Chapter 12

Human Safety Aspects of an Accelerator

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Human safety should be the utmost concern of any system designer as loss of human life is unrecoverable. Even a minor damage to the human being is a life time blot on the head of the system designer. A design should be so fail safe that an operator should fail utterly even in case of intentional attempt.

12.1 Introduction

The moment we hear the word safety a shivering runs through our spinal cord and we start fearing that may be we are facing some dangerous situation. This is typical human psychology. Everyday millions of people travel by road and train without any fear and even most of the time without taking any safety measures like tightening the seat belt in the car, wearing the helmet while riding on the bike etc. But same person when boards in an aeroplane and when the air hostess starts explaining about the safety measures during travelling he/she starts fearing and starts praying for his/her safe journey. Although thousands of people are losing their life daily in the road accident across the world and hardly any air accident takes place in a year on average. Air accidents rarely take place and air travel is almost accident free because stringent safety measures are taken in air travelling. Moral of the introduction is that if you want to avoid the war be always ready for the war. On the same tone if you want to run something safely, in accident free manner, discuss all the probable aspects of accidents, design your system fail safe, breed defence-in-depth approach in your system design, do all the fault tree analysis, do all event analysis and design the system in such a way that even something goes wrong after all your precautions there should not be any damage to the human life and your system should face minimum damage. In this context let us discuss about the safety aspects of any accelerator and human safety aspects in particular.

12.2 Safety Aspects

Primarily following three are the main safety aspects of any accelerator:

a) Human Safety

b) Radiation Safety

c) Machine Safety

While considering the three safety aspect of accelerator in our design top most priority should be given to the human safety. The design should be planned on a single point agenda of safety that in no way human safety should ever be compromised and which in turn takes care of radiation safety and machine safety also. Loss of human life is unrecoverable and must be protected at any cost. All the modern day technologies like smart sensors, camera surveillance, biological attendance, face recognition software, alarm, hooter, fire resistance cable, personal protection equipments like helmet, gloves, Shoes, breathing equipment etc should be incorporated at the design level as well as during operation of the accelerator without considering the cost implications to protect human life.

12.2.1 Human Safety

Before taking any safety measure in the design one should first list down all the accident scenarios and probable threats in which human safety will get endangered. Let us list down those for the safe operation of any accelerator. Following are the major concerns with respect to human safety:

- **High Radiation Exposure from Accelerator**

- **Radiation Leakage in the Plant**
- **Human being Trapped inside the Accelerator Cell Area during Operation**
- **Lethal High Voltage Shock to Operator or any Human being**
- **Damage due to Noise Pollution**
- **Fire Accident**
- **Air Deficiency inside the Plant**

12.3 Safety Measures Taken

We shall now discuss the major steps taken in the accelerator design to ensure human safety against the above mentioned probable accident scenarios and threats to human life.

12.3.1 High Radiation Exposure from Accelerator

The most relieving and enlightening part of the accelerator operation is that in contrast with nuclear reactors, accelerators are inherently safe. Being an electrical system radiation is generated till the accelerator is ON, the moment accelerator is OFF radiation generation is also stopped [46]. There is nothing like residual radiation in case of accelerator (up to 10 MeV). Now to stop radiation during operation a concrete shielding is provided around the accelerator. For example at Electron Beam Centre, Kharghar, BARC around 2.6-meter thick concrete shielding is provided around 10 MeV, 10 kW RF Linac Electron Beam Accelerator and 1.4 m thick concrete shielding is provided around 1 MeV, 100 kW DC Electron Beam Accelerator. The concrete shield is designed using jig jag structure to reduce X-ray intensity outside the radiation shielding wall up to permissible level of 1 μSv/h [56, 57]. For low power accelerator based X-ray sources used at various airports as baggage scanner or cargo scanners at various seaports, localised shielding is provided using lead or steel. In every Accelerator some entry mechanism is provided for material handling for example in 10 MeV RF Linac a motorized mobile shield of graded fashion to avoid radiation leakage is provided for material handling (depicted in Fig. 12.1). Mobile shield closed position is electrically interlocked with the accelerator operation ensuring the trip of the accelerator in case of opening of the mobile shield during operation. The closed position limit switch sensor interlock also ensures that accelerator cannot be energized unless the mobile shield is closed. The very high dose rate like 1 MGy (or MSv) per hour below the scan horn of 10 MeV RF Linac and X-rays produced all around the accelerator is confined within the cell area by 2.6 m thick concrete shield and reduced up to 1 μSv/h [41, 46].
This thick concrete shield with various door interlocks ensures that there is no radiation hazard to any human being including the accelerator operating personnel during the accelerator operation. A hooter is buzzed all around outside the accelerator cell area before the start of the accelerator. Flash light starts rotating all around the accelerator areas during the operation. “Beam ON” display is provided at various points inside and outside accelerator area as an indicative sign to display that accelerator is under operation. Various door interlocks ensure that accelerator should get tripped in case of any opening of the entry points of the accelerator. This door limit switch sensor interlock also ensures that accelerator cannot be energized with the any doors in open state. Various fault tree analysis has been done to visualize all the probable accidents and their repercussions. It was concluded that accelerator being an electricity generated radiation source even in any probable worst accident scenario the accelerator system will get short circuited. In case of power supply failure, when no interlock works on time, the lack of power will ensure that the radiation source is OFF. Therefore, in no situation any high radiation exposure is going to take place in case of accelerator operation. Individual radiation dosimeter has been allotted to all radiation workers to record their life time radiation dose. This dosimeter is analyzed by independent expert

Figure 12.1: Motorized mobile shield with graded locking.

team on quarterly basis. In case of any abrupt variation from normal range is observed, a thorough investigation will be carried out as a precautionary safety measure and regulatory mandate.

12.3.2 Radiation Leakage in the Plant

Various S-band openings and maze type cable treys have to be provided to route the power and signal cables required for accelerator operation. Additional lead shielding in the form of balls and interlocked bricks are provided around the S-bend made for cable routing. Periodic radiation survey is done to observe any leakage radiation around the outer shielding walls while the accelerator is operating at rated power level. Various radiation monitors are installed outside the accelerator cell area to monitor the radiation level regularly. These are installed at Control Room, Power Supply Room and other required places. The radiation signal from the radiation monitor is interlocked with the accelerator operation. It ensures that if due to any reason radiation level increases beyond permissible limit the beam will be tripped ensuring the stop of radiation at source. All the radiation monitors are calibrated periodically.

12.3.3 Human being Trapped Inside the Accelerator Cell Area During Operation

It must be ensured that no human being should get trapped inside the cell area of any accelerator during operation of the accelerator. To achieve this “Search and Secure with Emergency Trip Modules” are installed in the accelerator cell area and at entrance doors of accelerator cell area. Before energizing the accelerator operator goes through the entire cell area and other connected shielded area and ensures the non-presence of any human being by manual operable Searched Area Button of the module (shown in Fig. 12.2). This is done sequentially ensuring that all the required area has been searched and hence operator has secured that area for operation. The “Searched Area” signal is interlocked with the accelerator operation providing the same protection what other safety interlocks implemented provides. The “Emergency Stop” press button is provided on all the modules to help any trapped human being to trip the accelerator in case of an almost non probable situation

where a human being left trapped and accelerator is ON. Various high definition CCTV cameras are installed inside the Cell Area, Scan Horn Area, Power Supply Room and in the jig jag corridors of radiation shielding to monitor the entire operation from control room on a big Monitor.

Figure 12.2: Search secure panel in 10 MeV cell area.

12.3.4 High Voltage Shock to Operator or any Human being

Utmost care is taken in the design of the various high voltage systems and high voltage high frequency systems of an accelerator to ensure human safety during the operation as well as maintenance of the accelerator. High Voltage Insulation Mats are laid down all along the Power Supply Room where High Voltage System Racks are installed. By default electron accelerators require 'negative voltage' to accelerate the electron and this allows the designer to keep the whole structure of accelerator and high voltage system structure at ground potential. RF ground pit and electrical power ground pit are provided separately in the accelerators. Power Ground and Signal Ground are provided separately. Earth Leakage Circuit Breakers (ELCBs) are used in various electrical panels to avoid any leakage current shock.

12.3.5 Damage due to Noise Pollution

The major source of noise is foil blower and ozone extraction pump. Noise level has been surveyed periodically with expert groups and documented. If at a particular location like Ozone Removal Pump Room, Chiller Room etc. and Low Conductivity Water (LCW) Plant Room, where high decibel noise is recorded, the room is designated as non-occupancy during the accelerator operation and remain locked. The operators, who operate these plants (start and stop), must have to use ear mask.

12.3.6 Fire Accident

Fire extinguishers are installed in the accelerator plant. All required types of fire extinguishers are placed inside the plant and their working is checked periodically by Fire Services Section

of BARC. Regular fire training program is arranged as per guideline of regulatory body along with fire drills. Fire zones have been marked inside the plant and one officer has been designated as the duty officer for that area. Emergency numbers are displayed on the notice boards of the accelerator premise and in accelerator control rooms. A well-defined organization responsibility chart is implemented to operate the plant which takes care of the day to day functioning of the plant. Approved fire order is implemented in the plant.

12.3.7 Air Deficiency Inside the Plant

During the operation of the accelerator as electron beam comes out in air, through a window made of titanium foil, it interacts with the air molecules and generates nascent oxygen which in turn reacts with air molecules and produce ozone. Ozone is generated and spread all around the scan horn area [47]. Since ozone molecules are much heavier than air molecules and so get settled down at the floor level up to little above of human height and in turn oxygen deficiency occurs in and around the accelerator cell area. To maintain the oxygen level ozone removal pumps are operated to provide sufficient air changes during the accelerator operation. Ozone level is being monitored during the accelerator operation at control room and permissible level of 100 ppb is interlocked with the accelerator operation [58]. After shutdown of the accelerator the mobile shield or any entry door can be opened only after the delay of 20 minutes to reduce the ozone level inside the cell area up to 100 ppb level. Air flow sensors are mounted on all the ozone pits to observe that ozone is being sucked properly. Additionally, periodic air changes verification has been carried out to ensure the proper working of ozone removal pumps and its duct.

12.4 Conclusions

Human safety must be ensured during the operation of the accelerator as loss of human life is irrecoverable. Hence a safety culture should be developed among the personnel of the plant. People should mandatorily use personnel protection equipment like the helmet, electrical insulation shoes etc, displaying board for wet floor etc during the day to day work of the plant.