# The Risk Assessment of Cancer Risk during Normal Operation of Tehran Research Reactor Due to Radioactive Gas Emission

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***Abstract*—**In this research, the risk assessment of radiation hazard for the Research Nuclear Reactor has been studied. In the current study, the MCNPx computational code has been used and coupled with a developed program using MATLAB software to evaluate Total Effective Dose Equivalent (TEDE) and cancer risk according to the BEIR equations for various human organs. In this study, the risk assessment of cancer has been calculated for ten years after exposure, in each of body organs of different ages and sexes. Also, the risk assessment of cancer has been calculated in each of body organs of different ages and sexes due to exposure after the retirement of the reactor staff. According to obtained results, a conservative whole-body dose rate, during a year, is 0.261 Sv and the probability the cancer risk for women is more than men and for children is more than adults. It has been shown that thyroid cancer was more possible than others.

***Keywords*—**MCNPx code, BEIR equation, equivalent dose, risk analysis.

## I. Introduction

THE main issue in reactor safety is fission products, which are mainly radioactive. These products are produced in the core of a reactor. These are divided into three categories: gas forms, soluble materials in water and solids. These fission fragments may increase absorbed dose of reactor staff [1]. Also, these may enter the environment; and so, affect the health of the community in addition to the staffs. The further dose will be absorbed by the staffs, due to the radioactive gases, that released into the environment from the core. These fission fragment gases include the noble gases (krypton and xenon), active gases (Cs, Ar, S, N, C, K, I) and ultrafine particles [2]. An undesirable ventilation system can cause public damage via excess cancer risk injection. Kojuri et al. have calculated the absorbed dose of the phantom for the VVER reactor. Then, they have calculated the increased risk of cancer associated with this absorbed dose through the BEIR equations [3]. Salmasian et al. have calculated the risk assessment of radiation hazard for a typical VVER1000 [4].

In this study, monthly and yearly absorbed dose calculation, due to the fission fragments and radioactive gases has been done. The standard phantom located in the top and below of the reactor has given absorbed dose medium. The fission fragments due to this study involved the radioactive gases ejected from the water pool.

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## II. Material and Methods

### A. Introduction

In the first step, the input file of the MCNPX Code of the Tehran Research Reactor, the pool space and the dome around it are have defined. Then, the amount of absorbed dose received in different modes will be calculated by calculating the gamma-ray energy spectrum of radioactive gases and defining them as sources in the input file of this program. The absorbed dose increases the risk of cancer in people.

### B. Geometries Definition

The Research Reactor Geometries Definition

The Tehran Research Reactor has been selected as a sample of a research reactor. The Tehran Research Reactor is a 5 MW research reactor of the MTR type fuel. Main specifications of the Tehran research reactor have been shown in Table I. In this reactor, light water plays a role of coolant, moderator and biological shielding. The pool has made from cement and reinforced concrete; in which the inner layer was covered by the stainless-steel plate. The reactor pool has two interconnected sections; in which core can be placed in both of them. The reactor containment is dome with the shape of the cylinder; this dome has a dimension of 30 m in diameter and 14 m in height. The dome area is 700 $m^2$ with a variable thickness wall from 80 cm to 1.80 m. The dummy plate which is constructed of stainless steel, has 8 mm thickness and 140 tons weight. The volume of air inside the containment is about 15,000 cubic meters. The air intake and discharging to the dome is 500 and 570 cubic meters per minute, respectively, so this difference causes a negative pressure of about 3 cm below the dome. The reactor has a ventilation system to eliminate radioactive fission fragments caused by the fission in the core. A nuclear reactor ventilation system is prepared for purposes such as controlling and reducing the emission of radioactive materials to the environment, protects staff and researchers from excessive exposure, provide negative pressure inside the reactor building, to reduce the environmental effects of radioactive material, especially gases and ultimately preparing an appropriate environment for staff. The Tehran research reactor has a 57 m height chimney. This chimney is located in the reactor building and presented in Table II. The fans were used for air conditioning under the dome. The rate of radioactive outflow

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from the chimney is 7.8 (m/s) [5].

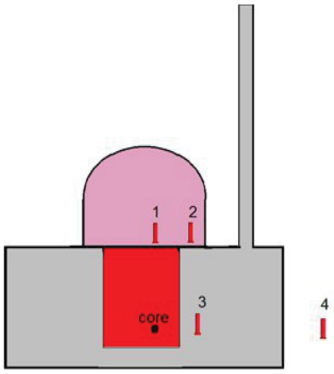


Fig. 1 The geometry of the Tehran Research Reactor Simulated with MCNPX Code

Fig. 1 is an illustration of the simulation geometry of the Tehran Research Reactor at MCNPx. the cooling tower, the cement dome, the containment, and the reactor core, as shown in Fig 1. The numbers from 1 to 4 refer to, around the core, above the pool, below the dome, and outside the reactor.

1. Body Equivalent Phantom Geometry

In this study, the dose calculation for the equivalent human phantom has been performed. (In the form of a cylinder filled with water and weighed 100kg). The simulation is performed using the MCNPX code shown in Figure 2. This phantom is placed inside the reactor at different parts to calculate the annual dose-absorbing fraction of radioactive gases produced by the reactor. The radioactive substances released into the environment during the operation of the reactor core are divided into two groups. These two groups are released in the form of gas or fine particles in the air. Also, the International Atomic Energy Agency's Standards Booklet shows released percent of radioactive materials for noble gases, halogen, alkali metals, thorium group, Br-Sr group, noble metal, serum group, lanthanides, release rates and activity have reported in various forms (Tables III and IV) [6].

TABLE I
TEHRAN RESEARCH REACTOR SPECIFICATIONS

| **thermal power** | **5MW** |
|---|---|
| **Fuel** | U-235 (low enriched) Al coated |
| **The average thermal neutron flux at 5 megawatts** | 3.1×1013 n/cm2.sec |
| **Number of fuel plates in each Fuel element** | 19 standard fuel element<br>14 control fuel element |
| **Core dimension** | 40.5×38.54×89.7 cm3 |
| **Coolant and moderator** | Light water |
| **Primary coolant flow** | 500 m3/h |
| **Inlet flow temperature (in 5MW)** | 37.8 'c |
| **Outlet flow temperature (in 5MW)** | 46 'c |

Also, in Table II, the reactor chimney specification is given. According to Table II, the Tehran Research Reactor has one chimney with a diameter of 2.5 m and a height of 57 m. The rate of radioactive release is 8.7 m / s.

2. Equivalent Dose Calculation

An equivalent dose calculation, the absorbed dose must be multiplied by a coefficient of quality that depends on its type of radiation. In this study, there are gamma and beta radiations, so the quality factor is equal to 1. So, the absorbed dose unit is equivalent to the equivalent dose unit. Also, the energy and dose calculation, that remaining in the phantom, the F6 * and the F8* tallies in the MCNPX code, were used respectively. Due to different reports, for the reactivity of the reactor gas elements of Tehran (Tables III and IV), it was decided to calculate the dose rate per microscope for each radioactive gas. Of course, regard to measured values, the activity of released gases, for each power reactor, or research in available resources, can also be used for the results of this research [7]-[9].

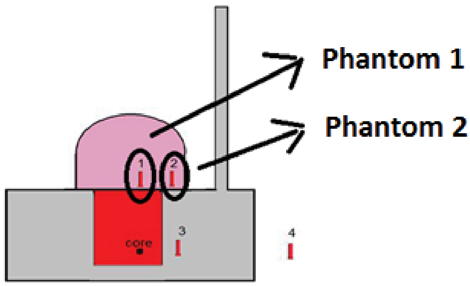


Fig. 2 Phantom geometry simulated with MCNPX code

TABLE II
TEHRAN RESEARCH REACTOR CHIMNEY SPECIFICATION

| **Chimney specification** | |
|---|---|
| **Number** | 1 |
| **Diameter (m)** | 2.5 |
| **Height (m)** | 57 |
| **Radioactive material release speed (m/s)** | 8.7 |

3. Cancer Risk

a. BEIR Equation

One of the indicators that widely used in epidemiological studies is the relative risk index. This indicator used to the comparison between two groups of people with interest an event such as cancer or death. The relative risks had derived from the two group cancer incidence ratios. The BEIR is a scientific committee that examines the biological effects of ionizing radiation. According to a studied about Japanese nuclear bombardment survivors, the committee presented several couple equations in the BEIR VII model; based on these equations, the risk of cancer caused by ionizing radiation can calculate [3]. The BEIR equation used as below form.

$$ERR\ and\ EAR = \beta D exp(\gamma e^{*})(\frac{a}{60})^{n} \quad (1)$$

The D is the absorbed dose rate of the individual and η, β, γ are constant coefficients for different organs and m and f of the individual's sex. e * = (e-30) / 10 for e> 30 and e ^ * = 0 for e <30, which “e” in this equation is the age of the person, at the time of exposure, and the age of the person at the time of the risk estimate for cancer. It is difficult, exclusively determine that cancer is a radiation hazard result [8]. Therefore, the Cancer

Risk Index, relative to the age-related effect of radiation-induced cancer, was raised by the American Institute of Health in 1985. Cancer risk depends not only on the gender and age of the person but also on other factors, such as genetics and lifestyle. Therefore, the risk of developing cancer is a statistical function but increases with increased absorbed dose.

b. Equation Condition

There are different conditions for estimating the likelihood of an increase in cancer for different people, different ages, different sexes, and cancerous organs. Therefore, different parameters η, β, γ are determined for each condition and embedded in (1). The parameters used in the BEIR equations had given in Table III. Also, the annual absorbed dose of total body D is 0.261 Sievert.

## III. Results

### A. Calculated Dose

1. The Calculated Dose Is Due to Each Gas

In the first step, the K-code card activated in the code input program. Then, received dose rate for the equivalent phantoms at the top and beside the pool was calculated. These phantoms had shown in figure1. In Table V, the result of absorbed dose, from the radioactive gas was activated in the interior of the dome and absorbed dose rate from each of the gases, on the equivalent human phantoms for 1µci was calculated. In this table, phantoms 1 and 2 are high above the pool and above the wall. Also, all computations for noble gases, halogen, alkali metals, thorium group, Br-Sr group, cerium group, and lanthanides have been calculated taking into account the release rate and activity of each of these radionuclides. this table is shown, the equivalent dose rate, in monthly 170-hours working and in yearly 2040-hours working, results from the reactor performance and its gases in Phantom 1 was (above the pool) equal 21.9 mSv/month and 261 mSv/year and in phantom 2 (above the pool wall) was 4.7 mSv/month and 56.4 mSv/year. Table VI shows the released percent of each radionuclide's gas and activity of each one.

TABLE III
PARAMETERS USED BY BEIR EQUATIONS

| Organ | $\beta_M$ | $\beta_F$ | γ | η |
|---|---|---|---|---|
| Stomach | 0.21 | 0.48 | -0.30 | -1.4 |
| Intestine | 0.63 | 0.43 | -0.30 | -1.4 |
| liver | 0.32 | 0.32 | -0.30 | -1.4 |
| Lung | 0.32 | 1.4 | -0.30 | -1.4 |
| Breast | - | 0.51 | 0 | -2.0 |
| Prostate | 0.12 | - | -0.30 | -1.4 |
| Uterus | - | 0.055 | -0.30 | -1.4 |
| Ovary | - | 0.38 | -0.30 | -1.4 |
| Bladder | 0.50 | 1.65 | -0.30 | -1.4 |
| Thyroid | 0.53 | 1.05 | -0.83 | 0 |

2. The Absorbed Dose Is Due to Each Gas

In Tables V and VI, we calculated the absorbent dose of the individual, which will give the same values as conservative, as the total absorption dose of the body in the calculation of safety hazards. Table V shows the dose absorbed in phantom number 1 for each micro curie of various nucleotide gases. Table VI shows the absorbed dose in Phantom No. 2 for each micro curie of different nucleotide gases.

3. Annular Whole-Body Absorbed the Dose

Table VII shows the annual absorbed dose in phantom number 1, due to different nucleotide gases. Table VIII shows the annual absorbed dose in phantom number 1, due to different nucleotide gases.

### B. Risk Assessment

The cancer risk estimation associated with one year working in the Tehran research reactor, shown in Tables IX-XII. In Table IX, the estimated risk of developing cancer after one year of dosing, at the age of a20, 30 and 40 at the age of 60, is known as retirement age; for the cancer of various organs of the body and sex of men and women, separately calculated.

TABLE IV
RELEASED PERCENT AND ACTIVITY OF EACH RADIONUCLIDES GASES

| Radionuclide | Activity (Becquerel) | Released percentage | Radionuclide | Activity (Becquerel) | Released percentage |
|---|---|---|---|---|---|
| Cs-137 | 9.591 E+11 | 30 | **Kr-83m** | 1.754 E+14 | 100 |
| Te-127 | 9.964 E+12 | 5 | **Kr85m** | 2.823 E+14 | 100 |
| Te-129 | 2.865 E+13 | 5 | **Kr-87** | 4.110 E+14 | 100 |
| Te-131 | 8.874 E+13 | 5 | **Kr-88** | 7.688 E+14 | 100 |
| Te-132 | 1.408 E+14 | 5 | **Kr-89** | 7.844 E+14 | 100 |
| Sr-90 | 0.208 E+11 | 2 | **Xe-131m** | 7.588 E+12 | 100 |
| Zr-95 | 6.537 E+12 | 2 | **Xe-133** | 3.260 E+14 | 100 |
| Ba-140 | 2.977 E+13 | 2 | **Xe-135m** | 6.989 E+14 | 100 |
| Ru-103 | 9.851 E+11 | 0.25 | **Xe-135** | 5.712 E+11 | 100 |
| Ru-106 | 1.807 E+11 | 0.25 | **Xe-137** | 3.569 E+15 | 100 |
| Rh-105 | 0.578 E+11 | 0.25 | **Xe-138** | 3.187 E+15 | 100 |
| Ce-141 | 2.201 E+11 | 0.5 | **I-131** | 5.434 E+14 | 40 |
| Ce-143 | 1.199 E+12 | 0.5 | **I-132** | 1.281 E+15 | 40 |
| Ce-144 | 0.442 E+11 | 0.5 | **I-133** | 1.515 E+15 | 40 |
| Nd-147 | 0.172 E+11 | 0.02 | **I-134** | 1.732 E+15 | 40 |
| Pr-143 | 0.3314 E+11 | 0.02 | **I-135** | 1.491 E+15 | 40 |

TABLE V
ABSORBED DOSE IN PHANTOM 1

| **Radio nuclide** | **Activity (micro curie)** | **Phantom 1 nSv/micro curie** | **Radio nuclide** | **Activity (micro curie)** | **Phantom 1 nSv/micro curie** |
|---|---|---|---|---|---|
| **I-131** | (3.5E-11)a | 3.99E-4 | S-35 | - | 1.87E-4 |
| **Cs-134** | (1.76E-9)a | 7.467E-4 | Kr-89 | (1.5E+2)b | 7.68E-4 |
| **Cs-137** | (2E-9)a | 7.12E-4 | Xe-137 | (4.5E+2)b | 5.44E-4 |
| **Xe-133** | (2.5E+3)b | 1.01E-4 | Xe-135m | (4E+3)b | 5.72E-4 |
| **Xe-135** | (9E+3)b | 2.88E-4 | Xe-138 | (1.3E+4)b | 8.72E-4 |
| **85-Kr** | (5E0)b | 5.58E-4 | Kr-87 | (8E+3)b | 9.23E-4 |
| **Ar-41** | - | 1.32E-3 | Kr-83m | (1.2E+3)b | 2.95E-6 |
| **Rn-222** | (2E-9)* a | 1.51E-3 | Kr-88 | (8E+3)b | 1.37E-3 |
| **N-16** | - | 4.36E-3 | Kr-85m | (2.9E+3)b | 1.96E-4 |
| **C-14** | - | 1.75E-4 | Xe-133m | (1E+2)b | 2.55E-4 |
| **K-40** | (6.75E-7)a | 1.46E-3 | Xe-131m | (5E0)b | 1.84E-4 |

TABLE VI
ABSORBED DOSE IN PHANTOM 2

| Radio nuclide | Activity (micro curie) | Phantom 2 nSv/micro curie | Radio nuclide | Activity (micro curie) | Phantom 2 nSv/micro curie |
|---|---|---|---|---|---|
| I-131 | (3.5E-11)a | 8.61E-5 | S-35 | - | 4.01E-5 |
| Cs-134 | (1.76E-9)a | 1.59E-4 | Kr-89 | (1.5E+2)b | 1.672E-4 |
| Cs-137 | (2E-9)a | 1.52E-3 | Xe-137 | (4.5E+2)b | 1.16E-4 |
| Xe-133 | (2.5E+3)b | 2.18E-5 | Xe-135m | (4E+3)b | 1.23E-4 |
| Xe-135 | (9E+3)b | 6.1E-5 | Xe-138 | (1.3E+4)b | 1.92E-4 |
| 85-Kr | (5E0)b | 1.2E-4 | Kr-87 | (8E+3)b | 1.98E-4 |
| Ar-41 | - | 2.81E-4 | Kr-83m | (1.2E+3)b | 1.66E-7 |
| Rn-222 | (2E-9)* a | 2.27E-4 | Kr-88 | (8E+3)b | 2.94E-4 |
| N-16 | - | 9.78E-4 | Kr-85m | (2.9E+3)b | 4.2E-5 |
| C-14 | - | 3.77E-5 | Xe-133m | (1E+2)b | 5.49E-5 |
| K-40 | (6.75E-7)a | 3.11E-4 | Xe-131m | (5E0)b | 3.93E-5 |

TABLE II
ANNULAR ABSORBED DOSE IN PHANTOM 1

| Radio nuclide | Activity (micro curie) | Phantom 1 Annular (2040 hour) nSv/micro curie | Radio nuclide | Activity (micro curie) | Phantom 1Annular (2040 hour) nSv/micro curie |
|---|---|---|---|---|---|
| I-131 | (3.5E-11)a | 1.03E-7 | S-35 | - | - |
| Cs-134 | (1.76E-9)a | 9.65E06 | Kr-89 | (1.5E+2)b | 8.46E+5 |
| Cs-137 | (2E-9)a | 1.05E-5 | Xe-137 | (4.5E+2)b | 1.80E+6 |
| Xe-133 | (2.5E+3)b | 2.41E-2 | Xe-135m | (4E+3)b | 1.68E+7 |
| Xe-135 | (9E+3)b | 1.90E+7 | Xe-138 | (1.3E+4)b | 8.33E+7 |
| 85-Kr | (5E0)b | 2.05E+4 | Kr-87 | (8E+3)b | 5.42E+7 |
| Ar-41 | - | - | Kr-83m | (1.2E+3)b | 2.60E+4 |
| Rn-222 | (2E-9)* a | 1.54E-5 | Kr-88 | (8E+3)b | 8.06E+7 |
| N-16 | - | - | Kr-85m | (2.9E+3)b | 4.17E+6 |
| C-14 | - | - | Xe-133m | (1E+2)b | 1.87E+5 |
| K-40 | (6.75E-7)a | 7.24E-3 | Xe-131m | (5E0)b | 6.76E+3 |

TABLE VIII
ANNULAR ABSORBED DOSE IN PHANTOM 2

| Radio nuclide | Activity (micro curie) | Phantom 2 Annular (2040 hour) nSv/micro curie | Radio nuclide | Activity (micro curie) | Phantom 2 Annular (2040 hour) nSv/micro curie |
|---|---|---|---|---|---|
| I-131 | (3.5E-11)a | 2.22E-8 | S-35 | - | - |
| Cs-134 | (1.76E-9)a | 2.06E-6 | Kr-89 | (1.5E+2)b | 1.85E+5 |
| Cs-137 | (2E-9)a | 2.24E-5 | Xe-137 | (4.5E+2)b | 3.83E+5 |
| Xe-133 | (2.5E+3)b | 5.15E-3 | Xe-135m | (4E+3)b | 3.61E+6 |
| Xe-135 | (9E+3)b | 4.03E+6 | Xe-138 | (1.3E+4)b | 1.83E+7 |
| 85-Kr | (5E0)b | 4.41E+3 | Kr-87 | (8E+3)b | 1.16E+7 |
| Ar-41 | - | - | Kr-83m | (1.2E+3)b | 1.46E+3 |
| Rn-222 | (2E-9)* a | 3.34E-6 | Kr-88 | (8E+3)b | 1.73E+7 |
| N-16 | - | - | Kr-85m | (2.9E+3)b | 8.93E+5 |
| C-14 | - | | Xe-133m | (1E+2)b | 4.03E+4 |
| K-40 | (6.75E-7)a | 1.54E-3 | Xe-131m | (5E0)b | 1.45E+3 |

TABLE IX
THE ESTIMATED CANCER RISK IN THE RETIREMENT (A=60)

| Organ | Age= 20 | | Age= 30 | | Age=40 | |
|---|---|---|---|---|---|---|
| | Male | Female | Male | Female | Male | female |
| Stomach | 0.074 | 0.169 | 0.055 | 0.125 | 0.041 | 0.093 |
| Intestine | 0.222 | 0.152 | 0.164 | 0.112 | 0.122 | 0.083 |
| liver | 0.113 | 0.113 | 0.084 | 0.084 | 0.062 | 0.062 |
| Lung | 0.113 | 0.493 | 0.084 | 0.366 | 0.062 | 0.271 |
| Breast | * | 0.133 | * | 0.133 | * | 0.133 |
| Prostate | 0.042 | * | 0.031 | * | 0.023 | * |
| Uterus | * | 0.019 | * | 0.014 | * | 0.011 |
| Ovary | * | 0.134 | * | 0.1 | * | 0.074 |
| Bladder | 0.176 | 0.581 | 0.131 | 0.431 | 0.097 | 0.32 |
| Thyroid | 0.317 | 0.629 | 0.138 | 0.274 | 0.06 | 0.12 |

In Table X, the risk estimate for an increase in cancer resulting from 1 year of dosing, at the age of 50 and 60, at the age of 60, the person, who is known as retirement age, for the cancer of various organs of the body and sex of men and women separately Calculation is presented.

TABLE X
THE ESTIMATED CANCER RISK IN THE RETIREMENT (A=60)

| Organ | Age= 50 | | Age= 60 | |
|---|---|---|---|---|
| | | Female | Male | Female |
| Stomach | 0.03 | 0.069 | 0.022 | 0.051 |
| Intestine | 0.09 | 0.062 | 0.067 | 0.046 |
| liver | 0.046 | 0.046 | 0.034 | 0.034 |
| Lung | 0.046 | 0.201 | 0.034 | 0.149 |
| Breast | * | 0.133 | * | 0.133 |
| Prostate | 0.017 | * | 0.0127 | * |
| Uterus | * | 0.008 | * | 0.006 |
| Ovary | * | 0.054 | * | 0.04 |
| Bladder | 0.072 | 0.236 | 0.053 | 0.175 |
| Thyroid | 0.026 | 0.052 | 0.012 | 0.023 |

### 1. Risk Increasing After Ten Years

In Table XI, the cancer risk estimation in 10 years after a year working, in the date of receipt dose, for the age of 20, 30, and 40 years old, for different organs of the body and male and female sex separately, were calculated. Table XII cancer risk estimation after 1 year working, 10 years after the date of receipt of the dose, for the age of 50 and 60 years ago, for the various organs of the body and male and female sex, were separately calculated.

TABLE XI
THE CANCER RISK ESTIMATION TEN YEARS AFTER YEARLY WORKING

| Organ | E= 20 age A= 30 age | | E= 30 age A= 40 age | | E= 40 age A= 50 age | |
|---|---|---|---|---|---|---|
| | Male | Female | Male | Female | Male | female |
| Stomach | 0.195 | 0.447 | 0.097 | 0.221 | 0.052 | 0.12 |
| Intestine | 0.586 | 0.4 | 0.289 | 0.198 | 0.157 | 0.107 |
| liver | 0.298 | 0.298 | 0.147 | 0.147 | 0.08 | 0.08 |
| Lung | 0.298 | 1.302 | 0.147 | 0.643 | 0.08 | 0.35 |
| Breast | * | 0.532 | * | 0.3 | * | 0.192 |
| Prostate | 0.112 | * | 0.06 | * | 0.03 | * |
| Uterus | * | 0.051 | * | 0.025 | * | 0.014 |
| Ovary | * | 0.353 | * | 0.175 | * | 0.095 |
| Bladder | 0.465 | 1.535 | 0.23 | 0.758 | 0.125 | 0.412 |
| Thyroid | 0.317 | 0.629 | 0.138 | 0.274 | 0.06 | 0.12 |

TABLE XII
THE CANCER RISK ESTIMATION TEN YEARS AFTER YEARLY WORKING

| **Organ** | **E= 50 age A= 60 age** | | **E= 60 age A= 70 age** | |
|---|---|---|---|---|
| | Male | Female | Male | Female |
| **Stomach** | 0.03 | 0.069 | 0.018 | 0.041 |
| **Intestine** | 0.09 | 0.062 | 0.054 | 0.037 |
| **liver** | 0.046 | 0.046 | 0.028 | 0.028 |
| **Lung** | 0.046 | 0.201 | 0.028 | 0.12 |
| **Breast** | * | 0.133 | * | 0.1 |
| **Prostate** | 0.017 | * | 0.01 | * |
| **Uterus** | * | 0.008 | * | 0.005 |
| **Ovary** | * | 0.054 | * | 0.033 |
| **Bladder** | 0.072 | 0.236 | 0.043 | 0.142 |
| **Thyroid** | 0.026 | 0.052 | 0.012 | 0.023 |

## IV. CONCLUSION

These calculations, due to absorbed dose limitation determination with interest the cancer risk limitation for any organs can be used. The absorbed equivalent dose rate of 170 hours of works per month and also 2040 hours per year from the reactor's operation and the gases emitted from it in the phantom above the pool is equal to 21.9 mSv/month and 261 mSv/year, respectively, and at the top of the phantom, The walls of the pool are respectively equal to the values of 4.7 mSv/month and 56.4 mSv/year. As it is evident, the risk of cancer in women is higher than that of males and at younger ages. Also, the possibility of thyroid cancer for both sexes is higher than that of other organ cancers.

## REFERENCES

[1] Thompson, T. J. (1964). The Technology of Nuclear Reactor Safety, vol. 1. MIT, Cambridge, Mass.
[2] Yousefzadeh Hassanluei, T. R. (2015). The Monte Carlo Simulation of the Absorbed Equivalent Dose in Humans Modeling Due to Tehran Research Reactor and Radioactive Gases Released from It. Journal of Environmental Health Engineering, 3(1), 61-68.
[3] BEIR, V. (1990). Health effects of exposure to low levels of ionizing radiation. Washington DC: EEUU, 22-45.
[4] Gharari, R. (2018). Risk Assessment of Radiation Hazard for a Typical WWER1000: Cancer Risk Analysis during a Hypothetical Accident. ICNEET 2018: 20th International Conference on Nuclear Energy Engineering and Technology. Prague, Czechia.
[5] Raza, S. S. (2005). Atmospheric dispersion modeling for an accidental release from the Pakistan Research Reactor-1 (PARR-1). Annals of nuclear energy 32.11, 1157-1166.
[6] Anvari, L. S. (2012). Assessment of the total effective dose equivalent for accidental release from the Tehran Research Reactor. Annals of Nuclear Energy 50, 251-255.
[7] FSAR. (n.d.). In F. (Table, Emission Rates of Noble Gases (pp. Chapter: 12, 18 of 30).
[8] Estimating Cancer Risk. National Research Council. (2006). In Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII Phase 2. Washington, DC: The National Academies Press.
[9] FSAR. (n.d.). FSAR (Final Safety Analysis Report) for TRR Table. In Air borne Radionuclide Analysis Report (pp. Chapter: 3, 24 of 52).