis are recorded in Table (3),

t_x = time of cloud travel to point x (s),

u_h = average wind-speed at the height of emission (m/s),

y = cross-wind distance, as measured from the center line (m), and

h = height of release above the ground level (m).

Table (2): Numerical values of stable atmospheric dispersion parameters

Parameters	Degrees of stability	
	Moderate	High
a	97 m^2	34 m^2
b	0.33 $m^2 s^{-1}$	0.025 $m^2 s^{-1}$
k^2	2.5 x $10^{-4} s^{-2}$	8.8 x $10^{-4} s^{-2}$

Table (3): Numerical values of atmospheric dispersion parameters for neutral and unstable atmospheres

Parameters	Release level	Wind-speed	Unstable	Neutral
C_Y	Ground	1 m/s	0.35	0.21
		5 m/s	0.30	0.15
		10 m/s	0.28	0.14
	Elevated	1 m/s	0.30	0.15
		5 m/s	0.26	0.12
		10 m/s	0.24	0.11
C_Z	Ground	1 m/s	0.35	0.17
		5 m/s	0.30	0.14
		10 m/s	0.28	0.13
	Elevated	1 m/s	0.30	0.15
		5 m/s	0.26	0.12
		10 m/s	0.24	0.11
N			0.20	0.25

From Eq. (1), it can be shown that, the air concentration at the ground level per becquerel per second emitted, corrected for cloud depletion in stable atmospheres is:

$$\left(\frac{E}{Q}\right) = \frac{q/Q}{\pi \sigma_Y \sigma_Z \bar{u}_h} \exp\left[-\frac{1}{2}\left(\frac{y^2}{\sigma^2_Y} + \frac{h^2}{\sigma^2_Z}\right)\right] \qquad (3)$$

The concentration again, corrected for depletion in neutral and unstable atmospheres can be expressed by

$$\left(\frac{E}{Q}\right) = \frac{2q/Q}{\pi C_Y C_Z \bar{u}_h x^{2-n}} \exp\left[-\frac{1}{x^{2-n}}\left(\frac{y^2}{C^2_Y} + \frac{h^2}{C^2_Z}\right)\right] \qquad (4)$$

The variation, with distance, of time-integrated concentration or ground deposition predicted that, by Eq. (3) inclusive assumes a constant wind velocity. This condition seldom prevails for any length of time and it certainly varies with distance, as the cloud moves down-wind. On the other hand, areas enclosed by contours of equal concentration or deposition are far less dependent upon the constant velocity assumption and have proved to be much more predictable than distance [8].

A rigorous determination of the area is not always possible. Areas can be very closely approximated, however, by re-writing Eq. (3) as follow:

$$\left(\frac{E}{Q}\right) = \left(\frac{E}{Q}\right)_0 \exp\left[-\frac{y^2}{2\sigma_Y^2}\right]$$

Where:

$\left(\frac{E}{Q}\right)_o$ = the centerline ($y = 0$) value of Eq. (3).

Solving for y yields:

$$y = \pm \sigma_Y [2 \ln \psi]^{\frac{1}{2}}$$

$$\psi = \left(\frac{E}{Q}\right)_o \div \left(\frac{E}{Q}\right).$$

Now, an estimate of the enclosed area is:

$$Area = \frac{\pi}{4}(\Delta x)(2y^*),$$

Where:

Δx $= x_2 - x_1$ = the length of the area (in the down-wind direction),

x_1 = minimum distance from the source to the isopleth,

x_2 = maximum distance from the source to the isopleth,

y^* = the distance from and on a line normal to the centerline at the point $\Delta x/2$ to the desired value of E/Q.

The substitution of y, as evaluated at $\Delta x/2$, for y^* results in an expression for areas enclosed by any given value of (E/Q) *is:*

$$Area = 0.114(x^*)^{1.8}[2\ln\psi']^{\frac{1}{2}}. \qquad (5)$$

Where:

x^* $= \Delta x/2$

ψ' $= (E/Q)'/(E/Q)$

$(\frac{E}{Q})'_0$ = center line value at x^*.

A similarly developed expression for areas based on Sutton's equation is:

$$Area = 0.0903(x^*)^{(4-n)/2}[2\ln\psi']^{\frac{1}{2}}. \qquad (6)$$

The areas estimated by Eq. (5) and Eq. (6) have been compared with numerically - integrated areas enclosed by x, y plots of Eq. (3) and Eq. (4). Comparable values were examined for several levels in four categories of atmospheric stability, three different release heights, three wind-speeds, and three values of deposition coefficients. The estimated areas are within 5% of the integrated areas.

The above derived equations were used to calculate the dose received to population during the normal operation assuming that the total activity released is about 0.1% during the normal operation. The calculated received dose to the population was less than 3 Sv/year i.e. within the permissible dose.

SUMMARY

Alph, beta and gamma radiometric mesurements were done around the reactor at a varying distances from the site up to 5 km. The obtained data showed that the studied area was in the background level of the apparatus and the dose rate was 1.0 to 3.0 USv/h. This means that such area is not contaminated by radioactive material and the dose is within the allowable limits.

However, only small zone around the first radioactive waste disposal repository showed a range of radiation levels between 3.0and 20.0 u Sv/h.

In the plant, soil (sand), and water samples, the results showed that the alpha, beta and gamma activities were within the background measurements.

In air the results showed that the alpha, beta and gamma activities level were unchangeable during the studied period. In the mean time it was found that the maximal and minimal activities are related to both the reactor operation and shutdown consequently. So, the activity measured was due to normal release of activity of some noble gasses and iodine during normal reactor operation.

The predicted dose, received by the population during normal operation, from the mathematical models used in this study was less than 3 Sv/year. This means that the dose is within the permissible limits.

RECOMMENDATIONS

From this study one can deduce the following recommendations:

a) Periodic radioactive measurements should done every year to detect any change in the background.

b) Periodical determination of the alpha, beta and be made gamma activities in plant, soil (sand), water and air samples be made in order to detect any adverse impacts.

c) Performing detailed studies and investigations to assess the dose in and around the reactor site is preferable.

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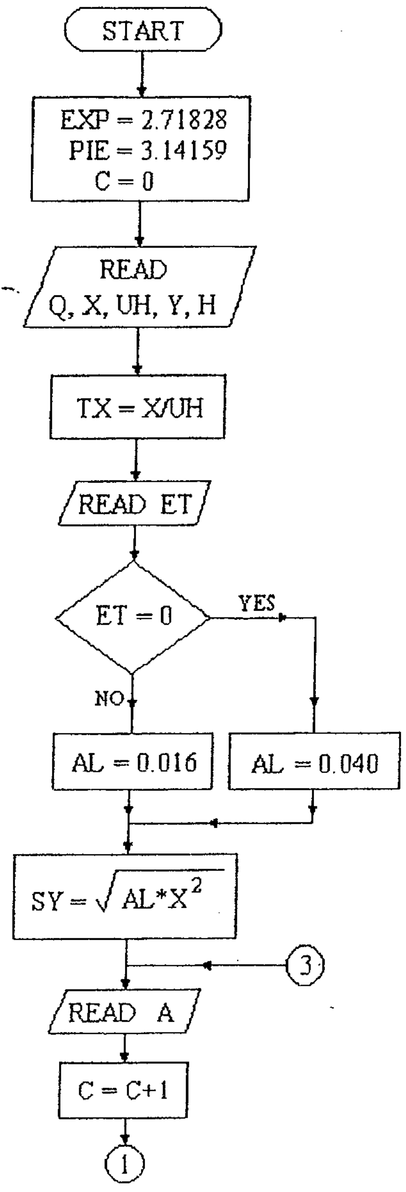
Flow chart of the proposed computer program model:

The flowchart of the proposed model is:



Start program

Values of π and exp.

Quantity emitted, down wind distance, wind speed, cross wind distance and height of release, respectively.

Time of cloud travel.

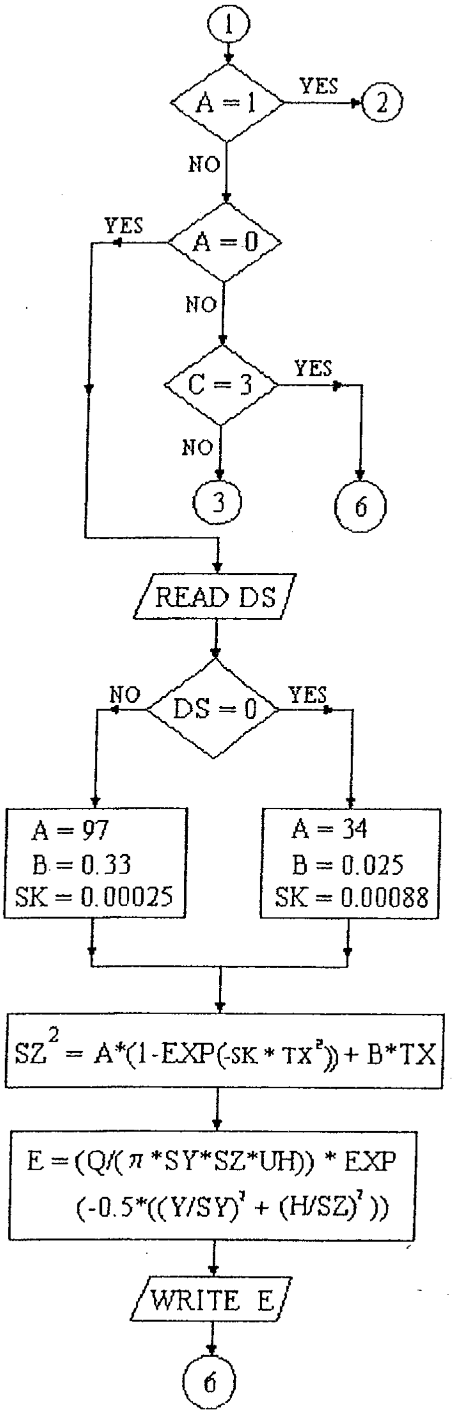
Duration of emission.

α Values.

σ_y calculation.

Atmosphere stability.

Continue



Degree of stability.

A, b & k^2 values.

$$\sigma_z^2 = a\,[1 - \exp(-k^2 t_x^2)] + bt_x$$

$$E = \frac{q}{\pi \sigma_Y \sigma_Z \bar{u} h} \exp[-\frac{1}{2}(\frac{y^2}{\sigma_Y^2} + \frac{h^2}{\sigma_Z^2})]$$

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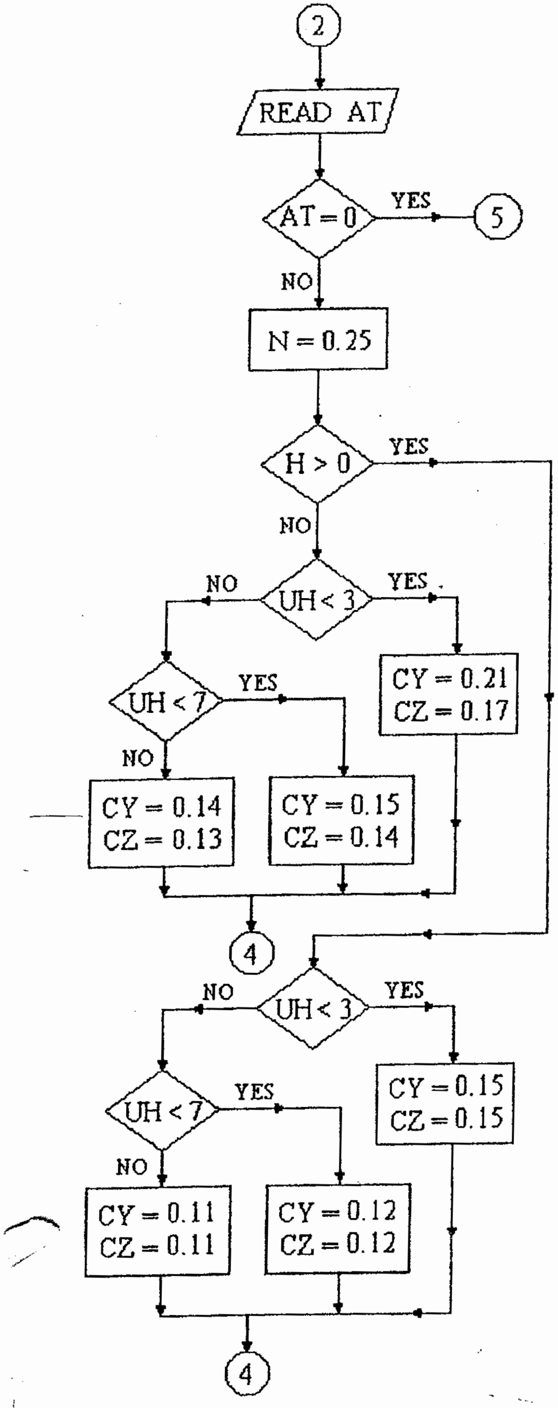

Unstable or neutral atmosphere.

Atmospheric dispersion parameters.

Atmospheric dispersion parameters.

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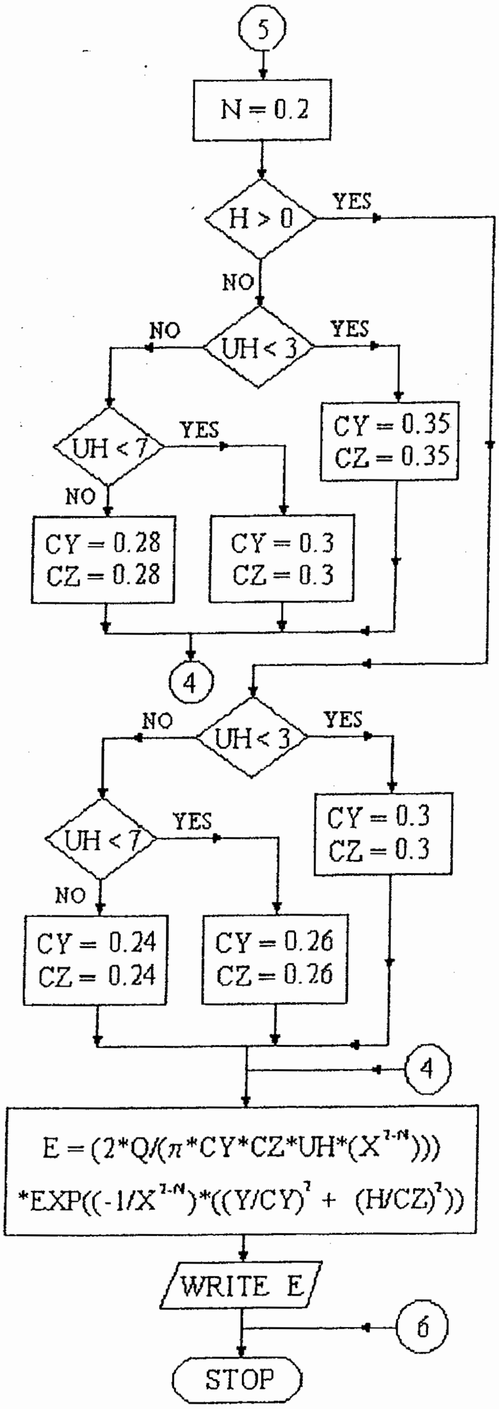

Atmospheric dispersion parameters.

Atmospheric dispersion parameters.

$$E = \frac{2q}{\pi C_\gamma C_Z \bar{u}_h x^{2-n}}$$

$$\exp\left[-\frac{1}{x^{2-n}}\left(\frac{y^2}{C^2{}_\gamma}+\frac{h^2}{C^2{}_Z}\right)\right]$$

END

تقنين الجرعة الإشعاعية الناتجة عن تشغيل المفاعل

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ملخص البحث :

درست الخطوات التقنية للتحفظ على النفايات المشعة للحصول على أماكن أمنه ملائمة بالإضافة إلى انه تتسرب بعض الإشعاعات عند التشغيل العادي للمفاعل واعتمادا على التجارب العملية والبيانات المنشورة في هذا المجال تم اقتراح برنامج حاسوب لحساب الجرعة الإشعاعية الممتصة الناتجة من المفاعل وأماكن التحفظ على النفايات.

تم الحصول على النتائج العملية بواسطة تقنين إشعاعي لمكونات البيئة المحيطة بالمفاعل وأماكن التحفظ وعينت كمية الإشعاع في كل من عينات الهواء والماء والنبات وذلك على فترات زمنية مختلفة وتقدر مساحة المنطقة التي تمت دراستها بحوالي ١٢,٥ كم^{٢} وتم قياس الأشعة الجاميه باستخدام كاشف الجيرمانيوم عالي النقاوة بينما قيست أشعة ألفا وبيتا باستخدام كاشف ألفا وبيتا ضعيف الخلفية الارضية.

استخدمت النتائج التي تم الحصول عليها بجانب البيانات الخاصة يالارصاد الجوية وجيولوجية وهيدروجيولوجيه المنطقة بعمل برنامج حاسوب لتعيين الجرعة الإشعاعية وتعريف متطلبات الآمان الخاصة بالتصميم والتشغيل للمنشآت النووية.

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