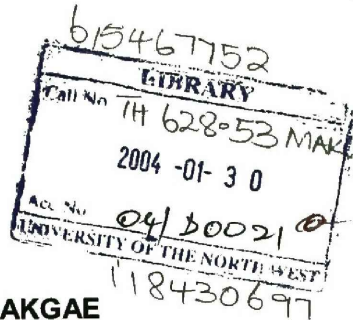


**INVESTIGATION OF THE LEVEL OF AIRBORNE
CONTAMINATION IN THE PEBBLE BED MODULAR REACTOR
(PBMR) BUILDING OR SPECIFIC ROOM DUE TO DESIGN BASE
LEAKRATE OF 0.1% OF HELIUM INVENTORY**

BY

REUBEN EPHRAIM MAKGAE



Submitted in part fulfillment of the requirement for the degree of

MASTER OF SCIENCE

In the subject

Applied Radiation Science and Technology

At the

University of North-West

October 2003

Supervisor: Mr. T. Vermaak

Co-supervisor: Dr J. Slabber

This desseertation is dedicated to my Family

Declaration of Authenticity

I, the undersigned Reuben Ephraim Makgae, hereby declare that the work presented in this dissertation is my own work except where otherwise indicated.



Reuben Ephraim Makgae

October, 2003

Abstract

The fission products release into reactor core and primary circuit lead to airborne contamination as a result of helium that leaks from the system into the room. The airborne activity was calculated by deriving and solving a differential equation considering room ventilation and a twin room ventilation to check the effects of ventilation system or migration of airborne activity to the other rooms. The HVAC system was optimized by considering and comparing the activity calculated for the three HVAC system models (i.e. recirculation with and without filter and no recirculation of air or once through model) and by increasing the air change rate.

The activity calculated for each nuclide was used to calculate the annual dose received by a worker spending 2000 working hours per year in the room. It was found that the dose received for the three HVAC models differs. The recirculation of air without filter was the most contributing in terms of dose followed by recirculation of air with filter model then no recirculation model was the least because there is no activity recirculated back into the room.

The filters used for recirculation of air with filter model are radioactively contaminated, but the calculated filter activity was found to be low and can be disposed as low level waste or can be continuously used with an efficiency test regularly performed on the filters.

Acknowledgements

The successful completion of this work is attributed to the following people, whose tireless efforts are highly appreciated;

- The God almighty, who guided and gave me strength, power, wisdom and understanding throughout my study.
- Mr. Tinus Vermaak the Auxilliary system-engineering manager who offered me an opportunity pursue the study and providing the necessary guidance.
- Dr Johan Slabber and Dr Gert de Beer who despite their tight schedule were always there to provide necessary supervision and guidance that led to ultimate completion of this work.
- Reactor and engineering group in general for their useful discussions and all other scientists who made this project a success.
- Mr. Thabang Makubire and Mr. Jeff Victor for all the courage and efforts they took in the whole program.
- University of North West (UNW) for initiating such an opportunity and the Pebble Bed Modular Reactor (PBMR) sponsor.
- My family, which was always there to support me through the incredible circumstances during all my years of studies.

TABLE OF CONTENTS

Abstract	ii
Acknowledgements	v
List Of Tables	viii
List Of Figures	x
LIST OF GRAPHS	xi
Definition of terms	xii
1. GENERAL INTRODUCTION	1
1.1 Description of Pebble Bed Modular Reactor	1
1.1.1 Main Power Systems (MPS)	1
1.1.1.1 Power conversion unit (PCU)	2
1.2 Research Overview	3
1.3 Aim	3
1.4 Objectives	3
1.5 Justification	4
1.6 Dissertation layout	4
2. THEORETICAL BACKGROUND	6
2.1 Fuel Elements	6
2.2 Source term general overview	7
2.2.1 Fission product release	8
2.2.2 Release rates of noble gases and halogens	9
2.2.3 Production and emission of tritium	9
2.2.4 Production and emission of carbon-14	11
2.3 Airborne contamination	12
2.4 Heating Ventilation and Air Conditioning (HVAC) System	13
2.4.1 Building zone segregation	13
2.4.2 System optimization	16
2.5 Classification of radioactive waste (filters)	16
2.5.1 Exemption criteria	17
2.5.2 Exemption levels	18
3. METHODOLOGY	19
3.1 Introduction	19
3.2 Radioactive Decay and Growth	19
3.2.1 Decay equation	20
3.2.2 Half-life	21
3.2.3 Radioactive equilibrium	21

3.3	Single room model of ventilation.....	24
3.3.1	Overview of the calculation model.....	26
3.3.2	The filtration of recirculated air model.....	27
3.3.3	No recirculation of air model.....	28
3.4	Recirculation of air without filter model	29
3.5	Contamination of the other rooms due to HVAC	30
3.5.1	Room A	32
3.5.2	Room B	32
3.6	Activity Calculation Procedure	33
3.7	Dose Calculations	34
3.7.1	Internal dose.....	34
3.7.2	Halogens	35
3.7.3	Noble gases.....	35
3.7.4	Tritium	35
3.7.5	Carbon-14	35
3.7.6	External exposure.....	36
3.7.6.1	Submersion in contaminated air.....	36
3.8	Calculation of Activity on the Filters	37
4.	RESULTS	38
4.1	Introduction	38
4.2	Activity filtered.....	55
5.	Interpretation of the results and discussion	56
5.1	Dose during maintenance.....	57
6.	Conclusion	58
6.1	Recommendations for the future.....	58
7.	References.....	60
8.	Appendix.....	62
8.1	Results for Single Room Airborne Activity and Annual Dose	68
8.2	Results for Twin Room Airborne Activity and Annual Dose	86
8.2.1	Room A	86
8.2.2	Room B	94

List Of Tables

Chapter 2

TABLE 2-1: PBMR ZONING SCHEME	15
TABLE 2-2: EXEMPT ACTIVITY CONCENTRATIONS AND EXEMPT ACTIVITIES OF RADIONUCLIDES	18

Chapter 4

TABLE 4-1: EXPECTED ACTIVITY.....	55
TABLE 4-2: DESIGN ACTIVITY	55

Chapter 8 (Appendix)

TABLE A- 1: INPUT DATA.....	65
TABLE A- 2: ACTIVITY ACHIEVED FOR RECIRCULATION OF AIR WITH FILTER MODEL AT THE EXPECTED LEAKRATE OF 0.0015% PER DAY.....	68
TABLE A- 3: DOSE RECEIVED FOR RECIRCULATION OF AIR WITH FILTER MODEL AT THE EXPECTED LEAKRATE OF 0.0015% PER DAY.....	70
TABLE A- 4: ACTIVITY ACHIEVED FOR RECIRCULATION OF AIR WITH FILTER MODEL AT THE DESIGN LEAKRATE OF 0.1% PER DAY.....	72
TABLE A- 5: DOSE ACHIEVED FOR RECIRCULATION OF AIR WITH FILTER MODEL AT THE DESIGN LEAKRATE OF 0.1% PER DAY.....	74
TABLE A- 6: (HALOGENS): THE ACTIVITY ACHIEVED FOR RECIRCULATION OF AIR WITHOUT FILTER MODEL AT THE EXPECTED LEAKRATE OF 0.0015% PER DAY.....	76
TABLE A- 7: (HALOGENS): THE DOSE RECEIVED FOR RECIRCULATION OF AIR WITHOUT FILTER MODEL AT THE EXPECTED LEAKRATE OF 0.0015% PER DAY	76
TABLE A- 8: (HALOGENS): THE ACTIVITY ACHIEVED FOR RECIRCULATION OF AIR WITHOUT FILTER MODEL AT THE DESIGN LEAKRATE OF 0.1% PER DAY.....	77
TABLE A- 9: (HALOGENS): THE DOSE RECEIVED FOR RECIRCULATION OF AIR WITHOUT FILTER MODEL AT THE DESIGN LEAKRATE OF 0.1% PER DAY	77
TABLE A- 10: THE ACTIVITY ACHIEVED FOR NO RECIRCULATION OF AIR (ONCE THROUGH) MODEL AT THE EXPECTED LEAKRATE OF 0.0015% PER DAY	78
TABLE A- 11: THE DOSE RECEIVED FOR NO RECIRCULATION OF AIR (ONCE THROUGH) MODEL AT THE EXPECTED LEAKRATE OF 0.0015% PER DAY.....	80
TABLE A- 12: THE ACTIVITY ACHIEVED FOR NO RECIRCULATION OF AIR (ONCE THROUGH) MODEL AT THE DESIGN LEAKRATE OF 0.1% PER DAY	82
TABLE A- 13: THE DOSE RECEIVED FOR NO RECIRCULATION OF AIR (ONCE THROUGH) MODEL AT THE EXPECTED LEAKRATE OF 0.1% PER DAY	84
TABLE A- 14: THE ACTIVITY ACHIEVED FOR RECIRCULATION OF AIR WITH FILTER MODEL AT THE EXPECTED LEAKRATE OF 0.0015% PER DAY (ROOM A).....	86
TABLE A- 15: THE DOSE RECEIVED FOR RECIRCULATION OF AIR WITH FILTER MODEL AT THE EXPECTED LEAKRATE OF 0.0015% PER DAY (ROOM A)	88
TABLE A- 16: THE ACTIVITY ACHIEVED FOR RECIRCULATION OF AIR WITH FILTER MODEL AT THE DESIGN LEAKRATE OF 0.1% PER DAY (ROOM A).....	90
TABLE A- 17: DOSE ACHIEVED FOR RECIRCULATION OF AIR WITH FILTER MODEL AT THE DESIGN LEAKRATE OF 0.1% PER DAY.....	92

TABLE A- 18: THE ACTIVITY ACHIEVED FOR RECIRCULATION OF AIR WITH FILTER MODEL AT THE EXPECTED LEAKRATE OF 0.0015% PER DAY (ROOM B).....	94
TABLE A- 19: DOSE RECEIVED FOR RECIRCULATION OF AIR WITH FILTER MODEL AT THE EXPECTED LEAKRATE OF 0.0015% PER DAY (ROOM B).....	96
TABLE A- 20: ACTIVITY ACHIEVED FOR RECIRCULATION OF AIR WITH FILTER MODEL AT THE DESIGN LEAKRATE OF 0.1% PER DAY (ROOM B).....	98
TABLE A- 21: DOSE ACHIEVED FOR RECIRCULATION OF AIR WITH FILTER MODEL AT THE DESIGN LEAKRATE OF 0.1% PER DAY (ROOM B).....	100

List Of Figures

Chapter 1

FIGURE 1-1: BRAYTON CYCLE (HELIUM FLOW)	2
---	---

Chapter 2

FIGURE 2-1: PBMR FUEL SPHERE	7
------------------------------------	---

Chapter 3

FIGURE 3-1: TRANSIENT EQUILIBRIUM	22
FIGURE 3-2 SECULAR EQUILIBRIUM	23
FIGURE 3-3: NO EQUILIBRIUM	24
FIGURE 3-4: SINGLE ROOM VENTILATION MODEL	24
FIGURE 3-5: TWIN ROOM VENTILATION MODEL	30

LIST OF GRAPHS

Chapter 4

Graph 4-1: Dose Contributed by Isotopes of different Nuclides for Recirculation of Air with Filter Model at the expected leakrate of 0.0015% per day	39
Graph 4-2: Dose Contributed by isotopes of different nuclides for recirculation of air with filter model at the design leakrate of 0.1% per day.....	41
Graph 4-3: Dose contributed by isotopes of different nuclides for recirculation of air without filter model at the expected leakrate of 0.0015% per day	43
Graph 4-4: Dose contributed by isotopes of different nuclides for recirculation of air without filter model at the design leakrate of 0.1% per day.....	45
Graph 4-5: Dose contributed by isotopes of different nuclides for no recirculation of air model at the expected leakrate of 0.0015% per day	47
Graph 4-6: Dose contributed by isotopes of different nuclides for no recirculation of air model at the design leakrate of 0.1% per day.....	49
Graph 4-7: Comparison of the three HVAC models	51
Graph 4-8: Dose due to migration of airborne activity from room A and room B due to HVAC system	54

Definition of terms

ALARA	As Low As Reasonably Achievable
AVR	Arbeitsgemeinschaft versuchsreaktor (jointly-operated prototype reactor)
CIS	Control and instrumentation system
HEPA	High efficient particulate air filter
HPC	High pressure compressor
HPT	High pressure turbine
HVAC	Heating, Ventilation and Air Conditioning system
IAEA	International Atomic Energy Agency
ICRP	International Commission for Radiological Protection
LEU-TRISO	Low Enriched Uranium-Triple coated particle
LPC	Low pressure compressor
LPT	Low pressure turbine
MPS	Main Power System
NNR	National Nuclear Regulator
PBMR	Pebble Bed Modular Reactor
PCU	Power conversion unit
PPSB	Power Plant Services Building
PT	Power Turbine
RU	Reactor Unit
THTR	Thorium High Temperature Reactor

1. GENERAL INTRODUCTION

1.1 Description of Pebble Bed Modular Reactor

The proposed PBMR will be the first kind in South Africa exploiting the advantage of circulating fuel reactors. It is designed to be both environmentally sustainable and economically viable. PBMR is a gas cooled, graphite-moderated high temperature reactor, which uses TRISO coated particles with low enriched uranium.

The PBMR fuel element is a graphite sphere containing approximately 14000 TRISO coated fissile particles. Fuel elements consist of ceramic materials that are suitable for operation at very high temperatures enhancing the potential for achieving higher thermal efficiency. The reactor uses helium gas as a coolant because it has high thermal conductivity, high specific heat and it is also chemically inert.

1.1.1 Main Power Systems (MPS)

According to [8] the MPS is divided into two major subsystems PCU, and a RU. The main function of MPS is to convert the nuclear energy into electricity. This is done in two processes:

- The transfer of nuclear energy in the form of heat to helium gas in the RU
- The conversion of the resultant thermal energy into electricity in the PCU

1.1.1.1 Power conversion unit (PCU)

PCU is based on the thermodynamic Brayton (gas turbine) cycle. During normal operation of the reactor, the thermal fission creates a heat and neutron source in the core.

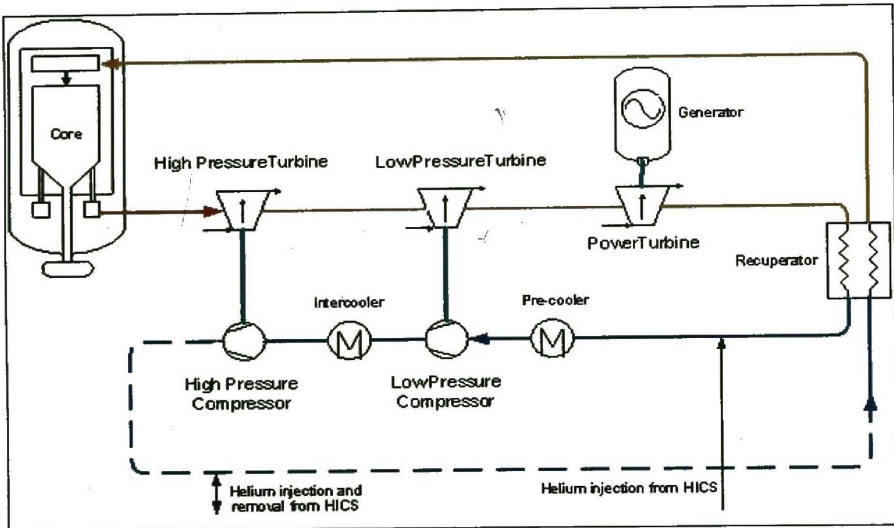


Figure 1-1: Brayton cycle (helium flow)

Refer to **Figure 1-1**; Helium enters the reactor at the temperature of approximately 500°C (932°F) and at the pressure of approximately 70 bar and move downwards between the hot fuel spheres. It picks up heat from the fuel spheres, which have been heated by nuclear fission reaction. Helium leaves the reactor at the temperature of approximately 900°C (1652°F) [8]. Helium then moves through the HPT, which drives the HPC, and then through the LPT, which drives the LPC. Helium moves through the PT, which drives the generator. At this point helium is still at high temperature.

It flows through the primary side of the recuperator, where it cooled to low temperature. Helium that is passed through the primary side of the recuperator is been cooled by means of a pre cooler, which increases the density of the helium

gas and improves the efficiency of the LPC. The LPC then compresses the helium, where after it is cooled in the inter cooler. This process also increases the density and improves the efficiency of the HPC. The cold high-pressured helium passes through the recuperator where it is pre-heated before returning to the reactor.

1.2 Research Overview

The PBMR plant concept is to design a modular reactor, in which no physical process can cause a radiation hazard outside the site boundary. Central to this safety objective is the fuel, which is designed to limit the release of radioactive fission products up to very high temperatures. Each nuclear power plant must have its offside activity release limits as proposed by the nuclear regulator, to ensure the safety to the environment. That is the nuclear power plant safety is determined by its design to limit the offside releases in accordance with the nuclear regulator limits.

Every facility that is handling the radioactive material is faced with the problem of its release to the environments either during normal operation or due to an unforeseen incidence. The environmental aspects relate to the workers and public. The workers inside the plant are involved in different radiation duties and are more likely to be exposed to ionizing radiation due airborne contamination and other radioactive materials. The chief potential hazard and associated environmental impact relates the radiological nature of the release.

1.3 Aim

The main aim is to determine the levels of airborne contamination for the various concepts of the heating, ventilation and air conditioning (HVAC) system.

1.4 Objectives

- To determine the effect of airborne radioactivity to the working personnel due to 0.1% leakrate of helium inventory.
- To determine the activity build-up on the filter for HVAC model of recirculation of air with filter

1.5 Justification

The significance of measuring the level of radioactivity will help to reduce the high potential exposure to the personnel, which can lead to deterministic effect. The ventilation system, where substances are handled that can give rise to airborne contamination must be designed and operated to protect the working personnel in the building. Essentially, this means that HVAC model that can be used for assessment of personnel exposure must lead to the reduction of the level of airborne contamination to ALARA.

According to [5], in order to ensure the reduction of the activity, the ventilation system must ensure that, the system does not spread airborne contamination throughout the building by taking into consideration the building zone segregation. The HVAC system recirculates the air through the filters that are used to filter the radioactive iodine. Therefore these filters can be treated as low, intermediate or high level waste. During recirculation of air a certain percentage of air is ventilated to the outside environment by exhaust air system.

The obtained results shall be used as an input data for the detailed design requirement for optimization and selection of the PBMR module HVAC model.

1.6 Dissertation layout

Chapter 1: In this chapter the main objective(s) of this projects are discussed together with the brief overview of PBMR, which entail the helium flow in all components of the reactor.

Chapter 2: Deals with detailed theoretical overviews of different components of the project. Also fuel failure, which results in the release of fission products, is discussed in which it is trying to explain basically where the course of airborne contamination originates. Finally the different HVAC models are discussed for optimization of the system to reduce airborne contamination.

Chapter 3: Deals with the assembly and description of the calculation methodology. The detailed development of activity equations considering

different HVAC models, for activity calculation in a given room. All the assumptions for the model development were made.

Chapter 4: Presents the calculated airborne activity and its corresponding annual doses.

Chapter 5: Deals with the interpretation of the obtained results from using the derived activity equation and it also presents the conclusion drawn from the outcomes and recommendations for the future work

Chapter 6: Conclusion

Chapter 7: References

Chapter 8: Appendix

2. THEORETICAL BACKGROUND

2.1 Fuel Elements

According to [8] the PBMR core is designed around the (LEU)-TRISO fuel elements developed for HTR in German from 1969 to 1988. The reactor consists of TRISO coated particles embedded in fuel spheres, which consist of ceramic materials that are suitable for very high operating temperatures, hence enhancing the potential for achieving higher thermal efficiency, refer to (Figure 2-1).

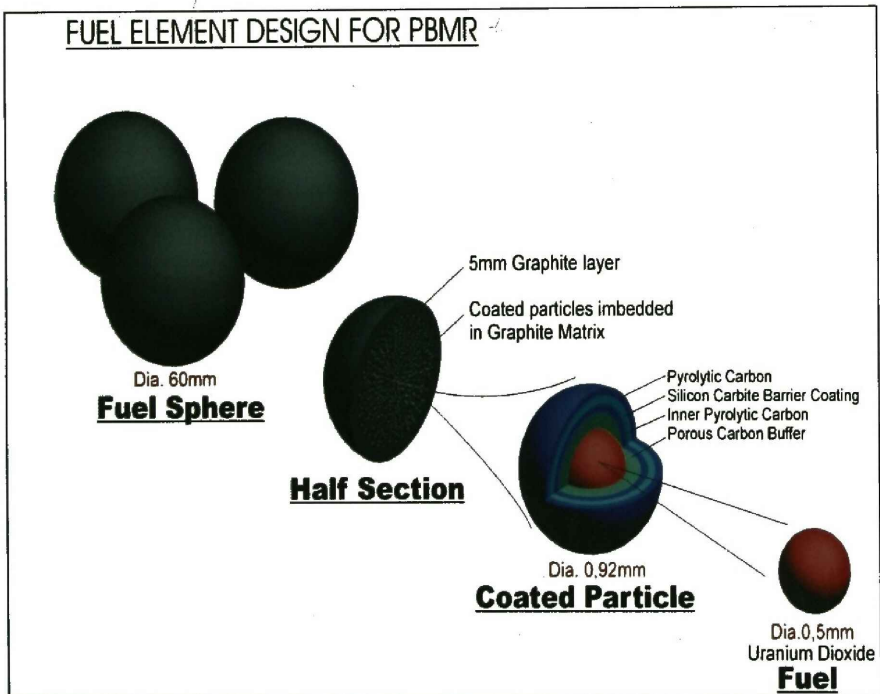


Figure 2-1: PBMR Fuel Sphere

Each fuel particle or kernel consists of low enriched uranium and of four layers or coatings surrounding it. Proceeding outwards of the kernel is the buffer layer, the inner pyrocarbon layer, the silicon carbide layer and the outer pyrocarbon layer.

The two high-density layers of pyrolytic carbon (which is a very dense form of heat-treated carbon) followed by silicon carbide which is a strong refractory material in between allows fission products to collect without over pressurizing the coated fuel particle. The buffer layer provides a void for gaseous fission products in order to limit the pressure build-up within the coated particle

The pyrolytic carbon and silicon carbide layer provide an impenetrable barrier containing the fuel and radioactive fission products that results from nuclear reaction. The use of coated particles among the most important factors is determining the radiological safety during the operation of the reactor. Thus, the fission product retention in the fuel elements, as well as the maximum fuel temperature that can be tolerated in the reactor core will be determined by the coated particles of the fuel [11].

2.2 Source term general overview

Fission products release behavior under normal operation condition is of significant interest in safety analysis. According to [7] for the purpose of identifying radiation fields in the PBMR, the following nuclear systems can be considered together as the main radiation sources:

- Reactor and power conversion unit
- Fuel handling equipments
- Primary coolant conveying systems
- Water carrying systems

The sources of all other radiation fields originate from the reactor. They are products of either the nuclear fission in the fuel or of activation in the radiation field of the reactor. Radiation fields outside the reactor are primarily caused by:

- Fission products in the fuel elements and as contaminants in the primary coolant.
- Activation products in the structural material around the reactor core

Most of the fission products is retained in the fuel elements, which form main radiation source in the fuel handling equipments.

2.2.1 Fission product release

The decision of a problem radiation safety to a certain degree is connected with the knowledge of fission product behavior in the reactor and nuclear power plant as a whole and first of all, in the nuclear fuel and the fuel elements which are first and main barrier of the fission product retention. According to [12] the key to achieving good fuel performance is the choice of right materials:

- High-density oxidic kernel
- Low-density buffer layer derived from ethyne
- TRISO coating, i.e. the sequence pyrocarbon, silicon carbide, pyrocarbon
- Low temperature isotropic pyrocarbon derived from propene
- High density SiC of near theoretical density derived from methyltrichlorosilane

Another essential is producible manufacturing processes of which emphasis on achieving spherical kernel and spherical particles with very low defects fractions. In modern HTGR fuel, the level of defective coated particles is practically zero. It is only during pressing of fuel bodies that particle defects do occur, but on a very low level. The main source of fission product escaping the fuel under normal operation conditions is from uranium outside of an intact SiC layer (graphite matrix contamination) which appears as heavy metal contamination in the fuel matrix or defective, failed fuel particles caused by manufacture and irradiation induced defects [12].

It is estimated that the failure fraction of fuel elements is 3×10^{-5} and the conservative design value is double the expected value, which is 6×10^{-5} [7].

There are several mechanisms, which can cause a particle to fail:

- Kernel migration
- Interaction of fission products with the SiC layers
- Failure of the coating as a pressure vessel
- Excessive diffusion through the kernel coating layers

The retention mechanisms for radioactivity are particle coatings, graphite, primary coolant pressure boundary and reactor building. Graphite has a high capacity for retaining some fission products (i.e. Sr, Rb, Cs, and rare earths) but is transparent to others, which are the noble gases (i.e. Kr and Xe). During reactor operation fission reaction takes place in the fuel spheres and fission products are released into reactor core and are entrained in the coolant gas and circulated around the MPS [23].

2.2.2 Release rates of noble gases and halogens

The measured average uncontained uranium fraction of 3×10^{-5} was chosen as the expected value of the failed particles in the calculation performed by NOBLE code to calculate a steady state release of noble gases (krypton and xenon) and halogens (bromine and iodine) from PBMR core [7]. The two sources of noble gases and halogens are the uranium contamination of the matrix material and failed coated particles.

The steady state fractional release from these sites due to diffusion processes, followed by the pressure and temperature-dependent gas phase transport through the porosity of the fuel sphere to the coolant is modeled in the program [7]. All German experimental findings confirmed that the transport behavior of halogens at elevated temperatures is similar to that of the noble gases.

2.2.3 Production and emission of tritium

According to [19] the expected production and release of tritium in the PBMR core are determined on the basis of best estimates of the relevant input parameters such as the interaction with the HPS (without cryogenic unit) and the

leakage of the MPS. Balancing all tritium sources and sinks, the emission rates to the environment during the whole PBMR lifetime are predicted. Most tritium of the PBMR is within the fuel by ternary fission. However, intact TRISO retain tritium practically 100%, so that this source is of minor importance for the overall balance.

From [7] the most effective tritium sources in the MPS are the neutron activation reactions with the He-3 contents of the coolant gas, and with the lithium contamination of the fuel and graphite spheres. During the initial operation phase, the lithium contamination of the reflector also contributes significantly to the total tritium production. This contribution is to a large extent compensated by the sorption capacity of the graphite reflector.

Due to its relatively long radioactive half-life (12.3 years) and its high mobility, tritium produced by the lithium contamination will be released more or less quantitatively from the sphere during their residence time in the core. Therefore, on average, the lithium production rate in the spheres equals its core release rate. The same holds true for the production rate of the He-3 induced tritium.

Lithium, He-3 and the following sinks determine the tritium balance in the MPS:

- Gas leakage from the MPS
- Extraction by the helium purification system
- Sorption in graphite
- Radioactive decay

The tritium emission to the environment during normal operation follows two pathways

- Leakage from the MPS in the form of CH_3T and HT
- Regeneration losses of the HPS in the form of gaseous HTO

2.2.4 Production and emission of carbon-14

From [18] the following summary gives the nuclear reactions and the release rates of carbon-14

In principle, the following C-14 sources take place in any HTR

- N-14 (n,p) C-14 in the coolant gas and in the fuel spheres
- O-17 (n, α) C-14 in the UO₂ kernels of the fuel spheres
- C-13 (n, γ) C-14 in the spheres and reflectors

Due to the low isotopic abundance of O-17 (0.04%) and the high retention capability of TRISO coated particles (tritium release fraction $<10^{-5}$), the O-17 (n,p) C-14 reaction can be neglected. Equally the C-13 (n, γ) C-14 reaction does not contribute to the C-14 core release, because of its extremely low neutron cross-section (3×10^{-4}) and low corrosive weight loss of the fuel spheres ($<0.02\%$). The only remaining reaction N-14 (n,p) C-14 takes place in the fuel spheres and in the coolant gas.

The C-14 release from the fuel spheres is controlled by selective corrosion of C-14, which was being produced by being absorbed in the matrix material. The C-14 production rate caused by N-14 in the coolant is identical with its release rate. The C-14 emission rates to the environment during the PBMR lifetime of 36 years are predicted of all C-14 sources and sinks in the MPS. The C-14 balance in the MPS is determined by the following sources:

- Neutron absorption of N-14 in the coolant gas
- Neutron absorption of N-14 in the fuel spheres following by selective corrosion

And the sinks are

- Molecular sieves of the HPS followed by stack discharge during generation cycle
- Leakage from the MPS

2.3 Airborne contamination

According to [7] the expected leakrate of helium from the MPS under conditions of normal operation is 0.0015% per day, however the limiting design leakrate during normal operation has been set to be 0.1% of helium inventory per day. The four main types of airborne contamination that can occur are gases, particulates, tritium, and radioiodine. The noble fission product gases and highly volatile fission products form the bases of the primary coolant activity.

The MPS activity is uniformly distributed within the entire helium inventory, therefore during 0.1% leakrate, helium carries the proportional amount of activity. The main activity-carrying components of helium purification system are dust removal filters, the molecular sieves, and the helium storage tank. They are all housed in the reactor building [7]. The prime importance of the released noble gases (key nuclide: Kr 88) and halogens (key nuclide: I 131) is the environmental radiological impact under the conditions of normal reactor operation, leakage of the primary circuit and loss of coolant accidents [20].

When a leak occurs in the primary boundary, it is only gas borne activity in the primary coolant and a portion of primary system that may be released into the reactor building. For the short-lived fission gases, the dominant removal mechanism is by radioactive decay and the condensable fission products the dominant removal mechanism deposited or plate-out on various helium wetted surface in the primary circulation.

The potential of airborne contamination exists in any of the rooms inside the controlled zone, where there is pipe work and components carrying primary coolant under pressure, waste processing activities and decontamination activities [7]. To reduce personnel exposure resulting from normal operational leak from the MPS, the module HVAC consists of independent systems, which service rooms according to the potential for airborne activities.

2.4 Heating Ventilation and Air Conditioning (HVAC) System

According to [1] the installed ventilation system maintains a negative pressure in the building with respect to the outside atmosphere. This ensures that any leakages that may occur are inwards, with no release to the outside of the building. The extracted air is ventilated via a HEPA filter bank, to the atmosphere. The operational buildings are to be fully contained, with thick reinforced concrete shell, including the roof and the floor, no windows and steel vault doors.

The doors to the outside of the buildings are specially sealed or protected by an outer wooden door for pressure control. As there are no openings directly to the outside environment from the process halls, no effluents, liquid or gases can be released to the outside.

The design features which should be emphasized in respect of radiological protection are the segregation of the building zones on the basis for the potential for airborne contamination, ensuring when required, that air flow from zone of lower contamination potential to zone of higher contamination potential, and provision for optimization studies to ensure that the ventilation system conforms to the ALARA requirements.

2.4.1 Building zone segregation

According to [5] the cross-section contamination of the building areas or contamination from higher to lower contaminated rooms can be limited by physically segregating the building zones from each other and by maintaining different static pressure inside the zones so that air will naturally flow from the zone with high static pressure to the zone with low static pressure.

The arrangement of the components of the module building and HVAC system ensures that the air flows from rooms with low airborne activity levels into rooms of higher airborne activity levels. This limits any spread of radioactive materials in the building during power generating operation. This will be maintained by high air extraction rate than supply air ventilation rate, and by segregating the zones with relatively airtight wall construction and airtight access doors between zones.

The identified static pressure control zones do not correspond to the radiation zones (red, green, and white), they have been selected on the following criteria; the lowest static pressure (pressure zone 3) consist of the rooms with the highest potential for airborne contamination due to system leaks. These are the rooms with the high-energy coolant piping or MPS subsystems. The second static pressure zone (pressure zone 2) consist of rooms with potential for airborne contamination, other than pressure zone 3 which consist of high energy system.

And the above atmospheric pressure static zone, consist of rooms with no potential for airborne contamination and correspond to the uncontrolled radiation zone or white zone. The ventilation systems in the module building are physically separated for each radiation zone, uncontrolled white zone and controlled zones (red and green) [5].

The zones to be served by active ventilation are those for which the potential for airborne contamination exist at the presence of high-energy pipework (carrying contaminated primary coolant under pressure), the performance of waste processing activities and performance of decontamination activities [7]. The air change rate provided for the active ventilation system will be required to be larger than that of the non-active system, due to the requirement for the removal of airborne contamination. Refer to **Table 2-1** for the zoning categories of PBMR.

Table 2-1: PBMR zoning scheme

PBMR Zoning Scheme-Summarized			
Zone Classification	Airborne Contamination	Surface Contamination	Ambient Radiation
Uncontrolled area	No airborne contamination allowed in this area	- Alpha limit 0.04Bq/cm² or 1E-6uCi/cm² - Beta or gamma limit: 0.4uBq/cm² or 1E-5uCi/cm²	- Maximum limit: 1mSv/a at 2000 h/a 0.5 uSv/h (limit to the uncontrolled area as well as to the public)
Supervised area	No airborne contamination allowed in this area	- Same limit as for uncontrolled area - Only low potential should exist for surface contamination	- Limit: <=6mSv per annum (three tenths of annual dose limit, 20mSv) - At 2000 h/a provided upper limit of 3 uSv/h (allowing a margin of latitude, the limit of 2.5uSv/h is chosen)
Controlled area	- Airborne contamination can be due to: - Pipework with primary coolant under pressure - Waste processing activities - Decontamination activity - Limit: less than one tenth of annual exposure <2mSv-to be fixed	- Contamination levels expected per room has to be determined - Necessary design features to follow above - Expected contamination depends on systems in specific rooms - The need for system breach due to maintenance and the impact to be determined	- Limit to workers are 20mSv/a-the lowest controlled level would be calculated for 2000 hours exposure per person - Controlled area subdivided into a number of zones. The subdivision is related to access requirement and occupancy. ALARA will play a particular role in this area. - R1<=10uSv/h - R2<=50uSv/h - R3<= 500 uSv/h - R4<= 5000 uSv/h - R5>5000uSv/h

2.4.2 System optimization

From [5] the optimization will be necessary during the detailed design phase. Certain trade-off studies need to be performed to select optimum system configuration. The once-through air concept has the advantage that no contaminated air can be recirculated, and that all rooms are always provided with clean outside air. The other option will be to limit the outside air intake to save on refrigeration plant capacity and circulate the room air through cleaning filtration units.

The disadvantage of the once-through concept is that the capital and running cost resulting from the latent cooling of outside air may be higher than that recirculating system, provided that the amount of outside air in a recirculating system is less than that of a once-through system. On the other hand a recirculating system require more expensive filtration units, more ducting, more fans and air-handling plenum, more controls, more space and more maintenance. Also recirculated air will have to be continuously monitored to ensure that filter malfunctioning is picked up .

2.5 Classification of radioactive waste (filters)

Radioactive waste is generated from the production of nuclear energy and from the use of radioactive material in industrial applications, research and medicine. The radioactive waste is generated in different kinds of facilities and arises in a wide range of concentrations of radioactive materials and variety of physical and chemical forms. There is also a variety of alternatives for treatment and conditioning of the waste prior to disposal. Like wise, there are number of alternatives for safe disposal of these waste, ranging from geological disposal to the near surface disposal and direct discharge to the environment.

According [10] to simplify their management, a number of schemes have evolved for classifying radioactive waste according to the physical, chemical and radiological properties of significance to those facilities managing these waste. The importance of safe management of radioactive waste for protection of human

health and environment has long been recognized and considerable experience has been gained in this field.

The classification system has previously been proposed by IAEA, placing radioactive waste into one of the three classes:

- High-level waste (HLW), (i) is the highly radioactive liquid, containing mainly fission products, as well as some actinides, which is separated during chemical reprocessing of irradiated fuel (aqueous waste from the solvent extraction cycle and those waste streams combined with it). (ii) Any other waste with radioactive levels intense enough to generate significant quantities of heat by the radioactive decay process. (iii) Spent reactor fuel, if declared a waste.
- Intermediate level waste (ILW), this is the medium level waste which because of its radionuclide content require shielding but needs little or no provision for heat dissipation during its handling and transport.
- Low-level waste is the waste, which because of its low radionuclide content does not require shielding during normal handling and transport.

2.5.1 Exemption criteria

From [11] practices and sources within practices may be exempted from the requirements of the standards, including those for notification, registration or licensing, if the regulatory authority is satisfied that the sources meet the exemption criteria. The general principles of exemptions are that:

- The radiation risks to individuals caused by the exempted practice or source be sufficiently low as to be of no regulatory concern
- The collective radiological impact of the exempted practice or source be sufficiently low as not to warrant regulatory control under prevailing circumstances

- The exempted practices and sources be inherently safe, with no appreciable likelihood of scenarios that could lead to a failure to meet the first two criteria

Table 2-2 gives the exemptions activity for each nuclide to be practiced under normal operations of the plant.

2.5.2 Exemption Levels

Table 2-2: Exempt Activity Concentrations and Exempt Activities of Radionuclides

Nuclide	Exemption activity concentration or specific activity (Bq/g)	Exemption activity in (Bq)
I-131	1×10^2	1×10^6
I-132	1×10^1	1×10^5
I-133	1×10^1	1×10^6
I-134	1×10^1	1×10^5
I-135	1×10^1	1×10^6
Kr-85m	1×10^3	1×10^5
Kr-85	1×10^5	1×10^4
Kr-87	1×10^2	1×10^9
Kr-88	1×10^2	1×10^9
Xe-131m	1×10^4	1×10^4
Xe-133	1×10^3	1×10^4
Xe-135	1×10^3	1×10^{10}
H-3	1×10^4	1×10^7
C-14	1×10^6	1×10^9

3. METHODOLOGY

3.1 Introduction

In terms of the reduction of personnel exposure resulting from normal operational leakage from the MPS, the HVAC is divided into subsystems which services the rooms according to the potential for airborne activity. The effectiveness of exposure reduction due to the removal of airborne contamination is dictated by the number of air changes per hour provided for the room.

The purpose of this calculation is:

- To establish a simple model, that can be used for assessment of the personnel exposure from airborne contamination resulting from the leakage into rooms taking into account the effects of ventilation.
- To determine the minimum air change rate, that can be used for ventilation system of the rooms with a potential airborne contamination in order to reduce the personnel doses ALARA. This assumes a standardized normal operational source term for the MPS with the leakrate of 0.1% per of helium inventory.

3.2 Radioactive Decay and Growth

Radioactive elements or nuclides normally undergo a decay process and as they decay some new nuclides are formed, and this is what is called growth of the formed nuclide. The decay and growth are two processes, which takes places simultaneously. These nuclides decay exponentially depending on their half-lives (refer to **Table A- 1**). The decay chains are arranged in order from mother to daughter ending up with a stable isotope. Each sequence is numbered. Sequences are classified as type A, B, C and D depending on the length of the decay chain. For type A sequences the first daughter is stable. For type B sequences the first daughter is radioactive but the second daughter is stable (etc).

3.2.1 Decay equation

The activity is defined as the number of disintegrations or nuclear transformation, which occurs per unit time and the SI unit is Becquerel (Bq). The objective is to derive a mathematical relation between the number of radioactive atoms released due to the MPS leakage into room and its decay. The numbers of atoms that will decay are determined by:

- The number of atoms that are present (ΔN)
- The change in time (Δt s)
- The probability that a particular atom will decay during one second ($\lambda \text{ s}^{-1}$), which is defined as the decay constant of that nuclide.

This can be expressed mathematically as:

$$\Delta N = -\lambda N \cdot \Delta t \quad (3.1)$$

The above relation can be presented as differential equation:

$$\frac{dN}{dt} = -\lambda N \quad (3.2)$$

$$N_t = N_o e^{-\lambda t} \quad (3.3)$$

The equation 3.3 is known as the decay equation and can be used to calculate the number of active atoms at any time t .

Since the activity of atoms is proportional to their number then following equation also applies to the activity:

$$A = \frac{dN}{dt} = \lambda N \quad (3.4)$$

Therefore, activity can be expressed as:

$$A = A_o e^{-\lambda t} \quad (3.5)$$

Where A_o is the initial activity

3.2.2 Half-life

Is normally written as $t_{1/2}$ and is defined as the period required to reduce the number of atoms by half. The reduction by half principle applies to every additional half-life, after two half lives the number of the atoms is reduced to 25% of the original value and to 12.5% after three half lives. Decay constant is useful when discussing the activity. The higher the value of λ the higher the activity expected from the number of atoms that are present. The mathematical relationship between λ and $t_{1/2}$ of an atom can be obtained from equation 2.4:

Therefore:

$$t_{\frac{1}{2}} = \frac{\ln 2}{\lambda} \quad (2.6)$$

If the decay constant is known then the half-life can be obtained. These relations will help so as to derive the equation describing the activity build-up in the room due to MPS leakage.

3.2.3 Radioactive Equilibrium

Radioactive equilibrium for a decay chain occurs when the each radionuclide decays at the same rate it is produced. At equilibrium, all radionuclides decay at the same rate. Understanding the equilibrium for a given decay series, helps scientists estimate the amount of radiation that will be present at various stages of the decay.

For example, as uranium-238 begins to decay to thorium-234, the amount of thorium and its activity increase. Eventually the rate of thorium decay equals its production its concentration then remains constant. As thorium decays to proactinium-234, the concentration of proactinium-234 and its activity rise until its production and decay rates are equal. When the production and decay rates of each radionuclide in the decay chain are equal, the chain has reached radioactive equilibrium

Equilibrium occurs in many cases. However if the half-life of the decay product is much longer than that of the original radionuclide, equilibrium cannot occur. The

graphs below illustrate the progress of ingrowth, and its effect on overall activity, and the potential for radioactive equilibrium in three general cases.

- The original radionuclide and decay product half-lives are similar
- The original radionuclide has a much longer half-life
- The decay product has a longer half-life

For simplicity's sake, the illustrations assume that the decay chain is only two steps, the decay product decays to a stable nuclide. As decay chains lengthen, the calculations become more complex.

3.2.3.1 Radionuclide and Decay Product Half-Lives Are Similar

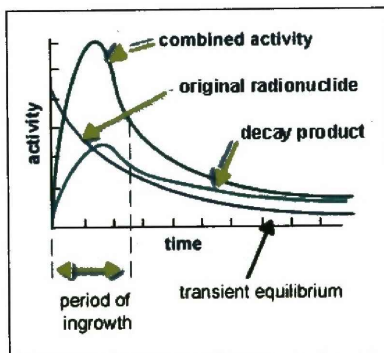


Figure 3-1: Transient Equilibrium

When the half-life of the original radionuclide is only slightly longer or about the same as the half-life of the decay product, the total activity rises initially. This results from the combined decay of both radionuclides. (It peaks slightly before the activity of the decay product does.) Eventually a balance (equilibrium) is reached. The total activity then decays at about the same rate as the original radionuclide. This is known as "transient equilibrium."

3.2.3.2 Radionuclide Has a Much Longer Half-Life

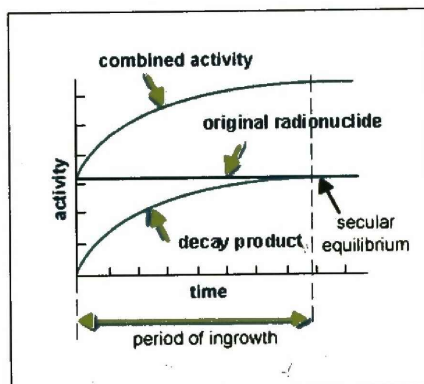


Figure 3-2 Secular Equilibrium

When the half-life of the original radionuclide is much longer than the half-life of the decay product, the decay product generates radiation more quickly. Within about seven half lives of the decay product, their activities are equal, and the amount of radiation (activity) is doubled. Beyond this point, the decay product decays at the same rate it is produced, a state called "secular equilibrium." This is illustrated in **Figure 3-2**

Most of the released fission products or source terms that are used in this project fall under this category of radioactive equilibrium.

3.2.3.3 Decay Product Has a Longer Half-Life

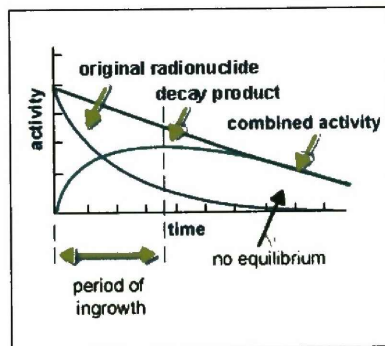


Figure 3-3: No Equilibrium

If the half-life of the decay products is much longer than that of the original radionuclide, its activity builds up to a maximum and then declines. The original radionuclide eventually decays away and no equilibrium occurs.

3.3 Single room model of ventilation

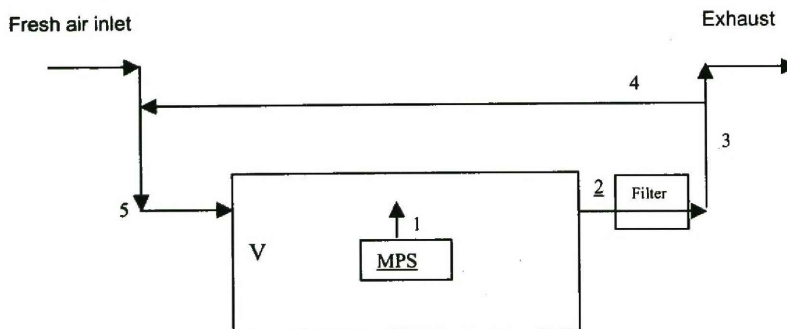


Figure 3-4: Single Room Ventilation Model

Figure 3-4 presents the ventilation flow of activity concentration. The diagram shows the recirculation of air with filter model of ventilation, for no recirculation of air model number 4 becomes zero and for recirculation without filter model the

filter decontamination factor turns to one. The numbers 1 to 5 describes change in activity concentration in the room until equilibrium and are described below.

Conditions at position(s):

1. $C_L V_L$ is the activity concentration leaking at a given leakrate with helium from MPS

Where: C_L = Activity concentration (atoms Kg^{-1})

V_L = leakrate from the MPS (kg s^{-1})

2. $\frac{N_i(t)}{V} \cdot V_V$ is the ventilation or removal rate of number of atoms of specific nuclide.

Where: $N_i(t)$ = Number of atoms of i^{th} nuclide formed at time t (atoms s^{-1})

V_V = Is a variable describing air change rate / flow rate ($\text{m}^3 \text{h}^{-1}$)

V = Volume of the room (m^3)

3. $\frac{N_i(t)}{V} \cdot V_V \cdot D_1$ Indicates the ventilation of number of atoms after filtration

Where: D_1 = Filtration value or decontamination factor of the filter (%).

4. $\frac{N_i(t)}{V} \cdot V_V \cdot D_1 \cdot BR$ Indicates the branching or recirculation of number of atoms

Where: BR = Branching factor (%)

5. $\frac{N_i(t)}{V} \cdot V_V \cdot D_1 \cdot BR + C_{OUT} \cdot V_1$ Shows the dilution of recirculated number of atoms with the concentrated air from the outside. (Note: The outside concentration is assumed to be clean therefore C_{OUT} is zero)

Where: C_{OUT} = Concentration from the outside.

V_1 = Volume of air inlet ($\text{m}^3 \text{h}^{-1}$)

HYPOTHESIS

- A system of five-coupled first order differential equation was derived from the given conditions above, which describe adequately the normal time behavior of activity build-up in the room due to helium leak.
- The arrangement also allows for the determination of the equilibrium concentration as the results of MPS leakage into the room.
- The arrangement of the system components and factors considered in the setting up of the equation(s) are shown in **Figure 3-4** and **Figure 3-5**.
- It should be noted that the components of the equation consider uniform distribution of activity concentration throughout the room.
- It has been postulated that only noble gases and halogens (specifically iodine) are considered to be the only radionuclides leaking from the MPS into the room, as the metallic fission products will plateout in different components surfaces of the primary circuit.
- The calculations are for normal operational conditions of the reactor
- The ventilation system has been presented simply as the single room system in **Figure 3-4** and a twin room system in **Figure 3-5** which describes the effect of HVAC on room B due contamination in room A or the migration of the airborne activity due to ventilation system.

3.3.1 Overview of the calculation model

The overall calculation requires finding the steady state activity concentration of each of the released and generated nuclides in the red zone area. The principal variables in the model are:

- Leakrate and composition of the primary coolant
- The decay chains for the released nuclides
- Ventilation flow circuit and filter efficiency
- Volume of various rooms

The following approach is used to find the solution:

- Set up and solve differential equations for the number of atoms released and activity for each radionuclide in the room(s)
- Calculate doses for each nuclide

Formulation

When the leak occurs in the room, the rate at which the number of radioactive atoms accumulates in the room is determined by two events:

- The rate at which number of radioactive atoms are produced into the room
- The removal rate

Therefore the change in number of atoms of radioactive nuclides in the given volume is described by differential equation:

$$\frac{dN(t)}{dt} = \text{source} - \text{removal}$$

The first term is the source of radioactivity, which is due to the leak from MPS and the activity recirculated due to recirculation of air model of HVAC system. The second term removal rate or sink of radioactivity, which is due to ventilation system and decay constant. The equation is a mass balance equation and is valid when the air is assumed to be well mixed and it accommodates the increase in air change rate.

3.3.2 The filtration of recirculated air model

The differential equation is given by:

$$\frac{dN_i}{dt} = C_{MPS} + C_{RECIR} + C_{OUT} - C_{VENT} - C_{DECAY} \quad (3.7)$$

$$\frac{dN_i(t)}{dt} = V_i C_i + \frac{N_i(t)}{V} D_i \cdot BR \cdot V_v + C_{OUT} V_i - \frac{N_i(t)}{V} \cdot V_v - \lambda_i \cdot N_i(t) \quad (2.8)$$

$$\frac{dN_i(t)}{dt} = V_i C_i + \frac{N_i(t)}{V} (D_i \cdot BR \cdot V_v) - \frac{N_i(t)}{V} \cdot V_v - \lambda_i \cdot N_i(t) \quad (2.9)$$

Parameters:

λ_i = Radiological decay constant of the i^{th} radionuclide (s^{-1})

Other parameters are explained in section 3.3

Solution:

$$N_i(t) = \frac{C_i V_i}{\frac{1}{V} [(-D_1 \cdot BR \cdot V_v) + V_v + \lambda_i \cdot V]} \left\{ 1 - e^{-\frac{t}{V} [(-D_1 \cdot BR \cdot V_v) + V_v + \lambda_i \cdot V]} \right\} \quad (2.10)$$

Refer to appendix for full derivation. From equation 2.5 the activity of radioactive atom is given by:

By substituting for N in equation 2.10 then:

$$A_i = \frac{\lambda_i C_i V_i}{\frac{1}{V} [(-D_1 \cdot BR \cdot V_v) + V_v + \lambda_i \cdot V]} \left\{ 1 - e^{-\frac{t}{V} [(-D_1 \cdot BR \cdot V_v) + V_v + \lambda_i \cdot V]} \right\} \quad (2.11)$$

This relation represents the activity build-up with time until the equilibrium is reached in the room.

When equilibrium is reached then $t = \infty$ therefore:

$$A_i = \frac{\lambda_i C_i V_i}{\frac{1}{V} [(-D_1 \cdot BR \cdot V_v) + V_v + \lambda_i \cdot V]} \quad (2.12)$$

3.3.3 No recirculation of air model

For this model the second term in equation 2.9 will turn to zero, therefore:

$$\frac{dN_i(t)}{dt} = V_i C_i - \frac{N_i(t)}{V} V_v - \lambda_i \cdot N_i(t) \quad (2.13)$$

By following the same derivation method used to derive equation 2.11, then:

$$A_i = \frac{\lambda_i C_i V_i}{\frac{1}{V}(V_v + \lambda_i V)} \left[1 - e^{-\frac{t}{V}(V_v + \lambda_i V)} \right] \quad (2.14)$$

When equilibrium is reached then $t = \infty$ therefore:

$$A_i = \frac{\lambda_i C_i V_i}{\frac{1}{V}(V_v + \lambda_i V)} \quad (2.15)$$

3.4 Recirculation of air without filter model

The activity equation for this model is derived from equation 2.8 where D for decontamination factor of the has the efficiency of one, then

$$\frac{dN_i(t)}{dt} = V_i C_i + \frac{N_i(t)}{V} (-BR V_v) - \frac{N_i(t)}{V} V_v - \lambda_i V \quad (2.16)$$

By following the same method to derive equation 2.8, then equation for determining activity for this model is given by:

$$A_i = \frac{\lambda_i C_i V_i}{\frac{1}{V} [(-BR V_v) + V_v + \lambda_i V]} \left\{ 1 - e^{-\frac{t}{V} [(-BR V_v) + V_v + \lambda_i V]} \right\} \quad (2.17)$$

At equilibrium where $t = \infty$, then

$$A_i = \frac{\lambda_i C_i V_i}{\frac{1}{V} [(-BR V_v) + V_v + \lambda_i V]} \quad (2.18)$$

3.5 Contamination of the other rooms due to HVAC

The equilibrium value of activity concentration following the leakage from the MPS into room A is described according to **Figure 3-5**.

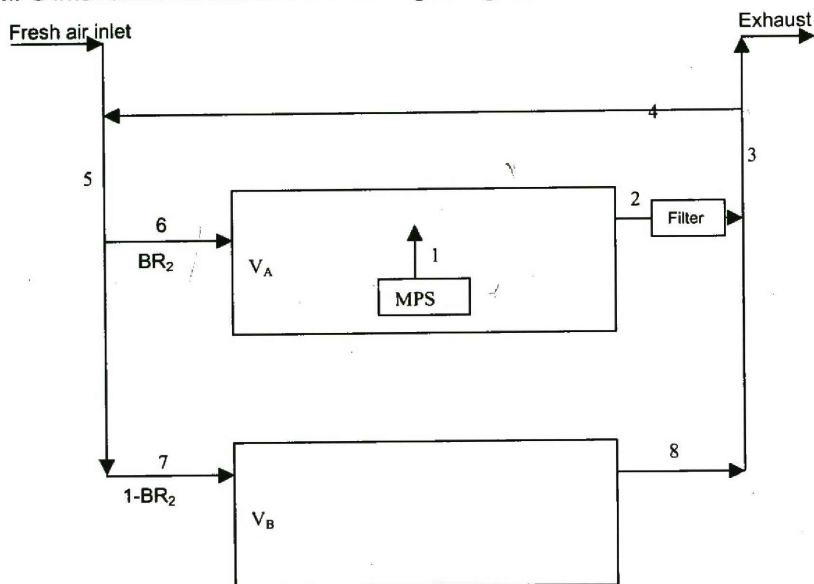


Figure 3-5: Twin Room Ventilation Model

The ventilation has been represented as a twin room system. The representation caters for what is described as the reactor room (room A) and a simple typical room (room B). The model describes the effects of HVAC system on room B due to the leak in room A. The arrangement allows for determination of the equilibrium activity concentration in room A as a results of MPS leakage into the room and determination of activity concentration in room B due to the effect of HVAC as a results of the contamination in room A. The diagram caters for the recirculation without filter and recirculation of air with filter models of ventilation. The number(s) 1 to 8 describes the equilibrium activity concentration considering ventilation system and is described below.

Conditions:

1. $C_i V_i$ Is the activity concentration leaking with helium gas from MPS
2. $\frac{N_{iA}}{V_A} \cdot V_v \cdot BR_2$ Indicates the ventilation or removal rate of radioactive atoms of specific nuclide from room A

Where: BR_2 = Fraction of air ventilated into room A

3. $\frac{N_{iA}}{V_A} \cdot V_v \cdot D_1 \cdot BR_2 + \frac{N_{iB}}{V_B} \cdot V_v \cdot (1 - BR_2)$ Indicates the addition of number of radioactive atoms from room A and room B

Where: $(1 - BR_2)$ = Fraction of air into room B

4. $\frac{N_{iA}}{V_A} \cdot V_v \cdot D_1 \cdot BR + \frac{N_{iB}}{V_B} \cdot V_v \cdot BR$ Indicates the fraction of recirculated number of atoms due to branching ratio BR

5. $\frac{N_{iA}}{V_A} \cdot V_v \cdot D_1 \cdot BR + \frac{N_{iB}}{V_B} \cdot V_v \cdot BR + C_{OUT} V_{OUT}$ Indicates the dilution of recirculated number of atoms with concentrated air from the outside

6. $\frac{N_{iA}}{V_A} \cdot V_v \cdot D_1 \cdot BR \cdot BR_2 + \frac{N_{iB}}{V_B} \cdot V_v \cdot BR \cdot BR_2$ The fraction of recirculated number of atoms from both rooms is ventilated into room A

7. $\frac{N_{iA}}{V_A} \cdot V_v \cdot D_1 \cdot BR \cdot (1 - BR_2) + \frac{N_{iB}}{V_B} \cdot V_v \cdot BR \cdot (1 - BR_2)$ The fraction of recirculated number of atoms from both rooms is ventilated into room B

8. $\frac{N_{iB}}{V_B} \cdot V_v \cdot (1 - BR_2)$ Indicates the ventilation of radioactive atoms of specific nuclide from room B

The development of equations for this models are addressed as:

$$\frac{dN(t)}{dt} = \text{source} - \text{removal}$$

3.5.1 Room A

The differential equation to calculate the number of atoms accumulating room A is given by:

$$\frac{dN_{IA}(t)}{dt} = C_I V_I + \frac{N_{IA}(t)}{V_A} V_V D_1 BR BR_2 + \frac{N_{IB}(t)}{V_B} V_V BR BR_2 - \frac{N_{IA}(t)}{V_A} V_V BR_2 - \lambda N_{IA}(t)$$

Equation (2.19)

Let:

$$X = V_V BR BR_2$$

$$Y = V_V BR_2$$

Solution:

$$A = \frac{\lambda C_I V_I [-M + N + \lambda V_B] V}{[-X(-M + N + \lambda V_B) - XM + Y(-M + N + \lambda V_B) + \lambda V_A (-M + N + \lambda V_B)]} \quad (2.20)$$

3.5.2 Room B

The differential equation to calculate the number of atoms accumulating room B is given by:

$$\frac{dN_{IB}(t)}{dt} = \frac{N_{IA}(t)}{V_A} V_V D_1 BR (1 - BR_2) + \frac{N_{IB}(t)}{V_B} V_V BR (1 - BR_2) - \frac{N_{IB}(t)}{V_B} V_V (1 - BR_2) - \lambda N_{IB}(t)$$

Equation (2.21)

Let:

$$M = V_V BR (1 - BR_2)$$

$$N = V_V (1 - BR_2)$$

Solution:

$$A = \frac{\lambda C_I V_I M [-M + N + \lambda V_B] V_B}{[-X(-M + N + \lambda V_B) - XM + Y(-M + N + \lambda V_B) + \lambda V_A (-M + N + \lambda V_B)] [-M + N + \lambda V_B]}$$

Equation (2.22)

Where:

N_{IA} and N_{IB} are the number of radioactive atoms in room A and room B respectively.

BR_2 = branching ratio into room A

$1-BR_2$ = branching ratio into room B

3.6 Activity Calculation Procedure

The calculations were performed using activity equation(s) 2.18 and 2.20, following the activity build up of each isotope with time until equilibrium for both no recirculation of model and filtration of recirculated air.

Assumption made

- The 268MW was used as a reference power
- Mass of helium at 268 MW is 6.87×10^3 Kg
- Volumes of the rooms were assumed to be equal and are 5000 m^3 each.
- The air change used was 1.8 air changes per hour

For iodine

- Assume 90% is trapped on the surface and the walls of the room and only 10% will be ventilated through filters.
- Assume 90% efficiency of the filter.

Therefore the effective decontamination factor of the filter is:

$$= \text{Activity}_{(in)} - \text{Activity}_{(out)} / \text{Activity}_{(in)}$$

$$= 1 - \text{Activity}_{(out)} / \text{Activity}_{(in)}$$

$$= 100 - 10 / 100$$

$$=0.9$$

Decontamination Factor (%) = 90%

For noble gases the effective decontamination factor = 0.09

For noble gases

The effective decontamination factor = 1

This is where activity before filter = activity after filter

3.7 Dose Calculations

The maximum permissible occupational dose of ionizing radiation to the gonads, blood-forming organs, total body, head and trunk, and lenses of the eyes is based on the amount assumed to cause only negligible injury if accumulated over a working period. The maximum permissible doses apply to internal exposure as to external or the combination of the two [15].

Internal exposures are considered separately because of greater uncertainty involved in the setting of minimum safety standards. Whether the material enters the body through a wound, through inhalation or ingestion by mouth, it establishes a source of radiation, the victim cannot escape except by surgery or elimination by decay or natural process. Some radionuclides remain in the body for years or for life.

3.7.1 Internal dose

To determine the internal exposure in this case, only the intake of radionuclides through inhalation is considered, ingestion is not considered because it is not expected any ingestion of food stuff in the area where there is a potential for radioactivity which are red and green areas.

To determine dose due to inhalation equation(s) 3.1 and 3.2 are used

$$\text{Specific activity} = \frac{A}{V} \quad (3.23)$$

The resultant committed dose rate is calculated as:

$$D = A_s \cdot B \cdot f \quad (3.24)$$

A_s = area airborne activity (Bq/m³)

B = breathing rate = 1.2 (m³/h)

F = dose conversion factor (Sv/Bq) for inhalation

3.7.2 Halogens

For the steady state halogen source terms, the expected and the design values are taken from [7]. For dose conversion factors taken from [11], the absorption class is taken to be "fast". Information on the dose conversion factors for I-136 was not available; therefore it was taken to be zero.

3.7.3 Noble gases

For the noble gases, inhalation is not usually the determinant in quantifying the radiological hazard on human tissue. Therefore the dose conversion factors for noble gases are taken as zero for inhalation.

3.7.4 Tritium

According to [14] tritium is a soft pure beta emitting radionuclide, which has no potential for harm from external exposure. Therefore it is necessary to only consider the inhalation pathway as relevant. The form of tritium assumed for the analysis of dose to workers is as HT since active effort is made to exclude water and oxygen from the MPS. The inhalation dose conversion factor for molecular HT is taken from [11].

3.7.5 Carbon-14

Carbon-14 is also a soft pure beta emitting radionuclide with no harm from external exposure. Therefore, it is necessary only to consider the inhalation pathway as relevant. The concentration of gaseous phase carbon in the MPS as 12 ppm CO and 50 ppm CH₄ is given in [18]. The dose conversion factor for carbon will depend upon the chemical form of carbon and the target age group. For CO, the inhalation dose conversion factor is given as 8×10^{-13} SvBq⁻¹ for the

workers [14]. For CH_4 is assumed to be no uptake into blood and therefore no inhalation dose conversion factor for carbon in this form [11].

Assuming carbon-14 is partitioned between the carbon existing as CO and CH_4 according to relative abundance, and then 19% is associated with CO and 81% of the total carbon is associated with CH_4 . Therefore, only a fraction of the total carbon-14 is available to give a dose to the operator. Therefore, in the calculation of the operator dose, the activity concentration of carbon-14 is modified by factor 0.19 and the dose conversion factor applicable to be inhaled by the workers is then $8.0 \times 10^{-13} \text{ SvBq}^{-1}$ [14].

3.7.6 External exposure

3.7.6.1 Submersion in contaminated air

According to [20] for an exposed individual standing at the boundary of semi-infinite, uniformly contaminated atmospheric cloud, it is assumed that the electron range in the air is less than the average height of the body, which is taken to be 1m. Therefore, the source region is assumed to be effectively infinite in extent, and electron dose coefficient at the depth of interest into tissue ($70 \mu\text{m}$) is given in terms of the geometrical reduction factor G_{skin} for immersion in contaminated air

$$h_{\text{skin}}(E) = \frac{E}{\rho_a} \frac{R^a}{\alpha} q(x, E) G_{\text{skin}}(E) \quad (3.25)$$

Where ρ_a is the density of air, R^a/α is the ratio of energy absorption in tissue to that in air at the emitted energy E . The energy-absorption rate R^a/α consists of two factors. The first factor is the ratio of mass stopping powers in tissue and air

$$R^a = \left(\frac{1}{\rho} \frac{dE}{dx} \right)_t \left(\frac{1}{\rho} \frac{dE}{dx} \right)_a \quad (3.26)$$

which is evaluated at the emitted energy E . The second factor α , also depend on the emitted energy and accounts for the variations in stopping powers in

tissue and air over the continuous energy spectrum of electrons incident on the body for a monoenergetic source of energy E in an infinite, uniformly-contaminated atmospheric cloud.

In order to determine what the relative contributions to operator dose would be, due to external exposure, the dose conversion factors for noble gases, halogens, tritium and carbon-14 are taken from [17], which are applicable for irradiation assuming the uniform distribution of airborne activity in the 5000m³ room.

3.8 Calculation of Activity on the Filters

Calculation of the activity trapped on the filter considering the filter efficiency is given by:

$$A_i = C_i \cdot V_f \cdot \frac{(1 - e^{-\lambda_i t})}{\lambda_i} \cdot D_i \quad (3.27)$$

Where:

A_i = Is the activity on the filters (Bq)

C_i = Is activity concentration (Bq/m³)

V_f = Is the flow rate (m³/h)

λ_i = Is the decay constant of specific nuclide

D_i = Is the decontamination factor of the filters

If the service life of filters is assumed to be one year then after maintenance the filters may be stored to decay for certain period if the potential activity is high. The equation to calculate the activity decay during storage time is given by:

$$A_i = \left[C_i \cdot V_f \cdot \frac{(1 - e^{-\lambda_i t})}{\lambda_i} \cdot D_i \right] \cdot e^{-\lambda_i t_2} \quad (3.28)$$

Where: $e^{-\lambda_i t_2}$ = Is the decay factor of specific nuclide

t_2 = Is the decay time

4. RESULTS

4.1 Introduction

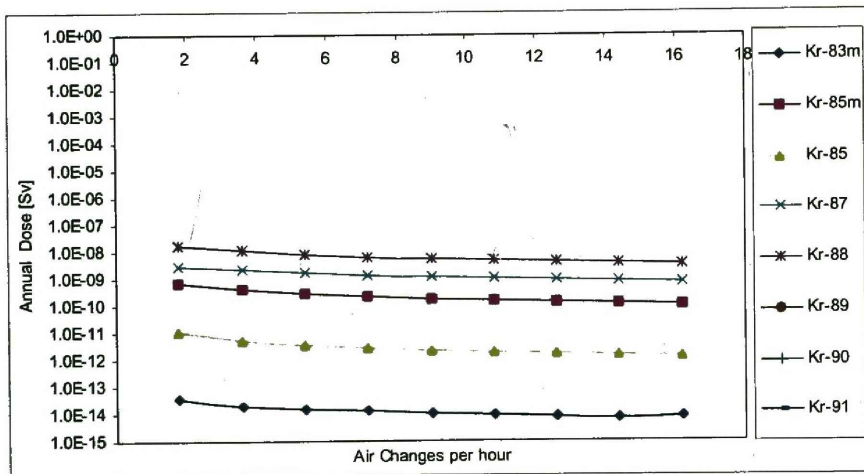
The scope of the radionuclides taken into consideration is taken from [7], [11], [17]. The data on radiological decay constants is taken from [7]. In all cases both a design and the expected MPS activity is calculated. However, it is the design source term, which will be used for the establishment of the air change rate of the HVAC system. Additionally the leakrate from the MPS is important in establishing the equilibrium values of activity of each radionuclide. In this case, the expected leakrate is established at a value of $0.0015\% \text{ day}^{-1}$ and the design leakrate at $0.1\% \text{ day}^{-1}$ of MPS inventory.

As a result of leak from the MPS, the immediate atmosphere will become contaminated with airborne (suspended and gaseous) radioactive material. This can be a consequence in terms of external and/or internal exposure from inhalation, depending upon the individual radiological attributes of the nuclide.

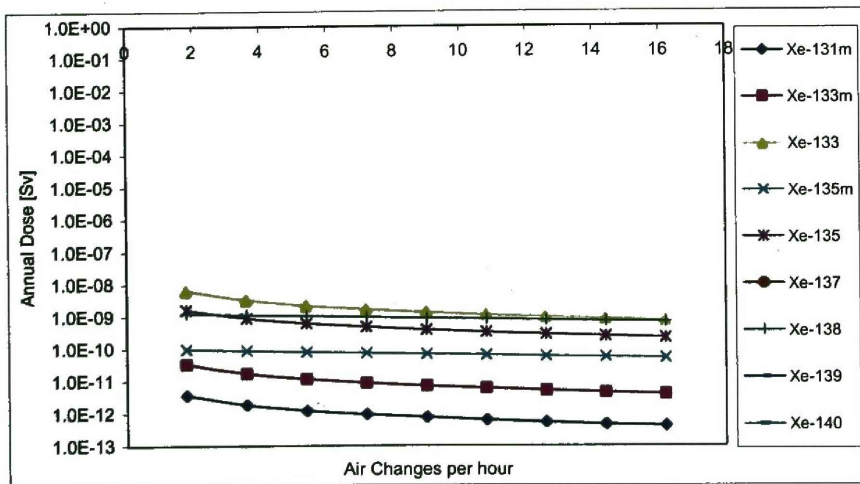
Table(s) A-2 to A-21 presents the annual dose due to calculated airborne activity for the design leakrate of 0.1% per day and the expected leakrate of 0.0015% per day and they are presented by the graphs in these chapter. This table(s) also presents the doses for the three models of ventilation, and each model with increase change in air change rate for reduction of personnel exposure.

Graph 4-1: Dose Contributed by Isotopes of different Nuclides for Recirculation of Air with Filter Model at the expected leakrate of 0.0015% per day

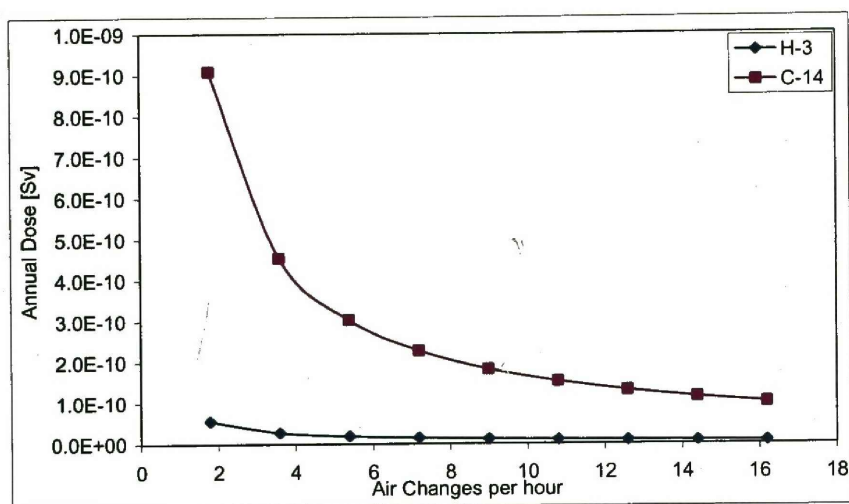
Graph 4-1 (a): Krypton dose with increase in air changes per hour



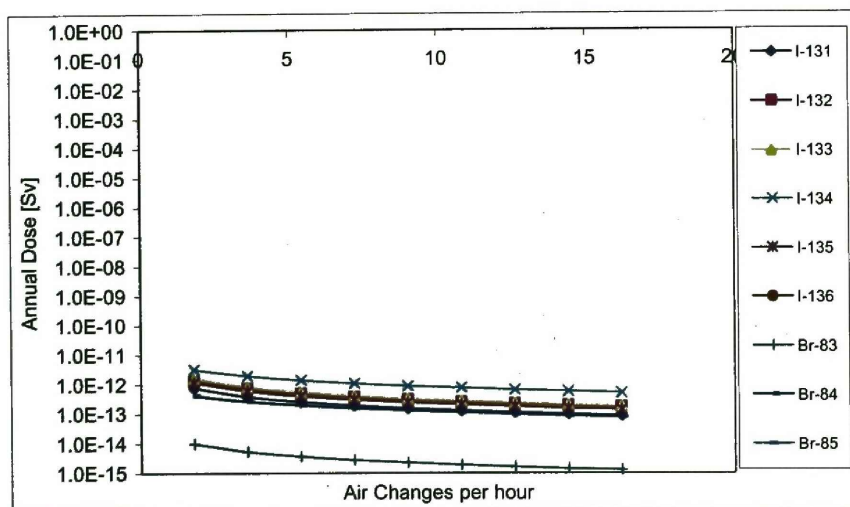
Graph 4-1 (b): Xenon dose with increase in air changes per hour



Graph 4-1 (c): C-14 and H-3 dose with increase in air changes per hour

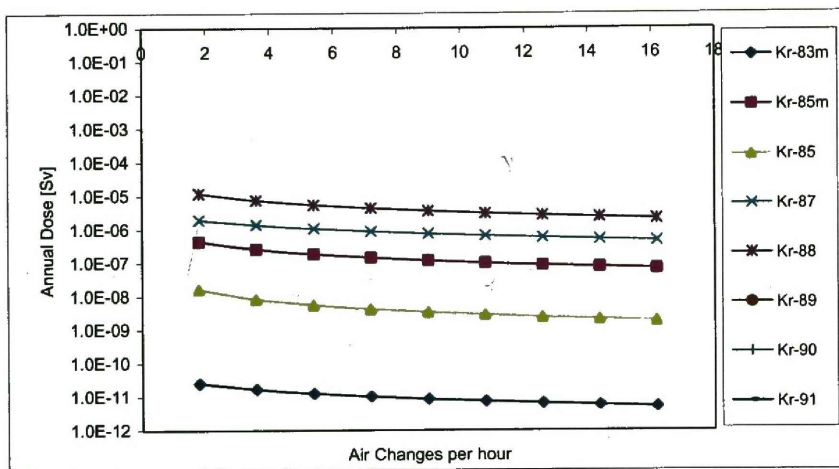


Graph 4-1 (d): Halogens dose with increase in air changes per hour

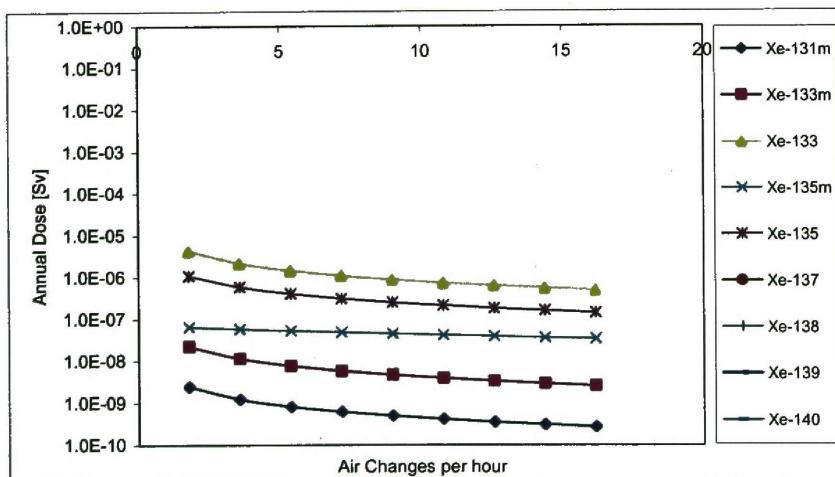


Graph 4-2: Dose Contributed by isotopes of different nuclides for recirculation of air with filter model at the design leakrate of 0.1% per day

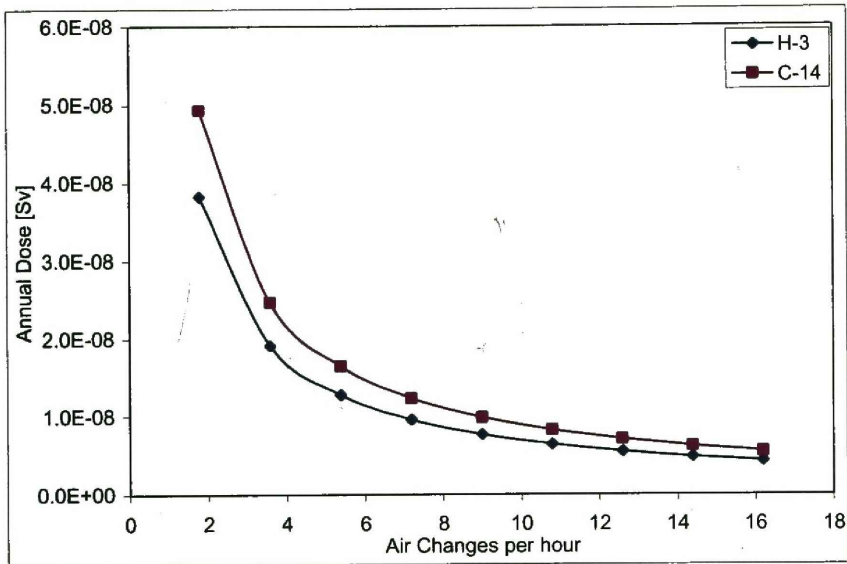
Graph 4-2 (a): Krypton dose with the air changes per hour



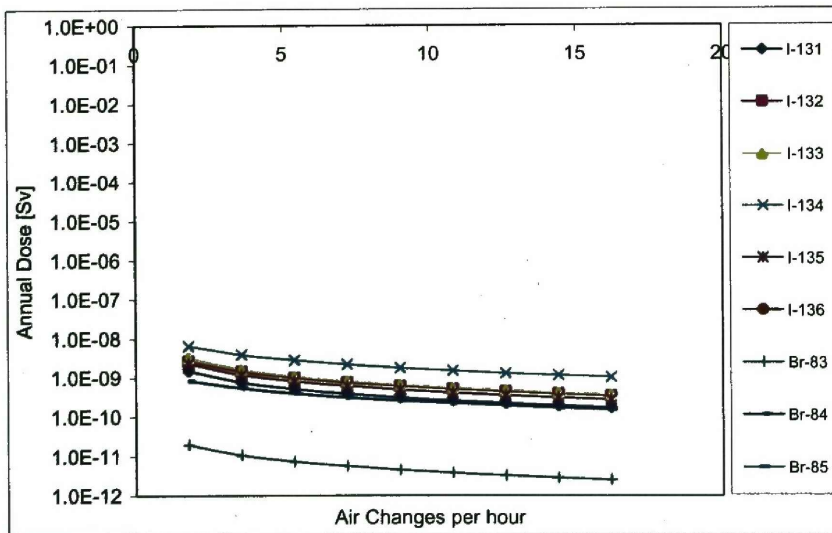
Graph 4-2 (b): Xenon dose with air changes per hour



Graph 4-2 (c): C-14 and H-3 dose with increase in air changes per hour

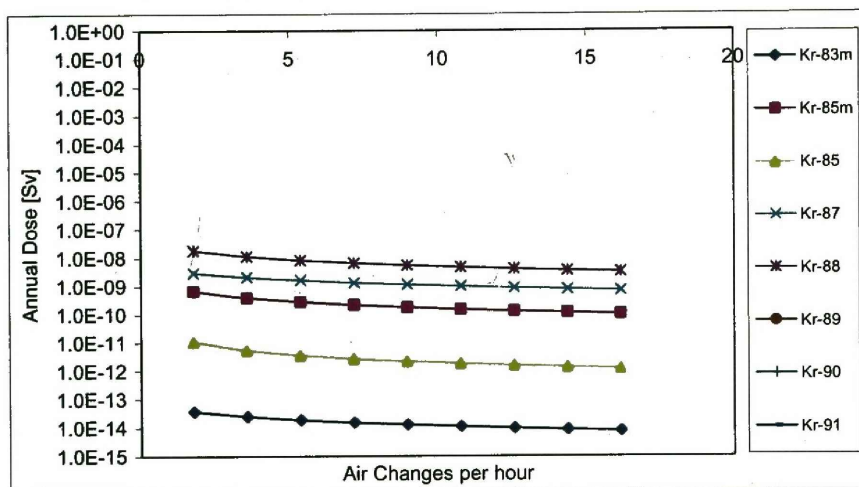


Graph 4-2 (d): Halogens dose with increase in air changes per hour

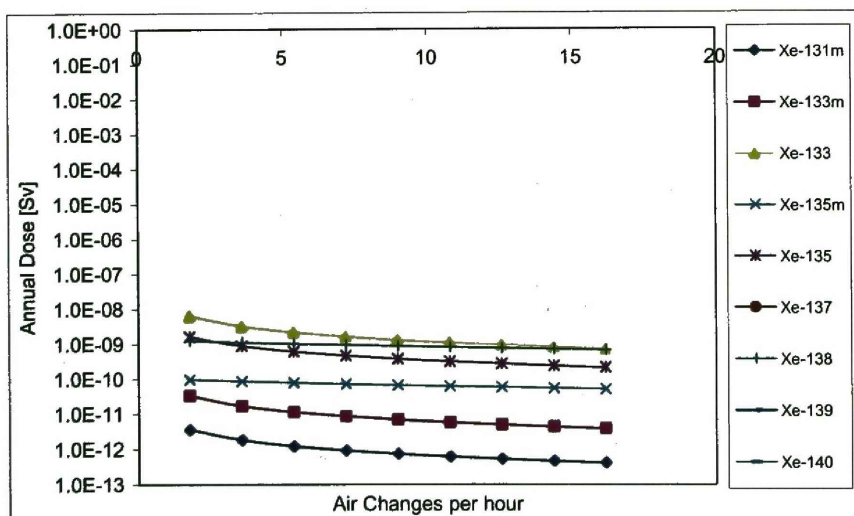


Graph 4-3: Dose contributed by isotopes of different nuclides for recirculation of air without filter model at the expected leakrate of 0.0015% per day

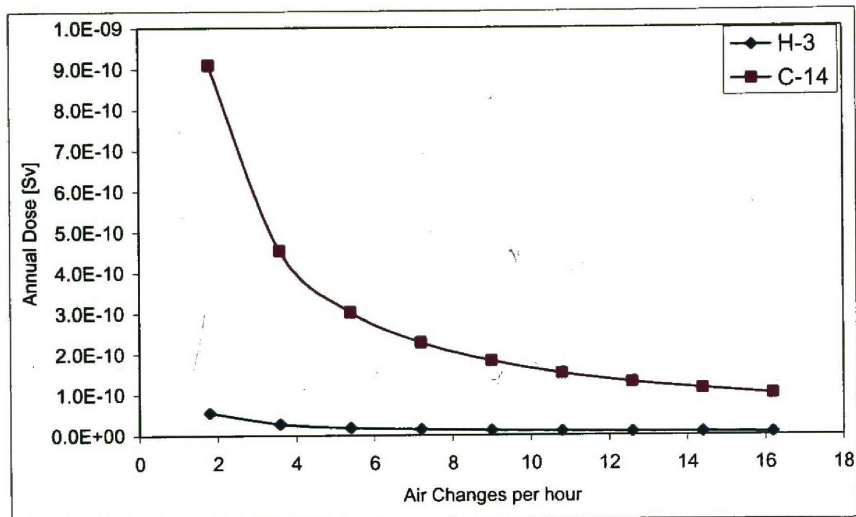
Graph 4-3 (a): Krypton dose with the air changes per hour



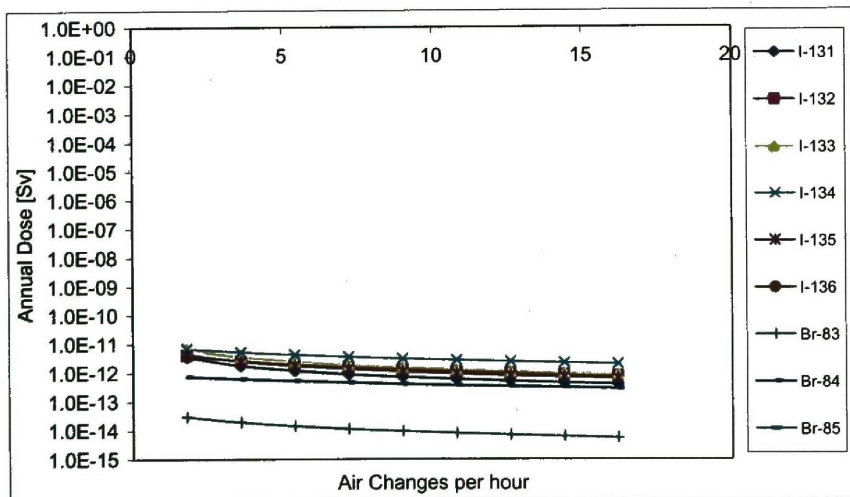
Graph 4-3 (b): Xenon dose with air changes per hour



Graph 4-3 (c): C-14 and H-3 dose with increase in air changes per hour

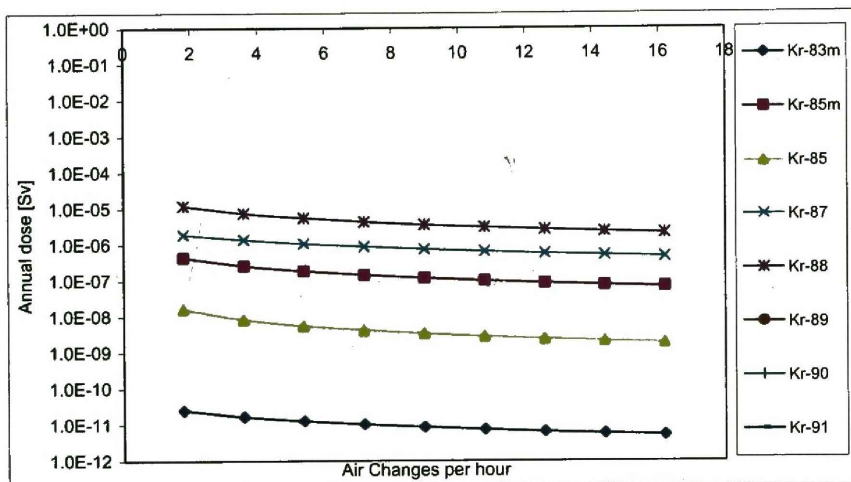


Graph 4-3 (d): Halogens dose with increase in air changes per hour

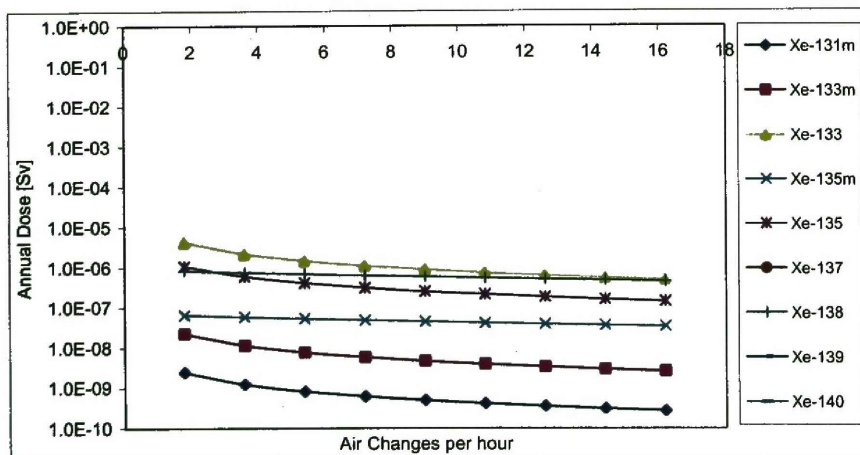


Graph 4-4: Dose contributed by isotopes of different nuclides for recirculation of air without filter model at the design leakrate of 0.1% per day

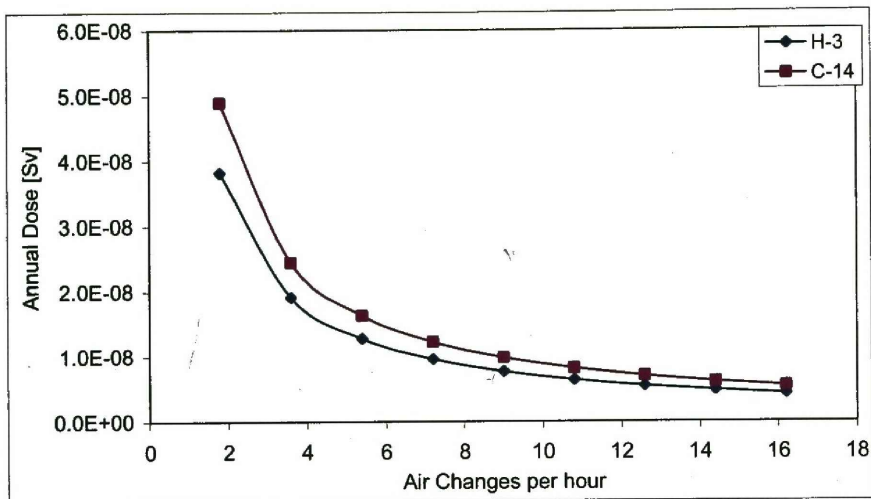
Graph 4-4 (a): Krypton dose with the air changes per hour



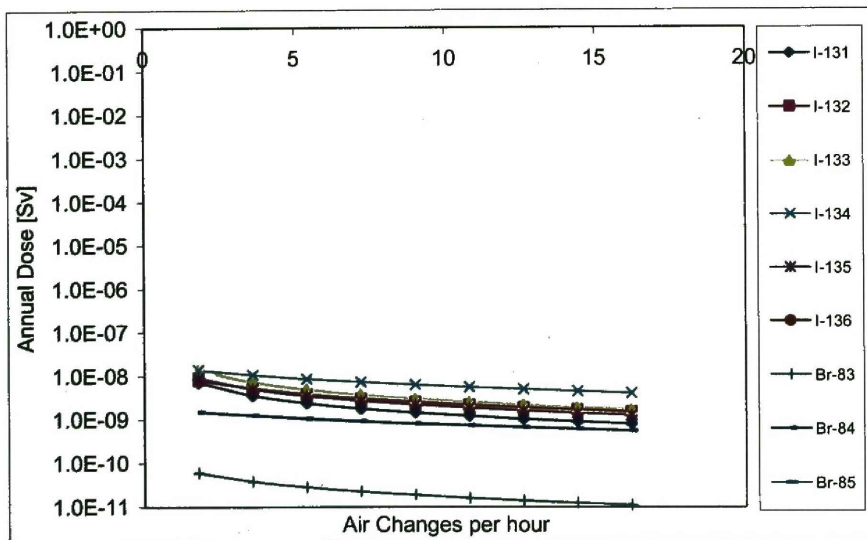
Graph 4-4 (b): Xenon dose with air changes per hour



Graph 4-4 (c): C-14 and H-3 dose with increase in air changes per hour

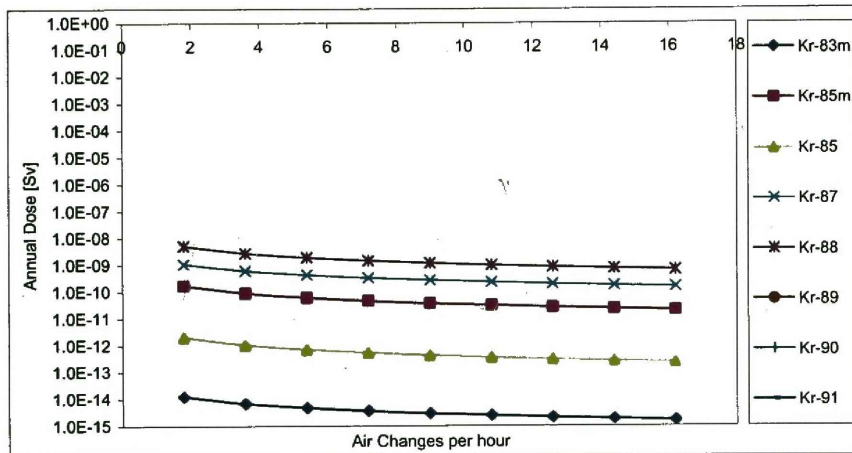


Graph 4-4 (d): Halogens dose with increase in air changes per hour

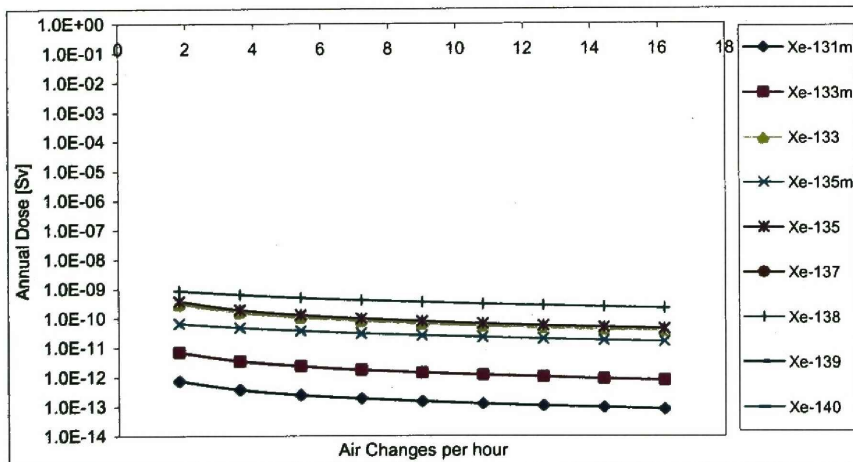


Graph 4-5: Dose contributed by isotopes of different nuclides for no recirculation of air model at the expected leakrate of 0.0015% per day

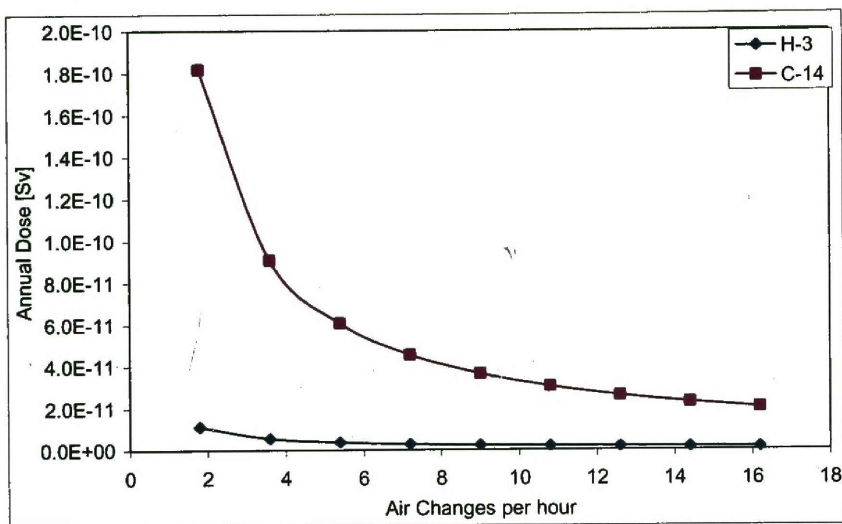
Graph 4-5 (a): Krypton dose with the air changes per hour



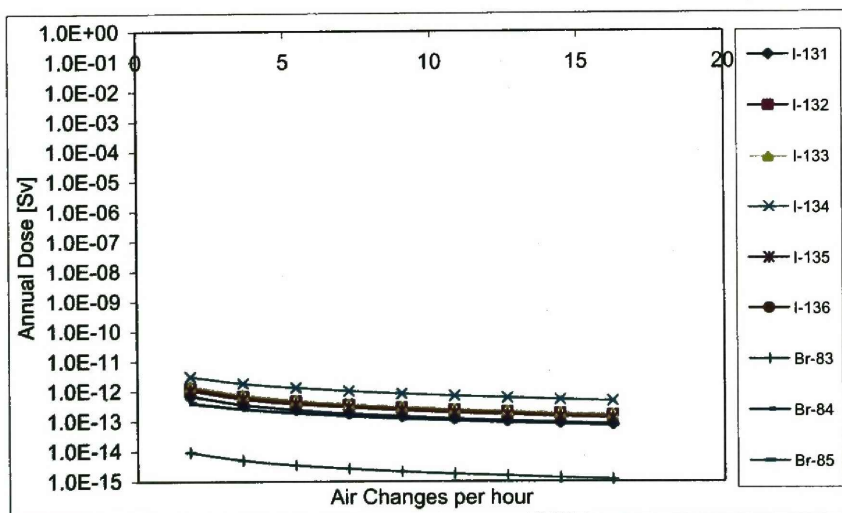
Graph 4-5 (b): Xenon dose with air changes per hour



Graph 4-5 (c): C-14 and H-3 dose with increase in air changes per hour

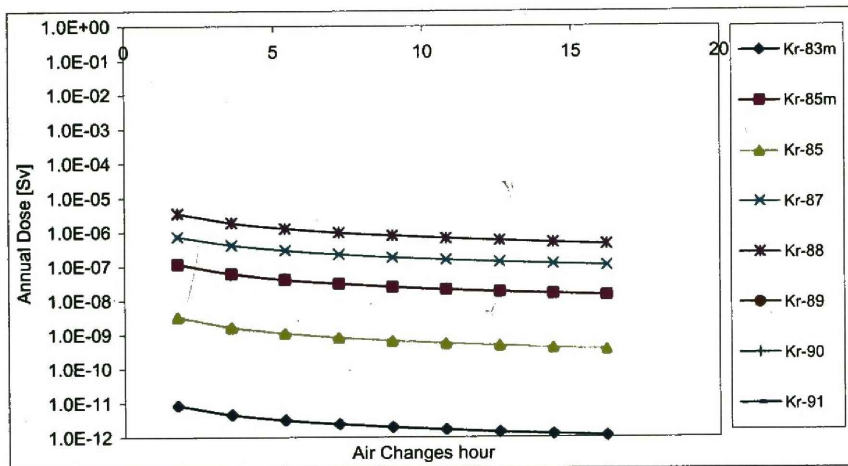


Graph 4-5 (d): Halogens dose with increase in air changes per hour

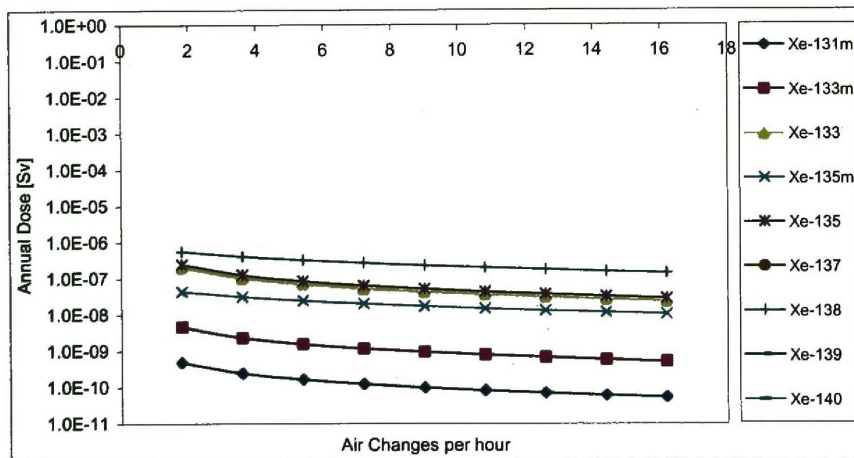


Graph 4-6: Dose contributed by isotopes of different nuclides for no recirculation of air model at the design leakrate of 0.1% per day

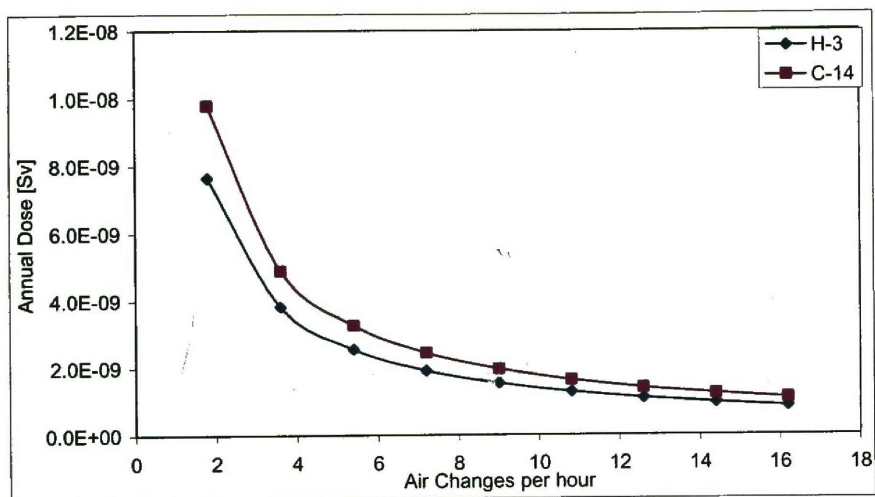
Graph 4-6 (a): Krypton dose with the air changes per hour



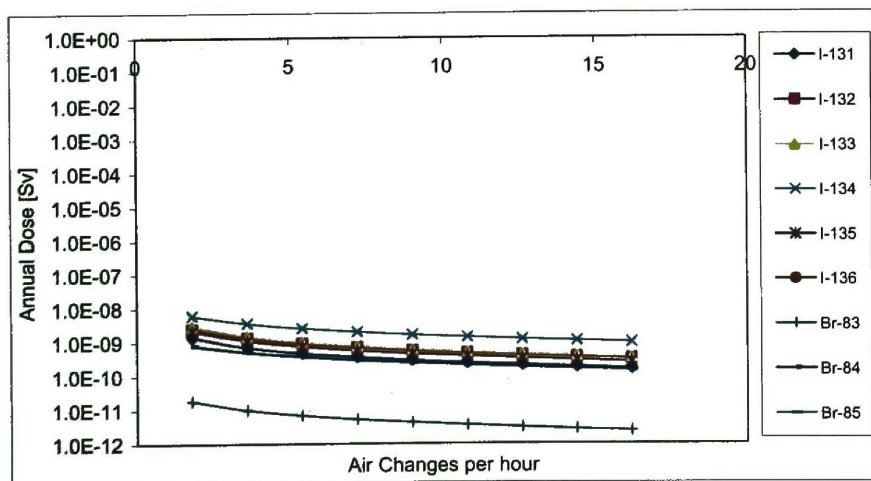
Graph 4-6 (b): Xenon dose with air changes per hour



Graph 4-6 (c): C-14 and H-3 dose with increase in air changes per hour

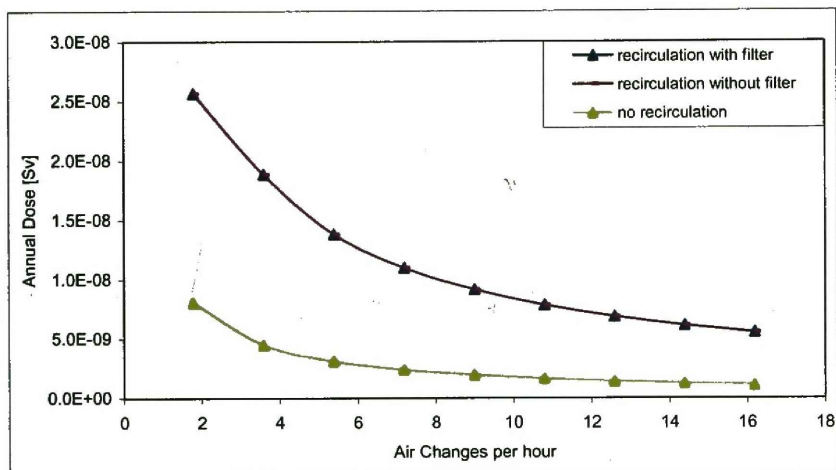


Graph 4-6 (d): Halogens dose with increase in air changes per hour

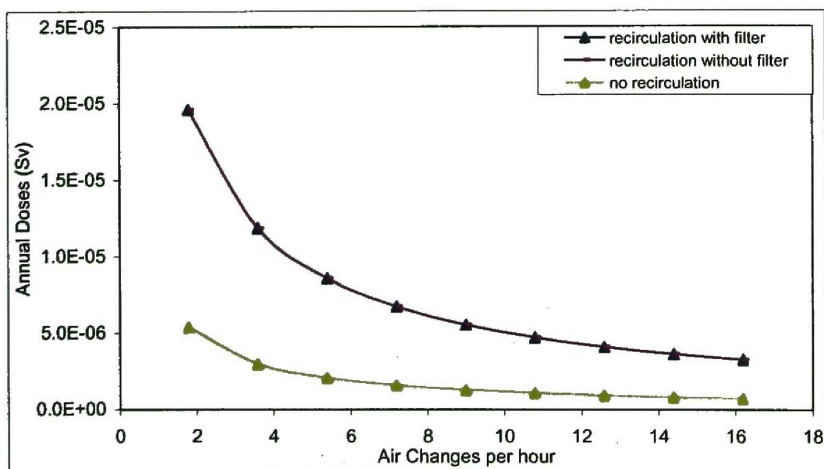


Graph 4-7: Comparison of the three HVAC models

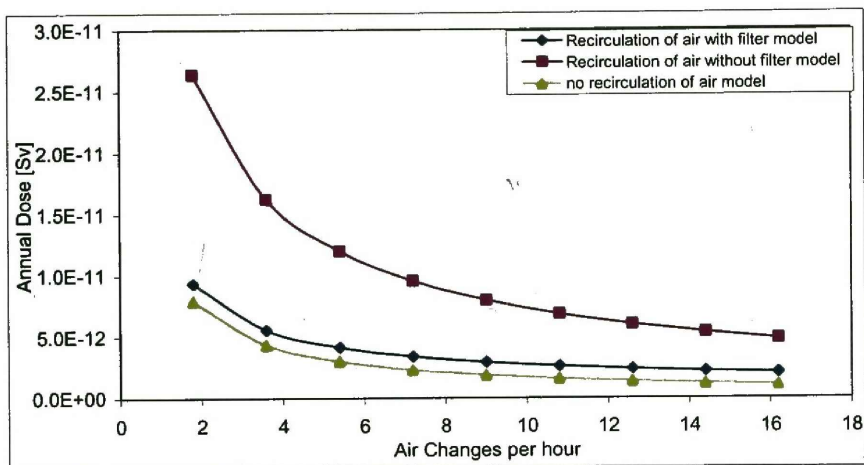
Graph 4-7 (a): Noble gases dose for different HVAC models at the expected leakrate of 0.0015% per day



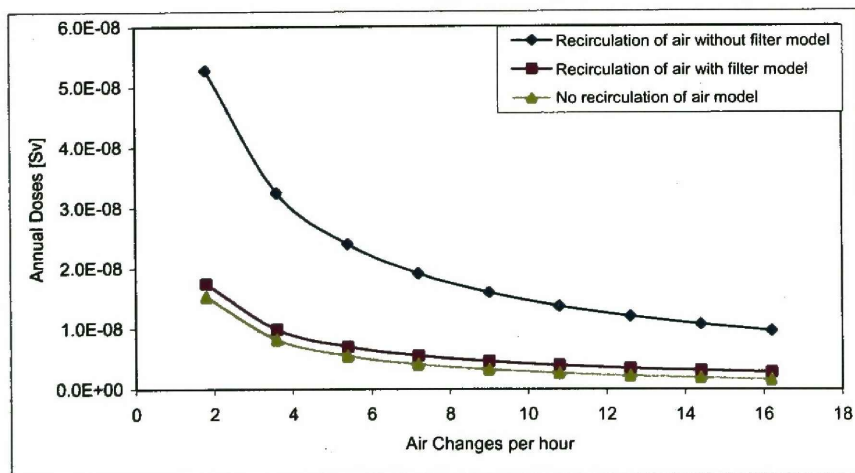
Graph 4-7 (b): Noble gas dose for different HVAC models at the design leakrate of 0.1% per day



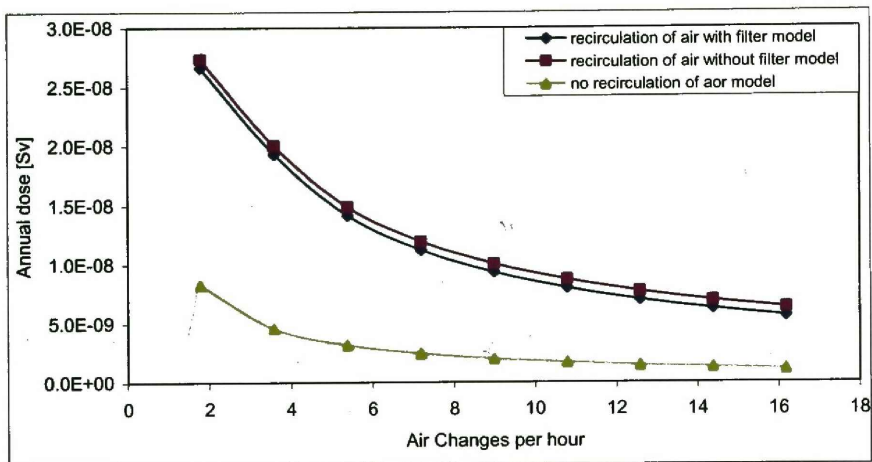
Graph 4-7 (c): Halogens dose for different HVAC models at the Expected leakrate of 0.0015% per day



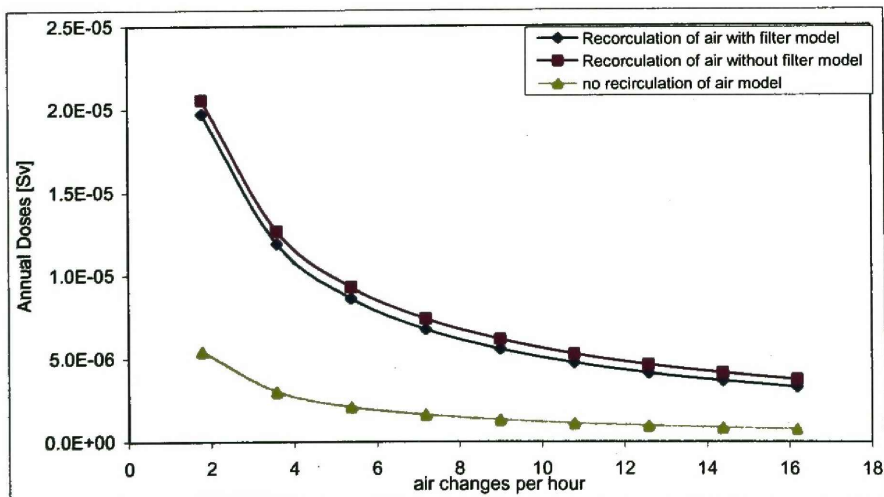
Graph 4-7 (d): Halogens dose for different HVAC model at the design leakrate of 0.1% per day



Graph 4-7 (e): Total annual dose for the three HVAC models at the expected leakrate of 0.0015% per day

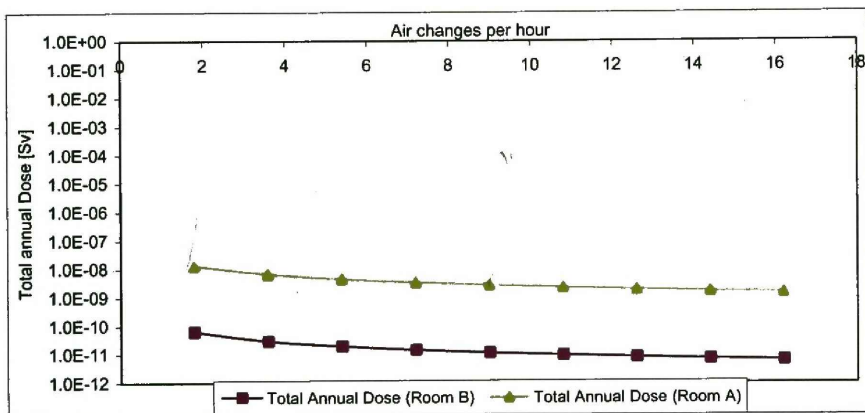


Graph 4-7(f): Total annual dose for the Three HVAC models at the design leakrate of 0.1% per day

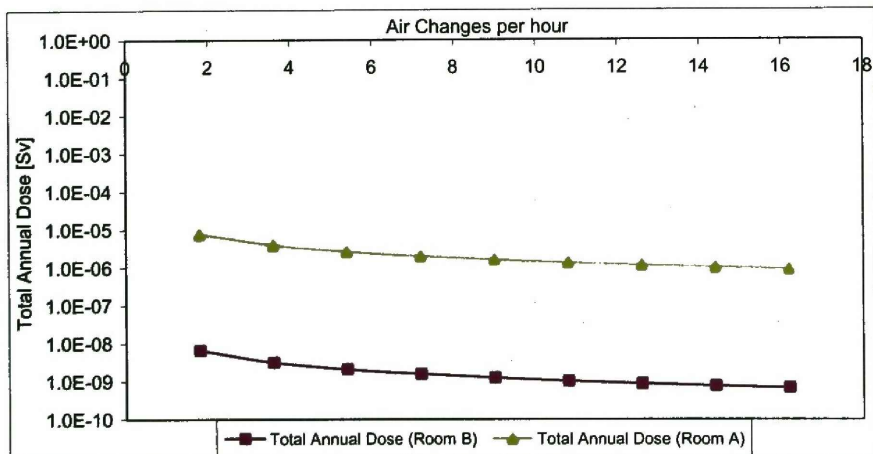


Graph 4-8: Dose due to migration of airborne activity from room A and room B due to HVAC system

Graph 4-8 (a): Dose for Room A and Room B at the leakrate of 0.0015% per day



Graph 4-8 (b): Dose for Room A and Room B at the leakrate of 0.1% per day



4.2 Activity filtered

Table 4-1: Expected Activity

Radionuclides	Activity filtered (Bq)	Specific activity (Bq/Kg)	Activity (Bq) after decay time of:		
			1 month	6 month	1 year
I-131	5.124E-04	7.217E-05	5.434E-06	1.315E-11	1.557E-18
I-132	1.020E-02	1.437E-03	1.229E-94	0.000E+00	0.000E+00
I-133	5.090E-03	7.168E-04	2.724E-14	2.157E-66	1.190E-130
I-134	1.590E-02	2.239E-03	1.835E-253	0.000E+00	0.000E+00
I-135	9.617E-03	1.354E-03	1.747E-36	6.237E-201	0.000E+00
I-136	1.274E-04	1.794E-05	0.000E+00	0.000E+00	0.000E+00
Br-83	1.566E-03	2.205E-04	1.083E-94	0.000E+00	0.000E+00
Br-84	2.060E-03	2.901E-04	0.000E+00	0.000E+00	0.000E+00
Br-85	2.431E-04	3.424E-05	0.000E+00	0.000E+00	0.000E+00
Total activity	4.532E-02	6.383E-03	5.434E-06	1.315E-11	1.557E-18

Table 4-2: Design Activity

Radionuclides	Activity filtered (Bq)	Specific activity (Bq/Kg)	Activity (Bq) after decay time of:		
			1 month	6 month	1 year
I-131	1.022E+00	1.440E-01	1.084E-02	2.624E-08	3.106E-15
I-132	2.037E+01	2.870E+00	2.454E-91	0.000E+00	0.000E+00
I-133	1.018E+01	1.434E+00	5.447E-11	4.314E-63	2.380E-127
I-134	3.185E+01	4.486E+00	3.676E-250	0.000E+00	0.000E+00
I-135	1.920E+01	2.704E+00	3.488E-33	1.245E-197	0.000E+00
I-136	2.545E-01	3.584E-02	0.000E+00	0.000E+00	0.000E+00
Br-83	3.130E+00	4.409E-01	2.164E-91	0.000E+00	0.000E+00
Br-84	4.126E+00	5.811E-01	0.000E+00	0.000E+00	0.000E+00
Br-85	4.862E-01	6.847E-02	0.000E+00	0.000E+00	0.000E+00
Total activity	9.062E+01	1.276E+01	1.084E-02	2.624E-08	3.106E-15

5. INTERPRETATION OF THE RESULTS AND DISCUSSION

Having ensured the initial conditions, the data input in appendix (A-1 (a) to A-1(c)) was used to calculate the airborne activity and the annual dose to the workers. Data in Appendix tables A-2 to A-21 was obtained. The data presents the equilibrium airborne activity and their corresponding doses received for a worker spending 2000 working hours per year in the room, and this is done for the three HVAC models. In all cases, both a design and expected leak(s) are calculated, however, it is the design source terms and their values that will be used for assessment of radiation exposure to the working personnel.

The **Graph 4-1** to **Graph 4-6** in chapter 4 indicates the doses contributed by each nuclide for the three HVAC models, due to leak into the room. From the results it is observed that the size of the leak is directly proportional to the dose received for each nuclide that is for the expected leakrate of 0.0015% per day the dose is lower than that of the design leakrate of 0.1% per day. By taking the logarithmic scale of the graphs it clearly shows that Kr-88 is the nuclide that contributes most of the in dose, in all the ventilation models.

Most of the radionuclides are short lived and they reach the radioactive equilibrium in the room within one year. The equilibrium in the room is considered where the production rate equals to the removal rate. The production rate is considered the as leak from MPS and the recirculated activity, and the removal rate as ventilation to the atmosphere and the decay of each nuclide.

Graph 4-7 shows the comparison of the three HVAC models for the expected and design leak rates. **Graph 4-7 (a)** and **(b)** indicates the noble gases dose for the HVAC models and it shows that the models of recirculation of air with filter and the recirculation of air without filter have no effect on the noble gases because the decontamination factor of the filter is one, that is only gases will pass through the filters and this is shown by the two graphs over the top of each other and the lower graph shows the lower dose for no recirculation of air model.

The no recirculation of air model has the lowest activity because there is no recirculated back activity that acts as the radiation source.

For halogens **Graph 4-7** (c) and (d) clearly shows the difference between the three HVAC models at the expected and design values. The graphs show that the recirculation of air with filter model applies only to the halogens or specifically iodine because of its radiological impact, which affects the thyroid. The difference between the recirculation of air with filter and recirculation of air without filter is shown by the effectiveness of the decontamination factor of the filter, which is 90%.

In PBMR the airborne activity has the annual dose limit of 1/10 of the recommended ICRP annual dose limit of 20mSv, this is because it is not easy to shield airborne activity, therefore the PBMR annual dose limit for airborne activity is 2mSv. Then **Graph 4-7** (4-7 (e) and 4-7 (f)), gives the total annual dose for each model, which are below the annual dose limit of PBMR.

During ventilation the airborne activity migrates to the other rooms. **Graph 4-8** (4-8 (a) and 4-8 (b)), gives the annual doses in room A and room B for recirculation with filter model. The total annual dose in room A is greater than in room B, this is because of the continuous leak, which acts as the radiation source from MPS.

5.1 Dose during maintenance

Table 4-1 and **Table 4-2** gives the activity trapped on the filters for design and expected leak rates calculated using equation 3.27. If the routine maintenance of one year is assumed the activity on the filters is calculated to be low. If the filters are replaced during maintenance, they can be stored to decay prior disposal and the decay time was calculated for one month, Six months and one year using equation 3.28.

6. CONCLUSION

The main aim of this project was to determine the effects of airborne contamination for various concepts of HVAC system and this section evaluates the success of the study in realizing based on this objective. Then the following conclusions are drawn from the study:

- The three HVAC models give the annual dose below the ICRP annual dose of 20 mSv and 2 mSv of PBMR airborne activity annual dose limit.
- Referring to **Graph 4-7** (e) and (f) for both expected and design leak rates the rooms has the potential of low radiation dose to the worker performing duties for 2000 working hour per year, therefore by referring to **Table 2-1** the rooms can be classified as controlled areas.
- The use of 1.8 air changes per hour and above shows the decrease in exposure risks or dose to the personnel, which are below the ICRP and NNR annual dose limit of 20 mSv, and any use of air changes below 1.8 will increase the exposure risks to above 20mSv.
- The activity on the filters is below the regulatory exemption activity given in **Table 2-2**, therefore is either they could be continuously used with the yearly efficiency test or they could be stored to decay for year and disposed as low level waste.

6.1 Recommendations for the future

From the experience gained in the whole project, the following recommendations can be drawn:

- The recirculation of air with filter and no recirculation of air models can be used in PBMR, for assessment of personal exposure.
- The use of the 1.8 air changes per hour and above must be considered to optimize the use of the HVAC system.

- To derive a model that will allow the initial condition of the activity that is not uniformly distributed throughout the room volume.
- To derive a model that will allow the leaks in all other rooms with the different room volumes.

7. REFERENCES

• Internet Search

- [1]. <http://www.pebble-bed.co.za/docs/necsa.htm>
- [2]. http://www.triumf.ca/safety/rpt/rpt_9/node14.html.
- [3]. http://www.aivc.org/air/20_4kraenzmer.html
- [4]. <http://www.epa.gov/radiation/understanding.htm>

• Documents And Text Books

- [5]. **Drodskie. I., Zdziarski. C, and Vermaak. T,** Pbm SAR Section 3, Chapter 6: Auxiliary Systems, November 2001, Document no: 001929-207sec6
- [6]. **Dudestadt J.J., Hamilton L.J,** 1976 Nuclear reactor analysis, John Wiley and Sons, New York
- [7]. **Fourie .P** Section 6, chapter 1, Design aspects of radiological protection, 2000, Document no: 001929-207.
- [8]. **George A. P** Introduction To The Pebble Bed Modular Reactor (PBM), August 2001, Document no: 009949-185.
- [9]. **Glasstone .S., Sesonske .A,** Nuclear reactor engineering, D. VAN NOSTRAND COMPANY, INC., 1955,1963
- [10]. **IAEA safety series no 111-G-1.1.** Classification of radioactive waste.1994
- [11]. **IAEA safety series no.115** International basic safety standards for protection against ionizing radiation and for the safety of radiation sources, 1996
- [12]. **IAEA-TECDOC-978 [Nov 1997].** Fuel performance and fission product behavior in gas cooled reactors. Vienna.
- [13]. **John R. Lamarsh,** Introduction to nuclear engineering, 2nd edition, 1993

- [14]. **Keenan H.N**, calculation in support of the HVAC system design, document number: 010794-192. 2001
- [15]. **Keith F., Eckerman, Jeffrey C. Ryman** External exposure to radionuclides in air, water, and soil. Oak Ridge national laboratory, Federal guidance report no: 12, 1993
- [16]. **Kenneth, J Shultis., Richard, E Faw** Radiation shielding, 2000
- [17]. **Lester. A, Bernard Shleien, Slaback J.R, Brian K. Barky** Handbook of health physics and radiological health, third edition, 1998
- [18]. **Röllig K., Benkert J., Schöning .J** Production and emission of carbon-14, Westinghouse reactor, doc no; GBRA 052 612. 2001
- [19]. **Röllig K., Benkert J., Schöning .J** Production and emission of tritium, Westinghouse reactor, doc no; GBRA 052 343. 2001
- [20]. **Röllig K., Benkert J., Schöning .J** Release of noble gas and halogens from the PBMR core, Westinghouse reactor, doc no; GBRA 052 336. 2001
- [21]. **Union Carbide Corporation for the U.S Atomic Energy Commission**, radiation safety and control, Oak Ridge National laboratory, June 1961
- [22]. **Van Rooyen J.T**, The science of radiation protection, national accelerator center. 2001
- [23]. **Wichnerr .P** Fission products plateout and lift off in the MHTGR primary system: a review, April 1991, Oak Ridge National Laboratory, TN37831-6285

• **Personal communication**

- [24]. Dr Johaan Slabber (Reactor Science and Engineering Manager)
- [25]. Dr Gert De Beer (NECSA)
- [26]. Mr. Tinus Vermaak (Auxilliary Systems Engineering Manager)
- [27]. Mr. Nick Keenan (Nuclear Safety Case Group Manager)

8. APPENDIX

Detailed derivation of the activity equation

The differential equation is given by:

$$\frac{dN_{IB}}{dt} = C_{MPS} + C_{RECIR} + C_{OUT} - C_{VENT} - C_{DECAY} \quad (A.1)$$

$$\frac{dN(t)}{dt} = V_I C_I + \frac{N_i(t)}{V} D_1 \bullet BR \bullet V_v + C_{OUT} V_1 \approx \frac{N_i(t)}{V} \bullet V_v - \lambda \bullet N_i(t) \quad (A.2)$$

Assuming there no number radioactive atoms from the outside then third term in the equation is zero because C_{OUT} is zero.

$$\frac{dN_i(t)}{dt} = \left[V_I C_I + \frac{N_i(t)}{V} (D_1 \bullet BR \bullet V_v) \right] - \left[\frac{N_i(t)}{V} \bullet V_v + \lambda \bullet V \right] \quad (A.3)$$

$$\frac{dN_i(t)}{dt} = V_I C_I + \frac{N_i(t)}{V} (D_1 \bullet BR \bullet V_v) - \frac{N_i(t)}{V} \bullet V_v - \lambda \bullet N_i(t) \quad (A.4)$$

$$\frac{dN_i(t)}{dt} = V_I C_I + N_i(t) \left\{ -\frac{1}{V} [(-D_1 \bullet BR \bullet V_v) + V_v + \lambda \bullet V] \right\} \quad (A.5)$$

Let

$$X = C_I V_L$$

$$Y = -\frac{1}{V} [(-D_1 \bullet BR \bullet V_v) + V_v + \lambda \bullet V]$$

By substituting X and Y in equation A.5 then:

$$\frac{dN_i(t)}{dt} = X + N_i(t)Y \quad (A.6)$$

By rearranging equation A.6 and introducing integration on both sides then:

$$\int_{N_0}^N \frac{dN_i(t)}{X + N_i(t)} = \int_0^t dt \quad (A.7)$$

$$\frac{1}{Y} \{ \log_e [X + N(t)Y] - \log_e [X + N_0(t)Y] \} = t \quad (A.8)$$

$$\log_e \frac{[X + N(t)Y]}{[X + N_0(t)]} = Yt \quad (\text{A.9})$$

$$\frac{[X + N(t)Y]}{[X + N_0(t)Y]} = e^{Yt} \quad (\text{A.10})$$

$$[X + N(t)Y] = Xe^{Yt} + N_0(t)Ye^{Yt} \quad (\text{A.11})$$

$$N(t)Y = Xe^{Yt} - X + N_0(t)Ye^{Yt} \quad (\text{A.12})$$

$$N(t) = \frac{X}{Y}e^{Yt} - \frac{X}{Y} + N_0(t)e^{Yt} \quad (\text{A.13})$$

Then it follows that the number of radioactive atoms following the leakage into the room is given by:

$$N(t) = N_0(t)e^{Yt} - \frac{X}{Y}(1 - e^{Yt}) \quad (\text{A.14})$$

At the initial conditions $N_0 = 0$

$$N(t) = -\frac{X}{Y}(1 - e^{Yt}) \quad (\text{A.15})$$

Since $X = C_i V_i$

$$Y = -\frac{1}{V} [(-D_1 \bullet BR \bullet V_r) + V_r + \lambda V]$$

Substituting back X and Y in equation A.15:

$$N(t) = \frac{-C_i V_i}{-\frac{1}{V} [(-D_1 \bullet BR \bullet V_r) + V_r + \lambda \bullet V]} \left\{ 1 - e^{-\frac{t}{\lambda} [(-D_1 \bullet BR \bullet V_r) + V_r + \lambda \bullet V]} \right\} \quad (\text{A.16})$$

Therefore:

$$N(t) = \frac{C_i V_i}{\frac{1}{V} [(-D_1 \bullet BR \bullet V_r) + V_r + \lambda \bullet V]} \left\{ 1 - e^{-\frac{t}{\lambda} [(-D_1 \bullet BR \bullet V_r) + V_r + \lambda \bullet V]} \right\} \quad (\text{A.17})$$

The activity of radioactive atom is given by:

$$A = \lambda N \quad (\text{A.18})$$

By substituting for N in equation A.18 then:

$$A = \frac{\lambda C_I V_I}{\frac{1}{V} [(-D_I \bullet BR \bullet V_v) + V_v + \lambda \bullet V]} \left\{ 1 - e^{-\frac{t}{V} [(-D_I \bullet BR \bullet V_v) + V_v + \lambda \bullet V]} \right\} \quad (\text{A.19})$$

This relation represents the activity build-up with time until equilibrium is reached in the room.

At equilibrium $t = \infty$ therefore:

$$A = \frac{\lambda C_I V_I}{\frac{1}{V} [(-D_I \bullet BR \bullet V_v) + V_v + \lambda \bullet V]} \quad (\text{A.20})$$

Table A- 1: INPUT DATA

Table A-1 (a):

DECAY SEQUENCES FOR ACTIVE COMPONENTS IN GAS LEAKING FROM PBMR													
Seq num	Seq type	Nuclide	Gas/solid	Half life	Units	% Yield daughter 1	Decay Prod	Stable	Gas or solid?	% Yield daughter 2	Decay Prod	Stable	Gas or solid?
1	A	Kr_83m	g	1.83E+00	h	100	Kr_83	yes	g	79	Rb_85	yes	s
2	B	Kr_85m	g	4.48E+00	h	21	Kr_85	no	g				
2	B	Kr_85	g	1.07E+01	a	100	Rb_85	yes	s				
3	B	Kr_87	g	7.63E+01	m	100	Rb_87	no	s				
3	B	Rb_87	s	4.80E+10	a	100	Sr_87	yes	s				
4	B	Kr_88	g	2.84E+00	h	100	Rb_88	no	s				
4	B	Rb_88	s	1.78E+01	m	100	Sr_88	yes	s				
5	C	Kr_89	g	3.18E+00	m	100	Rb_89	no	s				
5	C	Rb_89	s	1.52E+01	m	100	Sr_89	no	s				
5	C	Sr_89	s	5.06E+01	d	100	Y_89	yes	s				
6	D	Kr_90	g	3.23E+01	s	100	Rb_90m	no	s	19	Ba_138	yes	s
6	D	Rb_90m	s	2.55E+00	m	100	Sr_90	no	s				
6	D	Sr_90	s	2.85E+01	a	100	Y_90	no	s				
6	D	Y_90	s	2.67E+00	d	100	Zr_90	yes	s				
7	B	I_131	vs	8.04E+00	d	100	Xe_131m	no	g				
7	B	Xe_131m	g	1.19E+01	d	100	Xe_131	yes	g				
8	A	I_132	vs	2.38E+00	h	100	Xe_132	yes	g				
9	C	I_133	vs	2.08E+01	h	100	Xe_133m	no	g				
9	C	Xe_133m	g	2.19E+00	d	100	Xe_133	no	g				
9	C	Xe_133	g	5.24E+00	d	100	Cs_133	yes	s				
10	A	I_134	vs	5.26E+01	m	100	Xe_134	yes	g				
11	A	Cs_134	s	2.06E+00	a	100	Ba_134	yes	s				
12	D	I_135	vs	6.59E+00	h	100	Xe_135m	no	g				
12	D	Xe_135m	g	1.53E+01	m	100	Xe_135	no	g				
12	D	Xe_135	g	9.17E+00	h	100	Cs_135	no	s				
12	D	Cs_135	s	3.00E+06	a	100	Ba_135	yes	s				
13	B	Xe_137	g	3.82E+00	m	100	Cs_137	no	s				
13	B	Cs_137	s	3.01E+01	a	100	Ba_137	yes	s				
14	C	Xe_138	g	1.41E+01	m	100	Cs_138m	no	s				
14	C	Cs_138m	s	2.90E+00	m	81.00	Cs_138	no	s				
14	C	Cs_138	s	3.22E+01	m	100	Ba_138	yes	s				
15	C	Xe_139	g	3.97E+01	s	100	Cs_139	no	s				
15	C	Cs_139	s	9.27E+00	m	100	Ba_139	no	s				
15	C	Ba_139	s	1.41E+00	h	100	La_139	yes	s				
16	A	Ag_110m	s	2.50E+02	d	100	Cd_110	yes	s				
17	A	H_3	s	1.24E+01	a	100	He_3	yes	g				
18	A	C_14	s	5.74E+03	a	100	N_14	yes	s				

Table A-1 (b)

Radionuclide(s)	MPS activity (Bq) for expected value of 0.0015% day ⁻¹	MPS activity (Bq) for design value of 0.1% day ⁻¹	Dose conversion factors (Sv/Bq)	
			Internal exposure (inhalation)	External exposure
Kr-83m	6.000E+09	8.301E+10	0.000E+00	1.856E-18
Kr-85m	1.770E+10	5.995E+11	0.000E+00	7.704E-15
Kr-85	6.450E+09	1.055E+16	0.000E+00	2.510E-16
Kr-87	2.440E+10	2.346E+11	0.000E+00	4.257E-14
Kr-88	4.200E+10	8.891E+11	0.000E+00	1.034E-13
Kr-89	1.450E+10	5.810E+09	0.000E+00	0.000E+00
Kr-90	7.230E+09	4.904E+08	0.000E+00	0.000E+00
Kr-91	3.450E+09	6.520E+07	0.000E+00	0.000E+00
Xe-131m	1.220E+09	2.656E+12	0.000E+00	4.372E-16
Xe-133m	3.430E+09	1.369E+12	0.000E+00	1.474E-15
Xe-133	1.490E+11	1.430E+14	0.000E+00	1.610E-15
Xe-135m	5.840E+09	1.126E+10	0.000E+00	2.070E-14
Xe-135	2.300E+10	1.594E+12	0.000E+00	1.221E-14
Xe-137	1.530E+10	7.364E+09	0.000E+00	0.000E+00
Xe-138	2.810E+10	4.992E+10	0.000E+00	5.877E-14
Xe-139	4.420E+09	3.680E+08	0.000E+00	0.000E+00
Xe-140	1.950E+09	5.573E+07	0.000E+00	0.000E+00
H-3	1.408E+09	1.452E+10	1.730E-11	0.000E+00
C-14	5.702E+08	7.059E+08	8.0 x 10 ⁻¹³	2.654E-18
I-131	1.39E+05	4.16E+06	1.100E-08	1.850E-14
I-132	5.81E+06	1.74E+08	2.000E-10	1.136E-13
I-133	1.52E+06	4.56E+07	2.100E-09	2.998E-14
I-134	2.03E+07	6.10E+08	7.900E-11	1.319E-13
I-135	3.54E+06	1.06E+08	4.600E-10	8.091E-14
I-136	5.24E+07	1.57E+09	0.000E+00	0.000E+00
Br-83	8.87E+05	2.66E+07	2.470E-11	5.400E-16
Br-84	4.56E+06	1.37E+08	4.910E-11	9.328E-14
Br-85	2.55E+07	7.65E+08	0.000E+00	0.000E+00

Table A-1 (c)

Description	Value(s)	Units
Air Changes	<1.8	h^{-1}
Branching Ratio	80	%
Branching ratio into rooms	50	%
Breathing rate	1.2	m^3/h
Design leakrate	0.1	% per day
Expected leakrate	0.0015	% per day
Decontamination Factor		
1. Halogens	90	%
2. Gases	1	%
Mass of helium	6.87×10^3	Kg
Reference power	268	MW
Volume of the room A	5000	m^3
Volume of the room B	5000	m^3
Working hours per year	2000	h

8.1 Results for Single Room Airborne Activity and Annual Dose

Table A-2: Activity Achieved for Recirculation of Air With Filter Model at the Expected Leakrate of 0.0015% per Day

Table A-2 (a): Noble gases

Radionuclide(s) Air change rate	Activity (Bq) for different Air Change Rate											
	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2			
Kr-83m	1.39E+01	9.35E+00	7.04E+00	5.64E+00	4.71E+00	4.04E+00	3.54E+00	3.15E+00	2.83E+00			
Kr-85m	5.88E+01	3.46E+01	2.45E+01	1.90E+01	1.55E+01	1.30E+01	1.13E+01	9.98E+00	8.92E+00			
Kr-85	3.06E+01	1.53E+01	1.02E+01	7.67E+00	6.13E+00	5.11E+00	4.38E+00	3.83E+00	3.40E+00			
Kr-87	4.61E+01	3.30E+01	2.57E+01	2.10E+01	1.78E+01	1.54E+01	1.36E+01	1.22E+01	1.14E+01			
Kr-88	1.18E+02	7.43E+01	5.41E+01	4.26E+01	3.51E+01	2.98E+01	2.59E+01	2.29E+01	2.06E+01			
Kr-89	1.84E+00	1.79E+00	1.75E+00	1.71E+00	1.66E+00	1.62E+00	1.59E+00	1.55E+00	1.52E+00			
Kr-90	1.59E-01	1.58E-01	1.58E-01	1.57E-01	1.56E-01	1.55E-01	1.55E-01	1.54E-01	1.53E-01			
Kr-91	2.12E-02	2.12E-02	2.12E-02	2.12E-02	2.11E-02	2.11E-02	2.11E-02	2.10E-02	2.10E-02			
Xe-131m	5.76E+00	2.89E+00	1.93E+00	1.44E+00	1.15E+00	9.66E-01	8.28E-01	7.24E-01	6.44E-01			
Xe-133m	1.57E+01	8.01E+00	5.37E+00	4.04E+00	3.23E+00	2.70E+00	2.31E+00	2.03E+00	1.80E+00			
Xe-133	6.98E+02	3.51E+02	2.35E+02	1.76E+02	1.41E+02	1.17E+02	1.01E+02	8.84E+01	7.86E+01			
Xe-135m	3.29E+00	2.90E+00	2.63E+00	2.40E+00	2.21E+00	2.05E+00	1.90E+00	1.78E+00	1.67E+00			
Xe-135	9.04E+01	4.95E+01	3.40E+01	2.59E+01	2.10E+01	1.76E+01	1.51E+01	1.33E+01	1.18E+01			
Xe-137	2.39E+00	2.25E+00	2.18E+00	2.12E+00	2.06E+00	2.00E+00	1.95E+00	1.90E+00	1.85E+00			
Xe-138	1.45E+01	1.31E+01	1.19E+01	1.09E+01	1.01E+01	9.41E+00	8.79E+00	8.25E+00	7.77E+00			
Xe-139	1.19E-01	1.18E-01	1.18E-01	1.17E-01	1.16E-01	1.16E-01	1.15E-01	1.15E-01	1.14E-01			
Xe-140	1.88E-02	1.81E-02	1.81E-02	1.80E-02	1.80E-02	1.80E-02	1.79E-02	1.79E-02	1.79E-02			
Total activity	1.10E+03	5.99E+02	4.170E+02	3.21E+02	2.62E+02	2.22E+02	1.92E+02	1.70E+02	1.52E+02			

Table A-2 (b)

Radionuclide(s)	Activity for different Air Change Rate								
Air Change Rate	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2
H-3	6.69+00	3.34E+00	2.23E+00	1.67E+00	1.34E+00	1.11E+00	9.56E-01	8.37E-01	7.44E-01
C-14	3.35E+00	1.67E+00	1.11E+00	8.39E-01	6.71E-01	5.56E-01	4.79E-01	4.19E-01	3.73E-01

Table A-2 (c): Halogens

Radionuclide(s) Air Change Rate	Activity for Air Change Rate									
	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2	16.2
I-131	1.42E-04	7.11E-05	4.74E-05	3.56E-05	2.84E-05	2.37E-05	2.03E-05	1.78E-05	1.58E-05	1.58E-05
I-132	5.07E-03	2.73E-03	1.87E-03	1.42E-03	1.15E-03	9.64E-04	8.30E-04	7.28E-04	6.49E-04	6.49E-04
I-133	1.52E-03	7.71E-04	5.16E-04	3.87E-04	3.10E-04	2.58E-04	2.22E-04	1.94E-04	1.72E-04	1.72E-04
I-134	1.40E-02	8.39E-03	5.98E-03	4.64E-03	3.79E-03	3.21E-03	2.78E-03	2.45E-03	2.19E-03	2.19E-03
I-135	3.41E-03	1.75E-03	1.18E-03	8.93E-04	7.16E-04	5.98E-04	5.13E-04	4.50E-04	4.00E-04	4.00E-04
I-136	2.89E-03	2.74E-03	2.61E-03	2.48E-03	2.37E-03	2.27E-03	2.18E-03	2.10E-03	2.02E-03	2.02E-03
Br-83	7.75E-04	4.18E-04	2.86E-04	2.17E-04	1.75E-04	1.47E-04	1.26E-04	1.11E-04	9.91E-05	9.91E-05
Br-84	2.62E-03	1.68E-03	1.23E-03	9.77E-04	8.08E-04	6.89E-04	6.00E-04	5.32E-04	4.77E-04	4.77E-04
Br-85	2.72E-03	2.46E-03	2.25E-03	2.07E-03	1.92E-03	1.79E-03	1.67E-03	1.57E-03	1.48E-03	1.48E-03
Total activity	3.32E-02	2.10E-02	1.59E-02	1.31E-02	1.12E-02	9.96E-03	8.95E-03	8.16E-03	7.51E-03	7.51E-03

Table A- 3: Dose Received for Recirculation of Air With Filter Model at the Expected Leakrate of 0.0015% per Day
Table A-3 (a): Noble gases

Radionuclide(s) Air Change Rate	Dose for different Air Change Rate										
	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2		
Kr-83m	3.71E-14	2.02E-14	1.52E-14	1.22E-14	1.01E-14	8.74E-15	7.65E-15	6.81E-15	7.58E-15		
Kr-85m	6.53E-10	3.84E-10	2.72E-10	2.10E-10	1.72E-10	1.45E-10	1.25E-10	1.10E-10	9.90E-11		
Kr-85	1.10E-11	5.54E-12	3.69E-12	2.77E-12	2.21E-12	1.84E-12	1.58E-12	1.38E-12	1.23E-12		
Kr-87	2.83E-09	2.02E-09	1.57E-09	1.29E-09	1.09E-09	9.46E-10	8.35E-10	7.47E-10	6.76E-10		
Kr-88	1.76E-08	1.10E-08	8.06E-09	6.34E-09	5.22E-09	4.46E-09	3.86E-09	3.42E-09	3.06E-09		
Kr-89	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
Kr-90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
Kr-91	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
Xe-131m	3.62E-12	1.82E-12	1.21E-12	9.11E-13	7.29E-13	6.08E-13	5.21E-13	4.56E-13	4.05E-13		
Xe-133m	3.34E-11	1.70E-11	1.14E-11	8.57E-12	6.87E-12	5.73E-12	4.92E-12	4.30E-12	3.83E-12		
Xe-133	1.61E-09	3.30E-09	2.21E-09	1.66E-09	1.32E-09	1.10E-09	9.50E-10	8.31E-10	7.39E-10		
Xe-135m	9.68E-11	8.66E-11	7.84E-11	7.16E-11	6.59E-11	6.11E-11	5.69E-11	5.32E-11	5.00E-11		
Xe-135	1.59E-09	8.70E-10	5.99E-10	4.57E-10	3.69E-10	3.09E-10	2.66E-10	2.34E-10	2.08E-10		
Xe-137	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
Xe-138	1.23E-09	1.11E-09	1.01E-09	9.27E-10	8.57E-10	7.96E-10	7.44E-10	6.98E-10	6.57E-10		
Xe-139	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
Xe-140	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
Total dose	2.56E-08	1.88E-08	1.38E-08	1.09E-08	9.12E-09	7.82E-09	6.85E-09	6.10E-09	5.50E-09		

Table A-3 (b)

Radionuclide(s) Air Change Rate	Dose (Sv) for different Air Change Rate							
	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4
H-3	5.56E-11	2.78E-11	1.85E-11	1.39E-11	1.11E-11	9.27E-12	7.94E-12	6.95E-12
C-14	9.09E-10	4.54E-10	3.03E-10	2.27E-10	1.81E-10	1.51E-10	1.29E-10	1.13E-10

Table A-3 (c): Halogens

Radionuclide(s) Air Change Rate	Dose (Sv) for different Air Change Rate							
	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4
I-131	7.54E-13	3.77E-13	2.51E-13	1.88E-13	1.51E-13	1.26E-13	1.08E-13	9.44E-14
I-132	1.31E-12	7.11E-13	4.87E-13	3.70E-13	2.98E-13	2.50E-13	2.15E-13	1.89E-13
I-133	1.60E-12	8.10E-13	5.42E-13	4.07E-13	3.26E-13	2.72E-13	2.33E-13	2.04E-13
I-134	3.20E-12	1.91E-12	1.36E-12	1.05E-12	8.65E-13	7.31E-13	6.33E-13	5.59E-13
I-135	1.15E-12	5.93E-13	3.99E-13	3.01E-13	2.41E-13	2.01E-13	1.73E-13	1.51E-13
I-136	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Br-83	9.79E-15	5.28E-15	3.62E-15	2.75E-15	2.22E-15	1.86E-15	1.60E-15	1.40E-15
Br-84	4.14E-13	2.65E-13	1.95E-13	1.54E-13	1.27E-13	1.08E-13	9.48E-14	8.40E-14
Br-85	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total dose	8.4E-12	4.67E-12	3.24E-12	2.48E-12	2.01E-12	1.69E-12	1.46E-12	1.28E-12

Table A- 4: Activity Achieved for Recirculation of Air With Filter Model at the Design Leakrate of 0.1% per Day

Table A-4 (a): Noble gases

Radionuclide(s) Air Change Rate	Activity (Bq) for different Air Change Rate										
	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2		
Kr-83m	9.27E+03	6.23E+03	4.69E+03	3.76E+03	3.14E+03	2.69E+03	2.36E+03	2.10E+03	1.89E+03		
Kr-85m	3.92E+04	2.31E+04	1.63E+04	1.26E+04	1.03E+04	8.72E+03	7.55E+03	6.65E+03	5.95E+03		
Kr-85	4.69E+04	2.34E+04	1.56E+04	1.17E+04	9.38E+03	7.82E+03	6.70E+03	5.86E+03	5.21E+03		
Kr-87	3.07E+04	2.20E+04	1.71E+04	1.40E+04	1.18E+04	1.03E+04	9.08E+03	8.13E+03	7.35E+03		
Kr-88	7.89E+04	4.95E+04	3.61E+04	2.84E+04	2.34E+04	1.99E+04	1.73E+04	1.53E+04	1.37E+04		
Kr-89	1.23E+03	1.20E+03	1.16E+03	1.14E+03	1.11E+03	1.08E+03	1.06E+03	1.03E+03	1.01E+03		
Kr-90	1.06E+02	1.05E+02	1.05E+02	1.04E+02	1.04E+02	1.03E+02	1.03E+02	1.03E+02	1.02E+02		
Kr-91	1.41E+01	1.41E+01	1.41E+01	1.41E+01	1.41E+01	1.40E+01	1.40E+01	1.40E+01	1.40E+01		
Xe-131m	3.84E+03	1.92E+03	1.28E+03	9.65E+02	7.72E+02	6.44E+02	5.52E+02	4.83E+02	4.29E+02		
Xe-133m	1.04E+04	5.34E+03	3.58E+03	2.69E+03	2.16E+03	1.80E+03	1.54E+03	1.35E+03	1.20E+03		
Xe-133	4.65E+05	2.34E+05	1.56E+05	1.17E+05	9.42E+04	7.85E+04	6.73E+04	5.89E+04	5.24E+04		
Xe-135m	2.16E+03	1.93E+03	1.75E+03	1.60E+03	1.47E+03	1.36E+03	1.27E+03	1.19E+03	1.11E+03		
Xe-135	6.02E+04	3.30E+04	2.27E+04	1.73E+04	1.40E+04	1.17E+04	1.01E+04	8.88E+03	7.91E+03		
Xe-137	1.55E+03	1.50E+03	1.45E+03	1.41E+03	1.37E+03	1.33E+03	1.30E+03	1.26E+03	1.23E+03		
Xe-138	9.69E+03	8.74E+03	7.96E+03	7.30E+03	6.75E+03	6.27E+03	5.86E+03	5.50E+03	5.18E+03		
Xe-139	7.97E+01	7.92E+01	7.88E+01	7.83E+01	7.79E+01	7.75E+01	7.70E+01	7.66E+01	7.62E+01		
Xe-140	1.21E+01	1.20E+01	1.20E+01	1.20E+01	1.20E+01	1.20E+01	1.19E+01	1.19E+01	1.19E+01		
Total activity	7.60E+05	4.12E+05	2.86E+05	2.20E+05	1.80E+05	1.52E+05	1.32E+05	1.17E+05	1.04E+05		

Table A-4 (b)

Radionuclide(s) Air Change Rate	Activity (Bq) for different Air Change Rate									
	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2	
H-3	4.60E+03	2.3E+03	1.5E+03	1.15E+03	9.21E+02	7.67E+02	6.58E+02	5.75E+02	5.11E+02	
C-14	1.80E+02	9.0E+01	6.03E+01	4.52E+01	3.62E+01	3.01E+01	2.58E+01	2.26E+01	2.01E+01	

Table A-4 (c): Halogens

Radionuclide(s) Air Change Rate	Activity (Bq) for different Air Change Rate									
	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2	
I-131	2.83E+01	1.42E+01	9.47E+02	7.10E+02	5.68E+02	4.73E+02	4.06E+02	3.55E+02	3.15E+02	
I-132	1.01E+01	5.46E+00	3.74E+00	2.84E+00	2.29E+00	1.92E+00	1.65E+00	1.45E+00	1.29E+00	
I-133	3.05E+00	1.54E+00	1.03E+00	7.75E-01	6.20E-01	5.17E-01	4.43E-01	3.88E-01	3.45E-01	
I-134	2.81E+01	1.68E+01	1.19E+01	9.30E+00	7.60E+00	6.43E+00	5.57E+00	4.91E+00	4.39E+00	
I-135	6.81E+00	3.51E+00	2.36E+00	1.78E+00	1.43E+00	1.19E+00	1.02E+00	8.98E-01	7.99E-01	
I-136	5.77E+00	5.47E+00	5.21E+00	4.97E+00	4.75E+00	4.55E+00	4.36E+00	4.19E+00	4.03E+00	
Br-83	1.55E+00	8.36E-01	5.72E-01	4.35E-01	3.51E-01	2.94E-01	2.53E-01	2.22E-01	1.98E-01	
Br-84	5.25E+00	3.36E+00	2.47E+00	1.95E+00	1.61E+00	1.38E+00	1.20E+00	1.06E+00	9.57E-01	
Br-85	5.45E+00	4.93E+00	4.51E+00	4.15E+00	3.84E+00	3.58E+00	3.35E+00	3.15E+00	2.97E+00	
Total activity	6.6E+01	4.21E+01	3.19E+01	2.63E+01	2.25E+01	1.99E+01	1.79E+01	1.63E+01	1.50E+01	

Table(s) A-5 (b)

Radionuclide(s) Air Change Rate	Dose (Sv) for different Air Change Rate									
	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2	
H-3	3.82E-08	1.91E-08	1.27E-08	9.55E-09	7.64E-09	6.37E-09	5.46E-09	4.77E-09	4.24E-09	
C-14	4.93E-08	2.46E-08	1.64E-08	1.23E-08	9.86E-09	8.21E-09	7.04E-09	6.16E-09	5.47E-09	

Table A-5 (c): Halogens

Radionuclide(s) Air Change Rate	Dose (Sv) for different Air Change Rate									
	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2	
I-131	1.50E-09	7.53E-10	5.02E-10	3.77E-10	3.01E-10	2.51E-10	2.15E-10	1.88E-10	1.67E-10	
I-132	2.62E-09	1.41E-09	9.72E-10	7.39E-10	5.96E-10	4.99E-10	4.30E-10	3.77E-10	3.36E-10	
I-133	3.21E-09	1.62E-09	1.08E-09	8.14E-10	6.52E-10	5.44E-10	4.66E-10	4.08E-10	3.63E-10	
I-134	6.42E-09	3.83E-09	2.73E-09	2.12E-09	1.73E-09	1.46E-09	1.27E-09	1.12E-09	1.00E-09	
I-135	2.29E-09	1.18E-09	7.97E-10	6.01E-10	4.82E-10	4.03E-10	3.46E-10	3.03E-10	2.69E-10	
I-136	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Br-83	1.95E-11	1.05E-11	7.23E-12	5.50E-12	4.44E-12	3.72E-12	3.20E-12	2.81E-12	2.50E-12	
Br-84	8.29E-10	5.31E-10	3.90E-10	3.09E-10	2.55E-10	2.17E-10	1.89E-10	1.68E-10	1.51E-10	
Br-85	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Total dose	1.6E-08	9.35E-09	6.48E-09	4.96E-09	4.027E-09	3.38E-09	2.92E-09	2.56E-09	2.29E-09	

Table A- 6: (Halogens): The Activity Achieved for Recirculation of Air Without Filter Model at the Expected Leakrate of 0.0015% per Day

Radionuclide(s) Air Change Rate	Activity for different Air Change Rate									
	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2	
I-131	6.54E-04	3.28E-04	2.19E-04	1.64E-04	1.32E-04	1.10E-04	9.43E-05	8.25E-05	7.33E-05	
I-132	1.52E-02	9.83E-03	7.25E-03	5.74E-03	4.75E-03	4.05E-03	3.53E-03	3.13E-03	2.81E-03	
I-133	6.61E-03	3.45E-03	2.33E-03	1.76E-03	1.42E-03	1.18E-03	1.01E-03	8.93E-04	7.95E-04	
I-134	2.99E-02	2.28E-02	1.84E-02	1.55E-02	1.33E-02	1.17E-02	1.04E-02	9.44E-03	8.60E-03	
I-135	1.30E-02	7.34E-03	5.11E-03	3.92E-03	3.18E-03	2.67E-03	2.30E-03	2.03E-03	1.81E-03	
I-136	3.01E-03	2.98E-03	2.94E-03	2.91E-03	2.87E-03	2.84E-03	2.81E-03	2.78E-03	2.75E-03	
Br-83	2.34E-03	1.50E-03	1.11E-03	8.78E-04	7.27E-04	6.20E-04	5.40E-04	4.79E-04	4.30E-04	
Br-84	4.68E-03	3.85E-03	3.27E-03	2.84E-03	2.51E-03	2.25E-03	2.04E-03	1.86E-03	1.71E-03	
Br-85	2.97E-03	2.89E-03	2.83E-03	2.76E-03	2.70E-03	2.64E-03	2.59E-03	2.53E-03	2.48E-03	
Total activity	7.85E-02	5.50E-02	4.35E-02	3.65E-02	3.16E-02	2.81E-02	2.54E-02	2.32E-02	2.14E-02	

Table A- 7: (Halogens): The Dose Received for Recirculation of Air Without Filter Model at the Expected Leakrate of 0.0015% per Day

Radionuclide(s) Air Change Rate	Dose for different Air Change Rate									
	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2	
I-131	3.47E-12	1.75E-12	1.17E-12	8.75E-13	7.00E-13	5.84E-13	5.00E-13	4.38E-13	3.89E-13	
I-132	3.97E-12	2.55E-12	1.88E-12	1.49E-12	1.23E-12	1.05E-12	9.19E-13	8.14E-13	7.31E-13	
I-133	6.96E-12	3.63E-12	2.46E-12	1.86E-12	1.49E-12	1.25E-12	1.07E-12	9.39E-13	8.36E-13	
I-134	6.83E-12	5.21E-12	4.21E-12	3.54E-12	3.05E-12	2.68E-12	2.39E-12	2.15E-12	1.96E-12	
I-135	4.40E-12	2.48E-12	1.73E-12	1.32E-12	1.07E-12	9.03E-13	7.79E-13	6.85E-13	6.11E-13	
I-136	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Br-83	2.96E-14	1.90E-14	1.40E-14	1.11E-14	9.19E-15	7.84E-15	6.83E-15	6.06E-15	5.44E-15	
Br-84	7.39E-13	6.08E-13	5.16E-13	4.49E-13	3.97E-13	3.56E-13	3.22E-13	2.94E-13	2.71E-13	
Br-85	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Total dose	2.6E-11	1.625E-11	1.197E-11	9.542E-12	7.952E-12	6.826E-12	5.984E-12	5.329E-12	4.804E-12	

Table A- 8: (Halogens): The Activity Achieved for Recirculation of Air Without Filter Model at the Design Leakrate of 0.1% per Day

Radionuclide(s) Air Change Rate	Activity for different Air Change Rate									
	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2	
I-131	1.30E+00	6.56E-01	4.38E-01	3.29E-01	2.63E-01	2.19E-01	1.88E-01	1.64E-01	1.46E-01	
I-132	3.05E+01	1.96E+01	1.44E+01	1.14E+01	9.49E+00	8.10E+00	7.06E+00	6.26E+00	5.62E+00	
I-133	1.32E+01	6.91E+00	4.67E+00	3.53E+00	2.83E+00	2.37E+00	2.03E+00	1.78E+00	1.59E+00	
I-134	6.00E+01	4.58E+01	3.70E+01	3.10E+01	2.67E+01	2.35E+01	2.09E+01	1.89E+01	1.72E+01	
I-135	2.60E+01	1.46E+01	1.02E+01	7.83E+00	6.35E+00	5.34E+00	4.60E+00	4.05E+00	3.61E+00	
I-136	6.02E+00	5.95E+00	5.88E+00	5.81E+00	5.75E+00	5.68E+00	5.62E+00	5.55E+00	5.49E+00	
Br-83	4.68E+00	3.01E+00	2.21E+00	1.75E+00	1.45E+00	1.24E+00	1.08E+00	9.58E-01	8.60E-01	
Br-84	9.37E+00	7.71E+00	6.55E+00	5.69E+00	5.03E+00	4.51E+00	4.08E+00	3.73E+00	3.43E+00	
Br-85	5.94E+00	5.79E+00	5.66E+00	5.53E+00	5.41E+00	5.29E+00	5.17E+00	5.07E+00	4.96E+00	
Total activity	1.5E+02	1.10E+02	8.71E+01	7.30E+01	6.33E+01	5.62E+01	5.08E+01	4.65E+01	4.29E+01	

Table A- 9: (Halogens): The Dose Received for Recirculation of Air Without Filter Model at the Design Leakrate of 0.1% per Day

Radionuclide(s) Air Change Rate	Dose for different Air Change Rate									
	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2	
I-131	6.93E-09	3.48E-09	2.32E-09	1.74E-09	1.39E-09	1.16E-09	9.98E-10	8.73E-10	7.76E-10	
I-132	7.91E-09	5.09E-09	3.76E-09	2.97E-09	2.46E-09	2.10E-09	1.83E-09	1.62E-09	1.46E-09	
I-133	1.39E-08	7.26E-09	4.91E-09	3.71E-09	2.98E-09	2.49E-09	2.14E-09	1.87E-09	1.67E-09	
I-134	1.36E-08	1.04E-08	8.43E-09	7.08E-09	6.10E-09	5.36E-09	4.77E-09	4.31E-09	3.92E-09	
I-135	8.77E-09	4.94E-09	3.44E-09	2.64E-09	2.14E-09	1.80E-09	1.55E-09	1.36E-09	1.22E-09	
I-136	0.0E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Br-83	5.91E-11	3.80E-11	2.80E-11	2.21E-11	1.83E-11	1.56E-11	1.36E-11	1.21E-11	1.08E-11	
Br-84	1.48E-09	1.21E-09	1.03E-09	8.98E-10	7.94E-10	7.12E-10	6.45E-10	5.89E-10	5.43E-10	
Br-85	0.0E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Total dose	5.2E-08	3.24E-08	2.39E-08	1.90E-08	1.59E-08	1.36E-08	1.19E-08	1.06E-08	9.609E-09	

Table A- 10: The Activity Achieved for no Recirculation of Air (Once Through) Model at the Expected Leakrate of 0.0015% per Day

Table A-10 (a): Noble gases

Radionuclide(s) Air Change Rate	Activity for different Air Change Rate									
	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2	
Kr-83m	4.71E+00	2.58E+00	1.77E+00	1.35E+00	1.09E+00	9.19E-01	7.91E-01	6.95E-01	6.19E-01	
Kr-85m	1.55E+01	8.07E+00	5.45E+00	4.12E+00	3.31E+00	2.76E+00	2.37E+00	2.08E+00	1.85E+00	
Kr-85	6.13E+00	3.06E+00	2.04E+00	1.53E+00	1.22E+00	1.02E+00	8.76E-01	7.67E-01	6.81E-01	
Kr-87	1.78E+01	1.00E+01	7.02E+00	5.39E+00	4.37E+00	3.68E+00	3.17E+00	2.79E+00	2.49E+00	
Kr-88	3.51E+01	1.86E+01	1.27E+01	9.65E+00	7.77E+00	6.51E+00	5.59E+00	4.91E+00	4.37E+00	
Kr-89	1.66E+00	1.48E+00	1.34E+00	1.22E+00	1.12E+00	1.04E+00	9.66E-01	9.03E-01	8.48E-01	
Kr-90	1.56E-01	1.53E-01	1.49E-01	1.46E-01	1.43E-01	1.40E-01	1.37E-01	1.35E-01	1.32E-01	
Kr-91	2.11E-02	2.10E-02	2.09E-02	2.07E-02	2.06E-02	2.05E-02	2.03E-02	2.02E-02	2.01E-02	
Xe-131m	1.15E+00	5.79E-01	3.86E-01	2.90E-01	2.32E-01	1.93E-01	1.65E-01	1.45E-01	1.28E-01	
Xe-133m	3.23E+00	1.62E+00	1.08E+00	8.14E-01	6.51E-01	5.43E-01	4.65E-01	4.07E-01	3.62E-01	
Xe-133	1.41E+02	7.07E+01	4.72E+01	3.54E+01	2.83E+01	2.36E+01	2.02E+01	1.77E+01	1.57E+01	
Xe-135m	2.21E+00	1.58E+00	1.23E+00	1.00E+00	8.53E-01	7.39E-01	6.52E-01	5.84E-01	5.28E-01	
Xe-135	2.10E+01	1.07E+01	7.19E+00	5.41E+00	4.34E+00	3.62E+00	3.10E+00	2.72E+00	2.42E+00	
Xe-137	2.06E+00	1.80E+00	1.60E+00	1.44E+00	1.31E+00	1.20E+00	1.11E+00	1.03E+00	9.67E-01	
Xe-138	1.01E+01	7.34E+00	5.76E+00	4.74E+00	4.02E+00	3.49E+00	3.09E+00	2.77E+00	2.51E+00	
Xe-139	1.16E-01	1.13E-01	1.10E-01	1.07E-01	1.05E-01	1.02E-01	1.00E-01	9.78E-02	9.56E-02	
Xe-140	1.80E-02	1.78E-02	1.76E-02	1.75E-02	1.73E-02	1.72E-02	1.70E-02	1.68E-02	1.67E-02	
Total activity	2.6E+02	1.38E+02	9.51E+01	7.27E+01	5.89E+01	4.96E+01	4.29E+01	3.78E+01	3.38E+01	

Table A-10 (b)

Radionuclide(s) Air Change Rate	Activity for different Air Change Rate									
	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2	
H-3	1.34E+00	6.69E-01	4.46E-01	3.34E-01	2.67E-01	2.23E-01	1.91E-01	1.67E-01	1.48E-01	
C-14	6.71E-01	3.35E-01	2.23E-01	1.67E-01	1.34E-01	1.11E-01	9.59E-02	8.39E-02	7.46E-02	

Table A-10 (c): Halogens

Radionuclide(s) Air Change Rate	Activity for different Air Change Rate									
	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2	
I-131	1.32E-04	6.60E-05	4.40E-05	3.30E-05	2.64E-05	2.20E-05	1.88E-05	1.65E-05	1.46E-05	
I-132	4.75E-03	2.55E-03	1.74E-03	1.32E-03	1.07E-03	8.97E-04	7.71E-04	6.77E-04	6.03E-04	
I-133	1.42E-03	7.16E-04	4.79E-04	3.59E-04	2.88E-04	2.40E-04	2.06E-04	1.80E-04	1.60E-04	
I-134	1.33E-02	7.90E-03	5.60E-03	4.34E-03	3.54E-03	2.99E-03	2.59E-03	2.28E-03	2.04E-03	
I-135	3.18E-03	1.63E-03	1.10E-03	8.29E-04	6.65E-04	5.55E-04	4.77E-04	4.17E-04	3.71E-04	
I-136	2.87E-03	2.72E-03	2.58E-03	2.45E-03	2.33E-03	2.23E-03	2.13E-03	2.05E-03	1.96E-03	
Br-83	7.27E-04	3.90E-04	2.67E-04	2.02E-04	1.63E-04	1.37E-04	1.17E-04	1.03E-04	9.21E-05	
Br-84	2.51E-03	1.59E-03	1.16E-03	9.17E-04	7.57E-04	6.44E-04	5.61E-04	4.97E-04	4.46E-04	
Br-85	2.70E-03	2.43E-03	2.21E-03	2.02E-03	1.87E-03	1.73E-03	1.62E-03	1.51E-03	1.43E-03	
Total activity	3.2E-02	2.00E-02	1.52E-02	1.25E-02	1.07E-02	9.46E-03	8.50E-03	7.74E-03	7.13E-03	

Table A- 11: The Dose Received for no Recirculation of Air (Once Through) Model at the Expected Leakrate of 0.0015% per Day

Table A-11 (a): Noble gases

Radionuclide(s) Air Change Rate	Dose for different Air Change Rate										
	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2		
Kr-83m	1.26E-14	6.90E-15	4.75E-15	3.62E-15	2.92E-15	2.45E-15	2.11E-15	1.85E-15	1.65E-15		
Kr-85m	1.72E-10	8.95E-11	6.05E-11	4.57E-11	3.67E-11	3.06E-11	2.63E-11	2.31E-11	2.05E-11		
Kr-85	2.21E-12	1.10E-12	7.39E-13	5.54E-13	4.43E-13	3.69E-13	3.16E-13	2.77E-13	2.46E-13		
Kr-87	1.09E-09	6.17E-10	4.30E-10	3.30E-10	2.68E-10	2.25E-10	1.94E-10	1.71E-10	1.53E-10		
Kr-88	5.22E-09	2.78E-09	1.89E-09	1.43E-09	1.15E-09	9.68E-10	8.33E-10	7.30E-10	6.50E-10		
Kr-89	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
Kr-90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
Kr-91	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
Xe-131m	7.29E-13	3.65E-13	2.43E-13	1.82E-13	1.46E-13	1.21E-13	1.04E-13	9.13E-14	8.11E-14		
Xe-133m	6.87E-12	3.45E-12	2.30E-12	1.72E-12	1.38E-12	1.15E-12	9.88E-13	8.64E-13	7.68E-13		
Xe-133	3.27E-10	1.64E-10	1.09E-10	8.20E-11	6.56E-11	5.47E-11	4.69E-11	4.10E-11	3.64E-11		
Xe-135m	6.59E-11	4.71E-11	3.67E-11	3.00E-11	2.54E-11	2.20E-11	1.94E-11	1.74E-11	1.57E-11		
Xe-135	3.69E-10	1.88E-10	1.26E-10	9.51E-11	7.63E-11	6.36E-11	5.46E-11	4.78E-11	4.25E-11		
Xe-137	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
Xe-138	8.57E-10	6.21E-10	4.87E-10	4.01E-10	3.40E-10	2.96E-10	2.61E-10	2.34E-10	2.12E-10		
Xe-139	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
Xe-140	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
Total dose	8.1E-09	4.51E-09	3.15E-09	2.42E-09	1.97E-09	1.66E-09	1.43E-09	1.26E-09	1.13E-09		

Table A-11 (b)

Radionuclide(s)	Dose for different Air Change Rate								
Air Change Rate	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2
H-3	1.11E-11	5.56E-12	3.70E-12	2.78E-12	2.22E-12	1.85E-12	1.58E-12	1.39E-12	1.23E-12
C-14	1.81E-10	9.09E-11	6.06E-11	4.54E-11	3.63E-11	3.03E-11	2.59E-11	2.27E-11	2.02E-11

Table A-11 (c): Halogens

Radionuclide(s) Air Change Rate	Dose for different Air Change Rate									
	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2	16.2
I-131	7.00E-13	3.50E-13	2.33E-13	1.75E-13	1.40E-13	1.16E-13	1.00E-13	8.76E-14	7.79E-14	7.79E-14
I-132	1.23E-12	6.63E-13	4.53E-13	3.44E-13	2.77E-13	2.32E-13	2.00E-13	1.75E-13	1.56E-13	1.56E-13
I-133	1.49E-12	7.53E-13	5.03E-13	3.78E-13	3.02E-13	2.52E-13	2.16E-13	1.89E-13	1.68E-13	1.68E-13
I-134	3.04E-12	1.80E-12	1.27E-12	9.89E-13	8.08E-13	6.82E-13	5.91E-13	5.21E-13	4.65E-13	4.65E-13
I-135	1.07E-12	5.51E-13	3.71E-13	2.79E-13	2.24E-13	1.87E-13	1.60E-13	1.41E-13	1.25E-13	1.25E-13
I-136	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Br-83	9.18E-15	4.93E-15	3.37E-15	2.56E-15	2.08E-15	1.73E-15	1.48E-15	1.30E-15	1.16E-15	1.16E-15
Br-84	3.96E-13	2.51E-13	1.83E-13	1.44E-13	1.19E-13	1.01E-13	8.86E-14	7.84E-14	7.04E-14	7.04E-14
Br-85	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total dose	7.9E-12	4.4E-12	3.02E-12	2.31E-12	1.87E-12	1.57E-12	1.35E-12	1.19E-12	1.06E-12	1.06E-12

Table A- 12: The Activity Achieved for no Recirculation of Air (Once Through) Model at the Design Leakrate of 0.1% per Day

Table A-12 (a): Noble gases

Radionuclide(s)	Activity for different Air Change Rate										
	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2		
Air Change Rate											
Kr-83m	3.14E+03	1.71E+03	1.18E+03	9.03E+02	7.30E+02	6.12E+02	5.27E+02	4.63E+02	4.13E+02		
Kr-85m	1.03E+04	5.31E+03	3.63E+03	2.74E+03	2.20E+03	1.84E+03	1.58E+03	1.38E+03	1.23E+03		
Kr-85	9.38E+03	4.63E+03	3.12E+03	2.34E+03	1.87E+03	1.56E+03	1.34E+03	1.17E+03	1.04E+03		
Kr-87	1.18E+04	6.72E+03	4.68E+03	3.59E+03	2.91E+03	2.45E+03	2.11E+03	1.86E+03	1.66E+03		
Kr-88	2.34E+04	1.24E+04	8.49E+03	6.43E+03	5.18E+03	4.34E+03	3.73E+03	3.27E+03	2.91E+03		
Kr-89	1.11E+03	9.92E+02	8.95E+02	8.16E+02	7.49E+02	6.93E+02	6.44E+02	6.02E+02	5.65E+02		
Kr-90	1.04E+02	1.02E+02	9.98E+01	9.77E+01	9.56E+01	9.37E+01	9.18E+01	9.00E+01	8.83E+01		
Kr-91	1.41E+01	1.40E+01	1.39E+01	1.38E+01	1.37E+01	1.36E+01	1.35E+01	1.35E+01	1.34E+01		
Xe-131m	7.72E+02	3.86E+02	2.57E+02	1.93E+02	1.54E+02	1.28E+02	1.10E+02	9.67E+01	8.59E+01		
Xe-133m	2.16E+03	1.08E+03	7.23E+02	5.42E+02	4.34E+02	3.62E+02	3.10E+02	2.71E+02	2.41E+02		
Xe-133	9.42E+04	4.71E+04	3.14E+04	2.36E+04	1.88E+04	1.57E+04	1.34E+04	1.18E+04	1.05E+04		
Xe-135m	1.47E+03	1.05E+03	8.21E+02	6.72E+02	5.68E+02	4.93E+02	4.35E+02	3.89E+02	3.52E+02		
Xe-135	1.40E+04	7.14E+03	4.79E+03	3.60E+03	2.89E+03	2.41E+03	2.07E+03	1.81E+03	1.61E+03		
Xe-137	1.37E+03	1.20E+03	1.07E+03	9.65E+02	8.78E+02	8.05E+02	7.43E+02	6.90E+02	6.44E+02		
Xe-138	6.75E+03	4.89E+03	3.84E+03	3.16E+03	2.68E+03	2.33E+03	2.06E+03	1.84E+03	1.67E+03		
Xe-139	7.79E+01	7.58E+01	7.38E+01	7.19E+01	7.01E+01	6.84E+01	6.68E+01	6.52E+01	6.37E+01		
Xe-140	1.20E+01	1.19E+01	1.17E+01	1.16E+01	1.15E+01	1.14E+01	1.13E+01	1.12E+01	1.11E+01		
Total activity	1.80E+05	9.5E+04	6.5E+04	4.97E+04	4.03E+04	3.39E+04	2.9E+04	2.58E+04	2.31E+04		

Table A-12 (b)

Radionuclide(s) Air Change Rate	Activity for different Air Change Rate									
	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2	
H-3	9.20E+02	4.60E+02	3.06E+02	2.30E+02	1.84E+02	1.53E+02	1.31E+02	1.15E+02	1.02E+02	
C-14	3.61E+01	1.80E+01	1.20E+01	9.04E+00	7.23E+00	6.02E+00	5.16E+00	4.52E+00	4.01E+00	

Table A-12 (c): Halogens

Radionuclide(s) Air Change Rate	Activity for different Air Change Rate									
	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2	
I-131	2.63E+01	1.31E-01	8.78E-02	6.59E-02	5.27E-02	4.39E-02	3.76E-02	3.29E-02	2.93E-02	
I-132	9.49E+00	5.10E+00	3.49E+00	2.65E+00	2.13E+00	1.79E+00	1.54E+00	1.35E+00	1.20E+00	
I-133	2.83E+00	1.43E+00	9.58E-01	7.197E-01	5.76E-01	4.80E-01	4.12E-01	3.60E-01	3.20E-01	
I-134	2.67E+01	1.58E+01	1.12E+01	8.70E+00	7.10E+00	6.00E+00	5.19E+00	4.58E+00	4.09E+00	
I-135	6.35E+00	3.26E+00	2.19E+00	1.65E+00	1.32E+00	1.11E+00	9.52E-01	8.34E-01	7.42E-01	
I-136	5.75E+00	5.43E+00	5.15E+00	4.90E+00	4.67E+00	4.46E+00	4.27E+00	4.09E+00	3.93E+00	
Br-83	1.45E+00	7.80E-01	5.33E-01	4.05E-01	3.26E-01	2.73E-01	2.35E-01	2.06E-01	1.84E-01	
Br-84	5.03E+00	3.18E+00	2.33E+00	1.83E+00	1.51E+00	1.29E+00	1.12E+00	9.95E-01	8.93E-01	
Br-85	5.41E+00	4.86E+00	4.42E+00	4.05E+00	3.74E+00	3.47E+00	3.24E+00	3.03E+00	2.85E+00	
Total activity	6.33E+01	4.00E+01	3.4E+01	2.50E+01	2.14E+01	1.89E+01	1.70E+01	1.55E+01	1.42E+01	

Table A- 13: The Dose Received for no Recirculation of Air (Once Through) Model at the Expected Leakrate of 0.1% per Day

Table A-13 (a): Noble gases

Radionuclide(s) Air Change Rate	Dose for different Air Change Rate										
	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2		
Kr-83m	8.40E-12	4.60E-12	3.16E-12	2.41E-12	1.95E-12	1.63E-12	1.41E-12	1.23E-12	1.10E-12		
Kr-85m	1.14E-07	5.97E-08	4.03E-08	3.04E-08	2.44E-08	2.04E-08	1.75E-08	1.54E-08	1.37E-08		
Kr-85	3.39E-09	1.69E-09	1.13E-09	8.48E-10	6.78E-10	5.65E-10	4.84E-10	4.24E-10	3.76E-10		
Kr-87	7.28E-07	4.11E-07	2.87E-07	2.20E-07	1.78E-07	1.50E-07	1.29E-07	1.14E-07	1.02E-07		
Kr-88	3.48E-06	1.85E-06	1.26E-06	9.58E-07	7.71E-07	6.45E-07	5.55E-07	4.87E-07	4.33E-07		
Kr-89	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
Kr-90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
Kr-91	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
Xe-131m	4.86E-10	2.43E-10	1.62E-10	1.21E-10	9.74E-11	8.11E-11	6.95E-11	6.08E-11	5.41E-11		
Xe-133m	4.58E-09	2.30E-09	1.53E-09	1.15E-09	9.22E-10	7.68E-10	6.58E-10	5.76E-10	5.12E-10		
Xe-133	2.18E-07	1.09E-07	7.29E-08	5.47E-08	4.37E-08	3.64E-08	3.12E-08	2.73E-08	2.43E-08		
Xe-135m	4.39E-08	3.14E-08	2.44E-08	2.00E-08	1.69E-08	1.47E-08	1.29E-08	1.16E-08	1.05E-08		
Xe-135	2.46E-07	1.25E-07	8.43E-08	6.34E-08	5.08E-08	4.24E-08	3.64E-08	3.19E-08	2.83E-08		
Xe-137	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
Xe-138	5.71E-07	4.14E-07	3.25E-07	2.67E-07	2.27E-07	1.97E-07	1.74E-07	1.56E-07	1.41E-07		
Xe-139	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
Xe-140	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
Total dose	5.41E-06	3.01E-06	2.10E-06	1.6E-06	1.31E-06	1.10E-06	9.59E-07	8.45E-07	7.55E-07		

Table A-13 (b)

Radionuclide(s)	Dose for different Air Change Rate								
Air Change Rate	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2
H-3	7.64E-09	3.82E-09	2.54E-09	1.91E-09	1.52E-09	1.27E-09	1.09E-09	9.55E-10	8.49E-10
C-14	9.79E-09	4.89E-09	3.26E-09	2.44E-09	1.95E-09	1.63E-09	1.39E-09	1.22E-09	1.08E-09

Table A-13 (c): Halogens

Radionuclide(s) Air Change Rate	Dose for different Air Change Rate									
	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2	18.0
I-131	1.39E-09	6.99E-10	4.66E-10	3.49E-10	2.79E-10	2.33E-10	1.99E-10	1.75E-10	1.55E-10	1.39E-10
I-132	2.46E-09	1.32E-09	9.05E-10	6.88E-10	5.54E-10	4.64E-10	3.99E-10	3.50E-10	3.12E-10	2.80E-10
I-133	2.98E-09	1.50E-09	1.00E-09	7.56E-10	6.05E-10	5.05E-10	4.33E-10	3.79E-10	3.37E-10	3.03E-10
I-134	6.10E-09	3.60E-09	2.55E-09	1.98E-09	1.61E-09	1.36E-09	1.18E-09	1.04E-09	9.33E-10	8.37E-10
I-135	2.14E-09	1.10E-09	7.41E-10	5.58E-10	4.48E-10	3.74E-10	3.21E-10	2.81E-10	2.50E-10	2.24E-10
I-136	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Br-83	1.83E-11	9.86E-12	6.74E-12	5.12E-12	4.13E-12	3.46E-12	2.97E-12	2.61E-12	2.32E-12	2.08E-12
Br-84	7.94E-10	5.03E-10	3.68E-10	2.90E-10	2.39E-10	2.03E-10	1.77E-10	1.57E-10	1.41E-10	1.27E-10
Br-85	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total dose	1.59E-08	8.75E-09	6.05E-09	4.63E-09	3.751E-09	3.15E-09	2.71E-09	2.39E-09	2.13E-09	1.91E-09

8.2 Results for Twin Room Airborne Activity and Annual Dose

8.2.1 Room A

Table A- 14: The Activity Achieved for Recirculation of Air With Filter Model at the Expected Leakrate of 0.0015% per Day (room A)

Table A-14 (a): Noble gases

Radionuclide(s) Air Change Rate	Activity (Bq) for different Air Change Rate										
	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2		
Kr-83m	7.13E+00	3.56E+00	2.37E+00	1.78E+00	1.42E+00	1.18E+00	1.01E+00	8.91E-01	7.92E-01		
Kr-85m	2.10E+01	1.05E+01	7.01E+00	5.26E+00	4.20E+00	3.50E+00	3.00E+00	2.63E+00	2.33E+00		
Kr-85	6.63E+00	3.31E+00	2.21E+00	1.69E+00	1.32E+00	1.10E+00	9.47E-01	8.29E-01	7.37E-01		
Kr-87	2.90E+01	1.45E+01	9.67E+00	7.25E+00	5.80E+00	4.83E+00	4.14E+00	3.62E+00	3.22E+00		
Kr-88	4.99E+01	2.49E+01	1.66E+01	1.24E+01	9.98E+00	8.32E+00	7.13E+00	6.24E+00	5.54E+00		
Kr-89	1.04E+01	7.33E+00	5.30E+00	4.10E+00	3.33E+00	2.80E+00	2.41E+00	2.12E+00	1.89E+00		
Kr-90	6.80E-02	1.31E-01	1.87E-01	2.34E-01	2.73E-01	3.03E-01	3.25E-01	3.41E-01	3.51E-01		
Kr-91	7.15E-04	1.42E-03	2.12E-03	2.82E-03	3.50E-03	4.13E-03	4.88E-03	5.51E-03	6.16E-03		
Xe-131m	1.45E+00	7.25E-01	4.83E-01	3.62E-01	2.90E-01	2.41E-01	2.07E-01	1.81E-01	1.61E-01		
Xe-133m	4.07E+00	2.03E+00	1.36E+00	1.02E+00	8.15E-01	6.79E-01	5.82E-01	5.09E-01	4.53E-01		
Xe-133	1.77E+02	8.85E+01	5.96E+01	4.42E+01	3.54E+01	2.95E+01	2.53E+01	2.21E+01	1.96E+01		
Xe-135m	6.89E+00	3.46E+00	2.31E+00	1.73E+00	1.38E+00	1.15E+00	9.91E-01	8.67E-01	7.71E-01		
Xe-135	2.73E+01	1.36E+01	9.11E+00	6.83E+00	5.47E+00	4.55E+00	3.90E+00	3.41E+00	3.03E+00		
Xe-137	1.31E+01	8.23E+00	5.77E+00	4.41E+00	3.56E+00	2.98E+00	2.56E+00	2.25E+00	2.00E+00		
Xe-138	3.31E+01	1.66E+01	1.11E+01	8.34E+00	6.67E+00	5.56E+00	4.77E+00	4.17E+00	3.71E+00		
Xe-139	7.62E-02	1.43E-01	1.99E-01	2.40E-01	2.69E-01	2.87E-01	2.96E-01	3.00E-01	2.98E-01		
Xe-140	1.39E-03	2.76E-03	4.11E-03	5.43E-03	6.72E-03	7.96E-03	9.17E-03	1.03E-02	1.14E-02		
Total activity	3.87E+02	1.97E+02	1.32E+02	1.00E+02	8.02E+01	6.70E+01	5.76E+01	5.05E+01	4.5E+01		

Table A-14 (b)

Table A- 15: The Dose Received for Recirculation of Air With Filter Model at the Expected Leakrate of 0.0015% per Day (room A)

Table A-15 (a): Noble gases

Radionuclide(s)	Dose for different Air Change Rate									
	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2	
Air Change Rate										
Kr-83m	1.90E-14	9.53E-15	6.35E-15	4.76E-15	3.81E-15	3.17E-15	2.72E-15	2.38E-15	2.11E-15	
Kr-85m	2.33E-10	1.16E-10	7.78E-11	5.83E-11	4.67E-11	3.89E-11	3.33E-11	2.91E-11	2.59E-11	
Kr-85	2.39E-12	1.19E-12	7.99E-13	5.99E-13	4.79E-13	3.99E-13	3.42E-13	2.99E-13	2.66E-13	
Kr-87	1.77E-09	8.89E-10	5.92E-10	4.44E-10	3.55E-10	2.96E-10	2.54E-10	2.22E-10	1.97E-10	
Kr-88	7.43E-09	3.71E-09	2.47E-09	1.85E-09	1.48E-09	1.23E-09	1.06E-09	9.29E-10	8.25E-10	
Kr-89	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Kr-90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Kr-91	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Xe-131m	9.13E-13	4.56E-13	3.04E-13	2.28E-13	1.82E-13	1.52E-13	1.30E-13	1.14E-13	1.01E-13	
Xe-133m	8.65E-12	4.32E-12	2.88E-12	2.16E-12	1.73E-12	1.44E-12	1.23E-12	1.08E-12	9.61E-13	
Xe-133	4.10E-10	2.05E-10	1.36E-10	1.02E-10	8.21E-11	6.84E-11	5.86E-11	5.13E-11	4.56E-11	
Xe-135m	2.05E-10	1.03E-10	6.88E-11	5.16E-11	4.13E-11	3.44E-11	2.95E-11	2.58E-11	2.29E-11	
Xe-135	4.80E-10	2.40E-10	1.60E-10	1.20E-10	9.61E-11	8.01E-11	6.87E-11	6.01E-11	5.34E-11	
Xe-137	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Xe-138	2.80E-09	1.41E-09	9.41E-10	7.06E-10	5.65E-10	4.71E-10	4.03E-10	3.53E-10	3.14E-10	
Xe-139	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Xe-140	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Total dose	1.33E-08	6.6E-09	4.45E-09	3.34E-09	2.67E-09	2.23E-09	1.91E-09	1.7E-09	1.4E-09	

Table A-15 (b)

Radionuclide(s) Air Change Rate	Dose (Sv) for different Air Change Rate							
	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4
H-3	1.20E-11	6.01E-12	4.00E-12	3.00E-12	2.40E-12	2.00E-12	1.71E-12	1.50E-12
C-14	1.96E-10	9.82E-11	6.55E-11	4.91E-11	3.93E-11	3.27E-11	2.80E-11	2.45E-11

Table A-15 (c): Halogens

Radionuclide(s) Air Change Rate	Dose (Sv) for different Air Change Rate							
	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4
I-131	8.77E-13	4.38E-13	2.92E-13	2.19E-13	1.75E-13	1.46E-13	1.25E-13	1.09E-13
I-132	1.79E-12	8.96E-13	5.97E-13	4.48E-13	3.58E-13	2.98E-13	2.56E-13	2.24E-13
I-133	1.90E-12	9.50E-13	6.33E-13	4.75E-13	3.80E-13	3.16E-13	2.71E-13	2.37E-13
I-134	5.49E-12	2.74E-12	1.83E-12	1.37E-12	1.10E-12	9.16E-13	7.85E-13	6.87E-13
I-135	1.42E-12	7.09E-13	4.73E-13	3.55E-13	2.84E-13	2.36E-13	2.02E-13	1.77E-13
I-136	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Br-83	1.33E-14	6.66E-15	4.44E-15	3.33E-15	2.66E-15	2.22E-15	1.90E-15	1.66E-15
Br-84	8.54E-13	4.27E-13	2.85E-13	2.14E-13	1.71E-13	1.42E-13	1.22E-13	1.07E-13
Br-85	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total dose	1.23E-11	6.17E-12	4.11E-12	3.08E-12	2.47E-12	2.06E-12	1.76E-12	1.54E-12

Table A- 16: The Activity Achieved for Recirculation of Air With Filter Model at the Design Leakrate of 0.1% per Day (room A)

Table A-16 (a): Noble gases

Radionuclide(s)	Activity (Bq) for different Air Change Rate											
	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2			
Air Change Rate												
Kr-83m	4.75E+03	2.37E+03	1.58E+03	1.18E+03	9.51E+02	7.92E+02	6.79E+02	5.94E+02	5.28E+02			
Kr-85m	1.40E+04	7.01E+03	4.67E+03	3.50E+03	2.80E+03	2.33E+03	2.00E+03	1.75E+03	1.55E+03			
Kr-85	1.01E+04	5.07E+03	3.38E+03	2.53E+03	2.02E+03	1.69E+03	1.45E+03	1.26E+03	1.12E+03			
Kr-87	1.93E+04	9.67E+03	6.44E+03	4.83E+03	3.86E+03	3.22E+03	2.76E+03	2.41E+03	2.14E+03			
Kr-88	3.32E+04	1.66E+04	1.11E+04	8.32E+03	6.65E+03	5.54E+03	4.75E+03	4.16E+03	3.69E+03			
Kr-89	6.96E+03	4.89E+03	3.53E+03	2.73E+03	2.22E+03	1.86E+03	1.61E+03	1.41E+03	1.26E+03			
Kr-90	4.53E+01	8.75E+01	1.24E+02	1.56E+02	1.82E+02	2.02E+02	2.17E+02	2.27E+02	2.34E+02			
Kr-91	4.77E-01	9.49E-01	1.41E+00	1.88E+00	2.33E+00	2.79E+00	3.23E+00	3.67E+00	4.10E+00			
Xe-131m	9.67E+02	4.83E+02	3.22E+02	2.41E+02	1.93E+02	1.61E+02	1.38E+02	1.20E+02	1.07E+02			
Xe-133m	2.71E+03	1.36E+03	9.06E+02	6.79E+02	5.43E+02	4.53E+02	3.88E+02	3.39E+02	3.02E+02			
Xe-133	1.18E+05	5.90E+04	3.93E+04	2.95E+04	2.36E+04	1.96E+04	1.68E+04	1.47E+04	1.31E+04			
Xe-135m	4.59E+03	2.30E+03	1.54E+03	1.15E+03	9.25E+02	7.71E+02	6.61E+02	5.78E+02	5.14E+02			
Xe-135	1.82E+04	9.11E+03	6.07E+03	4.55E+03	3.64E+03	3.03E+03	2.60E+03	2.27E+03	2.02E+03			
Xe-137	8.78E+03	5.49E+03	3.84E+03	2.94E+03	2.37E+03	1.99E+03	1.71E+03	1.50E+03	1.33E+03			
Xe-138	2.20E+04	1.11E+04	7.41E+03	5.56E+03	4.45E+03	3.71E+03	3.18E+03	2.78E+03	2.47E+03			
Xe-139	5.08E+01	9.58E+01	1.32E+02	1.60E+02	1.79E+02	1.91E+02	1.97E+02	2.00E+02	1.99E+02			
Xe-140	9.30E-01	1.84E+00	2.74E+00	3.62E+00	4.48E+00	5.31E+00	6.11E+00	6.89E+00	7.64E+00			
Total activity	2.64E+05	1.34E+05	9.04E+04	6.81E+04	5.46E+04	4.56E+04	3.92E+04	3.44E+04	3.06E+04			

Table A-16 (b)

Radionuclide(s) Air Change Rate	Activity (Bq) for different Air Change Rate									
	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2	
H-3	9.95E+02	4.97E+02	3.31E+02	2.48E+02	1.99E+02	1.65E+02	1.42E+02	1.24E+02	1.10E+02	
C-14	3.91E+01	1.95E+01	1.30E+01	9.77E+00	7.81E+00	6.51E+00	5.58E+00	4.88E+00	4.34E+00	

Table A-16 (c): Halogens

Radionuclide(s) Air Change Rate	Activity (Bq) for different Air Change Rate									
	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2	
I-131	3.29E-01	1.64E-01	1.09E-01	8.24E-02	6.59E-02	5.49E-02	4.71E-02	4.12E-02	3.66E-02	
I-132	1.37E+01	6.89E+00	4.59E+00	3.44E+00	2.75E+00	2.29E+00	1.97E+00	1.72E+00	1.53E+00	
I-133	3.61E+00	1.80E+00	1.20E+00	9.03E-01	7.23E-01	6.02E-01	5.16E-01	4.51E-01	4.01E-01	
I-134	4.83E+01	2.41E+01	1.61E+01	1.20E+01	9.67E+00	8.05E+00	6.90E+00	6.04E+00	5.37E+00	
I-135	8.40E+00	4.20E+00	2.80E+00	2.10E+00	1.68E+00	1.40E+00	1.20E+00	1.05E+00	9.33E-01	
I-136	1.51E+01	2.14E+01	2.19E+01	2.03E+01	1.83E+01	1.64E+01	1.48E+01	1.34E+01	1.22E+01	
Br-83	2.10E+00	1.05E+00	7.02E-01	5.27E-01	4.21E-01	3.51E-01	3.01E-01	2.63E-01	2.34E-01	
Br-84	1.08E+01	5.42E+00	3.61E+00	2.71E+00	2.17E+00	1.81E+00	1.55E+00	1.35E+00	1.20E+00	
Br-85	3.21E+01	2.43E+01	1.80E+01	1.41E+01	1.15E+01	9.72E+00	8.40E+00	7.39E+00	6.59E+00	
Total activity	1.35E+02	8.95E+01	6.91E+01	5.64E+01	4.74E+01	4.08E+01	3.57E+01	3.18E+01	2.86E+01	

Table A- 17: Dose Achieved for Recirculation of Air With Filter Model at the Design Leakrate of 0.1% per Day

Table A-17 (a): Noble gases

Radionuclide(s) Air Change Rate	Dose (Sv) for different Air Change Rate												
	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2				
Kr-83m	1.27E-11	6.36E-12	4.23E-12	3.17E-12	2.54E-12	2.11E-12	1.81E-12	1.58E-12	1.41E-12				
Kr-85m	1.55E-07	7.78E-08	5.18E-08	3.89E-08	3.11E-08	2.59E-08	2.24E-08	1.94E-08	1.73E-08				
Kr-85	3.66E-09	1.83E-09	1.22E-09	9.16E-10	7.33E-10	6.11E-10	5.23E-10	4.58E-10	4.07E-10				
Kr-87	1.18E-06	5.92E-07	3.95E-07	2.96E-07	2.37E-07	1.97E-07	1.69E-07	1.48E-07	1.31E-07				
Kr-88	4.95E-06	2.47E-06	1.65E-06	1.23E-06	9.91E-07	8.25E-07	7.07E-07	6.19E-07	5.50E-07				
Kr-89	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.0E+00	0.00E+00	0.00E+00				
Kr-90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.0E+00	0.00E+00	0.00E+00				
Kr-91	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.0E+00	0.00E+00	0.00E+00				
Xe-131m	6.08E-10	3.04E-10	2.03E-10	1.52E-10	1.21E-10	1.01E-10	8.69E-11	7.61E-11	6.76E-11				
Xe-133m	5.77E-09	2.88E-09	1.92E-09	1.44E-09	1.15E-09	9.61E-10	8.24E-10	7.21E-10	6.41E-10				
Xe-133	1.11E-06	5.55E-07	3.70E-07	2.77E-07	2.22E-07	1.85E-07	1.58E-07	1.38E-07	1.23E-07				
Xe-135m	1.36E-07	6.88E-08	4.59E-08	3.44E-08	2.75E-08	2.29E-08	1.97E-08	1.72E-08	1.53E-08				
Xe-135	3.20E-07	1.60E-07	1.06E-07	8.01E-08	6.413E-08	5.34E-08	4.58E-08	4.00E-08	3.56E-08				
Xe-137	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.0E+00	0.00E+00	0.00E+00				
Xe-138	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.0E+00	0.00E+00	0.00E+00				
Xe-139	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.0E+00	0.00E+00	0.00E+00				
Xe-140	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.0E+00	0.00E+00	0.00E+00				
Total dose	7.87E-06	3.93E-06	2.62E-06	1.96E-06	1.57E-06	1.31E-06	1.12E-06	9.84E-07	8.75E-07				

Table A-17 (b)

Radionuclide(s)	Dose (Sv) for different Air Change Rate								
Air Change Rate	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2
H-3	2.06E-09	1.03E-09	6.88E-10	5.16E-10	4.13E-10	3.44E-10	2.95E-10	2.58E-10	2.29E-10
C-14	2.66E-09	1.33E-09	8.88E-10	6.66E-10	5.33E-10	4.44E-10	3.80E-10	3.33E-10	2.96E-10

Table A-17 (c): Halogens

Radionuclide(s) Air Change Rate	Dose (Sv) for different Air Change Rate									
	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2	
I-131	1.75E-09	8.75E-10	5.83E-10	4.37E-10	3.50E-10	2.91E-10	2.50E-10	2.18E-10	1.94E-10	
I-132	3.58E-09	1.79E-09	1.19E-09	8.95E-10	7.16E-10	5.96E-10	5.11E-10	4.47E-10	3.97E-10	
I-133	3.80E-09	1.90E-09	1.26E-09	9.50E-10	7.60E-10	6.33E-10	5.42E-10	4.75E-10	4.22E-10	
I-134	1.10E-08	5.50E-09	3.67E-09	2.75E-09	2.20E-09	1.83E-09	1.57E-09	1.37E-09	1.22E-09	
I-135	2.83E-09	1.41E-09	9.44E-10	7.08E-10	5.66E-10	4.72E-10	4.04E-10	3.54E-10	3.14E-10	
I-136	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Br-83	2.66E-11	1.33E-11	8.88E-12	6.66E-12	5.32E-12	4.44E-12	3.80E-12	3.33E-12	2.96E-12	
Br-84	1.71E-09	8.56E-10	5.71E-10	4.28E-10	3.42E-10	2.85E-10	2.44E-10	2.14E-10	1.90E-10	
Br-85	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Total dose	2.47E-08	1.23E-08	8.24E-09	6.18E-09	4.94E-09	4.12E-09	3.53E-09	3.09E-09	2.74E-09	

8.2.2 Room B

Table A- 18: The Activity Achieved for Recirculation of Air With Filter Model at the Expected Leakrate of 0.0015% per Day (room B)

Table A-18 (a): Noble gases

Radionuclide(s) Air Change Rate	Activity (Bq) for different Air Change Rate									
	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2	
Kr-83m	5.82E-04	1.92E-04	1.06E-04	7.16E-05	5.33E-05	4.22E-05	3.48E-05	2.96E-05	2.57E-05	
Kr-85m	4.20E-04	1.61E-04	9.69E-05	6.86E-05	5.30E-05	4.30E-05	3.62E-05	3.13E-05	2.75E-05	
Kr-85	1.65E+00	8.29E-01	5.52E-01	4.14E-01	3.31E-01	2.76E-01	2.36E-01	2.07E-01	1.84E-01	
Kr-87	4.42E-03	1.38E-03	7.35E-04	4.82E-04	3.52E-04	2.75E-04	2.24E-04	1.89E-04	1.63E-04	
Kr-88	2.03E-03	7.24E-04	4.17E-04	2.88E-04	2.18E-04	1.75E-04	1.46E-04	1.25E-04	1.10E-04	
Kr-89	6.99E-01	2.48E-01	1.21E-01	7.14E-02	4.70E-02	3.33E-02	2.49E-02	1.94E-02	1.55E-02	
Kr-90	1.57E-01	1.51E-01	1.44E-01	1.36E-01	1.27E-01	1.18E-01	1.08E-01	1.00E-01	9.17E-02	
Kr-91	2.12E-02	2.11E-02	2.10E-02	2.09E-02	2.08E-02	2.07E-02	2.06E-02	2.05E-02	2.04E-02	
Xe-131m	2.45E-07	1.22E-07	8.11E-08	6.08E-08	4.86E-08	4.05E-08	3.47E-08	3.03E-08	2.69E-08	
Xe-133m	3.99E-06	1.92E-06	1.27E-06	9.46E-07	7.54E-07	6.27E-07	5.36E-07	4.69E-07	4.16E-07	
Xe-133	6.92E-05	3.41E-05	2.26E-05	1.69E-05	1.35E-05	1.12E-05	9.63E-06	8.42E-06	7.48E-06	
Xe-135m	2.09E-02	5.59E-03	2.63E-03	1.56E-03	1.05E-03	7.67E-04	5.90E-04	4.72E-04	3.89E-04	
Xe-135	2.03E-04	8.68E-05	5.45E-05	3.96E-05	3.11E-05	2.56E-05	2.17E-05	1.88E-05	1.67E-05	
Xe-137	6.12E-01	1.94E-01	9.23E-02	5.37E-02	3.52E-02	2.50E-02	1.87E-02	1.45E-02	1.17E-02	
Xe-138	1.17E-01	3.13E-02	1.47E-02	8.71E-03	5.85E-03	4.25E-03	3.26E-03	2.60E-03	2.14E-03	
Xe-139	1.16E-01	1.10E-01	1.02E-01	9.29E-02	8.34E-02	7.44E-02	6.61E-02	5.86E-02	5.20E-02	
Xe-140	1.81E-02	1.79E-02	1.78E-02	1.76E-02	1.75E-02	1.73E-02	1.71E-02	1.69E-02	1.66E-02	
Total activity	3.430+00	1.61E+00	1.07E+00	8.19E-01	6.70E-01	5.71E-01	4.97E-01	4.4E-01	3.95E-01	

Table A-18 (b)

Radionuclide(s) Air Change Rate	Activity for different Air Change Rate									
	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2	
H-3	3.62E-01	1.81E-01	1.20E-01	9.05E-02	7.24E-02	6.03E-02	5.17E-02	4.52E-02	4.02E-02	
C-14	1.81E-01	9.07E-02	6.05E-02	4.53E-02	3.63E-02	3.02E-02	2.59E-02	2.26E-02	2.01E-02	

Table A-18 (c): Halogens

Radionuclide(s) Air Change Rate	Activity for different Air Change Rate									
	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2	
I-131	4.20E-11	2.08E-11	1.38E-11	1.03E-11	8.27E-12	6.89E-12	5.90E-12	5.16E-12	4.59E-12	
I-132	3.65E-07	1.26E-07	7.16E-08	4.90E-08	3.69E-08	2.95E-08	2.45E-08	2.10E-08	1.83E-08	
I-133	4.95E-09	2.28E-09	1.48E-09	1.09E-09	8.67E-10	7.18E-10	6.13E-10	5.34E-10	4.74E-10	
I-134	7.29E-06	2.15E-06	1.10E-06	7.07E-07	5.06E-07	3.88E-07	3.13E-07	2.60E-07	2.22E-07	
I-135	4.87E-08	1.98E-08	1.22E-08	8.81E-09	6.86E-09	5.62E-09	4.75E-09	4.12E-09	3.63E-09	
I-136	2.54E-03	1.81E-03	1.24E-03	8.69E-04	6.31E-04	4.74E-04	3.68E-04	2.93E-04	2.38E-04	
Br-83	5.50E-08	1.90E-08	1.08E-08	7.41E-09	5.58E-09	4.46E-09	3.71E-09	3.17E-09	2.76E-09	
Br-84	4.06E-06	1.14E-06	5.61E-07	3.46E-07	2.41E-07	1.81E-07	1.43E-07	1.17E-07	9.88E-08	
Br-85	1.29E-03	4.94E-04	2.47E-04	1.47E-04	9.72E-05	6.91E-05	5.18E-05	4.03E-05	3.23E-05	
Total activity	3.85E-03	2.30E-03	1.49E-03	1.01E-03	7.29E-04	5.44E-04	4.20E-04	3.34E-04	2.71E-04	

Table A- 19: Dose Received for Recirculation of Air With Filter Model at the Expected Leakrate of 0.0015% per Day (room B)

Table A-19 (a): Noble gases

Radionuclide(s)	Dose for different Air Change Rate													
	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2					
Air Change Rate														
Kr-83m	1.55E-18	5.14E-19	2.84E-19	1.91E-19	1.42E-19	1.12E-19	9.31E-20	7.91E-20	6.87E-20					
Kr-85m	4.66E-15	1.79E-15	1.07E-15	7.62E-16	5.88E-16	4.78E-16	4.02E-16	3.47E-16	3.05E-16					
Kr-85	5.99E-13	2.99E-13	1.99E-13	1.49E-13	1.19E-13	9.99E-14	8.56E-14	7.49E-14	6.66E-14					
Kr-87	2.71E-13	8.46E-14	4.50E-14	2.95E-14	2.16E-14	1.68E-14	1.37E-14	1.16E-14	9.99E-15					
Kr-88	3.03E-13	1.07E-13	6.21E-14	4.29E-14	3.25E-14	2.61E-14	2.18E-14	1.87E-14	1.63E-14					
Kr-89	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00					
Kr-90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00					
Kr-91	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00					
Xe-131m	1.54E-19	7.68E-20	5.11E-20	3.82E-20	3.06E-20	2.55E-20	2.18E-20	1.91E-20	1.69E-20					
Xe-133m	8.46E-18	4.09E-18	2.69E-18	2.00E-18	1.60E-18	1.33E-18	1.13E-18	9.95E-19	8.84E-19					
Xe-133	1.60E-16	7.90E-17	5.24E-17	3.92E-17	3.13E-17	2.60E-17	2.23E-17	1.95E-17	1.73E-17					
Xe-135m	6.24E-13	1.66E-13	7.84E-14	4.66E-14	3.13E-14	2.28E-14	1.76E-14	1.41E-14	1.16E-14					
Xe-135	3.58E-15	1.52E-15	9.59E-16	6.97E-16	5.47E-16	4.50E-16	3.82E-16	3.32E-16	2.93E-16					
Xe-137	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00					
Xe-138	9.97E-12	2.65E-12	1.24E-12	7.37E-13	4.95E-13	3.59E-13	2.76E-13	2.20E-13	1.81E-13					
Xe-139	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00					
Xe-140	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00					
Total dose	1.17E-11	3.31E-12	1.6E-12	1.00E-12	7.01E-13	5.26E-13	4.1E-13	3.40E-13	2.86E-13					

Table A-19 (b)

Radionuclide(s)	Dose (Sv) for different Air Change Rate									
	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2	
Air Change Rate										
H-3	3.00E-12	1.50E-12	1.00E-12	7.51E-13	6.01E-13	5.01E-13	4.29E-13	3.75E-13	3.34E-13	
C-14	4.91E-11	2.45E-11	1.63E-11	1.22E-11	9.82E-12	8.18E-12	7.01E-12	6.14E-12	5.45E-12	

Table A-19 (c): Halogens

Radionuclide(s)	Dose (Sv) for different Air Change Rate									
	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2	
Air Change Rate										
I-131	2.23E-19	1.10E-19	7.34E-20	5.49E-20	4.39E-20	3.65E-20	3.13E-20	2.74E-20	2.43E-20	
I-132	9.49E-17	3.28E-17	1.86E-17	1.27E-17	9.60E-18	7.67E-18	6.37E-18	5.45E-18	4.75E-18	
I-133	5.21E-18	2.40E-18	1.55E-18	1.15E-18	9.11E-19	7.55E-19	6.44E-19	5.62E-19	4.98E-19	
I-134	1.66E-15	4.91E-16	2.52E-16	1.61E-16	1.15E-16	8.85E-17	7.13E-17	5.93E-17	5.06E-17	
I-135	1.64E-17	6.70E-18	4.13E-18	2.97E-18	2.31E-18	1.89E-18	1.60E-18	1.39E-18	1.22E-18	
I-136	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Br-83	6.96E-19	2.40E-19	1.36E-19	9.36E-20	7.06E-20	5.64E-20	4.69E-20	4.01E-20	3.49E-20	
Br-84	6.41E-16	1.80E-16	8.86E-17	5.47E-17	3.81E-17	2.86E-17	2.26E-17	1.85E-17	1.56E-17	
Br-85	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Total dose	2.42E-15	7.14E-16	3.65E-16	2.32E-16	1.66E-16	1.27E-16	1.02E-16	8.5E-17	7.2E-17	

Table A- 20: Activity Achieved for Recirculation of Air With Filter Model at the Design Leakrate of 0.1% per Day (room B)

Table A-20 (a): Noble gases

Radionuclide(s) Air Change Rate	Activity (Bq) for different Air Change Rate									
	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2	
Kr-83m	3.88E-01	1.28E-01	7.09E-02	4.77E-02	3.55E-02	2.81E-02	2.32E-02	1.97E-02	1.71E-02	
Kr-85m	2.80E-01	1.07E-01	6.46E-02	4.57E-02	3.53E-02	2.87E-02	2.41E-02	2.08E-02	1.83E-02	
Kr-85	2.53E+03	1.26E+03	8.45E+02	6.34E+02	5.07E+02	4.22E+02	3.62E+02	3.17E+02	2.81E+02	
Kr-87	2.94E+00	9.20E-01	4.90E-01	3.21E-01	2.35E-01	1.83E-01	1.49E-01	1.26E-01	1.08E-01	
Kr-88	1.36E+00	4.83E-01	2.78E-01	1.92E-01	1.46E-01	1.17E-01	9.78E-02	8.38E-02	7.33E-02	
Kr-89	4.66E+02	1.65E+02	8.09E+01	4.76E+01	3.13E+01	2.22E+01	1.66E+01	1.29E+01	1.03E+01	
Kr-90	1.04E+02	1.01E+02	9.64E+01	9.09E+01	8.49E+01	7.87E+01	7.25E+01	6.67E+01	6.11E+01	
Kr-91	1.41E+01	1.41E+01	1.40E+01	1.39E+01	1.39E+01	1.38E+01	1.37E+01	1.37E+01	1.36E+01	
Xe-131m	1.63E-04	8.13E-05	5.41E-05	4.05E-05	3.24E-05	2.70E-05	2.31E-05	2.02E-05	1.79E-05	
Xe-133m	2.66E-03	1.28E-03	8.46E-04	6.31E-04	5.03E-04	4.18E-04	3.57E-04	3.12E-04	2.77E-04	
Xe-133	4.61E-02	2.27E-02	1.50E-02	1.12E-02	9.01E-03	7.50E-03	6.42E-03	5.61E-03	4.99E-03	
Xe-135m	1.39E+01	3.72E+00	1.75E+00	1.04E+00	7.02E-01	5.11E-01	3.94E-01	3.15E-01	2.59E-01	
Xe-135	1.35E-01	5.79E-02	3.63E-02	2.64E-02	2.07E-02	1.70E-02	1.44E-02	1.25E-02	1.11E-02	
Xe-137	4.08E+02	1.29E+02	6.15E+01	3.58E+01	2.35E+01	1.66E+01	1.24E+01	9.71E+00	7.80E+00	
Xe-138	7.85E+01	2.09E+01	9.81E+00	5.80E+00	3.90E+00	2.83E+00	2.17E+00	1.73E+00	1.42E+00	
Xe-139	7.79E+01	7.36E+01	6.81E+01	6.19E+01	5.56E+01	4.96E+01	4.40E+01	3.90E+01	3.46E+01	
Xe-140	1.20E+01	1.19E+01	1.19E+01	1.18E+01	1.16E+01	1.15E+01	1.14E+01	1.12E+01	1.11E+01	
Total activity	3.71E+03	1.79E+03	1.19E+03	9.03E+02	7.33E+02	6.19E+02	5.30E+02	4.7E+02	4.2E+02	

Table A-20 (b)

Radionuclide(s) Air Change Rate	Activity (Bq) for different Air Change Rate									
	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2	
H-3	2.48E+02	1.24E+02	8.29E+01	6.22E+01	4.97E+01	4.14E+01	3.55E+01	3.11E+01	2.76E+01	
C-14	9.77E+00	4.88E+00	3.25E+00	2.44E+00	1.95E+00	1.62E+00	1.39E+00	1.22E+00	1.08E+00	

Table A-20 (c): Halogens

Radionuclide(s) Air Change Rate	Activity (Bq) for different Air Change Rate									
	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2	
I-131	8.39E-08	4.15E-08	2.76E-08	2.06E-08	1.63E-08	1.37E-08	1.17E-08	1.03E-08	9.16E-09	
I-132	7.30E-04	2.52E-04	1.43E-04	9.79E-05	7.38E-05	5.90E-05	4.90E-05	4.19E-05	3.65E-05	
I-133	9.91E-06	4.57E-06	2.96E-06	2.18E-06	1.73E-06	1.43E-06	1.22E-06	1.07E-06	9.48E-07	
I-134	1.46E-02	4.32E-03	2.22E-03	1.41E-03	1.01E-03	7.79E-04	6.27E-04	5.22E-04	4.45E-04	
I-135	9.72E-05	3.96E-05	2.44E-05	1.75E-05	1.37E-05	1.12E-05	9.50E-06	8.23E-06	7.26E-06	
I-136	5.08E+00	3.61E+00	2.48E+00	1.73E+00	1.26E+00	9.48E-01	7.35E-01	5.86E-01	4.77E-01	
Br-83	1.10E-04	3.81E-05	2.16E-05	1.48E-05	1.11E-05	8.93E-06	7.42E-06	6.34E-06	5.53E-06	
Br-84	8.14E-03	2.28E-03	1.12E-03	6.94E-04	4.83E-04	3.63E-04	2.87E-04	2.35E-04	1.98E-04	
Br-85	2.58E+00	9.89E-01	4.95E-01	2.94E-01	1.94E-01	1.38E-01	1.03E-01	8.06E-02	6.47E-02	
Total activity	7.69E+00	4.61E+00	2.97E+00	2.03E+00	1.45E+00	1.08E+00	8.40E-01	6.67E-01	5.4E-01	

Table A- 21: Dose Achieved for Recirculation of Air With Filter Model at the Design Leakrate of 0.1% per Day (room B)

Table A-21 (a): Noble gases

Radionuclide(s) Air Change Rate	Doses (Sv) for different Air Change Rate									
	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2	
Kr-83m	1.03E-15	3.43E-16	1.89E-16	1.27E-16	9.50E-17	7.52E-17	6.21E-17	5.27E-17	4.58E-17	
Kr-85m	3.11E-12	1.19E-12	7.17E-13	5.08E-13	3.92E-13	3.18E-13	2.68E-13	2.31E-13	2.03E-13	
Kr-85	9.16E-10	4.58E-10	3.05E-10	2.29E-10	1.83E-10	1.52E-10	1.31E-10	1.14E-10	1.01E-10	
Kr-87	1.80E-10	5.64E-11	3.00E-11	1.97E-11	1.44E-11	1.12E-11	9.18E-12	7.73E-12	6.66E-12	
Kr-88	2.02E-10	7.18E-11	4.14E-11	2.86E-11	2.17E-11	1.74E-11	1.45E-11	1.24E-11	1.09E-11	
Kr-89	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Kr-90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Kr-91	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Xe-131m	1.03E-16	5.12E-17	3.40E-17	2.55E-17	2.04E-17	1.70E-17	1.45E-17	1.27E-17	1.13E-17	
Xe-133m	5.64E-15	2.72E-15	1.79E-15	1.33E-15	1.06E-15	8.87E-16	7.59E-16	6.67E-16	5.89E-16	
Xe-133	4.33E-13	2.13E-13	1.41E-13	1.06E-13	8.47E-14	7.05E-14	6.04E-14	5.28E-14	4.69E-14	
Xe-135m	4.16E-10	1.11E-10	5.23E-11	3.10E-11	2.09E-11	1.52E-11	1.17E-11	9.39E-12	7.74E-12	
Xe-135	2.39E-12	1.01E-12	6.39E-13	4.64E-13	3.64E-13	3.00E-13	2.54E-13	2.21E-13	1.95E-13	
Xe-137	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Xe-138	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Xe-139	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Xe-140	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Total dose	1.72E-09	7.00E-10	4.30E-10	3.09E-10	2.41E-10	1.97E-10	1.67E-10	1.44E-10	1.27E-10	

Table A-21 (b)

Radionuclide(s) Air Change Rate	Dose (Sv) for different Air Change Rate									
	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2	
H-3	8.26E-09	4.13E-09	2.75E-09	2.06E-09	1.65E-09	1.37E-09	1.18E-09	1.03E-09	9.18E-10	
C-14	1.06E-08	5.33E-09	3.55E-09	2.66E-09	2.13E-09	1.77E-09	1.52E-09	1.33E-09	1.18E-09	

Table A-21 (c): Halogens

Radionuclide(s) Air Change Rate	Dose (Sv) for different Air Change Rate									
	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2	
I-131	4.45E-16	2.20E-16	1.46E-16	1.09E-16	8.76E-17	7.30E-17	6.25E-17	5.47E-17	4.86E-17	
I-132	1.89E-13	6.54E-14	3.71E-14	2.54E-14	1.91E-14	1.53E-14	1.27E-14	1.08E-14	9.49E-15	
I-133	1.04E-14	4.80E-15	3.11E-15	2.30E-15	1.82E-15	1.51E-15	1.28E-15	1.12E-15	9.97E-16	
I-134	3.32E-12	9.85E-13	5.05E-13	3.22E-13	2.31E-13	1.77E-13	1.42E-13	1.18E-13	1.01E-13	
I-135	3.28E-14	1.33E-14	8.24E-15	5.93E-15	4.62E-15	3.78E-15	3.20E-15	2.77E-15	2.450E-15	
I-136	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.000E+00	
Br-83	1.39E-15	4.81E-16	2.73E-16	1.87E-16	1.41E-16	1.12E-16	9.38E-17	8.01E-17	6.995E-17	
Br-84	1.28E-12	3.60E-13	1.77E-13	1.09E-13	7.63E-14	5.73E-14	4.53E-14	3.71E-14	3.127E-14	
Br-85	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.000E+00	
Total dose	4.84E-12	1.43E-12	7.32E-13	4.66E-13	3.33E-13	2.5E-13	2.05E-13	1.71E-13	1.459E-13	

