33rd DAE SAFETY & OCCUPATIONAL HEALTH PROFESSIONALS MEET

November 23-25, 2016

Institute for Plasma Research, Gandhinagar

Monograph on

SAFETY IN HIGH POWER AND HIGH ENERGY ADVANCED TECHNOLOGIES

&

MEDICAL APPLICATIONS OF LASERS

Preface

This year, the 33rd DAE Safety and Occupational Health Professionals Meet is being jointly organized by Atomic Energy Regulatory Board (AERB), Mumbai and Institute for Plasma Research (IPR), Gandhinagar with themes, "Safety in High Power and High Energy Applications" and "Clinical Applications of Lasers".

Continuing with the tradition of bringing out theme specific monographs during these annual Meets, the monograph on this year's themes has been prepared. It consists of two parts: Part-A deals with the safety in high power and high energy applications and Part-B deals with Clinical Applications of Lasers.

In Part- A of the monograph, a brief introduction is provided to the different high power or high energy advanced technologies. Though Department of Atomic Energy is working on a number of advanced technologies, all may not have high power and high energy applications. The high power and high energy applications considered in this document are Nuclear Reactors, Fusion Technology, Particle Accelerators, Lasers, Neutron Generators and Gamma Irradiators. The hazards involved in such technologies are briefly described. There are a number of safety considerations and analyses involved in development and use of such technologies. However, for the better understanding of common people these are briefly described in two parts i.e. (i) Design & Construction" (ii) Commissioning & Operation. In addition regulatory requirements applicable for facilities involving advanced technologies in high power or high energy applications are also described.

Part-B of the monograph provides information on another important application of advanced technology related to health i.e., Clinical Applications of Lasers. There are a number of clinical applications of Lasers; diagnostic, treatment, cosmetic and surgical. The introduction of such applications will be informative to all but more useful for the medical fraternity attending the meet.

This monograph is intended for creating awareness amongst the safety and health professionals of nuclear and radiation facilities on hazards involved in high power and high energy advanced technologies as well as on how development of advanced technologies can benefit the common people. Although all efforts have been made to collect information from relevant experts in the field, the organizers do not necessarily endorse the correctness of the information.

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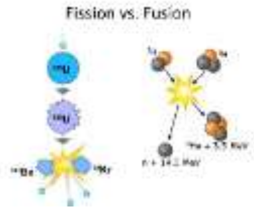

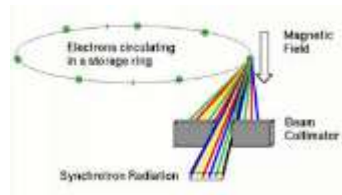

PART-A

SAFETY IN HIGH POWER AND HIGH ENERGY ADVANCED TECHNOLOGIES

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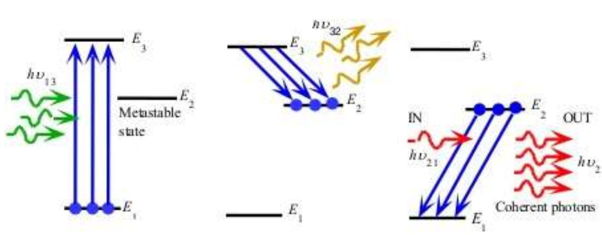
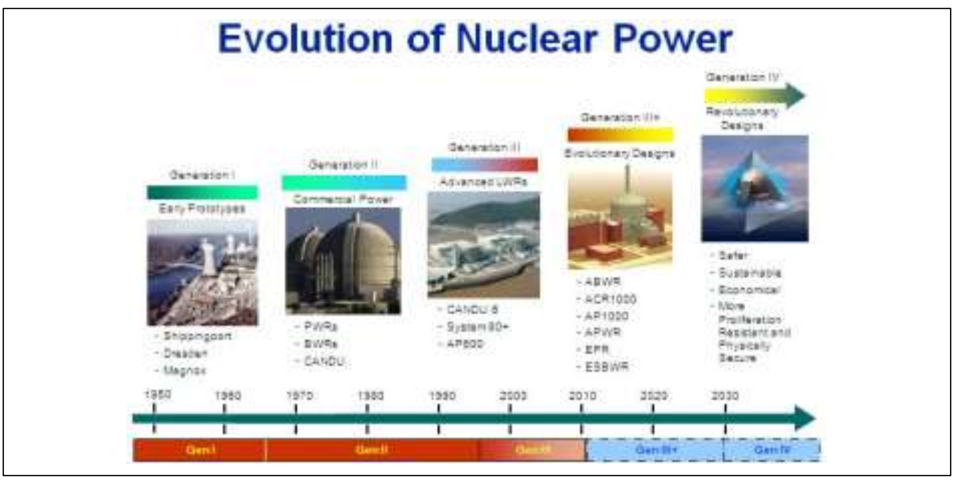


1.0 HIGH POWER & HIGH ENERGY TECHNOLOGIES AND ASSOCIATED HAZARDS

1.1 HIGH POWER NUCLEAR REACTORS

A nuclear reactor produces and controls the release of energy from splitting the nucleus of certain elements. In a nuclear power reactor, the energy released is used as heat to make steam to generate electricity. The principles for using nuclear power to produce electricity are the same for most types of reactor. The energy released from continuous fission of the atoms of the fuel is harnessed as heat in either a gas or water, and is used to produce steam. The steam is used to drive the turbines which produce electricity (as in most fossil fuel plants).

According to the classification adopted by the IAEA, 'small reactor' is a reactor with the equivalent electric power less than 300 MW, 'medium sized reactor' is a reactor with the equivalent electric power between 300 and 700 MW. Reactors with the equivalent electric power greater than 1000MWe are considered as 'large reactors'.



To accelerate growth of nuclear power capacity, India has planned to import foreign design Light Water Reactors (LWRs). These are Gen III + large power reactors (1000-1500MWe) requiring slightly enriched uranium as fuel and moderated by light water. Gen III+ reactor designs are of an evolutionary development of Gen III reactors, offering significant improvements in safety over Gen III reactor designs. The most significant improvement of Gen III+ systems over second-generation designs is the incorporation of passive safety features that do not require active controls or operator intervention but instead rely on gravity or natural convection to mitigate the impact of abnormal events. These reactors will have high fuel burn-up, thus reducing fuel consumption and waste production.

VVERs

Already one unit of 1000 MWe VVER is operational at Kudankulam and another is in advanced stage of commissioning. Four more of similar units have been planned at the same site. VVER is an acronym for "Voda Voda Energo Reactor" meaning water-cooled, water moderated energy reactor and belongs to Pressurized water reactor (PWR) type. It includes some advanced features like passive system of residual heat removal (PHRS), passive system of core flooding in case of loss of coolant accident, passive system of quick boron injection to shut-down the reactor, passive catalytic hydrogen recombiners (PCHRs) and passive system of creating vacuum between containment walls with filters.

VVER units at Kudankulam

EPR

European Pressurized Reactor (EPR) is an evolutionary descendant of the Framatome N4 and Siemens Power Generation Division KONVOI reactors. The EPR design has several active and passive protection measures against accidents such as four independent emergency cooling systems, each providing the required cooling of the decay heat that continues for 1 to 3 years after the reactor's initial shutdown, leak-tight containment around the reactor, an extra container and cooling area if a molten core manages to escape the reactor and two-layer concrete wall, designed to withstand impact by aeroplanes and internal overpressure.

EPR schematic diagram

AP1000 schematic diagram

AP1000

It is an evolutionary improvement on the AP600/The AP1000 design is considerably more compact in land usage than most existing PWRs, and uses under a fifth of the concrete and rebar reinforcing of older designs. The design also decreases the number of components, including pipes, wires, and valves. In the AP1000, Passive Core Cooling System uses multiple explosively-operated and DC operated valves which must operate within the first 30 minutes. This is designed to happen even if the reactor operators take no action. The electrical system required for initiating the passive systems doesn't rely on external or diesel power and the valves don't rely on hydraulic or compressed air systems. The design is intended to passively remove heat for 72 hours, after which its gravity drain water tank must be topped up for as long as cooling is required

ESBWR

Economic Simplified Boiling Water Reactor (ESBWR) is based on the Gen III ABWR. The ESBWR has achieved its basic plant simplification by using innovative adaptations of operating plant systems e.g. combining shutdown cooling and reactor water clean-up systems and combining the various pool cooling and clean-up systems. The passive safety systems in an ESBWR operate without using any pumps, which creates increased design safety, integrity, and reliability. It also uses natural circulation to drive coolant flow within the reactor pressure vessel (RPV); this results in fewer systems to maintain, and precludes significant BWR casualties such as recirculation line breaks. There are no circulation pumps or associated piping, power supplies, heat exchangers, instrumentation, or controls needed for these systems.

ESBWR schematic diagram

Gen IV

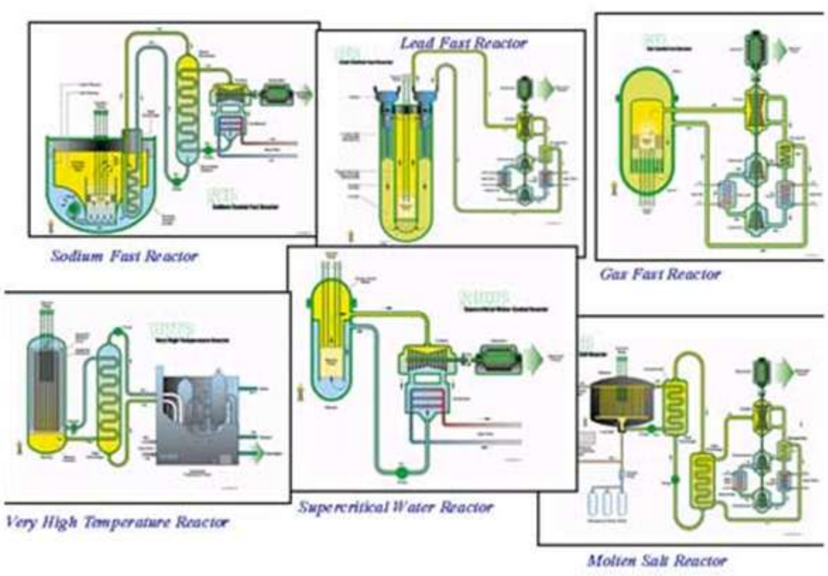
Conceptually, Gen IV reactors have all of the features of Gen III+ units, as well as the ability, when operating at high temperature, to support economical hydrogen production, thermal energy off-taking, and perhaps even water desalination. In addition, these designs include advanced actinide management.

The Generation IV International Forum (GIF), late in 2002 announced the selection of six reactor technologies which they believe represent the future shape of nuclear energy. These are the Sodium Fast Reactor (SFR), the Very High Temperature Reactor (VHTR), the Lead Fast Reactor (LFR), the Gas Fast Reactor (GFR), the Super-critical Water Reactor (SCWR), and the Molten Salt Reactor (MSR). Most of these six systems employ a closed fuel cycle to maximize the resource base and minimize high-level wastes to be sent to a repository. Three of the six are fast neutron reactors (FNR) and one can be built as a fast reactor, one is described as epithermal, and only two operate with slow neutrons like today's plants. Only one is cooled by light water, two are helium-cooled and the others have lead-bismuth, sodium or fluoride salt coolant. The latter three operate at low pressure, with significant safety advantage. The last has the uranium fuel dissolved in the circulating coolant.

Temperatures range from 510°C to 1000°C, compared with less than 330°C for today's light water reactors, and this means that four of them can be used for thermochemical hydrogen production. The sizes range from 150 to 1500 MWe (or equivalent thermal) , with the lead-cooled one optionally available as a 50-150 MWe "battery" with long core life (15-20 years without refuelling) as replaceable cassette or entire reactor module. This is designed for distributed generation or desalination.

Relative to current nuclear power plant technology, benefits for 4th generation reactors include:

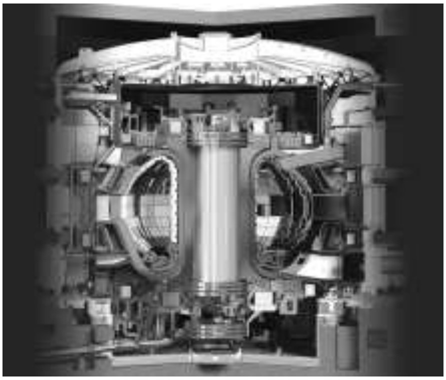
- Nuclear waste that remains radioactive for a few centuries instead of millennia.
- 100-300 times more energy yield from the same amount of nuclear fuel.
- Broader range of fuels, and even un-encapsulated raw fuels (non-pebble MSR, LFTR).
- In some reactors, the ability to consume existing nuclear waste in the production of electricity, that is, a Closed nuclear fuel cycle. This strengthens the argument to deem nuclear power as renewable energy.
- Improved operating safety features, such as (depending on design) avoidance of pressurized operation, automatic passive (un-powered, un-commanded) reactor shutdown, avoidance of water cooling and the associated risks of loss of water (leaks or boiling) and hydrogen generation/explosion and contamination of coolant water.



GEN IV: Six innovative systems

The radiation exposure to occupational workers is one of the prime concerns in nuclear plants. Radiation exposure is minimized by the use of remote handling equipment for many operations in the core of the reactor. Other controls include physical shielding and limiting the time workers spend in areas with significant radiation levels. These are supported by continuous monitoring of individual doses and of the work environment to ensure very low radiation exposure. Although nuclear power plants are designed to be safe in their operation, there is always a likelihood of an accident. The main safety concern is the possibility of an uncontrolled release of radioactive material, leading to contamination and consequent radiation exposure off-site.

1.2 FUSION TECHNOLOGY


ITER, the world's largest tokamak, under development

The fusion is a process which is exactly opposite to fission and although fusion reaction is successfully demonstrated, the first DEMO type fusion reactor is being built by many countries together in France and is called as ITER (International Thermonuclear Experimental Reactor).

The fusion technology is still under development and all associated hazards are yet to be understood. However the hazards associated with high electric power input, high magnetic field, large vacuum system with baking capability, Tens of MW level of RF and microwave power, large size cryo-systems, production of neutrons and nuclear radiation are well known.

There will be high vacuum in the reactor before introducing DT gas and then Tritium pallet will be injected in a controlled manner to have fusion reaction. The vacuum vessel is surrounded by cryostat with liquid H_e and liquid N_2 cooled system to get at least 5 K temperature for superconducting magnet to work.

The future fusion reactors will have a magnetic field of about 5.0 T or more and a power supply of current greater than 30 kA is required along with copper bus bar system. Few tonnes of superconducting magnets will be used to produce the steady magnetic fields to initiate, confine, shape and control the fusion plasma. In order to make magnets superconducting, one needs to cool down the magnets with Liquid H_e for which one needs to have proper insulation to decrease the heat load.

In order to produce plasma one needs an Ohmic system with superconducting solenoid which also gives rise to additional hazards.

In order to start the plasma, pre-ionization is required from 5 MW, 170 GHz high power microwave source like gyrotron and total power required is more than 20 MW for controlling plasma.

In order to heat the plasma for a temperature more than 40 keV (1 eV=11500 K) a very high power RF systems of the power 30 MW and more is required in the frequency range of 40-100 MHz.

In order to sustain the plasma for longer duration a very high microwave power of more than 30 MW is required in the frequency range of 3 to 5 GHz. Extremely high power electromagnetic radiation can cause electric currents strong enough to create sparks (electrical arcs) when an induced voltage exceeds the breakdown voltage of the surrounding medium (*e.g.* air at 30 kV/cm). These sparks can then ignite flammable materials or gases, possibly leading to an explosion.

In the initial phases of operation one needs to add hydrogen gas and certainly one needs to take all the precautions to avoid leakage not to have hydrogen explosion.

The hazards associated with radiation leakage are always there however they can be under control due to nature of fusion reactor where one produces a controlled fusion.

In order to extract heat to produce electricity from a hot steam normal heat extraction system is required and probably it is well developed and carries less hazards if standard precautions are followed.

1.3 LASER SYSTEMS

Advances in laser glass technology and chirped pulse amplification (CPA) technique have enabled new classes of high energy- high power (HEHP) and high peak power Petawatt (PW) laser systems that are being used for fusion energy ignition demonstration, fundamental physics research and material processing etc. In its simplest configuration a laser consists of a gain-medium inside a resonant cavity. The gain-media is the photon generator; it can be a solid, liquid, gas, or plasma. Energy is stored in the gain media by means of "pumping" viz. electrical or optical using an external energy source. The pump energy induces transitions in atoms or molecules from lower to higher energy levels (rotational, vibrational, and/or electronic), and under proper conditions, one achieves the necessary population inversion between two energy levels required for laser action. The resonant cavity that contains the gain medium is comprised of a high reflectivity mirror on one end and a partially reflective mirror ("output coupler"), on the other. The output coupler as the name implies, transmits a fraction of the light circulating in the resonator cavity into an output beam. If the output Coupler operates in a steady-state mode (constant energy output), it is termed "continuous wave" laser operation. In contrast, some output couplers are designed to abruptly change from near 0% transmission to 100%. This configuration allows one to dump all or part of the energy circulating in the resonator into a single pulse; hence, the term pulse-mode operation. The high-power glass lasers that are the focus of this article operate in the pulsed-mode. Glass lasers are a sub-set of solid state lasers where the gain medium consists of rods or plates (slabs) of optical quality glass doped with a lasant ion. Typically, Nd^{3+} - doped laser glass plates or rods are installed in a flash lamp pumped cavity. The Nd-phosphate glasses are used for high power lasers because of following advantages: large stored energy, efficient energy extraction, resistance to laser induced optical damage and mature manufacturing technology.

In general, current high power glass lasers can be divided into three broad classes i.e. High Energy High Power (HEHP) Laser, Petawatt Laser and High Average Power (HAP) laser. Out of these first two are single shot devices designed to fire and then allowed to cool several minutes to hours before re-firing. The HAP lasers are designed to operate continuously at repetition rates typically in the range of 1-10 Hz.

One example of a mega-joule scale HEHP laser system is the National Ignition Facility (NIF) that began full-scale operation in 2009 at the Lawrence Livermore National Laboratory (LLNL). The name of the facility is derived from its purpose: to achieve controlled thermo-nuclear (fusion) ignition in a laboratory setting. The NIF is the largest laser, as well as largest optical system, ever constructed and is capable of irradiating mm-size targets contained in a 10-m-diameter target chamber with energies up to 1.8 MJ at 351 nm and peak powers of 5.0×10^{14} W (500 TW, 1TW = 10^{12} watts).

HAP glass laser systems are predominantly used for commercial materials processing, particularly laser peening (LP) of metals. LP is a surface treatment process developed to improve fatigue performance and the strength of high-value metal parts, particularly those used in aerospace applications.

Now with the advances in CPA laser technology few advanced countries have developed high peak power Petawatt lasers. India has already commissioned

150 Terawatt, Ti:Sapphire Laser and now in the process of creating 1 PW Laser facility at Raja Ramanna Centre for Advanced Technology (RRCAT), Indore. The high power lasers are the current areas of interest with number of research applications. The intense beam of Petawatt laser can be powerful enough to induce nuclear reactions.

The HEHP lasers was developed originally to test the fast ignition path to inertial confinement fusion in the ongoing attempt to ignite a pellet of hydrogen fuel and harness the energy that powers the sun. The power of the Petawatt also opened up entirely new physical regimes to study. Now scientists can use PW lasers, not just particle accelerators, but to study high-energy-density physics and the fundamental properties of matter. With PW lasers one can studies matter at extreme conditions similar to astrophysics phenomenon and study astrophysics in the laboratory. The intense, ultra-short pulse of the Petawatt was expected to yield large doses of high-energy x rays, possibly enough to compete with the electron beam accelerators that are now used for x-ray radiography.

In general, the high power lasers are fall into two major categories: (i) large-scale, high-energy and long pulse duration (ns) systems that are constructed as add-ons to existing multi-kilojoule fusion-research lasers and (ii) smaller scale, lower energy ultra-short pulse duration (fs) "table-top" lasers now available at universities level.

BELLA Petawatt Laser at Lawrence Berkeley National Laboratory (LBL), California

The Texas Petawatt Laser based on Optical Parametric Chirped Pulse Amplification (OPCPA)

To generate PW powers requires simultaneously achieving two often conflicting operating conditions: short pulse lengths (femto to pico-seconds) and modest to high energies (>100 J). Either condition by itself is readily accomplished with today's laser technologies. However, to achieve both simultaneously requires amplification at short pulse lengths, which in turn can lead to unacceptable laser-induced damage to the amplifier gain medium.

The approach used to conquer this problem is to first generate the required short pulse, then temporally ”stretch” it to a longer pulse length (i.e. lower intensity) for amplification and finally recompress it back to the initial pulse length. Many PW laser researchers use laser-pumped titanium-doped sapphire (Ti:Al_2O_3) to generate the initial short pulse. Ti-sapphire offers high gain over a broad bandwidth which is essential to short pulse generation. Chirped-pulse amplification (CPA) is then used to stretch, amplify and recompress the pulse.

The hazards in Petawatt Laser facility are basically three types:

- *Ionizing Radiation Hazard*: Due to production of laser induced plasma, there is formation of ionizing radiation like bremsstrahlung photons, electrons, neutrons, protons, ions, induced radioactivity etc. However due to short femtosecond operations the integrated dose is not very high.
- *Electrical Hazard: D*ue to use of high voltage power supplies with voltage of the order of few kilo volts.
- *Laser Hazard:* Petawatt laser is a Class-4 Laser with femtosecond pulse i.e. most hazardous, viewing of even diffuse reflection is also hazardous, There is a need to enforce adequate safety measures to protect eyes of the working personnel.

1.4 PARTICLE ACCELERATORS

Accelerators are devices that accelerate charged particles to high energies for scientific research, industrial, medical, food processing and a variety of other applications. Accelerators provide the ability to control the particles (steer, focus, increase/decrease intensity etc.) in order to conduct experiments efficiently and in a controlled fashion. The development of accelerators has revolutionalized scientific research and led to the development of a host of technologies including ultrahigh vacuum systems, DC and AC magnets, high voltage and high current power supplies, Radio-frequency systems etc. Electric fields either from DC source or radiofrequency cavities accelerate particles inside accelerators, while powerful magnets focus or steer the particle beams as per requirement. Accelerators are either DC or cyclic. In DC accelerators, DC voltage is used for the acceleration and the particle move along a line. In the Linear accelerator too charge particle move in a linear path but for acceleration, RF field is used for developing the required accelerating potential. In Cyclic accelerators, charge particle moves in circular paths. In this case accelerating potential is developed across an RF cavity with the help of an RF field. Charge particle repeatedly pass through the RF cavity in cyclic accelerators and can achieve high energy in relatively smaller accelerating structure in comparison with DC accelerators or Linear accelerators. For this reason, most of the high energy accelerators are of cyclic type. In our country, Department of Atomic Energy has many accelerator programmes like room conducting and super conducting cyclotron, VECC, Kolkata, Indus-1 & Indus-2 synchrotron radiation sources at RRCAT, Indore, Pelletron accelerator at TIFR, Mumbai and at IUAC, New Delhi, Folded Tandem accelerator at BARC, Mumbai, There are other industrial electron accelerators under operational in the constituent units of DAE for radiation processing applications and some are under indigenously being development. High energy proton accelerator programmes are also under consideration by the department which will lead to Spallation Neutron Source in future, for basic and advanced research. The highest energy accelerator is at CERN where the accelerated proton energy is in TeV level (7 TeV) which has led to the discovery of a new particle, called as Higgs Boson in the year 2012.

The fundamental goal of nuclear physics is to understand the properties of nuclear matter, atomic nuclei and how nuclei are built up from elementary constituents. Nuclear Physics involves the study of diverse phenomena at vastly different scales from the interaction of elementary entities (quarks and gluons) inside nucleon or nuclei, to the synthesis of elements in stellar interiors and supernova explosions, to fundamental interactions during birth of the Universe in the "Big bang". Material science is another area where lot of research potential exists and accelerators play a vital role in it. Hence, for these future areas of research and development, the development of following facilities are very important:

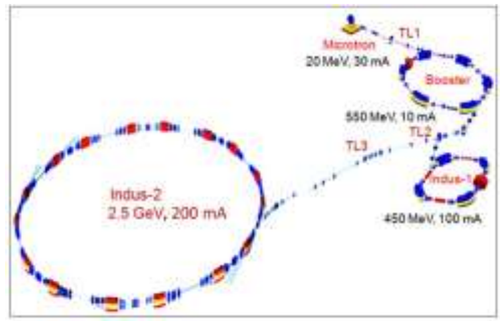
- Synchrotron radiation sources for material science and basic research
- Radioactive Ion beam Facilities for fundamental nuclear physics research
- Facilities for heavy ion collision at very high energies
- Neutron Spallation source for research in the physical, chemical and life sciences for material irradiation and for isotope production.
- Accelerator driven sub-critical devise for transmutation of nuclear waste. Industrial & medical accelerators etc.

High intensity proton accelerators are vital components for radioactive ion beam facilities and facilities for heavy ion collision.

Synchrotron Radiation Sources (SRS)

Raja Ramanna Centre for Advanced Technology, Indore houses two synchrotron radiation sources, Indus-I & Indus-II which are the highest energy accelerators operated in our country. Indus-I is a 450 MeV electron storage ring whereas Indus-II is a 2.5 GeV electron storage ring. The facility consists of an injector microtron (20 MeV), a booster synchrotron (450 / 550 MeV), and the storage rings, Indus-1 and Indus-II. Booster synchrotron is common injector for both Indus-I & Indus-II. . Synchrotron radiation is essentially an electromagnetic radiation produced when relativistic charge particles are bend in a transverse magnetic field and covers a broad spectrum of energies from infra-red to hard x-rays. The synchrotron radiation is guided to the experimental stations for research, using specifically designed arrangement of optical components called beamline.

A section of Indus-2 Storage Ring Tunnel



Schematic of Indus Accelerator Complex

Indus-2 has been set up and commissioned at RRCAT, Indore. In the process of setting up Indus-2, a strong indigenous base has been created in the country. Indus-2 is an electron storage ring cum synchrotron radiation source presently operates at 2.5 GeV and up to 200mA current. Synchrotron radiation is essentially an electromagnetic radiation produced in an electric synchrotrons and electron storage rings when the path of electron is bent by dipole magnets. In storage ring electrons are accelerated to almost speed of light by high electric field and confined to rotate in a circular orbit using series of magnets and RF cavities.

Indus-1 has been operational with a beam current of 100 mA at 450 MeV and five beam lines whereas Indus-II is operated at 2.5 GeV and up to 200 mA beam current. 26 beammlines are planned in Indus-II. Presently around 13 are operational and many others are under installation stage. Large number of users from various national research centers, universities and IITs etc. are utilizing Indus-II beam lines for high-tech research like photo-electron spectroscopy, X-ray diffraction (XRD), Extended X-Ray Absorption Fine Structure (EXAFS), Lithography, protein crystallography etc.

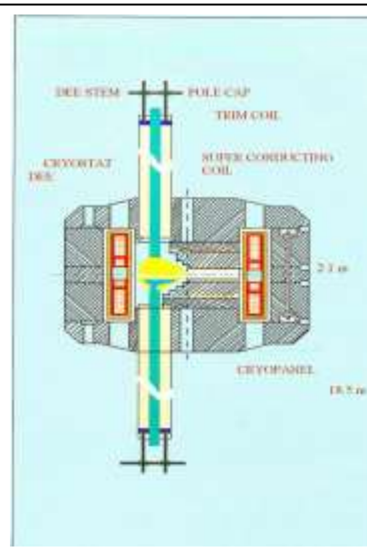
In the process of setting up Indus-II, a strong indigenous technological base for various high technology sub-systems has been created in the country. In storage ring electrons are accelerated to almost speed of light by high electric field and confined to rotate in a circular orbit using series of magnets and RF cavities.

Experimental Beamline Hutch in Indus-2

The SRS is housed inside a 1.5 m thick concrete shielding wall which has penetrations for installation of beamlines to tap the SR from 0°, 5° and 10° ports of each bending magnet. The radiation environment around the beamline comprises of Bremsstrahlung Radiation (BR) and Synchrotron Radiation (SR). This can be either direct or scattered. When SR beam is brought out in a beamline, shielded hutch (encloses the entire beamline) is required for the protection of personnel against radiation hazards. Various redundant safety interlocks prevent inadvertent exposure to users. Main objective of hutch with safety interlocks is to keep radiation levels in working areas within stipulated limits set by Atomic Energy Regulatory Board (AERB) under all machine operation conditions.

High Energy Proton and Radioactive Ion Acceleration

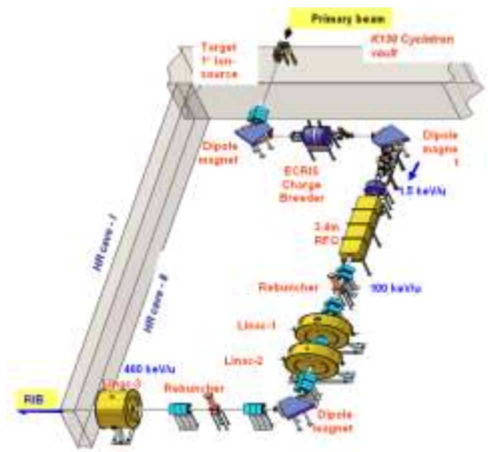
In India, Variable Energy Cyclotron at VECC, Kolkata became operational in June 1977. The machine is capable of giving up to 60MeV protons and 130 MeV alpha Particles and is in regular use since 1981. The component of cyclotron consists of magnets RF Oscillator, power supplies, ion injection and extraction system, vacuum and control systems, beam transport and data processing systems. With the demand for higher energy cyclotron, VECC initiated the project to develop a superconducting cyclotron, commissioning of which is in progress. This cyclotron will accelerator light ions to 80 MeV/Nucleon and heavy ions to 10 MeV/ Nucleons. The most important component of this cyclotron is the superconducting magnet coil which produces very high magnetic field for confining accelerated charged particles. The magnet coil of the superconducting cyclotron is immersed in liquid Helium (4.2K) in a specifically built stainless steel Cryostat. The superconductor is niobium-tin strands embedded in copper. It gives



Vertical Cross-sectional view of K-500 Superconducting Cyclotron at VECC, Kolkata very high magnetic field (5.5. Tesla) using very high current density of 5800 Amp/cm^2.

A Radioactive Ion Beam (RIB) Facility is being set up at VECC for acceleration of radioactive ion beams. Radioactive atoms will be produced inside a thick target using proton and a particle beams from K-130 variable energy cyclotron at VECC. The radioactive ions diffusing out from a thick target on bombardment of protons of suitable energy will be ionized in the integrated target ion source and transported to ECR ion source. After extraction from ECR ion source the desired RIB with an energy of 1 keV/u will be separated from other products in the low energy beam transport line and will be ultimately transferred to Radiofrequency Quadraupole (RFQ). RFQ is a RF Linear Accelerator. It is used for acceleration of very low energy ions from a few keV/u to about 420 keV/u for heavy ions and to about 7 MeV for protons. The unique feature of RFQ accelerator is that it provides transverse focusing and longitudinal bunching of the beam during acceleration. Due to these features the transmission efficiency through RFQ is very high and it is almost universally used at the front end of any accelerator facility. In RFQ, the RIB will be accelerated to about 90 keV/u. Subsequently the RIB will be accelerated to the desired final energy of about 4 MeV/u in a series of LINAC tanks.

Vane type (left) and rod type (right) RFQ



Schematic of Radioactive Ion Beam Facility

Hazards Associated with High Energy Particle Accelerator

The primary hazard associated with accelerator facility is intense prompt radiation which is present during operation of the accelerator and activation of structural materials which pose radiation hazard even if accelerator is not in operation. In high energy electron accelerators bremsstrahlung x-rays and photo-neutrons are the prompt radiation hazard whereas in high energy proton accelerators, neutron is the prompt radiation hazard. Induced activity is high in proton accelerators whereas it is relatively very less in electron accelerators. The high radiation in high energy particle accelerators may cause radiation damage of interlock switches, fire detectors, flashing warning lights in accelerator vaults, electrical cables, switches of high voltage equipment and other electronic devices. Additional hazards associated with high energy accelerator operation are noxious gases RF & MW, magnetic fields etc. The irradiation of air may result in various nuclear reactions like ^{16}O (γ, n) ^{15}O, ^{14}N (γ, n) ^{13}N whose products, ^{15}O & ^{13}N are radioactive.

1.5 NEUTRON GENERATORS

Neutrons can be produced with neutron generators (NG) by the deuterium–deuterium (DD) reaction at 2.5 MeV or deuterium–tritium (DT) reaction at 14 MeV . Unlike radioactive sources, NGs contain no radioactivity (except those based on the DT reaction) making them inherently safe when turned off. Once the generator is shut off, no radiation is produced. However, DT NGs must be sealed because of their tritium content. A limiting factor of these generators consists in the tritium target erosion which makes their typical lifetime of the order of few thousand hours with continually decreasing neutron flux. DD NGs are also available commercially but, because of the lower reaction cross-section, their neutron output is only 1% of the equivalent DT generators. They are also sealed systems requiring regular replacement of the deuterium.

Recently, a new generation of NG has been developed to produce up to at least 10^{11} n/s in different laboratories that overcome many of the deficiencies of early ones. The open design allows the continuous regeneration of the target so that these generators should be able to operate indefinitely at maximum neutron fluence. These generators can be continually pulsed on a very short time scale (10^{6} s^{-1}).

Compact Neutron Generators:

Compact NGs are becoming an attractive alternative to nuclear reactors and radioactive neutron sources in variety of fields of neutron science, medical research and various material analysis applications, ranging from coal and cement analysis to various explosive detection schemes, from homeland security applications to other explosive detection applications, like land mine detection. Traditionally compact NGs have been used in oil well logging industry, using D-T fusion reaction for high energy 14 MeV neutron production.

Commercial Neutron Generator

Currently the main commercial manufacturers of compact NGs are Thermo Electron, Sodern EADS and Schlumberger. These NGs generate D-T neutron yield in the range of 10^8 to 10^{11} n/s.

Applications of neutron generators:

NGs can effectively be used for elemental analysis with Neutron Activation Analysis (NAA) and Prompt Gamma Neutron Activation Analysis (PGNAA). They are also effective for analysis of hidden materials by neutron radiography. Traditional NGs have been shown to be effective for applications including borehole logging, homeland security, nuclear medicine and the on-line analysis of aluminium, coal and cement. Potential applications in land mine detection, cargo screening, archaeology, and isotope production have been proposed. The availability of a new generation of low cost NGs offers the opportunity for professional and technical training at universities, research institutes for physicists, chemists, nuclear engineers, biologists, radiologists and health physicists.

Neutron Sources:

Neutrons, not being stable particles, have to be released from nuclei. Most nuclear reactions, used for neutron generation, require high energy particles and produce fast neutrons on bombardment with appropriate targets. The most important reactions are listed below:

(1) $\gamma + {}^{9}Be \rightarrow 2\,{}^{4}He + n - 1.67$ MeV

(2) ${}^{9}Be + \alpha \rightarrow {}^{12}C + n + 5.91$ MeV

(3) ${}^{2}H + {}^{2}H \rightarrow {}^{3}He + n + 3.29$ MeV (neutron energy about 2.4 MeV)

(4) ${}^{3}H + {}^{2}H \rightarrow {}^{4}He + n + 17.6$ MeV (neutron energy about 14.1 MeV)

(5) ${}^{3}H + {}^{1}H \rightarrow {}^{3}He + n - 0.763$ MeV

The first two reactions are used in radio-isotopic neutron sources, where gamma and alpha radiation are obtained from other radioactive nuclides. The most commonly used photo-neutron source exploits reaction (1) with the ${}^{124}Sb$ nuclide with a half-life of 60 days, whose 1692 keV gamma radiation kicks out the loosely bound neutron from a ${}^{9}Be$ nucleus with an energy of 26±1.5 eV, i.e., it exceptionally produces relatively low energy, epithermal neutrons. Alpha particles emitted by the nuclides ${}^{210}Po$, ${}^{239}Pu$, and ${}^{241}Am$ are used most frequently for the reaction (2) to occur. Po–Be, Pu–Be and Am–Be sources emit a spectrum of neutrons. The spontaneous fission of ${}^{252}Cf$ also provides a widely used isotopic fast neutron source. Reactions (3) and (4) are used in NGs. Both of them are exothermic, thus requiring relatively low energy particle beams (100–500 kV). The DT reaction has a resonance at about 100 keV with the cross-section of 5 barns, while the D-D reaction has its weaker resonance at about 2 MeV (about 0.1 barn). Both of them have reasonable cross-sections at low energies, however the cross-section of reaction (4) is much higher than that of reaction (3), which results in a yield of about two orders of magnitude higher around 100 keV for the DT reaction. Because of their higher fluence, mainly D-T NGs were manufactured in past decades. However reaction (3) together with (5) is used to produce a beam of monochromatic neutrons to study inelastic neutron scattering of fast neutrons.

Hazards of Neutron Generator

There are two main hazards with NGs: the electrical hazard and the radiation hazard.

Electrical hazard

As seen in previous chapters, NGs generate neutrons due to a nuclear reaction obtained in a target on which ions have been accelerated by an electrical field. To obtain a high level electrical field (typically100 kV/cm) a high voltage power supply (typically 100 kV) is needed. However, if the generator is designed according to the norms of the manufacturer, there are no bare pieces with potential that are accessible. If the connections (mains, ground) are done as indicated in the user manual, and if the generator elements are not modified or opened, there is no electrical hazard. However, in compliance with the legislation (depending on the country), the user will discover legal labels on some parts of its generator warning him against Very High Voltage (VHV) hazards.

Radiation hazards

Neutron generator radiation hazards can be divided into three different categories:

(1) Radiation hazard due to the fact that 14 MeV neutron tubes contain tritium, a radioactive gas. Tritium is a hydrogen isotope that consists of one proton and two neutrons. It is a β emitter with a half-life of 12.33 years, the maximum energy of the β particle is 18 keV and the average energy is 5 keV. No radiation is measurable outside the tube, because the electrons do not have enough energy to penetrate the wall of the tube. On the contrary, 2.5 MeV neutron tubes (using DD reaction) only contain deuterium, which is not radioactive.

(2) Radiation hazard due to neutron and γ emission of a NG during normal operation.

(3) Radiation hazard due to the neutron activation phenomena that makes objects and materials radioactive, including the NG itself.

1.6 GAMMA IRRADIATORS

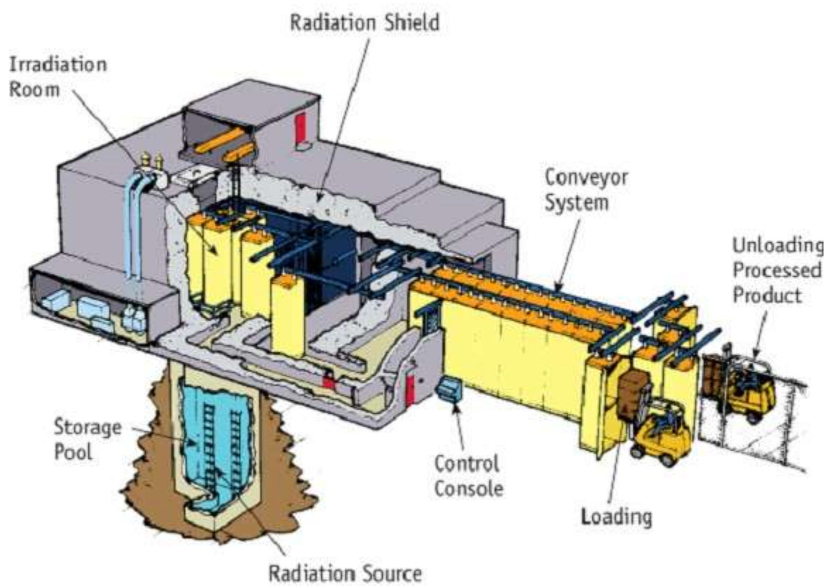
Radiation processing technology involves the controlled application of energy from ionizing radiations such as gamma rays, electrons and X-rays for sterilisation of healthcare products, preservation of food stuffs, polymer synthesis and modifications, eradication of insect infestation and in the management of public health and environment.

Basically, gamma irradiators may be divided into two broad types: (i) self-contained irradiators, and (ii) panoramic irradiators.

Self-contained irradiators are specially designed for research and applications that need small doses and relatively small throughputs, such as blood irradiation for preventing TA-GVHD and reproductive-sterilization of insects for pest management programmes. A large majority of these are dry-storage irradiators and the source activity is limited to about 25 kCi. These irradiators house the radiation source (either cobalt-60 or caesium-137) within a protective shield of lead or other suitable material, and have a mechanism to move the sample from the loading position to the irradiation position. Such units can be placed very conveniently in an existing laboratory or a room without needing extra shielding.

In panoramic irradiators, the source consists of either several cobalt-60 pencils arranged in a plane that can be moved into a large irradiation room. When retracted from this room, the source is shielded either by water (wet storage), or lead, or other appropriate high atomic number material (dry storage). Because a radionuclide source emits gamma rays in all directions, it may be surrounded by product containers to increase the energy utilization efficiency. Thus, several (sometimes 100 to 200) containers are typically irradiated simultaneously. For such an arrangement, the average dose rate is significantly lower and the product needs to be irradiated for longer time periods. However, this is compensated by the fact that several large containers are irradiated simultaneously

The number of gamma and electron radiation processing facilities (RAPFs) is increasing all over the world due to their multifarious applications in the field of medicine, industry, agriculture and research. There are currently more than 180 gamma radiation processing facilities and over 600 electron beam facilities in operation throughout the world. In India, at present, a total of 19 gamma radiation-processing facilities (GRAPFs) are under operation for various purposes, 8 are under construction of which5 facilities have obtained design and construction clearance and 3 facilities have obtained site clearance for installation of GRAPF. There are five radiation processing accelerator (RPA) facilities operating in the country for other than food irradiation purposes. ISOMED is the first commercial gamma radiation processing plant for sterilisation of medical products and was commissioned at the Bhabha Atomic Research Centre (BARC), Mumbai. Gamma Irradiation of municipal sludge for safe disposal and agricultural use was also setup by BARC, Mumbai at Baroda, Gujarat.



Schematic of Panoramic Gamma Irradiator

2.0 SAFETY CONSIDERATION IN HIGH POWER & HIGH ENERGY TECHNOLOGIES

The design of technologically advanced facilities shall incorporate the defence-in-depth concept such that multiple levels of protection are available against the release of radioactive and hazardous material. The level of protection needed depends on the risk to the workers, the public and the environment. It should consider the following points

- The selection of materials and other design processes to reduce radiological and hazardous material inventories
- The use of conservative design margins
- The use of a succession of physical barriers for protection against release of radioactive and hazardous materials.
- The provision of multiple means for ensuring the safety functions
- The use of basic design features, equipment and operating and administrative procedures to minimize anticipated operational occurrences, off-normal conditions, and control / mitigate their consequences should they occur.
- The implementation of a rigorous and formalized quality assurance program, the organization of surveillance activities and the establishment of a safety culture
- Use of emergency plans as required to mitigate the effects of radiological and hazardous releases to workers and the public

The various factors considered during design &construction and commissioning & operation of high power and high energy advanced technologies are given in the following sub-sections.

2.1 DESIGN & CONSTRUCTION

2.1.1 High Power Nuclear Reactors

Reactor Safety

Safety of a reactor is of prime concern to its owner, for several reasons: to ensure the safety of the public, the reactor operators, and of the investment itself. Therefore, the design of a reactor is developed according to industry standards, which are developed by expert committees. They incorporate the best design, construction and operational standards, which have been developed over many decades of experience.

The building of a reactor takes many steps: choice of a suitable site; design of the power plant to fit that site; fabrication of the components and construction of the plant; low power commissioning; and, finally, full power operation. At each stage, the designer assures the safety of operation.

In addition, the licensing authority, the Nuclear Regulatory Commission (NRC) overviews the process and issues permits and licenses at significant points to allow work to proceed. The NRC has previously reviewed the industry standards and issued them (sometimes with modifications) as NRC standards incorporated into law — thereby ensuring that the best of industrial practices are incorporated into all new plants.

Design Safety

Design Standards

Industry standards cover every aspect of plant design from its layout to the safety of individual components. For example, the construction of a 9″ thick stainless steel vessel has its fabrication standards, while the wiring of monitoring and control circuits has its own standards. Each set of standards has been developed and approved by experts in that particular part of the technology.

A reactor is designed for a particular **site** according to industry standards for safe design and construction of all its components and systems as well as its operation. These industry standards incorporate the best design, construction and operational standards, which have been developed over many decades of experience.

Safety Principles

There are six principles of safety that are the same for all machinery, from modern cars to windmills to dams to nuclear plants. These six safety principles that are to be complied:

i) **Multiple Barriers:** Typically, if one knows that one might get hurt from machinery, the primary safety requirement is to keep the user clear of any danger, by providing at least one or preferably multiple barriers. Cars offer multiple barriers in a similar fashion. They have collapsible front and rear ends; airbags; and seatbelts, to protect people from harm in case of a crash. Nuclear power plants also offer multiple barriers: the canned fuel, the pressure vessel and the containment, to protect the public from the release of radioactive materials.

ii) **Redundancy:** It is a good principle that if something must work, then more than one of them is included just like four wheel brakes on a car. In a nuclear power plant, there are four different ways of obtaining a shutdown when needed: shutdown by heat feedback; dual active-shutdown systems; operator shutdown, or triple electronic systems.

iii) **Diversity:** Then to be sure that one safety system works, it is preferable that the second be of a different design and even be made of different materials, just like foot brakes and hand brakes in a car. This ensures that if the first system fails, the second system won't fail for the identical reason. In a nuclear power plant, diversity is obtained through different designs of control rods and shutdown rods, and through different designs of electronic systems.

iv) **Protection from human error:** While humans can act rapidly and responsibly, they can also make mistakes, so incorporating automatic actions for times when the human makes a mistake is good safety practice. For example, some cars offer automatic fuel line cut-off on impact. In nuclear power plants, an automatic reactor shutdown offers that protection.

v) **Monitoring:** One needs to know how the machinery is working and whether there are signs that it might fail, like low oil pressure in your car, or in modern cars, low pressure in your tires. Nuclear power plants are monitored extensively throughout the entire heat production process.

vi) **Passive rather than active safety systems:** Where possible it is good practice to make use of the laws of nature to correct situations. In nuclear power plants, gravity is used to drop a barrier or a control rod more reliably than an active mechanism to do the same thing.

Designing a Reactor for Safe Operation

A reactor designer first makes sure that the fission process can be shut down in a variety of ways. The primary defence is by ensuring that the core is designed so that high temperatures automatically change the core characteristics, fission is reduced and the temperatures go back down. This is called inherent safety. Secondly, multiple automatic electronic systems monitoring the core for abnormal temperatures will insert control rods to stop the fission, and, if necessary, automatic fast shutdown rods are also available to act as brakes. Finally, there is always the operator who watches control room monitors. He can also instantly insert the shutdown rods from a single button.

Next, the **designer must ensure that the reactor is always cooled** – generally in current commercial reactors, by water. Thus, the plant has more-than-one water path (generally three loops) to bring cooled water into the vessel. Monitors alert automatic valves to open or close so that adequate water is brought in and that the pressures in various vessels in the steam side are within limits. In an emergency, there is also a completely separate fourth cooling system. Finally, the operator also watches significant water temperatures, pressures and flows on monitors, to be able to take manual action if needed. This might include shutting the system down and/or activating the separate emergency cooling system. He can also bypass any valves that might be sticking.

The plant itself is designed to **quality standards** that are higher than in any other industry with sufficient margins in materials and designs to take care of any accident conditions. Materials do not melt just because the temperature is a little raised and vessels do not burst even when the pressure is above normal operational values.

Furthermore, the whole plant is designed to **withstand earthquakes beyond any historically expected**, and to withstand extreme weather conditions and their consequences. For example, the outer containment can withstand hurricane missiles like a flying car or shafts of wood and metal. Greenpeace activists provided an excellent test of the containment when they fired mortar missiles at the French Super-Phenix plant from across the river. They could only chip the surface of its concrete. Later, during hurricane Andrew in Florida, the safest place for families of the operators as the hurricane passed directly over the plant was inside its containment.

Fabrication and Construction

As the design proceeds the safety of the plant is analyzed thoroughly to meet and better regulatory protection standards. The analysis is presented to the Nuclear Regulatory Commission as a Preliminary Safety Analysis Report (PSAR) and once that has been approved, the design is fixed. Then the owner can proceed to fabrication and construction.

Since it takes many months to construct a nuclear plant approval to fabricate and construct may be given in several steps depending on whether the item under consideration is safety-related or not. If it is safety-related and appears as part of the PSAR submission, then it is kept under close regulatory scrutiny during fabrication.

Fabrication will take place at a number of locations: the vessels being built by one firm and electronics by another, and pumps and valves by others. However, all fabrication is performed to regulatory-approved industry quality standards. Material integrity of the large components, for example, is tested in several ways including radiographing and dye-penetrant methods; each governed by a standard. In this way, the owner can be assured that every piece of the plant is of high quality. The chain of construction will have no weak links.

Construction, by the project's architect engineering firm, is performed also to industry standards for such things as concrete mixes, rebar strength and density, welding techniques and so on. It is under close regulatory scrutiny and there will be periodical regulatory inspection and review on site while the work goes on.

2.1.2 Fusion Technology

The size of the future fusion reactor will be at least 30 meters high and 30 meter diameter with a vessel thickness of more than 10 mm called cryostat. The stainless steel cryostat surrounds the vacuum vessel and superconducting magnets and ensures a super-cool, vacuum environment. By considering the size, weight and sensitivity of the subsystems one must take care of proper location by considering seismic data of the location and also the building and complete reactor should be able to withstand the earthquake of certain magnitude.

There will be high vacuum in such a large volume and one needs to take in design and construction itself to avoid implosion as well as leak. The blanket has to be designed to avoid the exposure to neutrons generated from fusion reaction and can be placed between high vacuum vessel and the external components. The whole building should have metallic double shield to avoid leakage of electromagnetic waves.

The high power RF and microwave sources must be tested for electromagnetic radiation and also should be in an enclosure to have proper shielding.

As far as grounding scheme is concerned, one needs to have separate grounds for gyrotron, klystron and tetrode systems and for reactor one has to have arrangement for star type grounding scheme.

Since the inner component needs replacement as well as repairs which get exposed to the radiation during operation, one needs to have a proper remote handling system to remove, examine, repair/replace the components in a secured area.

In short the fusion reactor should have multiple layers like radiation shield, vacuum system, cryostat, thermal shield, biological shield etc. which has to be added during the construction of the reactor.

2.1.3 Laser Systems

Laser Safety

Laser system is housed in a separate hall enclosed from all sides with brick walls and no window is provided in this area. This is to ensure no laser light (scattered or reflected) enters the user area outside the laser hall. The entrance to the laser hall is through an electronic conditional access system. Only authorized persons can enter the laser hall through this system. There is a flashing light signal at the entrance gate to the laser hall to display the laser running status. The complete laser system can be remotely controlled from the terminal kept outside. All the authorized laser persons who run and maintain the laser on day to day basis are allowed to take entry in the laser hall only wearing the compulsory laser safety goggles. The laser firing is interlocked with a buzzer, siren, and entrance access to the experimental area. At the time of the laser firing, the experimental area is inaccessible, and the siren and the flashing light get switched ON. The laser hall has an emergency exit gate in case of any eventualities. The laser hall has separate fire extinguishers to take care of fire hazard in the laser hall

For electrical Safety all the power supplies are kept in a separate place called "Technical Corridor", which is located at adjoining laser hall. All the high voltage cables and control and signal cables come to the laser head from the technical corridor through trenches on the floor which link the laser hall at various points from the service corridor. In this way all the high voltage hazard can be taken care through this trench. The trench is well connected with the electrical ground of the building. Laser hall has two entrance / exit gates for easy egress of personnel in case of any eventuality

Radiation Safety

- **Radiation Zoning Scheme***:* The level of radiation expected is marked by zone areas viz. Zone 3 (Prohibited Entry Area), Zone 2 (Restricted Entry Area), and Zone 1 (Normally Accessible Area) and should be depicted in layout by colour codes as red, blue, and green outline respectively. Zone 3 shall have maximum radiation hazard.

- ***Radiation Shielding System****:* Based on experiences from other similar laboratories, a shielded cell **of ~1m** thick concrete is built for the interaction area where laser interacts with solid or gas targets kept inside a vacuum chamber. The concrete shield provides radiation shielding to prevent any radiation reaching to accessible areas from the interaction area. Apart from concrete shielding, lead shielding and HDPE blocks are also required for neutrons to confine them in the interaction area. Similar to the laser hall, the interaction area has also electronic access (Conditional Access System) for entry and only authorized persons can enter in this room.

- **Induced Radioactivity***:* The plasma chamber for Terawatt / Petawatt laser is made up of aluminium to avoid Cr, Fe, and Ni present in stainless steel (which was earlier used for such chambers). These elements are avoided as they have proton induced radioactivity with long half-lives. The proton induced radioactivity cross-sections in aluminium are very low and the half live of the induced activity in aluminium is very short (~ 4 second). Therefore it will have very small residual radioactivity after the laser short is fired.

- **Radiation Monitoring System**: Following radiation monitors, instruments, dosimeters etc. are installed at appropriate locations of the high power laser plasma facility.

  - Area radiation Monitors (Pressurized Ion Chamber based)
  - Survey Meters (Ion chamber based)
  - Neutron Flux rate meters
  - Neutron Rem Meters
  - Bubble Detectors for fast neutrons, and for thermal neutrons
  - Direct Reading Dosimeters
  - Dosimeter charger
  - Personnel Dosimeters ($CaSO_4$:Dy TLDs)
  - MCA - HPGe based / NaI based portable Isotope Identifier

2.1.4 Particle Accelerators

The accelerator building design needs to address the radiological safety aspects including shielding, disposal/discharge of wastes and airborne radioactive/noxious gaseous products, sky shine etc., the impact of the same on surrounding environment and population. The layout design needs to consider the personnel access control details. The structural design criteria, including those for seismic and wind load etc., for the buildings housing the accelerator and auxiliaries, conforms to those for industrial plant category in relevant national building codes.

Firefighting capability is one of the key factors to handle fire emergency in a plant. Suitable fire detection and alarm system and fire suppression system should be available before commissioning of accelerator. In facilities (mainly electron accelerator) where possibility of ozone production exists, the ventilation should be designed on the basis of calculated production rate of ozone to reduce its concentration below permissible level of 0.1 ppm for light work and 0.05 ppm for heavy work.

Shielding Design
The site for locating an accelerator facility is chosen carefully to meet all aspects of operational requirement, safety and impact on the environment

under conditions of normal, off-normal operations as well as design basis accidents and situations arising out of natural or disruptive factors.

Factors like energy of radiation, occupancy factor, sky shine, penetrations like s-bend, ducts, beam catcher and dumps, sources of RF radiation, etc. are considered during shielding design. Special problems like dose build up effects due to electro-magnetic cascade and hadronic cascade in high energy electron and proton accelerators respectively are considered in the shield design. Materials for shielding are selected appropriate to the radiation encountered in the accelerator and its energy. When concrete is used as the shielding material, presence of voids and segregation in casting is taken care of. For this purpose, radiometric testing of specimen concrete blocks is done.

Safety interlock system
The systems should be fail-safe against loss of main power, pneumatic device, vacuum, electrical shorts etc. A reliability analysis of the proposed interlocking system should be carried out. Appropriate documentation should be done on functional description of the interlock system, physical and electrical configuration and management approval.

2.1.5 Neutron Generators

The safety consideration for design and construction Neutron Generator is similar to that of Particle accelerator.

Generally 3 design barriers are present to prevent the tritium, a radioactive gas in 14 MeV neutron tubes from escaping the tube:

(i) The barrier of the emission module housing. This housing contains the tube, the VHV connection and also the VHV insulator between the tube's VHV metallic parts and the metallic grounded housing.
(ii) The tube barrier itself.
(iii) The getter barrier (zirconium, titanium, vanadium, erbium, etc.) that stores the gas inside the tube as metallic hydride.

The escape of tritium is very rare. Moreover, if a leak occurs because of a mechanical problem, air immediately starts to flow inwards, because the pressure inside the tube is generally very low [~0.1 Pa (10^{-3}Torr)]. If a leak occurs, the right course of action is to put the tube in a plastic bag and close it. No radiation will come out then. The toxicity of tritium is very low, but it has to be considered. The transient time in the human body is just 10 days.

2.1.6 Gamma Irradiators

Gamma and electron beam facilities produce very high dose rates during irradiation, so that a person accidentally present in the irradiation chamber can receive a lethal dose within minutes or seconds, and fatalities have in fact occurred in Italy (1975), Norway (1982), El Salvador (1989) and Israel (1990).

Gamma and electron irradiation facilities have to be constructed so that during normal use any radiation exposure of workers will be very low and there is no significant exposure to individual members of the public. However, significant radiation exposure may result from loss of control over or damage to the radiation source. In extreme cases the exposures may be sufficient to cause serious injury or even fatalities in the short term. Damage to the source can also lead to widespread contamination.

Erection of any Gamma Irradiator needs siting consent from AERB. Apart from this permission for operation is issued by AERB only after ensuring the design and performance requirement specified in AERB safety standard AERB/RFIRRAD/SS-6 (Rev-1) on Land Based Stationary Gamma Irradiators are complied with.

2.2 COMMISSIONING & OPERATION

2.2.1 Nuclear Reactors

Low-Power Commissioning
After the plant design has been approved and the plant built, it must be tested before being placed into operation. This is called low-power commissioning and it is a time to make corrections if anything proves to be out of specifications.

The AERB will permit vessels and piping to be filled with liquids (generally water), pumps can be operated and valves can be opened and closed. This is especially so for emergency systems that, although never expected to be operated in the plant's lifetime, must operate if called upon. This is similar to the first fill of your newly installed replacement car engine with oil and the first cranking of the pistons. Although you are not going to drive it a hundred-miles-an-hour today, you would like to know that it all works and nothing leaks. If you installed a new car radiator, you would need to know that all the connecting hoses are tight even before you started the car.

Naturally, the inspectors of the AERB are involved throughout these low-power commissioning tests. When the plant operators and the regulators are satisfied with all the tests and that they agree with predictions (which go into the safety case), the plant may be granted a license for full-power operation.

Full-Power Operation
Full-power operation is a natural extension of low-power commissioning. It is exactly like starting and running your car when you buy it since you know that all the low-power commissioning tests have been done.

Sometimes, the AERB may license the plant to come to power in a series of steps: 25%, 50%. 90% and 100% of full power, but the effect is the same. The result is full-power operation and the quiet generation of clean electricity for the plant lifetime of 30 to 40 years or more.

Maintenance, Surveillance and In-service Inspections programmes
Effective maintenance, surveillance and in-service inspection (MS&I) are essential for the safe operation of a nuclear power plant. They ensure not only that the levels of reliability and availability of all plant structures, systems and components (SSCs) that have a bearing on safety remain in accordance with the assumptions and intent of the design, but also that the safety of the plant is not adversely affected after the commencement of operation.

- *Maintenance*: The maintenance programme for a nuclear power plant should cover all preventive and remedial measures, both administrative and technical, that are necessary to detect and mitigate degradation of a functioning SSC or to restore to an acceptable level the performance of design functions of a failed SSC. The purpose of maintenance activity is also to enhance the reliability of equipment. The range of maintenance activities includes servicing, overhaul, repair and replacement of parts, and often, as appropriate, testing, calibration and inspection.

- *Surveillance*: The objectives of the surveillance programme are: to maintain and improve equipment availability, to confirm compliance with operational limits and conditions, and to detect and correct any abnormal condition before it can give rise to significant consequences for safety. The abnormal conditions which are of relevance to the surveillance programme include not only deficiencies in SSCs and software performance, procedural errors and human errors, but also trends within the accepted limits, an analysis of which may indicate that the plant is deviating from the design intent.

- *In-service Inspection*: Over the plant's operating lifetime, the operating organization should examine SSCs for possible deterioration so as to determine whether they are acceptable for continued safe operation or whether remedial measures should be taken. Emphasis should be placed on examination of the pressure boundaries of the primary and secondary coolant systems, because of their importance to safety and the potentially severe consequences of their failure.

Other Items Contributing to Safety

Safety is a comprehensive state encompassing many things including good management, safe design, industry standards, and positive regulation. Safety also includes well-trained staff and operators, attention to emergency plans if anything went wrong, and, on another level, security.

- *Training and Licensing*
  Training is vital to ensure that operators and other staff such as maintenance crews know exactly what to do and why they are doing it that way. In addition, training ensures that everyone is trained to do the job the same way.

  Therefore, staff training at all levels is regular. Operators must go through yearly training (with exams) and success in training is necessary for them to continue in their position. It would not be too strong to say that good training of all staff, at all levels, is a basis for safe operation.

- *Emergency Plans & Severe Accident Management*
  While it is very unlikely that anything will go seriously wrong, nevertheless emergency plans are set in place to protect operators and anyone who might be in or in the vicinity of the plant. These emergency plans involve close cooperation with off-site agencies like the police, the fire department, and even school buses, if they are part of any evacuation plan that has been approved.

- *Security*
  Security is related to safety including and beyond plant operation. Therefore, security plans are confidential and known only to those with a need to know: plant management, the police, certain regulators, and anyone who needs to act.

  One part of security is aimed at those misguided individuals who might feel a need to disrupt the operation of the plant or who might want to prove that they could steal materials. It has never been done, nevertheless security plans are made for each plant. They do not contribute directly to safety of operation but they would stop anyone, like a terrorist, who might have harmful objectives.

2.2.2 Fusion Technology

During commissioning, one needs to take care of avoiding mixing of grounds and all the gyrotron, klystron and tetrode type systems must be tested on a dummy load. Each subsystem of the fusion reactor should have a separate data acquisition and control system and all these controllers should be connected to main control system through fibre optic system to avoid mixing of grounds as well as to avoid pick up and interference.

In order to avoid damage to the high power RF and microwave power tubes one needs to dump all the stored energy in DC power supply in a parallel path for which one must use crow bar system based upon ignitron or light triggered thyrister system called solid state crow bar system. Most of the guidelines are taken into consideration in an international project called International Themo-nuclear Experimental Reactor (ITER).

One needs to develop a protocol for the operation of every sub-system and the complete machine. All the interlocks for every subsystem as well as for the complete machine should be hardwired in the form of fast interlocks and slow interlocks can be through Data Acquisition and Control System.

Personnel safety is an utmost important while operating high power RF and microwave systems. It is well known that exposure to EM radiation can cause dielectric heating of the body and the heating effect varies with frequency and power. A measure of the heating effect is the Specific Absorption Ratio (SAR) which has units of watts per kilogram (W/kg). The IEEE and many international agencies have established safety limits for exposure to various frequencies of electromagnetic energy based on SAR.

In order to avoid the effect of high magnetic field the reactor hall should have interlock system to restrict the personnel entry during operation. The central control system should be able to collect the data of all subsystems as well as should be able to monitor all areas with cameras etc.

In short the future fusion reactor will have all the safety protections which are well established for a fission reactor and in addition the it the safety issues related to the magnets, vacuum, cryo-systems, high power RF and microwaves etc. need to be incorporated.

2.2.3 Laser Systems

Adequate administrative controls are taken to ensure entry of authorized persons only. Red flashing lamps are provided on both laser hall as well as plasma chamber concrete shielded room. These lamps flash repetitively whenever the laser is in operation and experiments are being conducted. “Search” operation is carried out inside laser plasma room before start of laser plasma experiments to ensure no occupancy inside during experiments. Search interlock and door interlock are provided such that machine can be started only when A CCTV camera has also been provided for visual confirmation. Once ‘Search” is over, doors are locked. In addition to these interlocks, scram switches are also provided within the shielded room such that any trapped person can put off the machine by activating the scram switch.

No serious ionizing radiation hazards to working personnel are anticipated during laser plasma experiments due to adequate radiation shielding system and personnel protection system (interlocks). Working personnel are given training in safe operation of facility. Only trained personnel shall be permitted to operate machine. List of personnel who shall be trained and authorized to operate is displayed at the entry point to the shielded room (Plasma chamber room, where experiments are carried out). All experiments are carried out remotely from the control room.

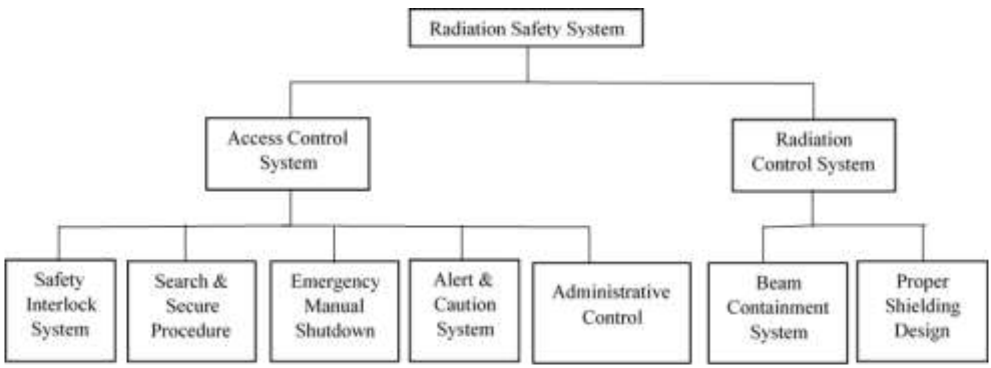
2.2.4 Particle Accelerators

The Accelerator machine should be operated by qualified, trained and authorized personnel. The control room of the accelerator should not be left unmanned during operation and operator should have control over the personnel movement in restricted areas. A search and secure procedure should be ensured before operation of the accelerator. Announcement for accelerator operation should be made on Public-Address system after completion of search and secure procedure. Also scram switches should be provided to shut down the accelerator. There should be engineered access control system provided in the facility. Breach of access control should be interlocked with the operation of the accelerator. A by-pass of any safety interlock during operation should be allowed only if backed by a work permit. For personnel protection there should be personal dose monitoring facility available. Area radiation monitors should be provided in consultation with the Radiological Safety Officer of the facility. The most important safety consideration during operation is availability of effective Radiation Safety System. The component of Radiation Safety System are described below:

Radiation Safety System

Two types of protection systems are considered for radiological safety of accerelators. These are passive protection system and active protection system. Passive protection system is implemented by proper shielding design whereas active protection system is implemented by engineered system and administrative controls.

The logical organization of the Radiation Safety System (RSS) is schematically presented in below:



Radiation safety system (RSS) consists of the Access Control System (ACS) and Radiation Control System (RCS). Role of ACS is to keep people away from radiation, while RCS keeps radiation away from people.

- *Safety Interlock*
  One of the key elements of safety in accelerators is the safety interlock system, which is designed to protect the machine and personnel under any abnormal/unsafe condition. Beam safety interlocks are an integral part of the safety interlock system. Beam safety interlocks ensure that the primary beam under no condition deviates from stipulated trajectory. Interlocks also ensure that the beam is shut off in case of any potentially unsafe condition. A rigorous program of testing & maintenance to keep the interlocks functional at all times need to be in place, introducing desired redundancy wherever necessary. Safety systems and administrative controls are reviewed periodically by the regulatory body and also by third party after any major modification.

- *Search & Secure Operation*
  A Search and Secure operation is conducted in Zone-3 or Zone-2 just before the primary particle beam is switched on, to ensure that no person

has remained in the interlocked areas. The Search and Secure procedure is successfully completed after a series of switches in the form of push buttons are activated in a specific sequence. Scram switches (emergency beam shut-off switches) are prominently marked to enable an inadvertently trapped person to easily locate them and abort the accelerator start up.

- *Emergency shutdown*
  Manually operated emergency shutdown switches (panic buttons) are installed in accelerator facility, which immediately shut off the electrical power supplies to the appropriate accelerator systems and bring it to safe shut down. In addition to this, one scram button is provided in the control room.

- *Alert & caution system*
  In order to alert/caution the personnel inside the facility about the operational status, a number of warning systems like an accelerator notification system comprising indicative signs and labels, verbal announcements, an appropriate intercom facility with UPS in Zone-3, Audio-visual warning signal in Zone-3, CC TV cameras, radiological hazard symbol, a public address system, display of emergency procedures, emergency lights with appropriate power back up etc. need to be in place.

- *Administrative control*
  Administrative control including a work permit system for each specific work duly signed by authorized personnel as well as the Radiological Safety Officer are followed. A two person 'buddy system' are preferably adopted in work involving hazardous agents. A display system in the control room indicating the status of the various activities covered by work permits is recommended.

- *Beam Containment System*
  Beam Containment System (BCS) consists of passive and active devices designed to contain the beam in its intended path. Examples of passive devices are beam dumps, stoppers, collimators and shield wall plugs. They insure beam containment simply by their physical presence. Active components, such as Average Current Monitors (ACM), steering magnets or current comparators may act as BCS devices when interlocked in a well-defined regime.

- *Zoning*
  Depending upon the nature and extent of radiation hazards, an accelerator facility may be categorized into following zones:

Zone-1: Area which is accessible at all times.
Zone-2: Controlled/restricted entry area, accessible with appropriate administrative controls.
Zone-3: Inaccessible area during accelerator operation and controlled entry during shutdown.

- *Radiation monitoring*
  All radiation workers entering the controlled areas are covered by personal dosimetry. In addition, electronic personal dosimetry devices with alarm setting needs to be available in the facility. Appropriate area radiation monitoring devices with alarms are installed in designated areas of the accelerator facility and these transmit dose rates to the control room. Radiation surveys are carried out by Radiological safety officer or health physicists at periodic interval and also before any maintenance job carried out in Zone-2 or Zone-3. Contamination checking of the zone2/ Zone -3 is periodically done. Contamination checking is also done for the area as well as for the persons whenever such situation is expected to arise and measures like de-contamination of the person, equipment, area are taken with suitable means already in place.

- *Ventilation*
  Ventilation plays a major role in accelerator facility. Ventilation design needs to consider formation of gaseous radioactivity such as ^{7}Be, ^{15}O, ^{13}N, ^{41}Ar, if it is expected. Possibilities of generation of other noxious fumes and gases like ozone during irradiation process are also considered in the ventilation design The effectiveness of ventilation designed are tested periodically to ensure that the required number of air changes is available in the area.

- *Documents & Records*
  Each accelerator facility needs to institute a radiation safety program to manage aspects of daily operations. An important aspect of the program is a set of documents and procedures. Some of these are radiation protection manual, technical specifications for operations, work permit, interlock testing and maintenance records, dose record, calibration record of radiation monitoring instrument.

  Non-radiological hazards like industrial & occupational health, fire, electrical, RF and microwave radiation, cryogenic and high magnetic field also exist in different accelerator facilities. These are taken care by appropriate safety management system.

2.2.5 Neutron Generators

The main hazard of NGs is obviously the fact that they are radiation emitters, which is what they are built for. The user must take that into consideration before operating them, and he has to know how to protect himself and others from their radiation. Neutrons are to be considered, and also gammas that are a consequence of the neutron interactions with the materials around the neutron tube target, where the neutrons are created. Biological consequences of the NG operations must be evaluated before any use. This must be done by calculating the dose rate due to neutrons and gammas. This has to be left to a radiological safety and shielding expert.

In most cases distance alone is not sufficient to lower the dose rate to an acceptable level and the NG must be operated with shielding to reduce the dose rate to operators. These shielding could be the walls of a lab room or shielding put directly around the neutron source. Typical thickness of shielding to reduce the neutron flux and dose rate by a factor of ten is about 38 cm of water or concrete. Highly sophisticated materials are developed to optimize the shielding, namely for fusion reactor research purpose. The hydrogen rich hydrides show superior neutron shielding capability compared to the conventional materials.

NGs generally must not be directly accessible while operational. If accessibility is possible by opening a door or moving a mobile shielding, the NG must be switched off. NGs are usually provided with a safety loop that can be connected to the safety circuit of the laboratory.

Radiation hazard due to the neutron activation phenomena and its management

Neutron activation is usually the required physical effect of neutron irradiation, as it allows performing measurements on the sample being irradiated. It is also a drawback as the sample becomes immediately active. Consequently ad hoc operations have to be considered for the management of the activated samples. The activation hazard risk is low with standard NGs, and most importantly one has to deal with the regulations aspects. Levels of activation can be very different depending on the considered object. The final level of activation depends on the mass of the object, the flux it receives and the duration of irradiation. Ranking the activated objects regarding their radioactivity from most activated to least activated generally gives the following list:

(1) NG emission module
(2) Lab structures supporting the NG emission module
(3) Fixed samples exposed to flux

(4) Mobile samples

General rules

The rules mentioned in this section are just common sense rules. They are not part of a safety procedure.

Dealing with electrical hazards

Read and follow all notices from the user's manual. Ensure that equipment is properly grounded. Do not open sub-assemblies.

Dealing with radiation hazards

Tritium hazards

Tritium can be inhaled, ingested, or absorbed through skin. There is no major leakage of tritium when working with a properly functioning NG (if there is a tritium leakage, some major defect is happening to the sealed tube and the NG can no longer sustain a VHV, thus does not work). A potential problem could arise due to permeation. Few tritium atoms could permeate the walls of the sealed tube, the neutron module housing and other barriers. The final amount of released tritium atoms would be very low, but not null. Permeation can be checked with smear sample measurements. Some rules to minimize the risks of tritium are:

- Do not open neutron modules.
- Install air extraction in the laboratory.
- Emergency protocol exits.
- In case of hazards enclose NG in plastic bags.

Radiation hazards due to neutron and gamma emission of the NG during normal operation

Some rules to minimize the risks due to radiation emission during normal operation are:

- Design shielding and walls according to the expected maximal flux (or limit the flux according to the existing facility).
- Map the expected dose rate through calculations and compare it with measurements.
- Close the active area access with a safety loop. If safety loop is broken, NG will automatically be stopped.
- Train people and ensure utilization of individual dosimeters.

Radiation hazards due to activation phenomena

- Some rules to minimize the risks of activation radiation are:

- Keep in mind the order of magnitude of level of activation for activated objects.
- Measure the activated objects when samples have to be moved.
- Use labels to store activated objects.

2.2.6 Gamma Irradiators

The risk of accidental exposures can, however, be kept to a minimum by proper design and construction, with specific attention to such matters as shielding and interlocks, and a good radiation protection programme with special emphasis on training and access control. It is therefore essential that adequate radiation safety measures be taken in keeping with the objectives laid down in the mission of AERB. The information here provides overview of regulatory control in safe use of gamma irradiators.

Safety system which must be functional during operation of panoramic gamma irradiator include:

- High temperature detector: it quickly recognizes abnormal heat build-up, which could lead to product damage and the increased potential for fire.
- Ozone time delay: when air is exposed to ionizing radiation, ozone and other toxic gases are formed, which decay quickly and are also removed by the ventilation system. This safety system prevents entry in the irradiation room for a short time period after the source has been moved to the shielded position till safe level of these gases is reached.
- Pool water level sensor: it continuously monitors the water level in the storage pool and alerts the operator of unusually high or low levels.
- Radiation monitor: it continuously monitors radiation level and alerts the operator if there is abnormal level; two most likely locations for these monitors are the product exit port and water deionizer tank.
- Source-down detector system: it provides direct indication of the position of each source rack when it reaches the bottom of the storage pool.
- Earthquake detector: it provides a means of automatically returning the source to the safe storage position in the event of a seismic event.
- Product over-exposure detector: it senses any malfunction in the product movement mechanism and automatically returns the source to the storage position to avoid over-exposure of the product.

Due to high strength sources, of the order of PBq, and high power beam, of the order of kW, used in this technology, exposure to any person accidentally present in the radiation processing cell could be fatal.

3.0 REGULATORY REQUIREMENTS

3.1 SITING

Detail assessment of the impact of the site on the plant as well as the impact of the plant on site is to be carried out, considering the effect of external events such as earthquake, flood etc. as well the site characteristic parameters such as hydrology, meteorology, ecology, demography etc.

3.2 DESIGN AND CONSTRUCTION

All the nuclear facilities are to be designed based on defense in depth principle which means that in case of any radioactivity release, several layers of barriers have to be crossed before radioactivity can find its way to environment. The philosophy of diversity, redundancy, and independence and 'fail-safe' design needs to be followed so as to avoid common cause failures and to meet single failure criterion. Lay out, zoning, shielding, ventilation etc. are to be in accordance with the applicable requirements.

Safety analysis for off normal conditions including possible accidental conditions covered by design as well as severe accidents needs to be carried out. It must include hazard analysis and response of the facility to a range of postulated initiating events under different conditions of operation, maintenance and shutdown such as equipment failure & malfunctions, operator errors and external events. Both, probabilistic and deterministic approaches are to be used in safety analysis. Safety analysis is to be used as the basis for operational limits and conditions of the facility and for the purpose of emergency planning. For nuclear power plants, analysis for severe accident conditions are required to be carried out so as to formulate severe accident management guidelines (SAMG).

In addition, job hazard analysis, fire hazard analysis, Quality assurance plans are required to be prepared and implemented during construction phase. Industrial safety precautions for working at height, confined space entry, material handling, working with electrical equipment etc. should be strictly adhered to.

3.3 COMMISSIONING

Commissioning is the process by which constructed plant components and systems are brought into service and are tested to ensure that their performance is in conformance with the design intent. Among various other requirements such as submission of commissioning results to regulatory body, the following major requirements are to be met:

i) Technical Specifications for Operation

It lays down various parameters for safe operation of the plant such as the limiting conditions for operation, the limiting safety system settings, which if exceeded actuates the trip settings, the over-arching safety limit, which if crossed will render the plant unsafe and the surveillance requirements for each of the above parameters. It is revised based on the commissioning experience and finally approved by regulatory body.

ii) Radiation Protection Procedures

It spells out radiation safety programme of the plant such as classification of radioactive areas inside the plant, radiation monitoring requirements, investigation levels etc.

iii) Hazardous Chemicals handling procedures & MSDS

Department of Atomic Energy (DAE) units use many chemicals in different plants such as Chlorine, Hydrogen Sulphide, Ammonia, LPG, Hydrogen, Fuel oil, Acetylene, Diesel, Petrol, Sodium Hydroxide, Sulphuric Acid etc. Safety requirements for hazardous chemicals are available in schedule I, II & III of Manufacture, Storage& Import of Hazardous Chemicals Rules (MSIHC), 1989 , as amended in 2000, &Atomic Energy (Factories) Rules, 1996.

Identification, classification and labelling is an important facet of chemical safety. Other than labelling on the outside of containers, the information may be produced by the manufacturers in the form of documents known as the Material Safety Data Sheets (MSDS), The details of a MSDS include the following information: supplier's information/identity; hazardous ingredients; physical and chemical characteristics; physical hazards and data; reactivity and data; health hazards and data; precautions for safe handling and use; and control measures.

iv) Waste management Scheme

It lays down the strategy adopted by the plant management for safe storage/disposal of radioactive or hazardous wastes which are released during operation of the plant inform of gas, liquid or solid. The scheme all also addresses the volume reduction techniques, disposal methodology and apportioned limits for various routes. AERB/SPCB approves these limits.

v) Emergency preparedness plans

Although the nuclear facilities are built with utmost level of safety, still there is a likelihood that in an unprecedented condition, there may be accidental releases. Hence, as an abundant precaution, emergency preparedness plans have to be drawn-up. These may be on site emergency plans where the consequence will be limited only to plant site or off-site emergency plans where there is possibility of impact on the outside environment. These off-site emergency plans also have to conform with the guidelines issued by National Disaster Management Authority (NDMA).

3.4 OPERATION

Throughout the operational phase, the facility has to operate within operational limits and conditions approved by regulatory body Continuous safety surveillance has to be maintained by way of periodic monitoring of personnel, workplace, waste discharged as well as the surrounding environment. Periodic reports of monitoring including safety performance, cases of over exposures, unanticipated releases of radioactive/hazardous chemicals, technical specifications violations and other safety related events are to be investigated and reported to regulatory body. Detailed in-service inspection (ISI) and preventive maintenance is required to be carried at specified intervals. Analysis of internationally reported events and their applicability to Indian facilities is to be checked and accordingly the systems, procedures and aspects related to training & safety culture are to be further improved. Compliance to the operational safety requirements is verified by conducting periodic regulatory inspections. The license for operation is granted for a period not exceeding five years. For the license to be renewed, detailed safety assessment is to be carried out by the plant taking into account applicable factors such as safety performance of the plant, cumulative effects of plant ageing, modifications, feedback of operating experience, improvements in safety standards and operating practices and development in science and technology.

Off-site Emergency Exercises

Off-site Emergency exercises, in those facilities which have off-site hazard potential, are conducted (once in two years in nuclear Power Plant and once every year in Heavy Water Plants) to assess the readiness of the local authorities and check availability of local infrastructure facilities so that in case of an actual emergency, the authorities are geared up to tackle the situation. An exercise starts with a simulated/postulated event or series of events in the plant in which an unplanned release of radioactive material is postulated. Based on the meteorological conditions affected sector (from among 16 sectors) is simulated for the protective actions. Such exercises provide reasonable assurance that, in the event of an emergency situation, appropriate measures can and will be taken to mitigate the consequences. National Disaster Response Force (NDRF) of NDMA have also started participating in these exercises.

Licensing of Personnel

It is a mandatory requirement that personnel in operational positions at nuclear facilities are formally licensed and qualified for various levels. For this purpose elaborate training and qualification programme for operators are chalked out, including simulator training for nuclear power plant personnel. The competence requirement and the depth of knowledge and skills for each operational position are verified through a series of performance and knowledge checks.

Approval of Radiological Safety Officers in all nuclear and radiation facilities as per the provision of Atomic Energy (Radiation Protection) Rules, 2004; and competent persons and certifying surgeons in units of DAE under the relevant sections of the Factories Act, 1948 are to be obtained from the regulatory body.

3.5 DECOMMISSIONING

Decommissioning is a process by which a nuclear or radiation facility is finally taken out of operation in a manner that provides adequate protection to the health and safety of the workers, the public and the environment. The feasibility of safe decommissioning and subsequent site remediation is required to be considered during site selection, design and construction stages of consenting process and conceptual decommissioning plan needs to submitted to AERB as a part of safety analysis report.

PART-B

MEDICAL APPLICATIONS OF LASERS

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1. INTRODUCTION

Since its invention in the 1960s, the laser technology is getting matured to establish itself as the versatile medical tool for providing improved health care [1-5]. The lasers have found applications in various medical fields like angioplasty, ophthalmology dentistry, vascular and renal diseases, cosmetic dermatology, medical imaging, surgery, cancer diagnosis and treatment to name a few, and also in the area of basic medical research. The widespread use of laser technology in medical field is based on some remarkable properties of laser light like its monochromaticity, directionality, focusability, pulsed or continuous wave mode of operation as well as its intensity [1, 5]. As the laser can be coupled effectively with optical fiber based endoscopes, it permits a doctor to see inside the body as well as helps perform the ultra-precise and minimally invasive surgery. The review will provide a brief overview of the various clinical applications of lasers.

2. LASER AND ITS CHARACTERISTICS

2.1 PRINCIPLE OF LASER OPERATION

The word 'laser' is an acronym for Light Amplification by Stimulated Emission of Radiation. The light emission occurs when an atom or molecule in an excited state returns to a lower energy state by radiating a photon with energy equal to the difference in energy between the two states. The emission process can be spontaneous or stimulated. The laser radiation is emitted by the process of the stimulated emission unlike the conventional sources of radiation such as the sun, light bulbs, or candles which emit through spontaneous process. In conventional light sources, the atoms or molecules are continuously pumped to the excited energy states following which they fall back to a lower energy state, on its own (spontaneously), by radiating randomly and independent of each other leading to incoherent light. In this process, the emitted photon from an atom/molecule has no definite phase relation to that emitted by the other atom/ molecule. Furthermore, each atom/molecule can emit in any random direction. However, in 1917 Einstein showed that it is possible to force the excited atoms/ molecules to emit a photon in the presence of a stimulating photon having energy equal to that of the difference between the two energy states. The fundamental characteristics of stimulated emission is that the emitted photon is an exact replica of the stimulating photon i.e. it has the same wavelength, direction, phase, polarization etc. The "stimulated emission" is one of the important essences of the laser operation that force the independent atoms to emit in phase. Another important phrase of laser operation is "light amplification". The amplification of stimulated light to achieve the lasing action requires a necessary condition referred to as "population inversion". The population inversion means that the atom/ molecule of a medium (generally referred as gain medium) in upper level (higher energy states) has more population than the lower level. However, this term is against the normal situation of thermal equilibrium in which the lower level always has more population. This requires different practical ways known as pumping to achieve population inversion and get light amplification.

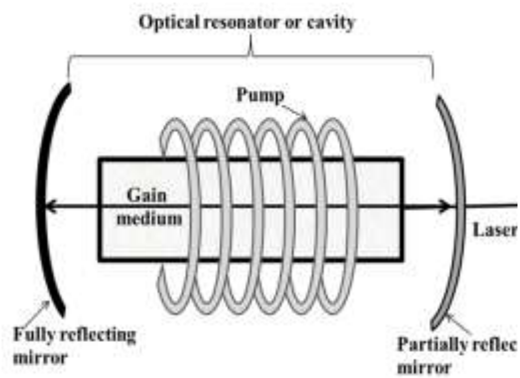

Figure 1: Schematic diagram of a typical Laser system

Laser is basically an oscillator (figure 1) at optical frequencies and mainly comprises three components: a gain medium, a pump source and an optical resonator. The light emission takes place in the gain medium. The gain medium can be a gas, a liquid or a solid and accordingly lasers are often classified as gaseous, liquid and solid state lasers. The pump source used for achieving the population inversion can be a flash lamp (as in Ruby and Nd:YAG lasers) or another laser (nitrogen or copper vapor lasers for pumping dye lasers) or an electric discharge as is the case with He-Ne and CO_2 lasers or electrical current as is the case with solid state lasers. The optical resonator is a set of two mirrors, one highly reflecting and the other partially transmitting, and provides feedback at the lasing frequency for laser operation. The radiation travelling in a direction perpendicular to the mirror bounces back and forth between the two mirrors, and gets amplified on its each pass through the gain medium. The leaked radiation from the partially transparent mirror is the useful output laser beam. The combination of stimulated emission and its controlled amplification achieved via the optical resonator contributes to the striking properties of laser light like high directionality, focusability, monochromaticity, etc.

2.2 CHARACTERISTICS OF LASER

***Directionality**:* One of the important properties of laser is its high directionality. Laser light is emitted as a relatively narrow beam in a specific direction with typical beam divergence of the order of a few milli-radians for commercially available lasers. The directionality of lasers arises because only the radiation propagating exactly normal to mirror surfaces undergoes multiple reflections and hence gets amplified during the repeated passes through the gain medium. Thus, the amplified radiation is a collimated beam and a fraction of this comes out of the output mirror as the laser light. In the collimated laser beam all the emitted waves are nearly parallel with very low divergence and so the beam does not expand much with distance. For the ordinary light sources, the light is emitted in many directions away from the source and has large divergence. It is important to note that one can obtain a directional beam from even an ordinary source of light, by keeping it at the focal point of a lens or a concave mirror – as in a torch or a lighthouse. However, to enhance the directionality of the beam the source dimension of the ordinary light source needs to be reduced with consequent reduction in intensity of the light beam.

***Radiance*:** The radiance is defined as the power emitted per unit surface area of source per unit solid angle. High radiance implies that the beam can be propagated to large distances without much loss of intensity (power per unit area). Due to their directionality the lasers have large radiance. In fact the radiance of a typical 1 mW He-Ne laser is two orders of magnitude larger than that of sun which emits more than 10^{26} W.

Focusability: The small laser beam divergence allows the focusing of laser beam to small spots with dimensions close to the wavelength. For tissue processing, it is necessary to focus the laser beams 'tightly' to produce highest possible radiance with minimum collateral damage. Also, due to its focusability, laser light can be efficiently coupled to thin optical fibers and can thus be guided endoscopically to internal organs for therapeutic applications without any major incision, considerably reducing the patient trauma and hospitalization time for several surgical procedures.

Intensity (Irradiance): The intensity is defined as the power per unit area. More tightly focused laser beam results in the higher intensities. The high intensity of a laser beam can be used to heat, melt or even vaporize small areas of any absorbing material. A laser beam with power of 1 W focused to a spot diameter of 1 μm will result in an intensity of ~ 10^8 W/cm^2.

Pulsed or continuous wave operation capability: Lasers operate in continuous wave (CW) as well as pulsed mode. By exercising control of the stimulating light, the whole energy stored in the active medium can be emitted in form of nanoseconds to sub-picoseconds light pulses. As all the energy of the laser beam is available in a short pulse this results in very large peak power. For example, the 100 J of energy that a 100 W bulb consumes in 1s, if available in 1 ps, will result in a peak power of 10^{14} W. The use of a pulsed laser offers the added advantage that the irradiated area on tissue can be vaporized before heat could flow out to the tissue in the vicinity of the exposed area. Moreover, the CW laser beams best suited for bacteria inactivation, protein denaturation, tissue coagulation and welding etc.

Monochromaticity: The lasers beam, in general, is highly monochromatic light source with minimal frequency spread. The frequency spread of typical He-Ne laser used in laboratories is ~ 10^9 Hz, which comes out to be 0.01nm bandwidth in terms of wavelength. As compared to this the frequency spread of sun is ~ 3×10^{14} Hz for the visible light. In medicine, the frequency dependent absorption of the components of a multi-component system can be exploited for selective processing of a desired component.

Spectral coverage: Lasers are available from vacuum ultra violet to millimeter spectral region. This makes the flexibility to choose the application specific laser light sources based on the characteristics of targeted sample and the purpose of medical outcomes. **Table 1** lists some of the important lasers (and their applications) which are widely used in medical field.

3. LASER TISSUE INTERACTION

When light falls on a tissue, part of it is reflected, transmitted or scattered from the tissue surface. The transmitted light while propagating through the tissue loses its directionality because of multiple scattering or gets attenuated because of absorption. The absorbed energy may also be re-emitted as fluorescence light. The molecules which absorb light radiation and then emit fluorescence light are collectively known as fluorophores. The fluorophores absorb light of particular wavelength more efficiently than other and re-emit light of higher wavelength (lower energy). The fluorescence from a native tissue is attributed to many endogenous fluorophores like the co-enzymes (NADH and Flavins), the structural proteins (collagen and elastin), aromatic amino acids (tryptophan, tyrosine, and phenylalanine), porphyrins [6] etc. believed to be present in tissue. The light in the ultraviolet (UV) spectral region below 300 nm is strongly absorbed by the DNA base pairs. The absorption and emission characteristics of few important endogenous chromophores present in tissue are shown in **figure 2**. Different fluorophores have their characteristics absorption and emission spectra. For a given wavelength of excitation only those molecules emit fluorescence whose absorption bands have an overlap with the excitation wavelength. The transformation of a tissue from normal to diseased state is accompanied by changes in the concentration/ chemical state of these fluorophores making tissue fluorescence sensitive to disease progression and particularly suitable for tissue diagnostics.

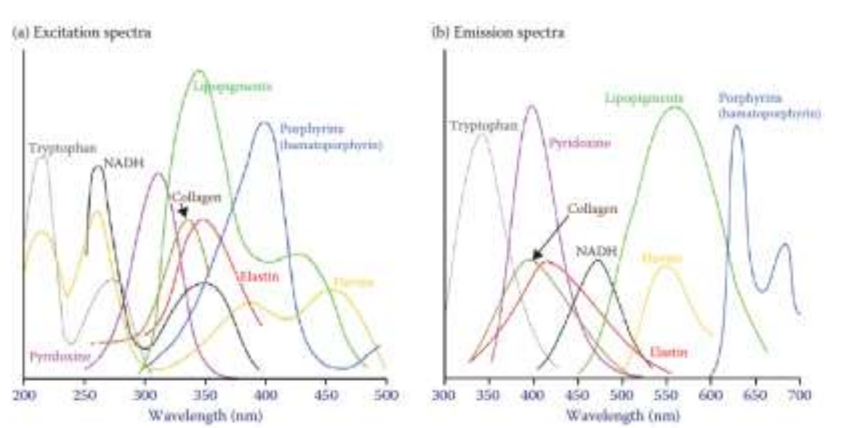

Figure 2: Excitation (a) and emission (b) spectra of the main endogenous fluorophores in biological tissues [Adapted from ref.6]

Apart from the fluorophores, many other molecules are present in tissue which absorb the light energy but do not emit fluorescence. These absorbers include oxyhemoglobin (absorption maxima at 415, 542 and 576nm), deoxyhemoglobin (absorption maxima at 433 and 556 nm), melanin (400-700nm) and water (strongly absorb near infrared light). The **figure 3** shows the absorption characteristics of a few important tissue absorbers.

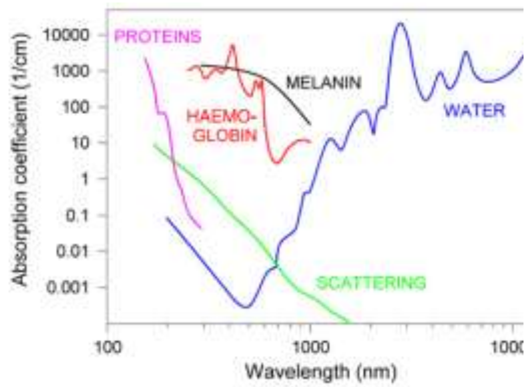

Figure-3: Absorption spectra of water, haemoglobin, melanin and proteins together with scattering in tissue [Adapted from ref.1].

However, in tissue, apart from absorption, light also gets scattered. The scattering can be elastic (without change in wavelength) or inelastic (with change in wavelength). The elastic scattering in tissue arises from the refractive index mismatches at the boundary of various microscopic inhomogeneities like macromolecules, cell organelles, organized cell structures, interstitial layers etc. The elastic scattering carries information about the size distribution and the density of the scatterers, which can be used to monitor neoplastic changes in biological tissues. The inelastic scattering probes the vibrational energy levels of molecules. Because of its molecular specificity, inelastic scattering also has the ability to discern the subtle biochemical changes associated with disease transformation thus making it particularly suited for diagnostic applications. The diagnostic applications of lasers are based on scattered or re-emitted light and generally visible (or near UV) light is used for illumination, because this region of light covers the excitation maxima of most of the important molecules.

The **figure 4** taken from reference [7] shows the absorption characteristics of biological tissues. In the ultraviolet (UV) region, the absorption of light in tissue is mainly due to protein and DNA molecules. In the infrared (IR), the absorption increases with longer wavelengths due to tissue water content (~75%). The haemoglobin has a structured absorption band spanning the whole of visible and NIR region. However, since the volume fraction of blood is a few percent in tissues so only when photons strike a local blood vessel they encounter the strong absorption by blood. Similarly, despite the local interaction of light with the melanosomes is strong but its contribution to the average absorption coefficient of tissue may be moderate and depends on its volume fraction present in the epidermis.

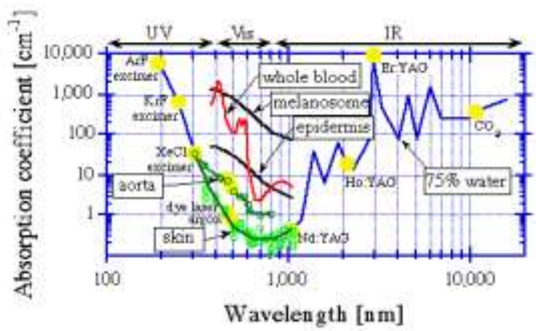

Figure-4: Absorption spectra for biological tissues [Adapted from ref. 7]

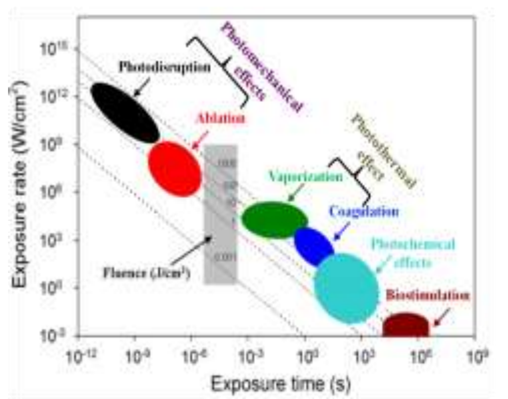

Figure-5: The laser–tissue interaction dependence on the exposure rate and interaction time (Adapted from ref. 1)

The diagnostic applications of laser require minimizing absorption in tissue to avoid the adverse effects. However, the therapeutic applications of laser depend on absorption of light. Depending on the total exposure, exposure rate and the duration of exposure the absorbed laser energy can lead to different photo-biological effects (**figure 5-6**). These effects can be broadly classified into three main categories. The most common effect is a rise in tissue temperature (photo-thermal effect). The short wavelength lasers can excite molecules or break the molecular bonds in the tissue to initiate photochemical reactions (photochemical effect). High intensity laser pulses with short pulse duration (nanosecond, picoseconds etc.) can lead to generation the pressure waves or shock waves (photomechanical effects). The rate of energy absorption largely determines whether photochemical, thermal, or photomechanical effects are dominant (**figure 5**). The therapeutic goal of the laser is to optimize these various photo-biological effects which are discussed in details in the following:

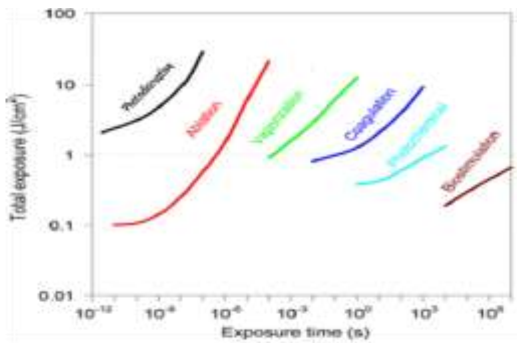

Figure-6: The laser–tissue interaction dependence on the total exposure and interaction time (Adapted from ref. 1).

Photothermal Effects:

The most important therapeutic applications of laser light are based on the photothermal effect i.e. conversion of light energy into heat. The thermal effect of the laser energy on tissue depends on the degree of temperature rise (figure 7). The rise in temperature is determined by various factors – the volume of tissue volume in which energy is deposited, the rate of energy deposition and the ability of tissue to dissipate the heat. The first event starting to occur with 5-10°C rise in temperature above the normal body temperature is hyperthermia which influences enzymes activities, changes in blood flow and vessel permeability. The non-sporulating bacteria are readily inactivated in temperature range between 50-60°C.

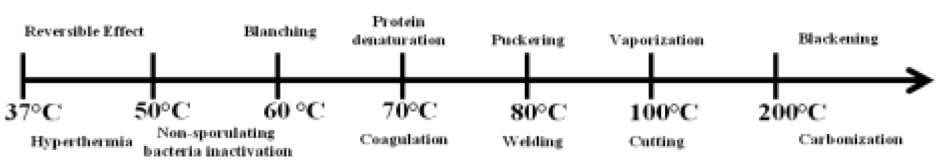

Figure 7: The evolution of thermal effect with their impact on optical processing of the tissue.

Tissues heated to a temperature of 60-70°C results in denaturation and coagulation of proteins due to breakage of Van der Wall bonds, which stabilize the conformation of proteins and other macromolecules. A controlled laser parameter to keep the temperature in this range can be used to remove diseased granulomatous tissue by destroying those cells without vaporization [4]. The temperature ~ 70-80°C causes the denaturation of triple helical collagen structure and initiates the interaction between adjacent collagen strands. This effect is exploited for tissue welding using the controlled laser light for uniform tissue heating. Hemostasis also occurs in this temperature range because of increased blood viscosity arising from denaturation of plasma proteins, haemoglobin and perivascular tissue [5]. Selection of the laser wavelength determined by haemoglobin absorption and the laser energy to maintain this temperature range can be used for stopping bleeding or to seal blood vessels with ultra-high precision. The laser with small penetration depth i.e. with a wavelength for which absorption in target tissue is very large, has smaller thermally affected region and produces coagulated region as thin as possible. However, if the application is to coagulate a large volume of tissue mass, the laser with a larger depth of penetration is more appropriate.

When the temperature exceeds 100°C vaporization of water within tissue occurs. This is the mechanism by which a laser knife works for tissue cutting in surgery. The laser light vaporizes the tissue water, this cause large and rapid expansion within tissue and physical separation or “cutting” occurs. This interaction requires laser solutions that have high average power and a wavelength that matches the absorption levels of target tissue. With further rise in temperature of above 200°C, the carbonization takes place after completion of tissue dehydration. It is important to mention here that tissue heating can be achieved by several other means, however none can provide the selectivity as offered by lasers.

Photomechanical Effects:

Photomechanical effects are usually observed with high intensity laser pulses of nanosecond or shorter pulses duration. If the rate of deposition of energy is faster than that required for boiling of water, the tissue is superheated and can be “*ablated*”. In ablation, most of the energy deposited in the tissue is converted into the kinetic energy of the ablation products. This interaction requires laser solutions with high power density and wavelengths in the UV or IR region in order to superheat the water molecule (**figure 3**). However, using the IR light, the heat may diffuse from the ablation center and can cause thermal damage to adjacent tissue as well. The laser-tissue interaction zone is determined by spot diameter and optical penetration depth. The UV light can be focused to a small-sized spot with better precision. Since it has less penetration depth in tissue, the ablation with UV lasers is sharp, localized and has minimal thermal damage to the adjacent tissue.

This is the reason why an excimer laser emitting at ~172 nm is the desired source of UV radiation for use in the refractive surgery of cornea (where photo-ablation effect is the underlying phenomenon). Although, both the thermal vaporization and ablation result in tissue removal, the kinetics involved in ablation are considerably faster and explosive removal of the ablation product causes minimum damage to the adjacent tissue.

The nanosecond or pico second pulses when focused to a very small spot would lead to "photo-disruption" of tissue. Focusing of a pico-second pulse of even a small energy 1 μJ can result in local exposure rates of 10^{10}–10^{12} W/cm^{-2} generating the local electric fields of 10^6–10^7 V/cm^{-1} [8]. These fields are sufficient for optical breakdown of tissue to yield micro-plasma with extremely high electron density within the tissue. When this plasma expands a mechanical shockwave travelling at supersonic velocities arises, and lead to localized photomechanical disruption. This effect is used for photo-disruption of large molecule of tattoo ink into smaller particles, so that lymphatic system can dispose them, leading in removal of tattoo marks. These plasma-mediated shock waves are also widely used for breaking stones in the kidney or urethra (lithotripsy), non-invasive treatment of iridectomies and in posterior capsulotomy for removal of opacified posterior capsule of the eye lens [1,5].

Photochemical Effects:

The photo-thermal and photomechanical effects are not possible if the power levels of light are below the hyperthermia threshold. However, the photons can be absorbed by biomolecules provided that the energy of laser photon is adequate to cause electronic excitation of molecules. The photo-excitation of molecules is followed by biochemical reactions and results in the generation of free radicals and reactive ions and oxygen species. The bio-activation of molecules, either endogenous present in tissue or externally injected is exploited in various phototherapies. A prominent example is Photodynamic therapy (PDT) where a photo-sensitive and lesion-localizing drug is administered followed by a low, non-thermal dose of light irradiation. When irradiated with UV or visible light, the PDT drug generates free radicals and/or reactive oxygen species in the vicinity of lesion for selective destruction of target tissue volume. For topical PDT applications the traditional fluorescent, incandescent and vapour light sources, as well as LEDs can be used. However, for PDT of internal organs through fibres, lasers are needed. Many photosensitizers and porphyrin precursors have already been approved by regulatory health agencies in many countries as a treatment modality for a number of non-oncological and oncological diseases.

4. MEDICAL APPLICATIONS OF LASERS

The utilities of lasers in medical field have already found widespread applications in several medical disciplines including ophthalmology, dentistry, dermatology, neurosurgery, urology, otolaryngology to name a few. Particularly, the use of lasers in various surgical procedures is well established and is expanding rapidly in the field of PDT and photo-detection of disease. The regulatory health agencies in many countries have already approved the lasers guided photochemical effects on the externally injected photosensitizers and porphyrin precursors as a treatment modality for a number of non-oncological and oncological diseases. The use of lasers plays a major role for in-vivo photo-detection of diseases based on spectroscopy and imaging techniques and the field is witnessing tremendous growth. The lasers have also made it possible to develop more sensitive analytical instruments for biomedical applications. With advancement in light delivery system the use of lasers in medical is continuous evolving field. Some common types of medical lasers and their major applications are summarized in **table 2**. Consideration for selection of laser for medical applications and few medical applications of lasers are discussed in the following subsection.

4.1 CONSIDERATION FOR SELECTION OF LASER

The selection of a laser for a given therapeutic or diagnostic application is very specific to the nature of the medical application. It depends on (i) the absorptive characteristics of the bio-molecules or tissue to be targeted, (ii) the wavelength of laser radiation, (iii) the total amount of power required, energy density, exposure rate and duration as well as repetition rate of exposure, and (iv) the mode (pulsed or continuous) of beam energy delivery to a target tissue. Few of the commonly used medical lasers and their important characteristics are summarized in **table 1**.

Depending on the absorptive characteristics of tissue, light of a given wavelength can penetrate only up to a certain depth known as the optical penetration depth (δ). The optical penetration depth is the thickness of medium that causes light to attenuate to 37% its initial value. It is the characteristics of the medium at a given wavelength of light, and plays an important role in making the right choice of laser for medical application. The typical penetration depth for some common medical lasers in human skin tissue is shown in **figure 8**. From figure it is clear that under direct exposure to skin the excimer laser light cannot penetrate more than few micrometers and so may not useful for application involving the dermis.

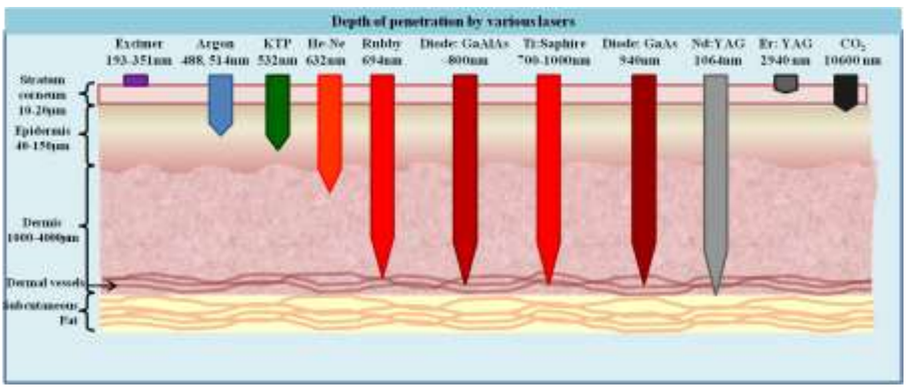

Figure-8: Penetration depth of some common medical lasers in human skin tissue (Adapted from ref. 9).

4.2 OPHTHALMOLOGY

The fact that light can be used for treatment of eye diseases was well established even before the laser came into existence. In the 1940s, a German ophthalmologist at the University of Hamburg, Gerd Meyer-Schwickerath had introduced the use of light energy from the sun to 'weld' the retina to the underlying epithelium [12]. Later using the xenon arc light, he invented the treatment methodology for retinal tears, macular holes, diabetic retinopathy and anterior as well as the posterior segment of ocular diseases [13]. Immediately after the invention of the first ruby laser in 1960, the Koester and Campbell in 1961 used a confocal laser transmission system for the first retinal laser coagulation to treat a retinal tumor in a human patient [1, 13].

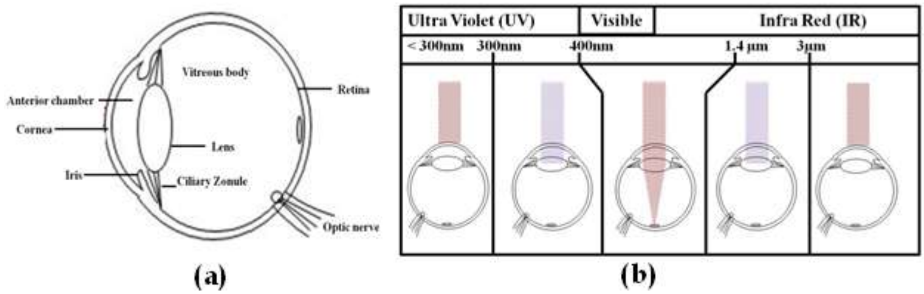

Figure-9: The structure (a) and the spectral transmission characteristic (b) of the human eye.

The selection of a laser for a given ophthalmological laser processing primarily depends on its emission wavelength. The figure 9 shows the schematic diagram of structure and spectral transmission characteristic of the human eye. The UV light with wavelengths less than 300nm or IR light with wavelengths greater than 3µm have least penetration depth and are absorbed within cornea, so the lasers operating in these wavelength regions are opted for corneal laser processing . Moreover, the final selection of a laser also depends on the light tissue interaction. For example, with the Nd:YAG laser emitting at 1064 µm, the light tissue interaction process is photodisruption [1]. This effect can be exploited to make tiny holes and is applied for iridotomy in the pupillary-block glaucoma caused by increased pressure in the eye, and also for lens capsulotomies [1]. However, a complete different tissue interaction process based on photoablation effect dominates with UV light less than 300nm. The Excimer lasers emitting in this spectral region are found to be able to etch a living tissue precisely without causing any thermal damage to the surrounding area and are opted for reprofiling of cornea to correct vision disorder [13]. Hyperopia, myopia and astigmatism are corrected by photorefractive keratectomy with minimal thermal damage using the excimer laser ablation. Using the excimer laser, the laser-assisted *in situ* keratomileusis, LASIK (Figure 9.1) has become a revolutionary photorefractive keratectomy procedure nowadays. In addition, the Excimer lasers are also used for removal of superficial corneal

Figure 9.1: LASIK Surgery

opacifications in scars and dystrophies and for closing the epithelium in non-infectious corneal ulcers [1].

The light having wavelength between 400nm to 1.4μm can be transmitted through the ocular tissue. The lasers having wavelength in this range can produce photocoagulation effect on absorption of light and therefore are used for intraocular applications. The Ar laser light being strongly absorbed by melanin and hemoglobin becomes a standard modality for retinal coagulation of diseases such as diabetic retinopathy, and for focal coagulation of trabecular meshwork to treat the glaucoma etc. [1, 13]. The green light of Ar laser (514.5nm) is preferred over blue light (488nm) to minimize the damage of macular region. In the presence of vitreous or retinal hemorrhage, the He-Ne laser is preferred for retinal procedures as red light can pass through hemoglobin. However, the red light from He-Ne laser penetrates deeper so have potential to damage the choroidal capillaries that can result in bleeding and increase pain [1, 13]. The CO_2 and Er-YAG lasers are used to seal the leaking blood vessels by reducing bleeding during surgery, this makes comfortable survey of surgical field. Apart from this, the laser based instrument such as scanning laser ophthalmoscope are used as diagnostic tool for eye disorders [1].

4.3 DENTISTRY

The lasers are used today in many fields of dentistry including hard tissue applications, soft tissue surgery, periodontology, endodontics, stimulated healing and aesthetic dentistry [14]. The hard dental procedures require the drilling and cutting of enamel and dentine tissue without damaging the dental pulp. The commonly used lasers (Nd:YAG, CO_2 and semiconductor diode laser) in medicine are not suited for this purpose as they could damage the underlying dental pulp because of deeper thermal effected zone. The introduction of the high power pulsed Er:YAG laser had addressed this limitation and made it possible to carry out laser procedures on hard dental tissues [15]. The Er:YAG laser operates at wavelengths of 2940nm which is strongly absorbed by hydroxyapatite and water limiting the penetration depth within 1μm for dental tissues [4, 14]. The strong absorption of Er:YAG laser light in the extremely small volume causes ablation of hard dental tissue without significant thermal effects and thus makes this laser attractive for sawing and drilling in enamel, dentin, and bone. The other lasers used for hard tissue procedures include Er:YSGG and Er:Cr:YSGG [1, 4]. The Er-based laser systems are attractive tools used for effective caries removal and cavity preparation without significant thermal effects.

The lasers with wavelength corresponding to the absorption of melanin, hemoglobin and water (the main light absorbers contained in gingiva and mucosa) are used for soft tissue applications. Numerous surgical procedures for soft tissues can be performed with lasers including cysts, fibroma, frenectomy, gingivectomy, gingivoplasty, hemangioma, herpes labialis, papilloma, pyogenic granuloma, vestibuloplasty, ulcers and tumour excision, aphthous removal, removal of gingival pigmentation etc. [1, 14]. The main advantages of laser soft tissue surgery are reduced bleeding intra-operatively and less pain postoperatively in comparison with conventional techniques such as electro- surgery [14]. For soft tissue application the radiations from argon (514 nm) or KTP (532 nm) lasers being optically tuned near to the absorption peaks of haemoglobin provide very good haemostatic effect [1]. The other commonly used laser for cutting, vaporization, and decontamination of soft tissue are the diode, Nd:YAG, Er :YAG, Er,Cr:YSGG and CO_2 lasers although they provide less hemostatic control [14]. However, as the power density also plays important role in tissue removal, the high power CO_2 lasers are preferred for major soft tissue surgery.

The lasers being able to produce bactericidal and detoxification effect provide a more attractive alternative approach to kill the bacteria *in situ* instead of the removal of the infecting microorganisms by drilling. The laser can also be used for removing the epithelium lining, granulation tissue, and accumulation of bacterial biofilms on the tooth surface above the level of the gingival margin, which are desirable properties for the treatment of periodontal pockets [14]. Generally, the Er:YAG laser is used for safe and effective debriding of root surface and gingival tissue of the periodontal pockets, and the Nd:YAG, diode and argon lasers are used for soft tissue curettage and disinfection of periodontal pockets [14]. Also, using the laser assisted PDT drugs like Toluidine Blue O or aluminium disulfonated phthalocyanine the bacteria present in dental plaques and caries can be killed more efficiently [1].

In Endodontics the lasers are used for treatment of root canals in teeth. The argon, KTP, Ho:YAG, and Nd:YAG laser irradiations were found to have efficient cleaning effect of root canal surfaces. Apart from this, the Er:YAG laser is used for root canal orifices and CO_2 laser is used to reduce dentin permeability. The clinical follow-up studies on the group of patient with root canal treatment with and without laser cleaning have shown that the laser-treated group with revealed significantly reduced postoperative discomfort or pain [14].

Lasers with low power and wavelength in the UV/visible region can be used for early caries detection. The accumulation of bacterial by products in caries such as porphyrins, when illuminated with blue light give a strong red fluorescence even if extensive and higher damage to tooth tissue has yet to be observed with visual and tactile methods [14].

The low power He-Ne, Ar and NIR diode lasers can influence healing stimulation and pain reduction and therefore, are used for therapeutic applications such as wound healing after tooth extraction, soft-tissue healing, temporomandibular joint rehabilitation, herpes labialis, glossodynia, angular cheilitis, etc [14].

Lasers can also be used for aesthetic dentistry such as tooth whitening and FDA (Food and Drugs Administration) has approved the argon, CO_2 and 980 nm GaAlAs diode for this procedure. The diode and CO_2 lasers are used to induce photothermal bleaching while argon lasers being absorbed by chelate compounds formed between apatites, porphyrins and tetracycline compounds are used for photochemical bleaching of the teeth [1, 14].

Apart from this, the CO_2 laser along with other lasers are also used in dental laboratory for application involving laser welding of new materials, computer-aided design and computer-aided manufacturing. The holographic imaging is a well- established method for storing the topographic information such as crown preparations, occlusal tables, and facial forms [14].

4.4 DERMATOLOGY AND PLASTIC SURGERY

Lasers were introduced in the dermatology in the mid-1960s by the Goldman and his co-workers. They have successfully demonstrated the effects of lasers on skin describing the selective destruction of pigmented structures and hair follicles with the beam of the ruby laser

[16]. The lasers invention has opened up a new era in specialty of dermatology [17]. For example, before the advent of lasers the portwine stains (purple birthmark) were treated using ionizing radiation, cryosurgery or skin grafting which used to cause a lot of patient discomfort. The lasers emitting in the visible range (Cu-vapour, KTP, pulsed dye, ruby etc) are absorbed by intravascular haemoglobin and therefore, are suitable for photothermolysis to selectively destroy the diseased blood vessels. The selectivity of the process depends on the fact that micro-vessels have a thermal relaxation time of 0.05-1.2 ms and so only vasculature is damage under short pulse operation of these laser sources without affecting the surrounding tissues and causing scarring. The figure 10 shows the effectiveness of laser treatment for PWS lesion.

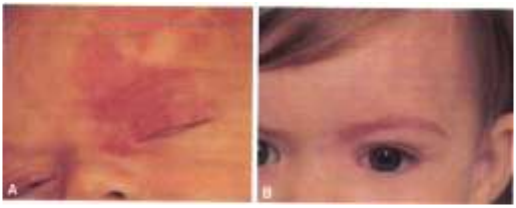

Figure- 10: Port-wine stain in infant before treatment (A) and resolution after 585-nm pulsed dye laser treatment (Adopted from ref. 18).

The other common use of laser in dermatology is the removal of tattoo ink by photo-disruption of large molecules of tattoo ink into smaller particles. Subsequently, the human immune system can throw out the smaller ink particles from dermal layer. As the process involved is photo-disruption, the lasers with short pulses and wavelength optimized for absorption by tattoo molecules are used. Depending of the colour of tattoo ink to be removed, the choices can vary from pulsed dye (for yellow orange, and purple ink) through KTP (for yellow orange, red ink) through ruby (for red, blue-black, and occasionally green and brown ink) to Nd: YAG (for blue and black ink) lasers. Figure 11 shows the effectiveness of laser for tattoo ink removal.

Figure- 11: Tattoo before (A), in between (B and C) and after (D) lesional clearance with laser treatment (Adopted from ref. 19)

The lasers are used for application of permanent hair loss by damaging the follicular stem cells in the bulge region of the outer root sheath and/or the dermal papilla at the base of the hair follicle. This application requires the deep tissue penetrating laser sources with high energy. The millisecond-domain ruby, diode (with NIR wavelength) and Nd:YAG lasers are most preferred laser sources for this purpose [16-18].

The lasers are also used for skin rejuvenation and number of cosmetic conditions by producing subtle thermal effects on the dermis to stimulate a wound healing response [16-18]. They create thousands of nearly invisible, microscopic zones of thermal injury for remodelling of both the epidermis and dermis for skin resurfacing to treat scars and skin aging. The process is called fractional photothermolysis. The pulsed CO_2 and Er: YAG lasers are the most preferred light source for this application. The fractional photothermolysis process can be non-ablative or ablative. The erbium (Er):YAG laser with a very short wavelength of 2,940 nm and minimum penetration depth allowed a more superficial vaporization of tissue for creating small vertical channels that can extend directly into the dermis [16]. This allows the effective mechanism for topical drug delivery, by providing many channels directly into the dermis.

The PDT drugs along with laser irradiation are used in applications like wound healing and selectively destroying the diseased vessels. In addition, lasers are applied for surgery of benign and malignant tumours and infectious lesions.

Apart from the therapeutic applications, laser based optical spectroscopy and imaging tools such as optical coherence tomography, fluorescence spectroscopy, reflectance spectroscopy, Raman spectroscopy, and confocal microscopy found to be effective in the diagnosis of skin cancer [20-21]. Researchers from the University of Texas at Austin's Cockrell School of Engineering have now developed a probe that combines three spectroscopic techniques fluorescence, diffuse reflectance and Raman spectroscopy into one device, to measure the properties of skin tissue and detect cancer. The device is in pilot clinical trials to help bring the device to dermatologists' offices.

4.5 NEUROLOGY AND NEUROSURGERY

Applications of light in neurology and neurosurgery include therapy, surgery, diagnosis, investigation and monitoring [22]. The laser assisted therapy due to their accurate and non-contact approach significantly reduces surgical brain trauma. The most effective laser in the treatment of central nervous system (CNS) tumours and vascular malformations are the CO_2, Nd :YAG and diode lasers [1]. The CO_2 laser radiation was highly appreciated for neurosurgical applications such as resection of intra-cerebral, extra-axial, skull base and spinal tumours [1, 22]. The CO_2 laser-assisted spinal surgeries are useful for pituitary tumours, spinal cord neuromas, intra-cerebral gliomas and metastases [1, 22]. Apart from this, the CO_2 laser is also used for tissue welding, treatment of Alzheimer's disease and activating light assisted nerve repair [22]. The Nd:YAG laser has proven very effective in coagulation of vascular malformations and for ablative stereotactic neuroendoscopy for guided resection of the third ventricle colloid cysts [22]. For ablation of brain tissue, the Er:YAG laser is also used as it minimizes the injury to the surrounding tissue because of limited thermal alteration of the adjacent tissue [22]. For intracranial bypass surgery of the brain the preferred technique is the excimer laser/catheter system known as Excimer laser assisted non-occlusive anastomosis (ELANA) [22]. The low power laser application of NIR laser light being able to penetrate deeper was found to be able to increased ATP production. PDT is a relative new technique that has been used for the treatment of brain tumours with hematoporphyrin derivative, Photofrin or Foscan drugs in combination with laser light [1].

Pascu et al. [23] demonstrated that a comparison of N_2 laser excited auto-fluorescence allows the identification of brain tumor tissues and normal tissues, by measuring the variation of the ratio of some fluorescence intensity peaks between normal and tumor tissue samples. The possibility of femtosecond laser to investigate the biological function of sub- cellular compartments in living cells was also explored [22]. The *in vivo* two-photon fluorescence imaging coupled to laser-induced nano-surgery is a promising tool to study the reparative properties of the adult CNS. The brain activities related to haemoglobin level can be also monitored by visible lasers light exploiting the fact that haemoglobin has high absorption in this wavelength range [22].

4.6 UROLOGY

The major application areas of laser in urology are lithotripsy and prostatectomy. With the technological improvement in the fiber optic based light guidance system, the laser applications in urology are expanding in almost all disciplines including endourology, laparoscopy, nephroscopy, pelviscopy, perinephroscopy, and retroperitoneoscopy. The clinical application of lasers in lithotripsy was first started in mid 1980s with the introduction of intense dye laser with short pulses to break down kidney stone into tiny fragments so that they can be flushed out or excreted through urine [1]. The laser beam is delivered through a fine optical fibre (with core diameter of ~200 µm) placed in direct contact with the stone resulting in a shockwave at the stone surface to fragment most types of stone. The optical fibre based light delivery to stones reduces the risk of any damage to surrounding tissue. The laser lithotripsy is less invasive than surgery, meaning patients recover more quickly and are less likely to experience complications. Nowadays, the Ho:YAG laser being of smaller sizes and having low maintenance cost has replaced the dye laser in lithotripsy. Apart from this, the Ho:YAG laser is strongly absorbed by water in the tissue, which allows to cut and coagulate tissue with a small zone of 0.3–0.4 mm [1].

This property makes the Ho:YAG laser ideal for a range of soft tissue procedures including surgery of benign prostate hyperplasia (BPH) and bladder tumour as well as incision of urethral strictures caused by surgery-induced tissue trauma. The KTP and Nd : YAG laser are other higher power, less expensive alternative sources for the surgery of benign prostate hyperplasia. Other common applications of lasers in urology include use of Nd:YAG and CO_2 laser for ablation of penile carcinoma, and use of Nd :YAG and Ho :YAG laser for incision of ureteroceles [1].

4.7 OTO-RHINO-LARYNGOLOGY

In oto-rhino-laryngology, lasers have applications in almost every field including laryngology, bronchology, rhinology, otology, general otolaryngology etc. The most widely used laser in the otolaryology is CO2 laser, particularly ideal for surgical excision in combination with operating microscope. The use of CO_2 laser for excision mainly depends on the size of the lesion and the degree of vascularity. It is widely used in laryngology for delicate phonatory surgery, precise excision of early tumors, and vaporization of bulky obstructing carcinoma of the upper airway [24]. It is also used for delineating or circumscribing the bigger lesion, which can be then excised using either microscissors or the laser. The CO2 laser is helpful in the treatment of lesions in the larynx, pharynx, upper trachea, and nasal and oral cavities, permitting longer reoccurrence interval for disease than obtained with cold instruments [24]. The CO_2 laser plays ideal role in tracheobronchial laser therapy for patients with resection of benign stenosis and tracheobronchial papillomatosis with minimal damage to the airway wall. The CO_2 laser has homeostatic capability and permits precise surgery of polyps without obscuring the surgeon's view. It has also been used for welding vocal cord mucosa, particularly after removing a cyst or raising a mucosal flap. Cysts found in the supraglottic larynx are also easily treated using the CO_2 laser by unroofing the cyst, aspirating its contents, and masupializing it completely [24]. Lasers have also been used to treat snoring by trimming away part of the uvula [1].

For nasal surgery application, the CO_2 laser is used for vaporization of hypertrophied turbinates and occasionally for coagulation of small blood vessels in the milder forms of hereditary hemorrhagic telangiectasia [24]. However, for vascular lesions of the nose, such as low-flow venous malformations and hereditary hemorrhagic telangiectasia, the Nd:YAG lasers are used because of its good coagulating property. The KTP and argon lasers have effective coagulating characteristics but have only superficial penetration. However, since they can be transmitted through small flexible endoscopic fibers they are also used for endonasal surgical applications [25].

The argon, CO_2, and KTP lasers are useful for ossicular surgery and particularly stapedotomy. The laser stapedotomy has greatly decreased the risk of a floating footplate [1, 24]. It minimizes the chance of fracturing or mobilizing the stapes footplate by laser vaporization of posterior crus before removing the superstructures.

5. HAZARDS AND SAFETY PRECAUTIONS

The controlled and safe use of laser is a boon in medical fields. However, the improper handling of lasers or accidental exposure may turn them into potentially hazardous tools. The major hazards include the injuries to eye and skin. The laser light can damage the retina as the eyes are designed to focus the light. The natural blink reflex of eyes is not fast enough to prevent the laser light reaching to delicate retina and possible damage could be irreversible. The UV and IR light, not visible to eyes, have more risk as compared to visible light since the protective response of eye "blink relax reflex" only operates if the light is visible. Regulatory agencies worldwide have proposed safety guidelines for the operation of lasers by setting limits for laser exposure and maximum permissible exposure (MPE) [26]. The MPE is the highest power or energy density of a light source that is considered safe. Typically it is set at 10% of the dose that has a 50% chance of creating damage under worst-case condition. The MPE standard is different for skin and eye tissue and is measured at the cornea of human eye or at the skin, for a given wavelength and exposure time. The hazard of a laser is not only related to output power, but also on several other factors such as wavelength, temporal characteristics (continuous or pulsed), duration of exposure, source size etc. The damage mechanics, such as photo-chemical and photo-thermal also depends on wavelength. Therefore, Laser hazard classification system is used which is based on the laser's potential for causing immediate injury to the eye or skin and / or potential for causing fires from direct exposure or diffuse reflective surfaces. The lasers are mainly classified into four categories:

(i) **Class 1**: Lowest power Lasers that do not emit hazardous levels, e.g. laser printers

(ii) **Class 2**: Low-power lasers that pose a hazard only if viewed directly for extended periods. These are visible laser light and natural blink reflex provides protection.

(iii) **Class 3**: Medium power lasers that pose moderate risk and can cause injury. These are further classified into

Class 3R: Potentially hazardous for intra-beam viewing either directly or after specular reflection

Class 3B: Normally hazardous for intra-beam viewing, either directly or after specular reflection (Power greater than 3R)

(v) **Class 4**: High energy, high risk lasers that can cause injury to the eyes and skin from direct beam or diffused reflection. It also pose fire hazard.

Based on the MPE standard for a specific laser, the standard operating procedures (SOP) should be prepared for working with lasers in clinics and laboratories [28]. All personnel involved must be fully familiar with the SOP document and should obtain laser safety practical training. It is pertinent to note that laser safety regulations do not apply to the exposure of the patient at the targeted site. However, accidental exposure to the patient by misdirected laser beam must be avoided. Apart from the radiation, other risk are also present in laser working environment, few of these includes toxic dye hazards, high voltage, laser generated air contamination, noise, collateral radiation, laser generated fire and explosion. These risks may turn into hazard if not addressed properly. The safety precautions needs to be incorporated in SOPs for clinical laser application:

- Adoption of proper lasers warning sign (figure. 12) based on hazard analysis and classification of the lasers.

Figure 12: Sample of Laser Warning Signs

- Restricted access for unauthorized personal in laser operating area.
- Adoption of proper alert mechanism for personals present in working area when the beam is operating
- Uses of appropriate safety goggle, which should be appropriate to wavelength used and labelled with appropriate optical density.
- Avoiding the direct viewing of any laser beam for any reason.
- Avoiding to operate lasers at sitting or standing eye level

- Enclosing of the laser beam path whenever possible
- Removing all the reflective (specially watches and jewellery) or combustible materials from beam path
- Shielding of all laser light pumping sources.
- Use of diffuse (non-reflecting) beam stops, barriers and enclosures
- Uses of low laser power for alignment
- Being aware of all non-beam hazards
- Avoiding the override of any laser system safety interlock
- Removal of all the keys from interlock when the laser is not in operation
- A local exhaust ventilation system should be provided in a laser operating room to reduce the risk of exposure to smoke/ plume generated during laser surgery.
- Maintenance, servicing, or repair of a laser should be perform only by authorized personals.
- All persons in laser treatment area should be protected from laser beam exposure to their skin and other non-targeted tissues. Anodized, dull, non-reflective or matte finished instrument should be near the laser site.
- When a fiber is used to deliver laser energy through an endoscope, the end of fiber must extend beyond the end of the endoscope. Most of the fiber optic endoscope sheathes re flammable and are easily damaged by heat.

6.0 CONCLUSION

Laser therapy is used in many procedures. It may be used to:

- shrink or destroy tumors, polyps, or precancerous growths
- relieve symptoms of cancer
- remove kidney stones
- remove part of the prostate
- repair a detached retina
- improve vision (“laser eye surgery”)

In medicine, lasers offer surgeons the ability to work very precisely. They can focus on a small area and damage less of the surrounding tissue. Patients who have laser therapy may experience less *pain*, swelling, and *scarring* than with traditional surgery. Lasers can have a cauterizing (sealing) effect, which reduce the pain after surgery, prevent blood loss, reduce swelling and limit spread of tumor cells. Laser surgery may be less complicated as fiber optics, laser light can be directed to parts of the body without making a large incision. The more procedures may be done on an outpatient basis.

The disadvantage with laser surgery is relatively few surgeons are trained in laser use, laser equipment are expensive and bulky compared with usual surgical tool such as scalpel, lasers can cause burns and damage to vital organs if used improperly and strict laser safety precautions must be observed in operating room.

However, the use of the laser will continue to be important as computer assisted surgery and robotics are used in conjunction with lasers to improve patient care.

7.0 TABLES

TABLE-1: SOME OF THE COMMONLY USED MEDICAL LASERS.

Laser system	λ (nm)	Operation mode (CW/ pulsed) and parameter	Penetration depth (δ)		Remarks
			Water	Tissue	
Excimer-laser					
ArF	193	5–25 ns pluses	25 cm	$<1\mu m$	Low penetration depth which makes the lasers suitable for precise tissue removal.
KrCl	222	250 ns pluses	90 cm	$1\mu m$	
KrF	248	2–50 ns pluses	1.5m	$1.2\mu m$	High photon energy for short pulse duration can cause photo-ablation.
XeCl	308	20–300 ns pluses	2.5m	$5\mu m$	High photon energy and low average fluence rates can cut tissue without heating.
XeF	351	1–30 ns pluses	5m	$20\mu m$	Used for re-profiling of cornea or Laser Assisted In-Situ Keratomileusis (LASIK).

Laser system	λ (nm)	Operation mode (CW/ pulsed) and parameter	Penetration depth (δ)		Remarks
			Water	Tissue	
HeCd laser	325 442	<100mW CW <200mW CW	3.2m 20m	8μm 0.3mm	Used for fluorescence spectroscopy and imaging based diagnostic applications.
Argon ion laser	488 514.5	2–10W CW 10–100W CW	18m 16m	1 mm 1.1mm	The laser has high average power blue / green output and is strongly absorbed by numerous tissue chromophores. Have excellent coagulative properties and can be used for vaporization of pigmented lesions in the skin, endometric lesions and retina.
Nitrogen laser	337.1	6–30 ns pluses	5m	~100μm	Can be used of fluorescence based photodiagnosis
Cu vapour Laser	511 578	2.5–20 ns pluses	19m 5m	0.9mm 1.6mm	Used for surgery and tissue destruction, since its lasing wavelength at 578 overlaps with one of the absorption peaks of haemoglobin. Owing to very poor efficiency (<0.05%), large sizes, and limited operational lifetime these systems are slowly being replaced by solid state laser systems.
KTP/Nd :YAG	532	100 ns–250μs pluses	10m	1.1mm	Have good coagulative and haemostatic properties.

Laser system	λ (nm)	Operation mode (CW/ pulsed) and parameter	Penetration depth (δ)		Remarks
			Water	Tissue	
He-Ne	632.8	100mW CW	4.8m	3.5 mm	Light weight and good beam qualities make it suitable for alignment and analytical purposes.
Ruby laser	694	20 ns–1 ms pluses	60 cm	5 mm	First laser used by ophthalmologists in 1964 for photocoagulating the retina, However, later replace by CW Ar-ion lasers which proved to provide better results. Mainly absorbed by melanin containing tissue structures. Provides minimum dermal scarring of applications like removal of tattoos and destruction of deep lying hair follicles.
Dye lasers	~ 300 – 1000	1–100 W	20-2m	0.1-5mm	Due to the wide tunability from near UV to near IR such lasers have a number of medical and biological applications. Dye lasers are generally used in PDT Has the disadvantage associated with handling of liquid dyes some of which are toxic, getting replaced by solid-state laser system.

Laser system	λ (nm)	Operation mode (CW/ plused) and parameter	Penetration depth (δ)		Remarks
			Water	Tissue	
Diode lasers					Operates well in both CW and pulsed mode.
GaN	405	1–100W CW	~10cm	~100μm	Compact, efficient (>20 %) reliable and high operational lifetime. Emerging as the lasers of choice for most applications.
InGaN	455	1–100W CW	20m	0.3mm	
GaAlAs	780	1–100W CW	60cm	7mm	
GaAlAs	820	1–100W CW	46cm	8mm	
GaAlAs	870	1–100W CW	25cm	7mm	
GaAs	940	150fs pluses	5cm	4 mm	Fluorescence and Raman diagnostics and PDT are typical application fields.
Ti: Sapphire	700 – 1000	10–100 fs pluses	60–1 cm	5–8mm	Offers widely tunable output without requiring change of gain medium. By second harmonic generation of high intensity near infrared beam best suited best suited source for fluorescence study.
Free electron laser	800–6000	2–10 ps pluses	20 cm–2μm	8 mm–30μm	Proposed for ablation related medical applications in ophthalmologic, otolaryngologic, neurosurgical. However, since laser operations require an electron particle accelerator, wide spread medical use is not feasible.

Laser system	λ (nm)	Operation mode (CW/ pulsed) and parameter	Penetration depth (δ)		Remarks
			Water	Tissue	
Nd :YAG	1064	30–100 ps pluses as well as high power (100W) CW	3 cm	4mm	Can act via the electromechanical mode, which is utilized in ophthalmology for the treatment of secondary cataract of the posterior capsule. By endoscopic delivery it can be used in urology, pulmonology and gastroenterology.
Ho :YAG	2100	100 ns–250μs pluses as well CW (10-10W)	0.1mm	1 mm	This laser is used in a refractive surgery procedure called laser thermal keratoplasty (LTK) to correct mild to moderate cases of farsightedness and some cases of astigmatism
Er :YAG	2940	10 ns	0.3μm	1μm	Wavelength corresponds to the main absorption peak of water, thus the extremely small penetration depth in water. Laser works via evaporation and ablation The strong absorption by hydroxyapatite and water makes it attractive for sawing and drilling in bone, enamel and dentin.

Laser system	λ (nm)	Operation mode (CW/ pulsed) and parameter	Penetration depth (δ)		Remarks
			Water	Tissue	
CO_2 laser	10600	100 ns–1 ms pluses as well as high power (100W) CW	10μm	20μm	Strongly absorbed in H_2O, the major constituent of tissue. Therefore, can be used for a number of surgical, ophthalmologic and cosmetic applications.

TABLE 2.
COMMON TYPES OF MEDICAL LASERS AND THEIR MAJOR APPLICATIONS

	Type of lasers	Major applications
Ophthalmology	Nd : YAG	Iridotomy in the pupillary-block glaucoma, lens capsulotomies
	Excimer	Photorefractive keratectomy of hyperopia, myopia and astigmatism. Removal of superficial corneal opacifications in scars and dystrophies and to close the epithelium in non-infectious corneal ulcers.
	Ar laser	Retinal coagulation of diabetic retinopathy and vascular diseases.
	CO_2 and Er-YAG lasers	For tissue coagulation to reduce bleeding, making the surgical field easy to survey
Dentistry	Ar, KTP, diode (820, 940nm), Nd:YAG, Er :YAG, Er,Cr:YSGG, CO_2	Soft tissue surgery
	Er : YAG, ErCr : YSGG	Removal of dental hard tissues including caries and cavity preparation
	Diode , CO_2, Argon, KTP	Tooth whitening
	Ar, KTP, Ho:YAG, Nd : YAG	Infected root canals. Periodontitis
	He-Ne, Nd : YAG,	Cavity preparation
	N_2, Ar, diode (405, 455 nm)	Fluorescence photo diagnosis

	Type of lasers	Major applications
Dermatology	Ar, Cu-vapour	Vascular lesions
	Cu-vapour, KTP, Pulsed dye, ruby	Port-wine stain, Pigmented lesions
	KTP, ruby, Nd : YAG	Blue/black/green tattoos,
	Ruby, diode (820nm)	Hair removal
	Diode, Nd : YAG (CW)	Leg veins
	Nd : YAG (CW), diode	Nonablative dermal remodeling
	Er :YAG, CO_2 (pulsed)	Ablative skin resurfacing
	Er :YAG, CO_2 (pulsed)	Epidermal lesions
	CO_2 (CW)	Actinic cheillitis, verrucae, rhinnophyma
	Er :YAG, CO_2 (pulsed)	Ablative skin resurfacing
	Er :YAG, CO_2 (pulsed)	Epidermal lesions
	CO_2 (CW)	Actinic cheillitis, verrucae, rhinnophyma
Neurology	CO_2	Surgery of brain vasculature and spinal tumours
	CO_2 or diode lasers	Laser- assisted nerve repair, tissue welding in neurosurgery
	Nd : YAG	Coagulation of vascular malformations, Stereotactic neurosurgery
	Excimer	Non- occlusive anastomosis
	Nitrogen laser	Identification of brain tumor tissues
Urology	Pulsed dye(508nm) , Ho :YAG	Laser lithotripsy
	Ho : YAG	Surgery of bladder tumour, incision of urethral strictures
	Ho : YAG, KTP, Nd : YAG,	Surgery of benign prostate hyperplasia
	Nd :YAG and CO_2	Ablation of penile carcinoma
	Nd :YAG and Ho :YAG	Incision of ureteroceles
Otolaryngology	CO_2	Precise excision of carcinoma in situ and vaporization of bulky obstructing carcinoma in laryngology, resection of benign stenosis and tracheobronchial papillomatosis, vaporization of hypertrophied turbinates,
	Ar, CO_2 and KTP	Ossicular surgery and particularly stapedotomy
	Ar, KTP and Nd : YAG	Coagulation of hereditary hemorrhagic telangiectasia
	CO_2, KTP	Surgery of stapedotomy

	Type of lasers	Major applications
Dentistry	diode, Nd:YAG, Er :YAG, Er,Cr:YSGG, KTP CO_2 ErCr : YSGG, Er : YAG Diode , CO_2, Argon, KTP Nd : YAG HeNe, Nd : YAG, N_2, diode (405, 455 nm)	Soft tissue minor surgery Soft tissue major surgery Removal of dental hard tissues including caries and cavity preparation Tooth whitening Infected root canals. Periodontitis Cavity preparation Polyps, nodules, cysts leukoplakia Fluorescence photo diagnosis
Gastroenterology	Nd : YAG , diode	Haemostasis, debulking of advanced tumours, palliation of advanced, inoperable cancers of the upper and lower gastrointestinal tract. Improving dysphagia in patients with cancers of the esophagus and gastric cardia. Fragmenting biliary stones.
Cardiology	Argon Ar, Excimer Pulsed dye laser Nd :YAG, argon and CO_2	Vaporization of atherosclerotic plaques. Coronary angioplasty. Coronary angioplasty. Photovaporization of thrombi and emboli . Treatment of ventricular and supraventricular arrhythmias.
Gynaecology	CO_2 CO_2 and KTP	For treatment of condyloma, leukoplakia and high-grade cervical, vulvar and vaginal intraepithelial neoplasia. To treat ectopic pregnancies, dysmenorrhea, endometriosis, ovarian cysts, etc.
Orthopaedics	Nd : YAG, Ho : YAG	Cutting and ablating soft/hard tissue, Smoothing cartilage, Knee surgery, Lumbar disc decompression

REFERENCES:

[1]. Q.Peng, A. Juzeniene, J.Chen, L.O. Svaasand, T. Warloe, K.E. Giercksky and J. Moan, “Lasers in medicine”, Rep. Prog. Phys.; 71: 056701 (2008).

[2]. M.A. Lomke, “Clinical applications of dental lasers”, Laser Therapy, 47-59 (2009).

[3]. A.M. Shaida and l.D. Bottrill, “Recent Advances in the Use of Lasers in Otolaryngology”, IJO & HNS; 50(3):222-229 (1998).

[4]. D.J. Coluzzi, “Fundamentals of lasers in dentistry: basic science, tissue interaction and instrumentation”, J Laser Dent; 16:4-10 (2008).

[5]. P.K. Gupta, N. Ghosh, H.S. Patel, “Lasers and laser tissue interaction” in *Fundamentals & Applications of Biophotonics in Dentistry,* Eds. A. Kishen and A. Asundi, Imperial College Press, London, 123-148, (2007).

[6]. L. Marcu, P. M. French, and D.S. Elson, “Fluorescence Lifetime Spectroscopy and Imaging: Principles and Applications in Biomedical Diagnostics” CRC Press (2014).

[7]. S.L.Jacques, S.A. Prahl, Biomedical Optics, Oregon Graduate Institute 1998.
http://omlc.org/classroom/ece532/class3/muaspectra.html

[8]. J.L. Boulnois “Photophysical processes in recent medical laser developments: a review” Laser Med. Sci.; 1: 47 (1986).

[9]. Premium Tattoo Removal| 3033 Chimney Rock Rd, 77056 Houston TX.
http://www.premiumtattooremoval.com/laser-physics

[10]. N. Ramanujam. Fluorescence spectroscopy of neoplastic and non-neoplastic tissue. Neoplaisa; 2:1-29 (2001).

[11]. T. Vo-Dinh (ed.), Biomedical Photonics Handbook, CRC Press, Washington DC, (2003).

[12] G. Meyer-Schwickerath, “Koagulation der Netzhaut mit Sonnenlicht”Ber. Dtsch Ophth. Ges.; 55:256 (1949).

[13] J. Pasta, “Lasers therapy in ophtalmology”, in book Lasers for Medical Applications, pp.395-458 (2013).

[14] T. Dostalova and H. Jelinkova, “Lasers in dentistry”, in book Lasers for Medical Applications, pp.604-627 (2013).

[15] R. Hibst and U. Keller, “ Experimental studies of the application of the Er YAG laser on dental hard substances: 1. Measurement of ablation rate”, Lasers Surg. Med.; 9:338– 44 (1989).

[16] L. Goldman L, D.J. Blaney, D.J. Kindel Jr, D. Richfield, and E.K. Franke "Pathology of the effect of the laser beam on the skin" Nature; 197:912– 914 (1963).

[17] M.L. Geiges, "History of Lasers in Dermatology" in Basics in Dermatological Laser Applications eds I. B. Allemann I, D.J Goldberg; 42, 1–6 (2011).

[18] E.L. Tanzi, J.R. Lupton, and T.S Alster, "Laser in dermatology: Four decades of progress", J Am Dermatol ; 49 (1), 1–31 (2003).

[19] Washington Institute of Dermatologic Laser Surgery, http://www.skinlaser.com/laser-treatments/tattoo-removal-washington-dc/#

[20] M.A. Calin, S.V. Parasca, R. Savastru, M.R. Calin, S. Dontu, "Optical techniques for the noninvasive diagnosis of skin cancer", J Cancer Res Clin Oncol.; 139(7):1083-104 (2013).

[21] M. Sharma, E.Marple, J.Reichenberg and J.W. Tunnell, "Design and characterization of a novel multimodal fiber-optic probe and spectroscopy system for skin cancer applications", Rev. Sci. Instrum. 85, 083101 (2014).

[22] D. Siposan, "Lasers in neurology", in book Lasers for Medical Applications, pp.573-603 (2013).

[23] A. Pascu, M.O. Romanitan, J.M. Delgado , L. Danaila and M.L. Pascu ' Laser-induced autofluorescence measurements on brain tissues', The Anatomical Record , 292 ,2013 – 2022 (2009).

[24] E.E. Rebeiz, "Lasers in otorhinolaryngology-head and neck surgery", J Med Liban. 42(4): 242-249. (1994).

[25] A.M. Shaida and I.D. Bottrill, "Recent advances in the use of lasers in otolaryngology", Indian J Otolaryngol Head Neck Surg, 50(3): 222–229 (1998).

[26] R.J. Thomas, B.A. Rockwell, W.J. Marshall, R.C., Aldrich, M.F. Gorschboth, S.A. Zimmerman and R.J. Rockwell Jr.4 "Procedure for the computation of hazards from diffusely scattering surfaces under the Z136.1-2000 American National Standard for Safe Use of Lasers", J. Laser Appl.; 19: 46 (2007).

[27] www.drs.uiuc.edu/rss/lasers

[28] C.J.P.M. Teirlinck and S.R. Vaartjes, "Dutch Committee on Laser Safety in Health Care Laser Safety in Health Care", Proc. SPIE; 4156: 102 (2001).