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ON THE COMPUTER COMPUTATION OF THE 'PROBACENT'-PROBABILITY EQUATION APPLICABLE TO BIOMEDICAL-PHENOMENA RESEARCH: A REVIEW OF THE 'PROBACENT' FORMULA

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Abstract:-

Marked variations are generally found in percentages of response occurring in human subjects and other living organisms exposed to external stressors, depending upon intensity of stressor, duration of exposure and individual sensitivity in biological phenomena. A clear and exact quantitative mathematical relationship among these three factors namely, intensity of stressor, duration of exposure and percentage of occurrence of response in biological phenomena such as human tolerance to total body irradiation is not known. The author proposed a general mathematical formula of 'probacent'-probability equation on the basis of results from animal experiments, clinical data reported in the literature, and theoretical reasoning that approximately expresses the relationship among the three factors. For calculation of the 'probacent'-probability equation, UBASIC program was primarily used in researches in various biomedical phenomena, employing Compaq Presario Windows 95 during a period of 23 years from 1995 to 2017. In this study, a possibility of use of Apple computer (OS-X) for mathematical calculation of the 'probacent'-probability equation was examined. Calcline and UBASIC programs were applied to computer computation of the author's previous publication, " Computer-assisted formulas predicting radiation-exposure-induced-cancer risk in interplanetary travelers: Radiation safety for astronauts in space flight to Mars" and compared with regard to accuracy and applicability in computer computation. Calcline program is found to be usable in place of UBASIC on Apple computer, MacBook. Similarity and difference between Calcline and UBASIC are presented.

Keywords:- *Computer Program, Calcline, UBASIC, 'Probacent'-Probability Equation, Statistics, Radiation Safety, Space Flight to Mars, Ultron-Logotron Theory, Probacent Formula*

1. INTRODUCTION

Marked variations are generally found in percentages of response occurring in human subjects and other living organisms exposed to external stressors (stimuli), depending upon intensity of stressor, duration of exposure and individual sensitivity to external stressor and internal stress caused by stressor within the body in biological phenomena. A clear and exact quantitative mathematical relationships among those three factors in biomedical phenomena such as human tolerance to total body irradiation is still not known (Chung, 20111, 2012, 2013, 2017, 2018). The time factor is often not taken into consideration in response. Biological phenomena are often observed and investigated after states of equilibrium have been reached.

Structural organizations of human bodies are complex and not uniform. Sensitivities of human bodies to external stressors as well as to internal stresses caused by external stressors show generally marked variations. The author postulates that the sensitivity distribution is in general in Gaussian normal distribution as shown in **Figures 1** and **2**. The Gaussian normal distribution is applied to the author's general equation to express relationships among those three factors as expressed **by Equations 1b and 2b**.

The author proposed a general mathematical formula of 'probacent'-probability equation on the basis of animal experiments, clinical data reported in the literature, and theoretical reasoning that approximately expresses relationships among intensity of stressor, duration of exposure and percentage of response in biological phenomena (Chung, 1958, 1959, 1960, 1986, 2013; Kim and Chung, 1962; Kim and Chung, 1961; Park and Chung, 1961; Hur and Chung, 1961, 1962; Lee and Chung, 1961; Kim and Chung, 1960; Chung and Kim, 1959; 1961; Chung, Kim and Kim, 1962; Lee, Hur and Chung, 1961; Cho and Chung, 1961; Chung and Cho, 1959).

$$P = [(i - a)\, t^{n} - c] / (b\, t^{n} + d) \quad (1a)$$

$$Q = \frac{10}{\sqrt{(2\pi)}} \int_{-\infty}^{P} \exp[-(P - 50)^2/200]\, dP \quad (1b)$$

Where i is intensity of stimulus, external stressor or noxious agent; *t* is duration of exposure; a, b, c, d and n are constants. *P* is 'probacent' (abbreviation of percent probability), a relative amount of internal stress caused by an external stressor or a relative amount of loss of reserve for survival. Probacent values of 0, 50, and 100 correspond to (mean-5 SD), mean and (mean+5 SD), respectively; the unit of 'probacent' is 0.1 SD. In addition, 0, 50 and 100 probacents seem to correspond to 0, 50, and 100 percent probability, respectively in mathematical prediction problems in terms of percentage. *Q* is mortality probability (%). Survival probability (%) is (100 - *Q*). **Equation 1** can be used for survival probability problems (**Figures 1** and **2**).The probacent model has been applied to data in biomedical literature to express a relationship among plasma acetaminophen concentration, time after ingestion and occurrence of hepatotoxicity in man (Chung, 1989); to express survival probability in patients with heart transplantation (Chung, 1993); to express survival probability in patients with chronic leukemia, acute myelogenous leukemia or malignant melanoma (Chung, 1989, 1991, 1994); to express a relationship among blood levels of carboxyhemoglobin as a function of carbon monoxide concentration in air and duration of exposure (Chung, 1988); to predict the percentile of serum cholesterol levels by age in adults (Chung, 1990, 1992); to express a relationship among age, height and weight, and percentile in Saudi and US children of ages 6-16 years (Chung, 1994); to predict the percentile of heart weight by body weight in subjects from birth to 19 years of age (Chung, 1990); to predict survival in mice inoculated with leukemia cells (Chung, 1991); to predict carcinoma-free possibility in rats exposed to carcinogenic DMBA (Chung, 1990) and to estimate survival/death rate for radiation risk in Indian context (Mehta and Joshi, 2004). **Equation 2** is further developed from **Equation 1** that expresses relationship between mortality and amount of stressor or dose of radiation or drug administered in biomedical phenomena.

$$P^{n} = A + B \times \log D \quad (2a)$$

$$Q = 10/\sqrt{2\pi} \int_{-\infty}^{P} \exp[-(P - 50)^2/200]\, dP \quad (2b)$$

Where *D* is amount of stressor or dose. A, B and n are constants. *P* and *Q* are same as in **Equation 1**.

Table 1 shows conversion of probacent probability, correlation between probacent and probability (%) that can be used in biomedical researches. The author used **Table 1** (conversion of probability to probacent and vice versa) for calculation of **Equations 1 and 2** in the author's researches since 1958. The author's hypothesis of ultron-logotron theory was developed during the period of studies of the 'probacent'-probability equation that would be applicable in biological phenomena (Chung, 2009, 2017).

Equation 2 was applied to the United States life tables, 1992 and 2001 reported by the National Center for Health Statistics (NCHS) to construct formulas expressing the age-specific survival pronability, death rate and life expectancy in US adults, men and women (Chung, 1995, 2007).

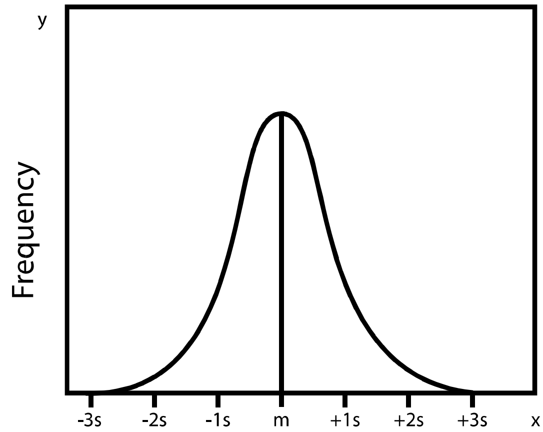

Figure 1. Gaussian normal distribution curve. m=mean; s=standard deviation.

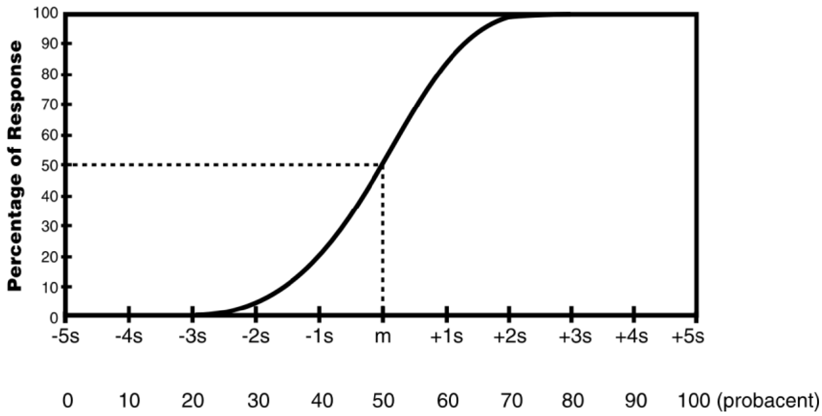

Figure 2. Gaussian normal frequency curve. Relationship between probacent and probability

(Percentage of Response) (See text).

Equations 1 is theoretically derivable and

Equation 2 can be derived from

Equation 1 (Chung, 2013). His relationship between external stressor and internal stress caused by external stressor can be demonstrated in one of the author's studies (Chung, 1988) as an example.

Equation 3

Expresses carboxyhemoglobin concentration in blood of human subjects at rest exposed to carbon monoxide in air.

$$P = (C - 0.00001)\ t0.957 - 0.00623 / (0.000318^{0.957} + 0.254) \qquad (3)$$

Where *C*=CO concentration (%=ppm/10^4) *t* = duration of exposure in minutes.

P = probacent representing percent COHb in blood as a function of carbon monoxide concentration in air. **Table 2** shows the the above results.

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TABLE 1

Conversion of percent probability (*Q*; bold) of response into "probacent" (*P*)

	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	–	19.1	21.2	22.5	23.5	24.2	24.9	25.4	25.9	26.3
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
0	–	26.74	29.46	31.19	32.49	33.55	34.45	35.24	35.95	36.59
10	37.18	37.73	38.25	38.74	39.20	39.64	40.06	40.46	40.85	41.22
20	41.58	41.94	42.28	42.61	42.94	43.26	43.57	43.87	44.17	44.47
30	44.76	45.04	45.32	45.60	45.87	46.15	46.42	46.68	46.95	47.21
40	47.47	47.73	47.98	48.24	48.49	48.74	49.00	49.25	49.50	49.75
50	50.00	50.25	50.50	50.75	51.00	51.26	51.51	51.76	52.02	52.27
60	52.53	52.79	53.05	53.32	53.58	53.85	54.13	54.40	54.68	54.96
70	55.24	55.53	55.83	56.13	56.43	56.74	57.06	57.39	57.72	58.06
80	58.42	58.78	59.15	59.54	59.94	60.36	60.80	61.26	61.75	62.27
	0.0	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**
90	62.82	62.87	62.93	62.99	63.05	63.11	63.17	63.23	63.29	63.35
91	63.41	63.47	63.53	63.59	63.66	63.72	63.79	63.85	63.92	63.98
92	64.05	64.12	64.19	64.26	64.33	64.40	64.47	64.54	64.61	64.68
93	64.76	64.83	64.91	64.98	65.06	65.14	65.22	65.30	65.38	65.46
94	65.55	65.63	65.72	65.80	65.89	65.98	66.07	66.16	66.26	66.35
95	66.45	66.55	66.65	66.75	66.85	66.95	67.06	67.17	67.28	67.39
96	67.51	67.62	67.74	67.87	67.99	68.12	68.25	68.38	68.52	68.66
97	68.81	68.96	69.11	69.27	69.43	69.60	69.77	69.95	70.14	70.33
98	70.54	70.75	70.97	71.20	71.44	71.70	71.97	72.26	72.57	72.90
99	73.26	73.66	74.09	74.57	75.12	75.76	76.52	77.48	78.78	80.90

Table 2. Percent carboxyhemoglobin of blood in relation to Carbon monoxide in air and time of exposure in men at rest.			
Carbon monoxide concentration (%)	Time of exposure (min)	Reported COHb	Computer derived COHb
1	5.5	20	20
1	7	25	25.1
0.5	5.5	10	10
0.5	11	20	19.3
0.5	15	26	25.8
0.3	4.5	5	4.9
0.3	9	10	9.5
0.3	18	20	18.4
0.3	27	27	26.9
0.2	7	5	5
0.2	14	10	9.7
0.2	30	20	19.7
0.2	50	30	31.6
0.15	9	5	4.8
0.15	18	10	9.2
0.15	42	20	20.2
0.15	72	30	32.9
0.12	12	5	5
0.12	25	10	10
0.12	54	20	20.3
0.12	92	30	32.7
0.1	15	5	5.1
0.1	30	10	9.9
0.1	68	20	20.8
0.1	80	23	24.1
0.08	20	5	5.4
0.08	40	10	10.3
0.08	87	20	20.7
0.08	135	28	30.3
0.06	25	5	5
0.06	52	10	9.8
0.06	120	20	20.5
0.06	200	28	31.3
0.06	218	30	33.6
0.05	30	5	4.9
0.05	62	10	10
0.05	150	20	20.6
0.05	200	24	26.1
0.05	235	27	29.7
0.04	40	5	5.1
0.04	80	10	9.6
0.04	200	20	20.9
0.04	245	23	24.5
0.03	50	5	4.7

0.03	110	10	9.5
0.03	200	15	15.7
0.03	260	18	19.2
0.02	80	5	4.8
0.02	190	10	10
0.02	300	14	14.3
0.01	190	5	5
0.01	290	7	6.9

Diffefences bdtween bothnvalues of reported and computer-derived COHb are statistically not significant (*p* > 0Correlation coefficient=0.966.

Computer cannot perform integral of **Equations 1b and 2b.** Therefore, an algebra equation was searched in 1962 to replace the integral in the general formula that approximately expresses Gaussian normal distribution (Chung, 1986, 2009). An approximation formula (Hastings, 1955**)** with mathematical transformation, **Equation 5** was found to be usable in place of integral of **Equation 4** in December 1962 (Chung, 1986, 2009). This discovery was introduced to the academic world for the first time 24 years later in 1986 (Chung, 1986, 2009).

$$Ø(X) = 2/\sqrt{\pi} \int_0^x e^{-t^2}\, dt \qquad (4)$$

The digital computer uses the following Equation **5** as an approximation for $0 < X < \infty$ (Hastings, 1955).

$$Ø(X) = 1 - 1/(1 + A_1 x X + A_2 x X^2 + A_3 x X^3 + A_4 x X^4)^4 \qquad (5)$$

$A_1 = 0.278393$
$A_2 = 0.230389$
$A_3 = 0.000972$
$A_4 = 0.078108$

For transformation **of Equations 1b and 2b** to **Equation 4:**

$t = (P\text{-}50)/\sqrt{200}$ (6) $dt = dP/\sqrt{200}$

(7) $X = (P\text{-}50)/\sqrt{200}$ (8)

If $(P\text{-}50) < 0$, then

$$Q = 50/(1 + A1\ x X + A_2\ x X^2 + A_3\ x X^3 + A_4\ x X^4)^4 \qquad (9)$$

If $(P\text{-}50) \geq 0$, then

$$Q = 100 - 50/(1 + A_1 x X + A_2 x X^2 + A_3 x X^3 + A_4 x X^4)^4 \qquad (10)$$

Equations 5 to 10 are used in computer computation in the author's researches.

The author (Chung, 2018) recently published general formulas that predicts mortality probability of solid cancer or leukemia death as a function of lethal dose in acute low dose total body ionizing radiation in humans (Chung, 2012) by applying the general mathematical model of "probacent"-probability equation. New formulas of tolerance in total body irradiation that expresses the radiation-exposure-induced death (REID) as a function of radiation dose or dose rate and duration of exposure in total body ionizing radiation in humans are constructed. In this study, the new formulas are applied to the measurements of the Mars Science Laboratory (MSL) spacecraft containing the Curiosity rover (2012-2013) in order to estimate radiation safety for astronauts in a future space flight to Mars. The following findings and conclusions in the author's mathematical approach are proposed:

(1) New general equations, **Equations 11** to 15 that express the radiation-exposure-inducedcancer death (REID) as a function of lethal dose or dose rate and duration of exposure are constructed from equations of the author's previous publication (Chung, 2018) that predict mortality probabilities of solid cancer death and leukemia death and radiation-exposureinduced-death (REID) in total body irradiation in humans.

(2) Estimates of REID in various circumstances of missions for astronauts in space flights to Mars are calculated and shown in **Table 4**. In case of the fastest round trip (240 days) and the shortest stay on Mars (100 days), its REID would be 3.65 %. This REID is still greater than 3 % of the NASA's permissible exposure limit (PEL).

(3) A lethal dose of 391 mSv seems to correspond to the NASA's permissible exposure limit (PEL) 3% of REID.

(4) Results of this study suggest that a future space flight to Mars would need increase in propulsion power for a faster speed and a shortened round trip, and increase in protective radiation shielding to reduce radiation dose rate, and a shortened stay on Mars for the astronauts' radiation safety in a future space flight to Mars. When the above described advancements in technologies are achieved, the space flight to Mars would be safe for astronauts against cosmic ray.

Further research would be needed for verification of the above presentations and propositions. The Compaq Presario (Windows 95) that the author used since 1995 for computer computation suddenly stopped to function in June 2017 when I had finished all necessary math calculations for the article entitled "Computer-assisted formulas predicting radiation-exposureinduced -cancer risk in interplanetary traveler: Radiation safety for astronauts in space flight to Mars"(Chung, 2018). Windows XP and 10 were found to be not usable for the author to apply to perform BASIC or UBASIC.

In this study, the author attempted to find a possibility that Calcline program for algebra equations can be used for computer computation with Apple MacBook of the author's probacent-probability equation in place of UBASIC program. For this purpose, results of solid cancer (Q), leukemia (R) and radiation-exposure-induced-death (REID) calculated by Calcline and UBASIC programs are compared in order for the author to use Apple computer, MacBook and iMac in biomedical- phenomena researches. Similarity and difference between Calcline- and UBASIC-derived results are presented. A complete agreement between both results of Calcline and UBASIC is found in this study.

Material

Zeitlin, Hassler, Cucinotta and other coauthors (2017) at Johnson Space Center, USA, Southwest Research Institute, USA, Christian Albrechts University, Germany, Jet Propulsion Laboratory, USA, German Aerospace Center, NASA Headquarter and other institutes, reported that MSL spacecraft containing the Curiosity rover launched to Mars on 26 November 2011 provided detailed measurements of energetic particle radiation environment inside RAD, the radiation dose, dose equivalent and dose rate.

Hassler, Zeitlin, Wimmer and other coauthors (2014) reported the measurements of the absorbed dose and dose equivalent from galactic cosmic rays and solar energetic particles on the Mars surface for up to 300 days of observations provided by MSL (2012-2013). The measurements of both reports shown in **Table 3** are used in this study (Chung, 2018) to compare results derived from Calcline and UBASIC computer computation.

Table 3. Radiation environment measured by Mars Science Laboratory/ Radiation Assessment Detector

RAD measurement	MSL cruise	Mars surface	Units
Dose rate	0.48 ± 0.08	0.21 ± 0.04	mGy/day
Dose-equivalent rate	1.84 ± 0.30	0.64 ± 0.12	mSv/day
Total mission dose equivalent	662 ± 108	320 ± 50	mSv
(NASA design reference mission)	(2x180 days)	(500 days)	

2. Methods

Calcline program for calculation of algebra equation is used for the probacent-probability equation that expresses human tolerance to total body irradiation and evaluate radiation safety for astronauts in space flight to Mars (Chung, 2018). Calcline-derived results are compared with UBASIC-derived results shown in **Figure 5.**

3. Statistical Analysis

A chi square goodness-of-fit test (logrank test) (Dixon and Massey, 1957) is used to test the fit of mathematical models to the data on solid cancer (Q), leukemia (R) and radiation-exposureinduced-death (REID) risks for astronauts in space flight to Mars (Chung, 2018). Differences are considered statistically significant when $p<0.05$.

5. Results

5.1. Equations of solid cancer (Q) and leukemia (R) risks

In this study, **Equations 11** and **12** published in the author's previous publication (Chung, 2012, 2018) are used to express the mortality probability of solid cancer (Q) and leukemia (R) and radiation-exposure-induced-death (REID) as a function of lethal dose (D) of radiation after exposure to acute low dose ionizing radiation in humans, respectively.

P2.425 = 34.252.425 - 1.96995x (34.252.425 - 162.425)
+
0.65665x $(34.25^{2.425} - 16^{2.425})$ x log D (11a)

$$Q = \frac{10}{\sqrt{(2\pi)}} \int_{-\infty}^{p} \exp[-\ (p - 50)^2/200]\ dP \quad (11b)$$

Where D = dose of radiation in mSv, P = probacent, and Q = solid cancer mortality probability (%).

$P^{1.47} = 25.875^{1.47}$ - 1.996995x $(25.875^{1.47} - 7.95^{1.47})$
+ 0.65665x $(25.875^{1.47} - 7.95^{1.47})$ x log D (12a)

$$Q = \frac{10}{\sqrt{(2\pi)}} \int_{-\infty}^{p} \exp[-\ (p - 50)^2/200]\ dP \quad (12b)$$

Where D = dose in mSv, P = probacent, and Q = leukemia mortality probability (%).
The **equations 11** and **12** are postulated to be applicable in case of use of millisylvert (mSv) unit, dose equivalent instead of milligray (mGy) unit.

Computer programs are written in UBASIC to calculate equations. The computer program uses a formula of approximation instead of integral of **Equations 11b** and **12b** because the computer cannot perform integral (Chung, 1986, 2012; Hastings, 1955). Calculation of **Equations 11, 12 and 15** is carried out with the computer programs as shown in **Figure 5.**

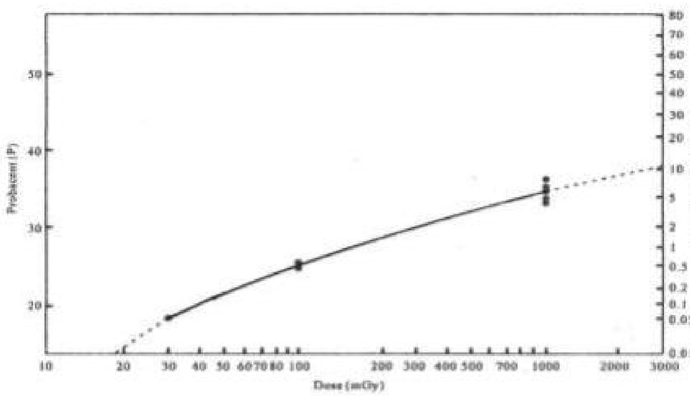

Figure 3. Relationship between dose and solid cancer mortality probability after exposure to acute low dose ionizing radiation in humans. The abscissa represents dose in mGy (log scale). The ordinate on the left side represents robacent" (P) corresponding to mortality probability (Q) in percentage in lognormal probability graph. The data points of closed circles of reported estimated solid cancer mortality probabilities after exposure to 30, 200 and 1000 mGy shown in **Table 2** of the author's previous publication (Chung, 2018) appear to fall on the solid curved line representing **Equation 11** (see text).

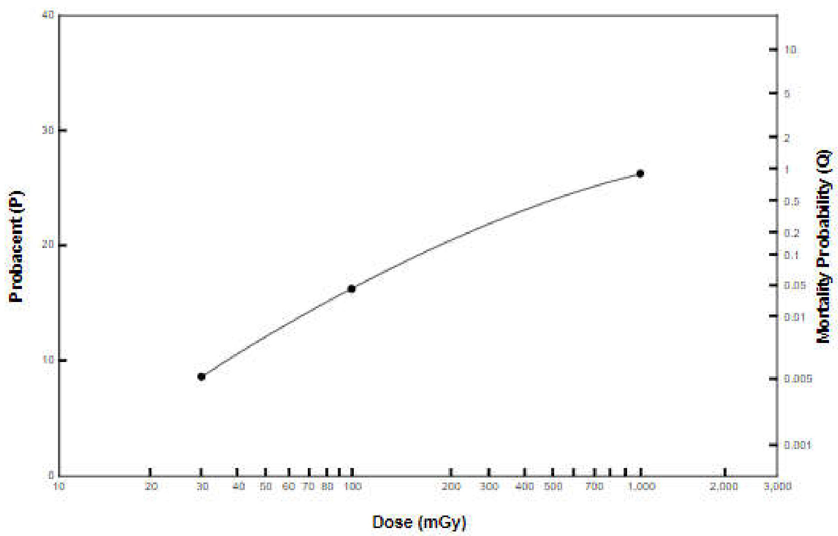

Figure 4. Relationship between dose and leukemia mortality probability of life-time risk after exposure to acute low dose ionizing radiation in humans. The abscissa represents dose in mGy (log scale). The ordinate on the right side represents leukemia mortality probability (*Q*) in percentgage. The ordinate on the left side represents "probacent" (*P*) corresponding to mortality probability (*Q*) in a lognormal probability graph. The data points of closed circles of reportedestimated leukemia mortality probabilities after exposure to 30, 100 and 1000 mGy shown **in Table 3** of the author's previous publication (Chung, 2018) **a**ppear to fall on the solid curved line representing **Equation 12.**

5. 2. Equations of Radiation-Exposure-Induced-Solid-Cancer-Death (REISCD) and Leukemia-Death (REILD)

Table 2 of the author's previous publication (Chung2018) shows the results of solid cancer mortality risk in percentage as a function of dose after exposure to acute low dose total body ionizing radiation in humans. Solid cancer means excluding leukemia from total cancer developed in life time follow-up observations after exposure in the life span studies (LSS). **Table 2** also shows comparison of formula-derived values with the reported data on acute low dose versus solid cancer mortality probability (%). Both values of formula-derived and reported solid cancer mortality probabilities in **Table 2** reveal a close agreement (p >0.99). The maximum difference is 0.75% in exposure to 1000 mSv.

Figure 3 illustrates the relationship between dose and solid cancer mortality probability after exposure to acute low dose ionizing radiation in humans. The closed circles of data points fall on or appear to fall close to the solid curved line expressed by **Equation 11**. Dashed lines below and above beyond the end points of the solid curved line of **Equation 11** represent extrapolation of **Equation 11**-expressed solid line.

Figure 4 illustrates the relationship between dose and leukemia mortality probability after exposure to acute low dose ionizing radiation in humans**.** The closed circles of data points of References, United Nations (2008, 2011) and Wall and his coworkers (2006) are the basis on which **Equation 12** is constructed. There is a close agreement between formula-derived and reported lethal radiation doses (P > 0.995).

The data points on which **Equation 12** are based fall on the solid curved line. The other points **of Table 2** of the author's previous publication (2018) are not plotted in **Figure 4** but, if plotted, would fall very close to the solid curved line at 1000 mSv expressed by **Equation 12.**

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REID (Q_{REID}) is equal to the sum of REISCD (Q_{REISCD}) + REILD (Q_{REILD}). Therefore, **Equations 13, 14** and **15** are newly constructed to express REID as a function of dose rate and duration of exposure in total body ionizing radiation in humans.

$$P2.425=34.252.425 - 1.96995 \times (34.252.425 - 162.425) + 0.65665 \times (34.252.425 - 162.425) \times \log D + 0.65665 \times (34.25^{2.425} - 16^{2.425}) \times \log T \quad (13a)$$

$$Q_{REISCD} == \frac{10}{\sqrt{(2\pi)}} \int_{-\infty}^{p} \exp[-(p-50)^2/200]\, dP \quad (13b)$$

Where D=dose rate (mSv/min), T = duration of exposure (minute), P = probacent and Q_{REISCD} = mortality probability of radiation-exposure-induced-solid-cancer death (REISCD).

$$P^{1.47}=25.875^{1.47} - 1.96995 \times (25.875^{1.47} - 7.95^{1.47}) + o.65665 \times (25.875^{1.47} - 7.95^{1.47}) \times \log D + 0.65665 \times (25.875^{1.47} - 7.95^{1.47}) \times \log T \quad (14a)$$

$$Q_{REILD} = \frac{10}{\sqrt{(2\pi)}} \int_{-\infty}^{p} \exp[-(p-50)^2/200]\, dP \quad (14b)$$

Where D=dose rate (mSv/min), T =duration of exposure (minute), P=probacent and Q_{REILD} =mortality probability of radiation-exposure-induced-leukemia death (REILD).

$$Q_{REID} = Q_{REISCD} + Q_{REILD} \quad (15)$$

Equations 11, 12 and 15 can be readily calculated with the computer program shown in **Figure 5.**

The REISCD, REILD and REID at the radiation dose of 30 mSv are 0.05, 0.005 and 0.55%; at the dose of 100 mSv, 0.565, 0.04 and 0.605%; at the dose of 1000 mSv, 5.75, 0.8 and 6.55% , respectively as shown in the computer program **(Figu**re **5)**, The REID of 391 mSv is associated with 3% of REID that is suggested to be PEL of NASA (Cucinotta and his coworkers, 2008, 2010) from the standpoint of the mathematical approach. The REID of 662 mSv is 4.76%. The average effective dose for the approximately 6-month missions of the 19 astronauts of the International

Space Station (ISS) was 72 mSv. The REID of 72 mSv is 0.36% in this study of a mathematical approach (Cucinotta

```
10   lprint "RELATIONSHIP BETWEEN DOSE AND CANCER MORTALITY RISK"
20   lprint "AFTER EXPOSURE TO ACUTE LOW DOSE RADIATION IN HUMANS"
25   lprint tab(1);"D",tab(9);"Q",tab(33);"R",tab(57);"REID=(Q+R)"
40   read D
50   'D stands for radiation dose in mSv
60   DeffnQ=34.25^2.425-1.96995*(34.25^2.425-16^2.425) + 0.65665*(34.25^2.425
     -16^2.425)*log(D) /log(10)
70   P=DeffnQ^(1/2.425)
80   A1=0.278393
90   A2=0.230389
100  A3=0.000972
110  A4=0.078108
120  if (P-50)<0 then 130 else 160
130  X=(50-P)/sqrt(200)
140  Q=50/(1+A1*X+A2*X^2+A3*X^3+A4*X^4)^4
150  goto 330
160  X=(P-50)/sqrt(200)
170  Q=100-50/(1+A1*X+A2*X^2+A3*X^3+A4*X^4)^4
180  'Q stands for solid cancer mortality probability
330  DeffnR=25.875^1.47-1.96995*(25.875^1.47-7.95^1.47)+0.65665*(25.875^1.47-
340  P=DeffnR^(1/1.47)
350  if (P-50)<0 then 360 else 380
360  X=(50-P)/sqrt(200)
361  R=50/(1+A1*X+A2*X^2+A3*X^3+A4*X^4)^4
370  goto 430
380  X=(P-50)/sqrt(200)
390  R=100-50/(1+A1*X+A2*X^2+A3*X^3+A4*X^4)^4
391  'R stands for leukenia mortality probability
430  REID=Q+R
440  lprint D,Q,R,REID
450  goto 40
460  data 30,100,1000
470  data 389,390,391,392,393,662,72
RELATIONSHIP BETWEEN DOSE AND CANCER MORTALITY RISK
AFTER EXPOSURE TO ACUTE LOW DOSE RADIATION IN HUMANS
 D       Q                       R                       REID=(Q+R)
 30      0.0499827999047218154   0.0050092941753312326   0.0549920940800530481
 100     0.565105050168922324    0.0401173659508529829   0.605222416119775307
 1000    5.7488969088216746058   0.8000685417746965633   6.5489654505963711692
 389     2.7237474117183385631   0.2641594901888472526   2.9879069019071858158
 390     2.7301248899668690933   0.2650133080433770001   2.9951381980102460935
 391     2.7364957274736344044   0.2658673744627783833   3.0023631019364127877
 392     2.7428599376187206813   0.2667216878241440365   3.0095816254428647178
 393     2.7492175337596306334   0.2675762465143889973   3.0167937802740196308
 662     4.2571380024187184334   0.5026077085375802266   4.7597457109562986601
 72      0.3364054495908233679   0.0239200496510356125   0.3603254992418589804
```

and his coworkers, 2008).

Figure 5. Computer program (UBASIC) for computation of **Equation 11** for solid cancer Mortality (Q), **Equation 12** for leukemia mortality (R) and **Equation 15** for radiationexposure-induced death (REID) (see text).

The Russian Space Agency, European Space Agency and Canadian Space Agency have adopted 1 Sv as the astronaut career exposure limit.(Zeitlin et al., 2017) NASA proposed 3% REID risk as PEL (Cucinotta et al., 2008, 2010).

In this study with the mathematical approach and the computer program of **Figure 5**, the dose of 391 mSv would correspond to the NASA's PEL. The REID of 1 Sv is 6.55%.

Table 4. Radiation-exposure-induced-death (REID).

Round trip	Stay on Mars	REID
240 days (120x2)	100 days	3.65%
240 days (120x2)	360 days	5.11%
240 days (120x2)	500 days	5.83%
360 days (180x2)	100 days	5.05%
360 days (180x2)	365 days	6.51%
360 days (180x2)	500 days	7.23%

5. 3. Results of Calcline calculation

5. 3.1. Solid cancer risk (Q) Dose=30 mSv:

*P*2.425=34.252.425 - 1.96995x (34.252.425- 162.425)+0.65665x(34.252.425- 162.425)x log 30 =831.75386

P=831.753861/2.425

=16.0006 $X=(50-P)/200^{1/2}$

=2.4046

$Q=50/(1+A_1x\ X + A_2\ x\ X^2 + A_3x\ X^3 + A_{4\ x}\ X^4)^4$

=0.04998

Dose=100 mSv:

$P^{2.425}$=2354.54263
P=24.57286
X=1.79797
Q=0.56492 Dose=1000 mSv:
$P^{2.425}$=5266.86147
P=34.25
X=1.11369 Q=5.74895
Dose=391 mSv:
$P^{2.425}$=4079.15039
P=30.82441
X=1.35592
Q=2.73649

5. 3. 2. Leukemia risk (*R*) Dose=30 mSv:
$P^{1.47}=25.875^{1.47}$ -1.96995x $(24.875^{1.47}- 7.95^{1.47})$ + 0.65665x $(25.875^{1.47}-7.95^{1.47})$x log 30 =21.0645
$P=21.0645^{1/1.47}$ *=7.95*
$X=(50-7.95)/200^{1/2}$
=2.973
$R=50/(1+A_1x2.973 + A_2x\ 2.973^2+ A_3x\ 2.973^3+ A_3x\ 2.973^4)^4$ =0.00502
Dose=100 mSv:
$P^{1.47}$=54.82140
P=15.2391
X=2.45797
R=0.04012 Dose=1000 mSv:
$P^{1.47}$=119.38110
P=25.87506
X=1.70589
R=0.80008
Dose=391mSv:
$P^{1.47}$=93.05215
P=21.84086
X=1.99115
R=0.26587

Numeric precision 5 that expresses multidecimal accuracy is taken in the above Calcline operation. Numeric precision 12 is taken for doses of 100 and 1000 mSv for solid cancer risk and dose of 391 mSv for leukemia risk in order to more accurately compare results derived from Calcline and UBASIC since there were very little, statistically insignificant differences between compare values (p>0.995).
Recalculated Q and R:
D=100 mSv, Q=0.565103050169
D=1000 mSv, Q=5.748896908819
D=391 mSv, R=0.265867374463

Table 5 shows comparison of Calcline- and UBASIC-derived *Q, R* and REID values. There is surprisingly a complete agreement between those Calcline- and UBASIC-derived values (p=1) as shown in **Table 5.**

Table 5. Comparison of Calcline- and UBASIC-derive values of solid cancer (Q), leukemia (R) and radiation-exposure-induced-death (REID).

	Calcline			UBASIC		
Dose (mSv)	Q	R	REID	Q	R	REID
30	0.0499	0.005	0.0549	0.0499	0.005	0.0549
100	0.5651	0.0401	0.6052	0.5651	0.0401	0.6052
1000	5.7488	0.8	6.5489	5.7488	0.8	6.5489
391	2.7364	0.2658	3.0023	2.7364	0.2658	3.0023

6. Discussion

Table 5 shows a complete agreement between results of Calcline- and UBASIC- derived solid cancer (Q), leukemia (R) and radiation-exposure-induced-death (REID). This comparative study strongly indicate that Calcline program can be used for computer computation with Apple MacBook of the probacent-probability equation in biological-phenomena researches.

There is a marked difference between computer operations with Calcline and UBASIC. Multiple steps are required for Apple computer (OS-X) with Calcline in order to obtain same data as results given by UBASIC. In contrast, only a single step is needed for UBASIC, including a final printing of the results. Calcline requires 91steps in order to obtain the same data given by UBASIC that needs only one step (**Figure 5).** Calcline would desirably need improvements to achieve simplification of operational steps by possibly including command statements such as "READ, GOTO, DATA and PRINT" that are used in UBASIC.

The general mathematical formula of probacent-probability equation seems to be possibly used to construct general mathematical formulas that express relationships among stressor, stress and response in biological phenomena, using Apple computer, iMac, MacBook etc. (OSX).

The study is primarily based on the UNSCEAR's report, 2010 (United Nations, 2011). The UNSCEAR has bee undertaking reviews and evaluations of global and regional exposures to radiation, and also evaluates evidence of radiation-induced health effects including cancers and deaths in exposed groups, including survivors of the atomic bombings in Japan. The UNSCEAR provides international standards for the protection of the general public and workers against ionizing radiation (United Nations, 2011).

A quantitative dose-response relationship in lethal ionizing radiation exposure in humans is not known (Cerveny and his coworkers, 1989). Several investigators have derived hypothetical dose-response curve based on experiences with reactor accidents and the atomic exposure in Japan. From these observations, LD_{50} for humans exposed to single dose of radiation delivered over a period of less than 24 hours is believed to be in the range of 2.50 to 4.0 Gy. (Damjanov and Linder, 1996). Levin, Young and Stohler (1992) published an estimate of the median lethal dose on humans exposed to total body ionizing radiation and not subsequently treated for the radiation sickness. The median lethal dose was estimated from calculated doses to young adults who were inside two reinforced concrete buildings that remained standing in Nagasaki, Japan after the atomic detonation. Median dose estimates were calculated using both logarithmic (2.9 Gy) and linear (3.9 Gy) dose scales. Both calculations supported previous estimates of the median lethal dose based solely on human data, which clustered around 3 Gy. The LD_{50} of 2.9 Gy was surprisingly consistent with estimates made by other researchers; 2.45 Gy by Langham (1967), 2.86 Gy by Lushbaugh et al. (1967), 2.65-2.70 Gy by Bond and Robertson (1957) (Levin and his coworkers 1992).

Fujita, Kato and Schull (1989) reported the LD_{50} of 2.3-2.6 Gy that is noticeably in a good agreement with the value of LD_{50} shown in **Table 5** of the author's previous publication (Chung, 2018). There is a remarkable agreement between the formula-derived LD_{50} in **Table 5** of the author's previous publication (Chung**,** 2018) and the above described published-estimated $LD_{50.}$ (Damjanov and Linder, 1996; Levin and his coworkers, 1992; Fujita and his coworkers, 1989). The dose-response relation in human exposure to ionizing radiation reveals a linear relationship in both high and low dose rates (Chung, 2018)

Cucinotta, Kim, Willingham and George at NASA, Lyndon B. Johnson Space Center, Wyle Laboratory Life Science Group and U.S.R.A. Division of Space Life Sciences, reported radiation damages in blood cells (lymphocytes) in the 19 astronauts of the International Space Station (ISS) after approximately 6-month missions (Cucinotta and his coworkers, 2008). Elon Musk, Chief Executive Officer (CEO) of the rocket company, SpaceX, and the autopilot car company, Tesla, recently published his vision to colonize Mars and save humanity (Musk, 2017; Haynes, 2017) If it is real and true that a 160-day round trip to Mars, a 100-day stay on Mars surface and a 1000-day stay in the radiation-shielded building and/or the underground shelter like gimme shelter caves with a skylight opening (Haynes, 2017) of Mars (NASA, 2017), then the REID of the planned space flight to Mars would be 2.86%

with dose 371 mSv that is less than 3% of the NASA's PEL of dose 391 mSv in the mathematical analysis of this study (see **Equation 16**).

$$1.84 \times 80 \times 2 + 0.64 \times 100 + 0.0128 \times 1000 = 371 \text{ mSv}. \quad (16)$$

The dose rate of radiation in the radiation-shielded building and the underground shelter of Mars is assumed to be 1/50 of the dose rate of Mars surface (1.64/50=0.0128). When the above described advancements in technologies are achieved, space flights to Mars would be safe for astronauts against cosmic ray.

7. Conclusion

There is a complete agreement between results of computer computation by Calcline and UBASIC programs.

1. Calcline can be used in place of UBASIC on Apple computer MacBook (OS-X) for calculation of the 'probacent'-probability equation that is applicable to a variety of biological phenomena.
2. There is a marked difference between Calcline and UBASIC computer operations in order to obtain same data. Multiple steps are required for Calcline. In contrast, only a single step is necessary for UBASIC.
3. It is suggested that Calcline would need further improvement with command statements such as READ, GOTO, and DATA, Print that are included in UBASIC in order to simplify operational steps.
4. The general mathematical 'probacent' formula of the 'probacent'-probability equation would be possibly used to construct mathematical relationships among stressor, stress and response in a variety of biological phenomena.

Further research would be needed for verification of the above conclusion as well as improvement in Calcline program for Apple computer.

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References

[1]. Cerveny, T. J., MacVittie, T. J. and Young, R. W.(1989). Acute radiation syndrome in humans. In:R.J. Walker RJ and T.J. Cerveny TJ, editors. Medical Consequences in Nuclear Warfare.

[2]. pp. 15-36. Falls Church, Virginia: TMM Publications, Office of the Surgeon General.

[3]. Cho, D. W. and Chung, S. J. (1961). Studies of tolerance of several kinds of animals to electricshock, hydrogen and hydroxyl ions. Bulletin of Yamaguchi Medical School, 8, 151-160.

[4]. Chung, S. J. (1958). Studies of tolerance of Paramecium to quinacrine hydrochloride. Aviation Medicine, 6, 77-87.

[5]. Chung, S. J. (1959). Studies of positive radial acceleration on mice. Journal of Applied Physiology, 14, 52-54.

[6]. Chung, S. J. and Kim, C. C. (1959). Studies of variation and adaptation of tolerance of Paramecium caudatum to heat stress. Theses of Catholic Medical College, 3, 66-71.

[7]. Chung, S. J. and Cho, D. W. (1959). Studies of tolerance of Paramecium caudatum to heat stress.

[8]. Theses of Catholic Medical College, 3, 59-65.

[9]. Chung SJ. (1960). Studies on a mathematical relationship between stress and response in biological phenomena. J. Nat. Acad. Sci. Rep. of Korea, 2: 115-62.

[10]. Chung, S. J.; Kim.C. C. and Kim, B. I. (1962). Studies of tolerance of loaches to eletroshock. Theses of Catholic Medical College, 5, 345-351.

[11]. Chung, S. J. (1986). Computer-assisted predictive mathematical relationship among metrazol dose and time and mortality in mice. Computer Methods and Programs in Biomedicine,

[12]. 22, 275- 284.

[13]. Chung S.J. (1988). Formula expressing carboxyhemoglobin resulting from carbon monoxid exposure. Veter. Hum. Toxicology, 30, 528-532.

[14]. Chung S. J. (1989). Computer-assisted predictive mathematical relationship among plasmaacetaminophen concentration and time after ingestion and occurrence of hepatotoxicity in man. Computer Methods and Program. In Biomedicine, 28, 37-43.

[15]. Chung, S. J. (1990). Formula predicting carcinoma-free probability in rats exposed to carcinogen

[16]. DMBA. International Journal of Biomedical Computing, 26, 171-181.

[17]. Chung, S. J. (1991). Formula predicting survival in mice inoculated with leukemia cells.

[18]. International Journal of Biomedical Computing, 28, 31-45.

[19]. Chung S. J. (1993). Formula predicting survival probability in patients with heart transplantation. International Journal of Biomedical Computing, 32, 211-21 Chung SJ. (1994). Formula expressing relationship among lesion thickness and time after diagnosis and survival probability in patients with malignant melanoma. International Journal of Biomedical Computing, 37, 171-80.

[20]. Chung S. J. (1994). Formulas expressing relationship among age, height and weight and percentile in Saudi and US children of aged 6 - 16 years. International Journal of Biomedical Computing, 37, 259-72.

[21]. Chung, S. J. (1995). Formulas expressing life expectancy, survival probability and death rate in life

[22]. Tables at various ages in US adults. International Journal of Biomedical Computing, 39, 209 217.

[23]. Chung S. J. (2007). Computer-assisted predictive formulas expressing survival probability and life expectancy in US adults, men and women, 2001. Computer Methods and Programs in Biomedicine, .86, 197-209.
[24]. Chung, S. J. (2009). Seeking a New World: A New Philosophy of Confucius and Kim Hang. Bloomington, ID: iUniverse.
[25]. Chung S. J. (2011). Predictive formulas expressing relationship among dose rate, duration of exposure and mortality probability in total body irradiation in humans. Journal of *Biomedical* Science and Engineering, 4, 497-505.
[26]. Chung S.J. (2012). Computer-assisted formulas predicting cancer mortality risk after exposure to acute low dose ionizing radiation in humans. Journal of Biomedical Science and Engineering, 5,176-85.
[27]. Chung S. J. (2013). Mathematical relationship of "probacent"-probability equation among exogenous stressor, stress and response in biological phenomena. International Journal of Education and Research, 1, 1-32.
[28]. Chung S.J. (2017). Comparison of mathematical equations applicable to tolerance of total body irradiation in humans and decay of isotopes, uranium and thorium: differences and
[29]. Similarity. Journal of Biomedical Science and Engineering, 10**,** 273-86. Chung, S. J. (2018). Computer-assisted formulas predicting radiation-exposure-inducedcancer- risk in interplanetary travelers: Radiation safety for astronauts in space flight to Mars.
[30]. Journal of Medical Sciences, 38, 150-159. Cucinatto F.A., Hu, S., Schwadron, N. A,, Kozarev, K., Townsend, L. W., Kim, M. H. (2010).
[31]. Space Radiation Risk Limits and Earth-Moon-Mars Environmental models. Space Weather,
[32]. 8**,** 1-12. onlinelibrary.wiley.com/doi/10.1029/2010sw000572/full
[33]. Cucinotta, F. A., Kim, M. H., Willingham, V., George, K. A. (2008). Physical and biological dosimetry analysis for International Space Station Astronauts. Radiation Research, 170, 127-38.
[34]. Damjanov, I. and Linder, J. (1996). Anderson's Pathology, 10th edition. New York: Mosby. Dixon, W. J. and Massey Jr., F. S. (1957). chi square test for goodness-of-fit. Introduction to Statistical Analysis (pp. 226-227.. New York: MacGraw-Hill,.
[35]. Fujjita, S., Kato, H. and Schull, W. J. (1989). The LD_{50} associated with exposure to the atomic bombing of Hiroshima. Journal of Radiation Research (Tokyo), 30:359-81. Hassler, D. M., Zeitlin, C., Wimmer-Schweingruber, R. F., Ehresmann, B., Rafkin, S., Eigenbrode, J. L. et al. (2014). MSL Science Team (2014) Mars' surface radiation environment measured with the Mars Science Laboratory's Curiosity rover. Science, 343**,** 1244797-6.
[36]. Hastings Jr. C. (1955). Approximation for Digital Computer. p. 185.Princeton, NJ: Princeton University Press,
[37]. Haynes, K. (2017). Surviving space: the solution, gimme shelter. *Discover*, July/August, 2017. p. 72.
[38]. Hur, B. and Chung, S. J. (1962). Studies on a relationship between dose, time and percentage of occurence of response and method of evaluation of combined action in drugs. New Hur, B. and Chung, S. J. (1961). Studies on tolerance of Paramecium caudatum to cold. Korean Medical Journal, 5, 35-82.
[39]. Choong An Medical Journal, 6, 657-662. Kim, C. C. and Chung, S. J. (1962). Studies on a relationship between intensity of stress, duration
[40]. of exposure and percentage of occurrence of response in goldfish exposed to single, double or triple stresses of acceleration, electroshock, heat, chemical and osmotic stimuli.
[41]. Theses of Catholic Medical College, 5, 257-336.
[42]. Kim, K. B. and Chung, S. J. (1961). Studies on a relationship between intensity and duration of stimuli and percentage of occurrence of response in phenomena of sensation and anesthesia. Korean Medical Journal, 6, 125-149.
[43]. Kim, K. S. and Chung, S. J. (1960). Studies of tolerance of living organisms to change of osmotic pressure. Journal of Tokyo Women's Medical University, 30, 1686-1708.
[44]. Kim, Y. K. and Chung, S. J. (1960). Studies on a relationship between intensity and duration of
[45]. stimuli and occurrence of response in a few different kinds of animals. Journal of the Osaka City Medical Center, 9, 1-15.
[46]. Lee, D. C. and Chung, S. J. (1961. Studies of tolerance of living Bodies to insulin and changes in blood sugar levels. Korean Medical Journal, 6, 1-13.
[47]. Lee, D. C.; Hur, B.; Kim, C. C.; Chung, C. C. (1961). Studies on tolerance of mice to hydrogen sulfide. Korean Choong An Medical Journal, 1, 737-746.
[48]. Levin, S. G., Young, R. W. and Stohler, R. I.(1992). Estimation of median human lethal radiation dose computed from data on occupants of reinforced concrete structure in Nagasaki, Japan. Health Physics, 64: 522-31.
[49]. Mehta, S. C. and Joshi, H. C. (2004). Model based estimates of survival/death rates: An input for radiation risk evaluation in Indian context. Ind. Journal of Nuclear Medicine, 19**:**16-8.
[50]. Musk, E. (2017). Here's Elon Musk's complete, sweeping vision on colonizing Mars to save humanity.
[51]. https://diyhpl.us/wiki/transcripts/spacex/elon-musk-making-humans-a-multiplanetary- species
[52]. NASA. (2017). Journey to Mars overview.
[53]. https://www.nasa.gov/content/journey-to-mars-overvie http://www.businessinsider.com/elon-musk-mars-speech-transcript-2016-9

[54]. Park, M. H. and Chung, S. J. (1961). Experimental studies of relationship among intensity of stimulus, time, dose and percentage of occurrence of response in neuropsychiatric electroshock, insulin shock and cardiazol cramp therapy. Korean Medical Journal, 6, 151- 181.

[55]. United Nations (2008). Report of the United Nations Science Committee on the Effects of Atomic Radiation 2006 (UNSCEAR 2006), Vol. I (Annex A. Tables 59 and 65). New York: United Nations.

[56]. http://www.unscear.org/unscear/en/publications/20061.html

[57]. United Nations (2011). Repot of the United Nations Scientific Committee on the Effects of Atomic Radiation 2010 (UNSCER 2010). New York. United Nations. http://uscear.org/unscear/about_us/sessions.html

[58]. Wall, B. F., Kendall, G. M., Edwards, A. A., Bouffler, S., Muirhead, C. R. (2006). What are the risks from medical X-rays and other low dose radiation? British Journal of Radiology,79:275-84.

[59]. Zeitlin, C., Hassler, D. M., Cucinotta, F. A., Ehresmann, B., Wimmer-Schweingruber, R. F.,Brinza, S. D. E. et al. (2917). Measurements of energetic particle radiation in transit to Mars on the

[60]. Mars Science Laboratory. Science, 340**:** 1080-1084.

Legends for Figures

Figure 1. Gaussian normal distribution curve. m=mean; s=standard deviation.

Figure 2. Gaussian normal frequency curve. Relationship between probacent and probability (Percentage of Response) (see text).

Figure 3. Relationship between dose and solid cancer mortality probability after exposure to acute low dose ionizing radiation in humans. The abscissa represents dose in mGy (log scale). The ordinate on the left side represents "probacent" (*P*) corresponding to mortality probability (*Q*) in percentage in a lognormal probability graph. The data points of closed circles of reported-estimated solid cancer mortality probabilities after exposure to dose of 30, 100 and 10000 mGy shown in **Table 2** of the author's previous publication (Chung, 2018) (see text) appear to fall on or very close to the solid curved line representing **Equation 11.**

Figure 4. Relationship between dose and leukemia mortality probability of life-time risk after exposure to acute low dose ionizing radiation in humans. The abscissa represents dose in mGy (log scale). The ordinate on the right side represents leukemia mortality probability (*Q*) in percentage. The ordinate on the left side represents "probacent" (*P*) corresponding to mortality probability (*Q*) in a lognormal probability graph. The data points of closed circles of reported-estimated leukemia mortality probabilities after exposure to 30, 100 and 1000 mGy shown in **Table 3** of the author's previous publication (Chung, 2018) appear to fall on the solid curved line representing **Equation 12.**.

Figure 5. Computer program (UBASIC) for computation of **Equations 11** for solid cancer mortality (Q), **Equation 12** for leukemia mortality (R) and **Equation 15** for radiationexposure-induced-death (REID) (see text).