Journal of Radiation and Nuclear Applications
An International Journal

http://dx.doi.org/10.18576/jrna/100101

Dispersion Modeling of Accidental Release of ^{131}I from Radioisotopes Production Factory

Amr Abdelhady *

Department of Reactors, Nuclear Research Center, Egyptian Atomic Energy Authority, Egypt.

Received: 2 Oct. 2024, Revised: 22 Nov. 2024, Accepted: 1 Dec. 2024.
Published online: 1 Jan 2025

Abstract: One of the main studies that must be conducted before installing or building a radioisotopes production factory (RPF) is the radiological effect of the accidental release of the radioisotopes on the personnel and the environment surrounding the factory. The expected dose levels and the radioactive contamination areas must be determined to prepare the proper countermeasure after the hypothetical accident. In this study, the radioisotopes production factory is built inside a nuclear research center for the production of ^{131}I and ^{99}Mo from irradiated low-enrichment uranium (LEU) plates. It contains hot cells for extracting and preparing the ^{131}I and ^{99}Mo after irradiating the LEU plates inside the reactor core. The study focuses on evaluating the dose levels around the RPF after the accidental release of ^{131}I due to malfunction during the ^{131}I preparation process inside the iodine hot cell. Conservatively, the maximum amount of the ^{131}I release would be considered to calculate the maximum dose received by the personnel after the accident. The radiation dose levels around the RPF would be computed using GENII-2 code considering the site meteorological data. The results show that the maximum dose would be located at distances from 800 to 5500 m from the RPF building in the direction ranging between 140^{o} and 200^{o}. The result shows that the maximum dose would be more than the permissible limit for the worker. The study ensures the importance of instant distributing the potassium iodide tablets to the persons who are located around the RPF building after the accident.

Keywords: ^{131}I release, emergency, radiation dose, ^{131}I production, radioactive dispersion.

1 Introduction

An emergency is one of the conditions that must be studied before installing any nuclear or radiological facilities. Radioisotope production factories (RPF) are classified as radiological facilities that prepare radioactive materials for utilization in industrial and medical applications. RPF is built inside the nuclear research center for the production of ^{131}I and ^{99}Mo for the sake of medical uses [1]. Extracting and preparing the radioactive materials in the RPF must be conducted inside a confinement place to avoid any leakage or release to the environment or exposing the workers and the public to a high radiological dose level. The extraction chemical processes are always conducted inside hot cells to maintain safe radiological conditions for the workers who are located beside them during normal operation [2]. The hot cells always are provided with the proper filters to avoid releasing the radioactive materials into the environment and public. Choosing and constructing the proper filter depends on the chemical behavior of the radioactive materials. So, the production of radioactive iodine inside the isolated hot cell needs to provide the cell with a charcoal filter type since it chemically has a high capability for adsorbing the released iodine before discharging into the environment via the ventilation system. A hypothetical accidental release of ^{131}I from the cell into the environment due to the loss of the charcoal filter must be studied carefully to determine the environmental and personnel impact. Several program codes have been developed to simulate the radioactive materials release and to study the radiation dose distributions around the accidental release point. GENII-2 code [3] is a program code that was developed to simulate the radioactive materials released into the environment and to determine the total radiation dose due to the contaminated air, the ground deposition, and the external exposure. The study focuses on using GENII-2 code to simulate releasing the ^{131}I from the hot cell into the environment around the RPF taking the meteorological conditions into account. Estimating the radiation dose levels distribution around the ^{131}I production factory after the accidental release is very important in determining the radiological zone levels and consequently estimating the urgent protective action zone (UPZ) and precautionary action zone (PAZ) [4].

*Corresponding author e-mail: amr.abdelhady@gmail.com

2 Materials and methods

2.1 Description of the radioisotopes production factory

The RPF is located in the vicinity of a multi-purpose nuclear reactor (MPR). MPR is an open pool-type reactor, of 22 MW power, that uses the low enrichment uranium plates (LEU) to produce ^{131}I and ^{99}Mo by irradiating to neutron flux of 1.48×10^{14} n/cm^2.s for 48 h in the reactor core [1, 5].

RPF is a building incorporating the hot cells for the processing of ^{99}Mo and ^{131}I including dissolution, purification, dispensing, and packaging. The RPF building has three types of areas classified by the radioactivity level handled inside them, namely: free, supervised, and controlled. No radioactive material is handled in the free area including offices, dressing rooms, and common services [6].

Radioactive material samples with minimum activity levels are handed in the supervised area, which generally comprises quality control laboratories and front cell operation areas. The controlled area is the region where hot cells are located and the factory's highest activity inventories are handled. This area contains the room and the cell ventilation filters, as well as the gas, liquid, and solid management areas. Maintenance operations on the hot cells are carried out from this area which also serves for the entry of raw material for the production and exit of the final product. The factory has twelve hot cells and each cell has viewing windows, tongs and master-slave manipulators, material entry and exit doors, and maintenance access doors as shown in Figure 1. The RPF includes waste storage to allow decay but not final waste stream processing. The radioactive waste treatment plant is located outside the RPF site [6].

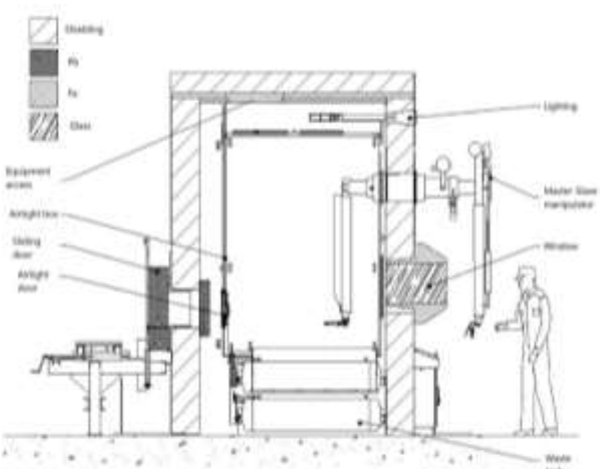

Fig. 1. The ^{131}I production hot cell

2.2 The ^{131}I extraction process

The irradiated target plates would be transferred from the MPR into the cell via a shielded flask and then the target plates would be loaded into the dissolver. The liquid would be filtered and transferred by nitrogen gas displacement through an ion exchange column where the ^{99}Mo and ^{131}I were retained [6]. The ^{99}Mo product would then be eluted from the column and transferred to the purification hot cell. The column containing the ^{131}I was then sealed and transferred to the ^{131}I production hot cell.

2.3 The ^{131}I accidental release scenario

The ^{131}I hot cell is connected to the RPF ventilation system and provided with a charcoal filter to prevent releasing ^{131}I into the environment during normal operation and accidental conditions. The amount of activity of ^{131}I during the extraction process depends on the neutrons flux and the irradiation time that the LEU plates that were exposed inside the reactor core. ORIGEN2.1 code [7] would be used to evaluate the activity of ^{131}I due to the ^{235}U fission in the LEU plates taking the decay time (transport time) into consideration. A breakage of the ^{131}I chemical process components may result in a spill of the radioactive ^{131}I into the cell. ^{131}I is a sublimed material that can be transported from the liquid phase to the vapor state. In case of loss of the charcoal filter, the ^{131}I would be transported from the cell to the environment through the RPF stack. So, the amount of ^{131}I released activity depends on the volume of the spilled ^{131}I and the air discharge flow rate. For conservative calculations and due to the complexity of determining the volume of the spilled ^{131}I during the accident, the amount of the ^{131}I released activity may be taken as the total activity conducted in the hot cell. The dose would be assessed by the maximum activity of ^{131}I released into the environment (120 Ci).

Figure 2 shows the activity of ^{131}I versus decay time, resulting from ORIGEN2.1 calculation, after irradiating 6 plates of LEU to neutron flux of 1.4×10^{14} n/cm^2.s during 48 h of irradiation time inside the core. The decay time represents the transport time after removing the LEU plates from the core including the chemical processing time required to extract the ^{131}I from the fission products.

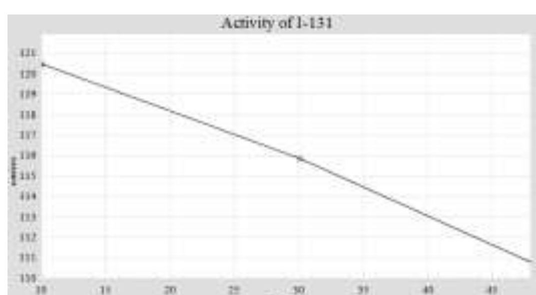

Fig. 2. The ^{131}I activity versus decay time.

2.4 RPF site meteorological condition

The meteorological data were simulated using the measured hourly data over 365 days for the reactor site [8]. Figure 3a indicates that 31.8 % of the wind direction data was distributed from the north (N), and 23.9 % from the north-north-west (NNW) directions. Winds from NNE (8 %), and west (8 %) directions were lowly distributed. Wind from the north occupied the maximum distribution in the annual data, whereas winds from the east had the minimum distribution.

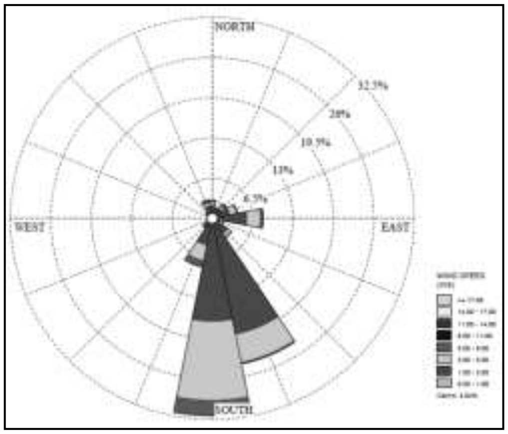

Figure 3a

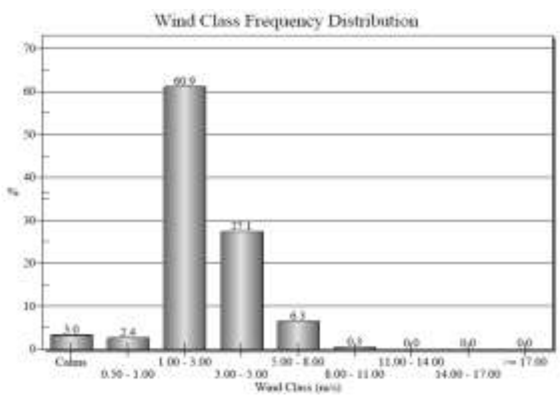

Figure 3b

Fig. 3. The windrose and the frequency distributions of RPF site.

The wind class frequency distribution in the reactor site shows that light breeze, gentle breeze, and moderate breeze would represent 60.9, 27.1, and 6.3 % of the wind speed distribution respectively as shown in Figure 3b. Where, light breeze represents the wind speed which ranges between 1 to 3 m/s, gentile breeze represents the wind speed which ranges between 3 to 5 m/s, and moderate breeze represents the wind speed which ranges between 5 to 8 m/s.

2.5 The sequence of the dose assessment

The GENII-2 computer code was developed at Pacific Northwest National Laboratory (PNNL) to implement dosimetry models recommended by the International Commission on Radiological Protection (ICRP). The GENII-2 system was developed to provide a set of programs for calculating radiation dose and risk from radionuclides released into the environment.

In this study, a model was built to simulate the transport of the ^{131}I released from the RPF stack at a height of 27 m into the environment due to the postulated breakage in the ^{131}I tubes accompanied by loss of the charcoal filter. A set of modules including air module, chronic plume, exposure pathways, receptor intake, and health impact were constructed to simulate the ^{131}I transportation and consequently estimate the distribution of effective doses within a distance of 80000 m from RPF building in all directions as shown in figure 4. Exposure pathways include direct exposure from the contaminated soil, air inhalation, and direct exposure from air submersion. A report module was generated to include the dose distributions along distances from 300 to 80000 m in all directions.

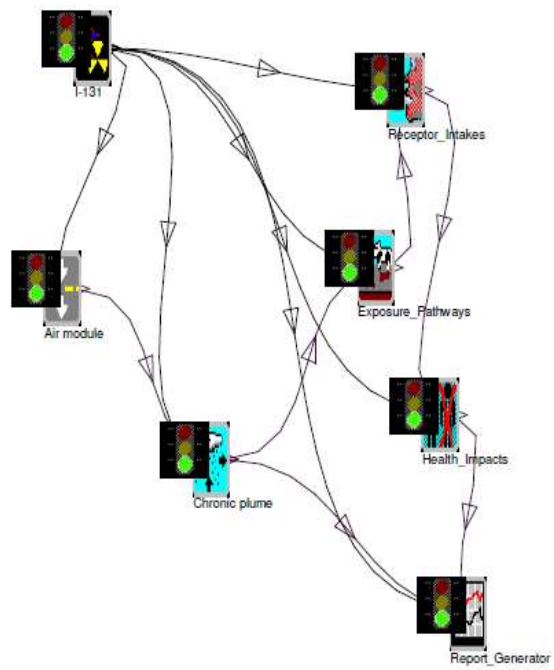

Fig. 4. GENII-2 dose assessment modules are due to ^{131}I release.

3 Results and the Discussion

The estimation of UPZ and PAZ that will be taken upon declaration of general emergency for avoiding the occurrence of severe deterministic health effects as well as to keep the doses below the generic criteria at which protective actions and other response actions are justified to reduce the risk of stochastic effects. The precautionary Action zone (PAZ) based on the equivalent dose of 1 Sv in one day to bone marrow is considered in the present study [4, 9]. Similarly for Urgent Protective Action Zone (UPZ) is inhalation dose of 0.1 Sv in seven days is considered [9].

Figures 5 and 6 show the total radiation dose distribution around the RPF illustrated in Sv due to accidental release ^{131}I. The total radiation dose includes ^{131}I inhalation, the ground shine from ^{131}I deposited on the soil, and the external dose from the air contaminated by ^{131}I. The total dose distributions show that the maximum dose, higher than the worker permissible limit (0.02 Sv) [10], would be located in the directions ranging between 140^{o} and 200^{o} in the distances ranging between 800 to 5500 m from the RPF as shown in figures 5 and 6 respectively. The maximum dose locations agree with the meteorological data that show that the main winds come from the N and NNW directions representing 56% of the total wind direction.

Figure 6 represents the total dose distribution with the distance from the RPF which focuses on the wind directions ranging between 140^{o} to 200^{o}. It obtained that the maximum dose would be 0.066 Sv which is lower than the UPZ limit (0.1 Sv). Table 1 shows the maximum equivalent dose for the organs and it shows that the equivalent dose for bone marrow is 3.61E-02 Sv which is lower than the PAZ limit (1 Sv). So, the amount of radioactive iodine released to the environment due to the accident would not need to prepare UPZ and PAZ after the accident.

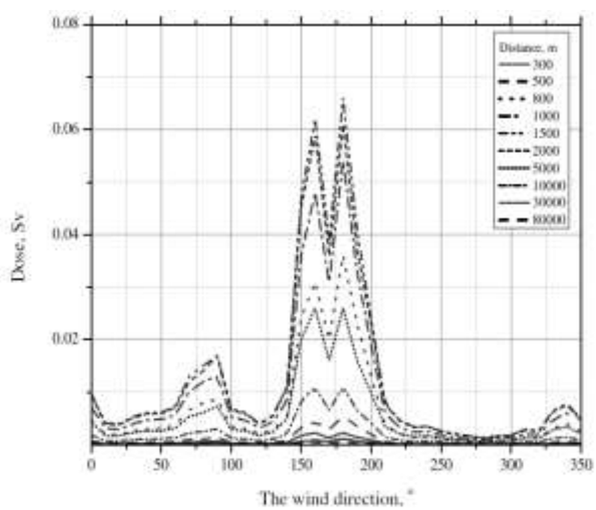

Fig. 5. The dose distribution due to accidental release of ^{131}I with the wind directions.

Table 1 shows the maximum equivalent dose for the organs after the radioiodine release accident. As mentioned above, the maximum dose would be located at a distance of 1000 to 2000 m from the RPF building, and this area is approximately inhabited. This area could be divided into two regions; the first region from the RPF building to 1300 m is located inside the working area. The second region from 1300 to 5500 m from the RPF building is located outside the working area. So, the persons who are located inside the first region would be considered as workers, and those located inside the second region would be considered as public.

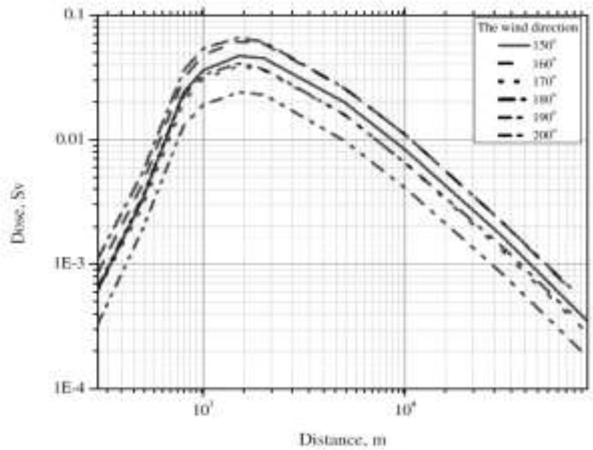

Fig. 6. The dose distribution due to accidental release of ^{131}I with the distance.

Generally, the presence of any person in the two regions is rare but conservatively the tabulated values would be compared with the dose permissible limit for the public and the worker.

The maximum effective dose, as shown in Table 1, is more than the annual permissible limit for the worker (20 mSv/yr) and the public (1 mSv/yr) according to ICRP60 [10]. This results from the high dose received by the thyroid gland and could be decreased by distributing the potassium iodide KI tablets to the persons who are located around the RPF building instantly after the ^{131}I release accident [9]. Distributing the KI tablets early on the person results in preventing the thyroid from receiving the radioactive iodine and then decreasing the thyroid equivalent dose and consequently the person's effective dose.

Comparing the maximum equivalent dose values with the permissible limit for the public (50 mSv) [10], shows that all the organs would receive equivalent doses less the permissible limit except bone surface, skin, and thyroid organs. The thyroid would receive the maximum equivalent dose, 620 mSv because it is the main target for the inhaled radioiodine.

Comparing the maximum equivalent dose values with the permissible limit for the worker (500 mSv) [10], shows that all the organs would receive an equivalent dose less than the permissible limit except the thyroid organ that would receive 620 mSv.

Table 1. The maximum equivalent doses for the organs.

Organ	Max. equivalent dose, mSv	Organ	Max. equivalent dose, mSv
Adrenals	31.8	Lungs	36
Bladder	35.2	Muscle	38.8
Bone	58.7	Ovaries	35.1

Surface			
Brain	33.7	Pancreas	31
Breasts	38.1	Bone marrow	36.1
Esophagus	30.3	Skin	63.8
Stomach Wall	33.9	Spleen	34
SI Wall	32.6	Testes	39.3
ULI Wall	33.4	Thymus	34.3
LLI Wall	33.8	Thyroid	620
Kidneys	34	Uterus	32.7
Liver	33.9	Effective dose	65.6

The previous calculations for the radiation dose distribution around the RPF building after the release accident were carried out supposing that the total amount of ^{131}I released was 120 Ci but the ^{131}I production now is less than this value, around 50 Ci, and so, the computed dose from the ^{131}I release would be less than the tabulated values. The effective dose in this value would be 27.33 mSv which is more than the permissible limit and so distributing KI tablets is very effective in decreasing the received dose after the accident.

In case of activating the charcoal filters provided to the ^{131}I hot cell during the accident would result in decreasing the maximum received dose to the worker to a level less than the worker's permissible limit (3.28 mSv for 120 Ci, and 1.3665 mSv for 50 Ci) but still more than the public permissible limit assuming that the charcoal filters efficiency is 95% [11].

4 Conclusion

A model of dispersion of ^{131}I due to accidental release from the radioisotope production factory was developed to evaluate the radiation dose distribution around the factory. The study was carried out assuming the maximum amount of ^{131}I release in case of loss of the charcoal filter. GENII-2 code was used to simulate the ^{131}I dispersion and to assess the dose distribution along distances from 300 to 80000 m from the factory. It was found that the radiation dose would be more than the permissible limit in the region ranging between 800 to 5500 m at the direction ranging between 140 to 200^{o}. In the case of proper working of the charcoal filter during the accident, the dose would be decreased to a level less than the worker permissible limit but still more than the public permissible limit. Accidentally, this area is unhabitated but it is recommended to distribute KI tablets to the persons who are located inside the area of concern to decrease the received radiation dose as low as possible. The following table shows the estimated maximum dose in each case and compares the values with the permissible limits:

Amount of ^{131}I released.	The estimated maximum dose, mSv			
	Without filter		With filter	
The promising production amount: 150 Ci	65.6	More than a worker and public limits	3.28	Less than the worker limit and more than the public limit
The current production amount: 50 Ci	27.3	More than a worker and public limits	1.366	Less than the worker limit and more than the public limit

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