Introduction
Every living being is exposed to radiations every day, either from low-level radiation found in food, soil, building materials, air, and/or from outer space. The average natural background radiation exposure is about 2.0–3.0 mSv per year. A radiation worker can get a radiation exposure dose of 20.0 mSv each year above this background level. However, the limit for a pregnant radiation worker is set at 1.0 mSv to the embryo/fetus as the developing embryo/fetus is considered as a member of the general public. Thus, a pregnant radiation worker during her pregnancy encounters a typical situation where she has to keep a balance between the prescribed radiation dose restrictions and the professional commitment.

Radiation Exposure
The radiation workers in a clinical nuclear medicine facility are occupationally exposed to different nuclear radiations (α, β, γ, and positrons). The exposure to the workers is generally received during the preparations of radio-pharmaceuticals, patients’ injections, and from injected patients during positioning and imaging. A nuclear medicine department has four designated areas, viz. restricted, controlled, supervised, and unrestricted areas. The radiation exposure levels vary in these different areas. An access to the restricted zone is limited from the viewpoint of radiation safety to keep the dose to the fetus within the prescribed limit without compromising the professional commitment.
The monitoring of radiation exposure to the radiation workers is a mandatory requirement. Each radiation worker in a nuclear medicine setting is required to wear two thermo-luminescent dosimeters (TLD) that is one as a chest badge and the second one as a wrist badge. The declaration of pregnancy by a female radiation worker is obligatory. Once the pregnancy status is confirmed, she is required to wear an additional badge at the level of abdomen during the entire pregnancy period to monitor the total exposure dose to the embryo/fetus. The TLD badges are changed every 3 months and sent to the approved agencies for radiation absorbed dose readings. The designated RSO in each department keeps the records of absorbed doses received by an individual radiation worker. The RSO ensures that the doses do not exceed the regulatory limits prescribed for radiation workers in general and pregnant workers in particular.

**Radiation Risks**

Risks associated with radiation exposure fall into two categories, stochastic risks and deterministic risks. The probability of stochastic effects increases with the dose while the deterministic effects (also called as nonstochastic effects) occur above a threshold dose. Risks associated with the embryo/fetus are divided into preconception and perinatal risks. The radiation exposure in the preconception period may lead to sterility or genetic mutations leading to hereditary effects. As per the BEIR V report, a temporary sterility results from a single acute exposure of 0.65–1.5 Gy and permanent sterility in adult ovary can occur at an acute radiation dose of 2.5–6.0 Gy. The long-term and repeated exposure of more than 0.2 Gy may lead to permanent sterility in female reproductive organs. These doses are well above the typical lifetime exposure in any nuclear medicine procedures. Thus, for the female radiation worker in the nuclear medicine department, the risks of sterility or hereditary effects are minimal. Most perinatal risks are nonstochastic in nature and very much depend on the stage of gestation. Table 1 summarizes the deterministic effects and threshold doses at different gestational weeks.

Radiation exposure during the period before the embryo is implanted may increase the radiation risk; but if the embryo is able to survive and implant, then it is expected to grow normally. The actual risks of the miscarriage at this stage are not known, as most of the times, the female worker is unaware of her pregnancy in the initial 1–3 weeks. At the time of organogenesis (from 3 weeks till 8 weeks), the effects of radiation exposure above the threshold level can result in the major malformations and growth retardation. The primary risks between 8 weeks and 15 weeks of the gestation are severe mental retardation and growth retardation. Risk of decrease in intelligence quotient and mental disability is observed in 16 weeks and above, if mother is exposed to high radiation doses.

![Fig. 2: Radiation exposure in μSv during the entire pregnancy period of 40 weeks](image)

The risk of developing cancer after prenatal radiation exposure does not hold a threshold and thus is a stochastic risk. The carcinogenic risk has a linear relationship with the radiation dose, stating that even a small perinatal radiation exposure can potentially increase the risk of cancer occurrence. The estimated absolute risk is about 6.0% per Gy of the fetal exposure.

Practically, it is extremely rare to encounter such an incident in view of the strict practice and regulations followed by the highly trained professionals and periodic surveillance of the nuclear medicine facilities by the regulatory authorities. As per the guidelines, the permissible radiation dose for the entire pregnancy is 1.0 mSv or approximately 25 μSv/week (1000 μSv/40 weeks).

In the present study, the total radiation doses received during the first and second pregnancy (as recorded by TLDs) on the surface of abdomen were 550.0 μSv and 400 μSv, respectively. The results of the radiation exposure (in μSv) during two pregnancies (40 weeks each) in the same radiation worker are presented in Figure 2. However, the radiation exposures as read by digital monitor (RAD 605, Rados Technology, Finland) over 2 pregnancies were 98.0 and 88.0 μSv, respectively. Therefore, the radiation exposures by digital monitor are underestimated. It is thus observed that TLD provides more realistic absorbed dose measurements received by the fetus/embryo and were well within the permissible limits. It has been previously reported by Sylvain et al. that a nuclear medicine worker performing majority of the routine duties in different locations typically receives radiation doses that are below 10.0 μSv per day.

The average dose received per procedure can be further reduced with training and use of shielding material.

**Recommendations to Reduce Radiation Exposure Dose**

Radiation doses to the radiation workers should be kept ALARA (as low as reasonably achievable), and this principle (ALARA) is practiced as a guide for dose reduction to occupational workers. Although the radiation dose limits specified by AERB are legal limits that must not be exceeded at any time, these are not the threshold values. The basic principles of radiation protection includes time, distance, and shielding. Decreasing the time of exposure and increasing the distance from the radioactive source can drastically reduce the radiation exposure to the worker. And further, a proper use of shielding is very effective in minimizing the radiation dose to a worker. Although wearing a lead apron is generally not recommended in a pregnant nuclear medicine worker, she should consult a RSO if additional protection is to be provided by a lead
Occupational Radiation Exposure During Pregnancy

apron. And duty roster modifications of a pregnant worker shifting her to low radiation dose areas may also be considered as an alternative approach for reducing the radiation dose exposures in pregnant workers.

In the present case scenario, the pregnant worker completely avoided the duties in the restricted zone like cyclotron room and radiotherapy ward and some controlled areas like PET radiopharmacy, PET/CT scanner room and SPECT/CT room. Her duties were further modified and she was told to avoid some supervised areas like hot lab for long durations and gamma imaging room on the day of scanning of radioiodine therapy patients. However, she performed duties for 40 hours per week with the job modifications. Till the full term of the pregnancy, she spent on an average 14–15 hours in an in vitro lab, 6 hours in the counting room, 6 hours in hot lab, and remaining 14 hours in the single head gamma imaging room. ICRP recommends not to terminate the pregnancy if fetal radiation exposure is less than 100 mGy. If the fetal dose is between 100 and 500 mGy, the decision lies on the female worker and RSO based on the circumstances. The termination is justified if the fetal radiation dose is more than 500 mGy, as significant fetal damage may happen.

**Conclusion**

In the past few decades, the involvement of females in the nuclear medicine fraternity has increased, and thus, understanding radiation exposure and risks is important part of the job profile. The general notion that it is not safe for pregnant workers to work in the nuclear medicine and radiological center is thus only a myth. Practically, pregnant workers can work safely by following appropriate shielding and radiation safety practices.

**References**

1. AERB Directive No. 01/2011—the dose limits for exposures from ionizing radiations for workers and the members of the public.