# CHAPTER I
# INTRODUCTION

## 1.1 Background

Globally, cancer is the second leading cause of death in the world. In 2022, cancer caused approximately 9.7 million deaths and resulted in 20 million new cases. About 1 in 9 men and 1 in 12 Women died from this disease. Cancer causes nearly 1 in 5 premature deaths in Indonesia due to non-communicable diseases (NCDs). Cancer deaths continue to increase, with an estimated 13.2 million people dying in 2030 (National Cancer Institute 2025). According to information from the Indonesian Ministry of Health, in 2025, the number of identified cancer cases in Indonesia is approximately 400.000 new cases each year, and cancer causes around 240.00 deaths annually. Various methods have been developed to treat cancer, one of which is through the use of radiation therapy or radiotherapy (Muhawarman 2025).

Radiotherapy is a treatment method that uses ionizing radiation to kill cancer cells by delivering therapy to damage them. One of the types of machines used in radiotherapy for cancer treatment is the Linear Accelerator (LINAC). With the advancement of technology, LINACs not only provide variations in photon and electron beam energies but have also introduced new beam modes such as Flattening Filter Free (FFF). LINAC FFF technology is more advanced than LINACs that still use a With Flattening Filter (WFF), as it can deliver higher dose rates, enabling shorter irradiation durations and better protection for healthy tissue.

However, analysis is needed to ensure that the LINAC can deliver accurate, stable doses that align with the treatment plan, so that the patient's healing effectiveness can be achieved without increasing the risk of damage to healthy tissue. This is in accordance with IAEA protocols in documents TRS-398 and TRS-483, which set a deviation of $\pm$2% as a reference for the calibration process to ensure that this limit can guarantee that the radiation is still clinically safe, thus preventing the risk underdosing cancer cells or of overdosing healthy tissue (Klein et al. 2009). Therefore, the calibration process is a crucial step in determining the deviation and output dose of the LINAC.

Based on a literature review, several studies have used various radiation sources as a form of cancer therapy. Dewang and Astuty (2024) analyzed the results of LINAC calibration measurements, mentioning the deviation for each WFF, FFF, and electron beam from the TrueBeam LINAC. They concluded that all results for each beam were within the tolerance limit of ±2% according to IAEA TRS-398 (Dewang and Astuty 2024). According to Sugiarta et al., 2022, the output dose for each photon beam energy (6 MV and 10 MV) still refers to 1 cGy/MU, and the deviation for each energy is within the range of ±3% (Sugiarta, Ratini, and Suyanto 2022). According to Mediawati et al., 2019, their research focused on comparing the deviation between photon and electron beams, which was within the tolerance limit of ≤5%, using TLD as a radiation output reader in a Solid Water Phantom medium (Mediawati, Nugroho, and Mutanto 2019). However, based on previous research, no study has been conducted comparing the accuracy and stability of deviation and dose measurement output for photon and electron beams in LINAC WFF and FFF modes, and there has been no study discussing the risk of damage impact on LINAC performance if the accuracy and stability of deviation and dose output exceed the tolerance limit of ±2%.

Therefore, this research was conducted to determine the deviation, dose, and stability of LINAC output for photon and electron beams in both WFF and FFF LINAC modes, ensuring that the deviation and dose of the LINAC output remain within the ±2% tolerance limit according to IAEA protocols.

### 1.2 Problem Formulation

1. What is the value of the electric charge and the output deviation of the LINAC for a photon beam with an energy of 6 MV for the With Flattening Filter (WFF) mode and the Flattening Filter Free (FFF) mode?
2. What are the values of electric charge and output deviation for the LINAC electron beam at energies of 6 MeV, 9 MeV, 12 MeV, 16 MeV, and 18 MeV?
3. Does the LINAC deviation still meet the International Atomic Energy Agency (IAEA) protocol standards, which is±2%?
4. How stable is the LINAC output against repeated measurements?

## 1.3 Problem Limitations

The limitations of this study are as follows:

1. The LINAC used is a Varian TrueBeam with measurements taken for beams in WFF, FFF, and electron beam modes. And the energy used is limited to clinical needs.
2. Environmental conditions, namely temperature, air pressure, and humidity, are corrected by the $K_{TP}$ correction factor.
3. The water phantom position, detector positon, SSD 100 cm, and field size 10×10 cm² are kept constant.
4. Voltages for the electron beam (+300 V, +75 V, −300 V) and the photon beam (+400 V, -400 V, +100 V) were repeated 5 times for each voltage.
5. The research follows international standard protocols, namely TRS-398 and TRS-483.
6. Data analysis includes electrical charge, deviation, and stability of LINAC output measurement repetition.

## 1.4 Research Objectives

1. Determine the values of electric charge and output deviation of photon beams with 6 MV energy for the With Flattening Filter (WFF) and Flattening Filter Free (FFF) modes.
2. Determine the values of electric charge and output deviation of electron beams for energies of 6 MeV, 9 MeV, 12 MeV, 16 MeV, and 18 MeV.
3. Verify that the LINAC output deviation still meets the standards of the International Atomic Energy Agency (IAEA) protocol, which is $\pm 2\%$.
4. Determine the stability level of the LINAC output based on repeated measurements.

## 1.5 Research Benefits

1. For BPAFK Surabaya: Provide data on LINAC performance evaluation that can be used for routine quality control, establish policies for LINAC maintenance, and validate calibration procedures performed at the installation.

2. For Radiotherapy Installation: Provide information on the output performance of the Varian TrueBeam LINAC, which can be used as a basis for improvement, strengthening the quality assurance (QA) program, and detecting potential dose deviations.
3. For Medical Physicists: Serve as a reference for evaluating the stability, deviations, and adjustment procedures of the Varian TruBeam LINAC output according to IAEA standards, thereby improving the accuracy and consistency of examinations.
4. For UPN "Veteran" Jawa Timur" Strengthen the institution's contribution to the field of medical physics by providing applied research and improving the academic quality and research output of students.
5. For Students: Serve as a learning source and reference for understanding radiotherapy QA procedures, calibration, deviation analysis, and experimental research methodologies using the Varian TrueBeam LINAC.

## 1.6 Research Hypothesis

**Table 1.1** Research hypothesis.

| **Problem Formulation** | **Null Hypothesis ($H_0$)** | **Alternative Hypothesis ($H_1$)** |
|---|---|---|
| What is the value of the electric charge and the output deviation of the LINAC for a photon beam with an energy of 6 MV for the With Flattening Filter (WFF) mode and the Flattening Filter Free (FFF) mode? | There is no significant difference in the values of electric charge and deviation between the photon beam in With Flattening Filter (WFF) mode and Flattening Filter Free (FFF) mode. | There are significant difference in the values of electric charge and deviation between the photon beam in With Flattening Filter (WFF) mode and Flattening Filter Free (FFF) mode. |
| What are the values of electric charge and output deviation for the LINAC electron beam at energies of 6 MeV, 9 MeV, 12 MeV, 16 MeV, and 18 MeV? | There is no significant difference in the values of electric charge and deviation between the electron beams at different energies. | There are significant difference in the values of electric charge and deviation between the electron beams at different energies. |
| Dose the LINAC deviation still meet the International Atomic Energy Agency (IAEA) protocol standards, whis is ±2%? | The output deviation of the LINAC exceeds the tolerance limit of ±2%. | The output deviation of the LINAC is still within the tolerance limit of ±2%. |
| How stable is the LINAC output against repeated mesurements? | There is no systematic change in the measurement repetitions. | There is a systematic change in the measurement repetitions. |