Occupational Radiation Protection at Accelerator Facilities: *Challenges*

Haridas.G

Health Physics Division

Bhabha Atomic Research Centre

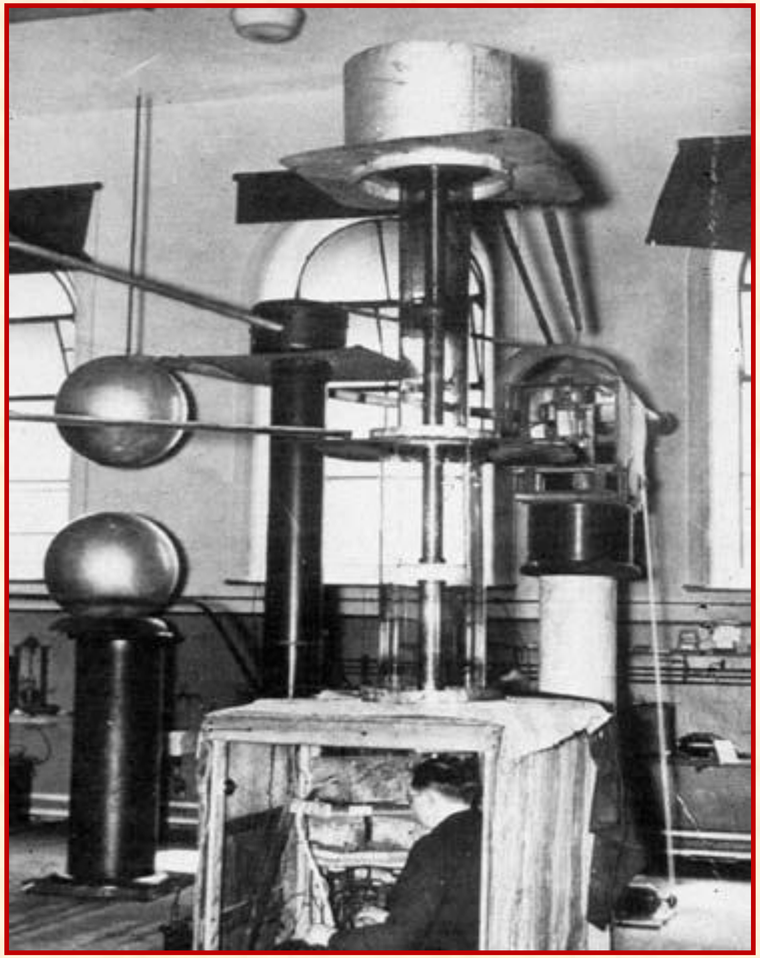
INDIA

Int. Conf. on Occupational Radiation Protection: Enhancing the protection of workers_Gaps, Challenges and Developments 1-5 Dec, 2014, IAEA, Vienna

Type of particle accelerators

- Electron
- Proton
- Heavy ion
    - Van-de-graff generator (Direct voltage driven)
    - Tendem accelerators (Direct voltage driven)
    - DC accelerators (Direct Voltage driven)
    - LINAC (RF driven)
    - Synchrotron Radiation Sources (RF driven)
    - Cyclotrons (RF driven)
    - Wake field (Laser driven)

First Accelerator



Cockcroft & Walton Accelerator(1932), LBNL

Source: http://en.wikipedia.org

- *First time accelerator is used to initiate a nuclear transmutation.*

- *Bombarded Lithium with 700 keV protons and transmuted it into Helium and other elements.*

- *Cockroft and Walton were awarded the Nobel prize in 1951.*

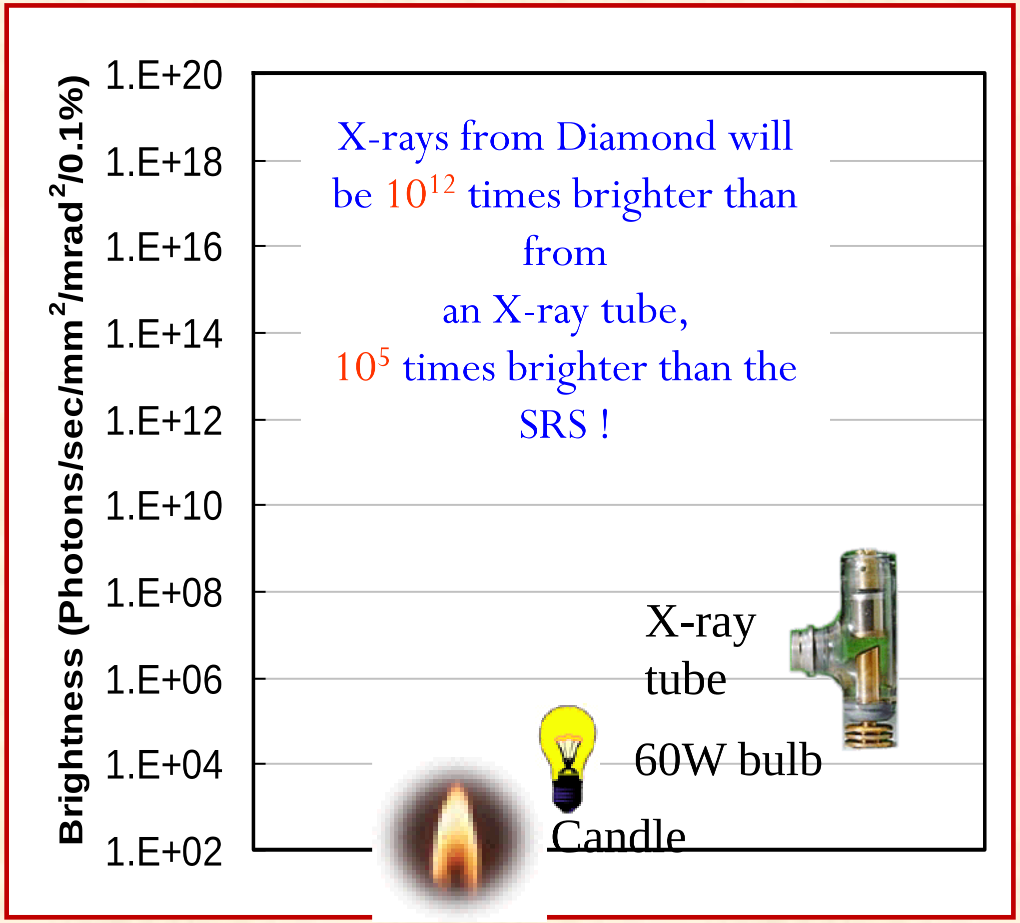
Largest Accelerator in the World !

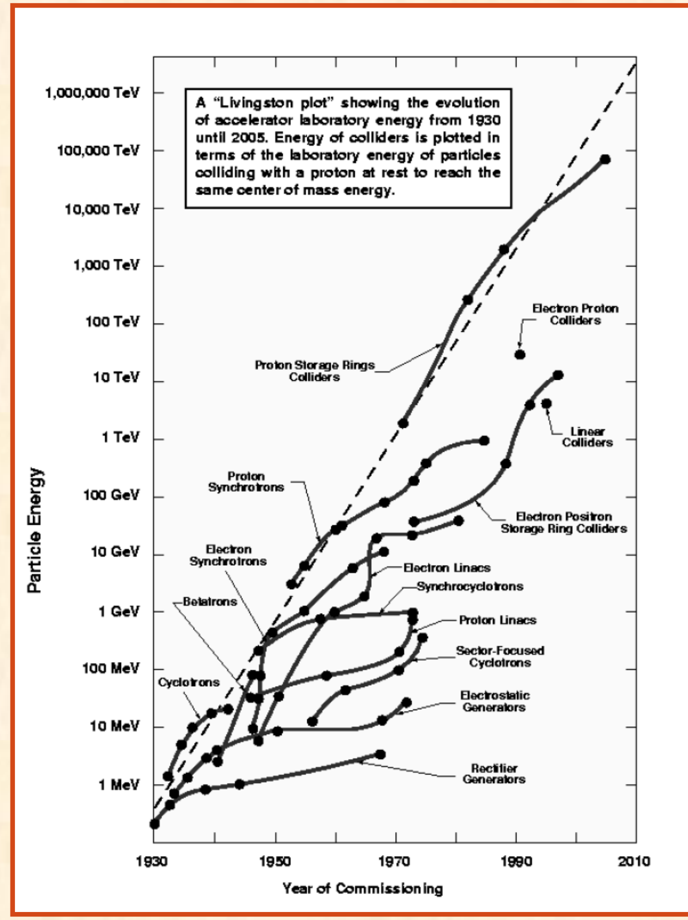
Large Hadron Collider (LHC), CERN , Geneva (7 TeV)
A view from the 27 Km circumference LHC Tunnel

On **4 July 2012**, experiments at CERN's Large Hadron Collider announced the discovery of a new particle, *Higgs Boson* in the mass region around 126 GeV.

*home.web.cern.ch/topics/**higgs-boson***

Synchrotron Light sources





Source: **Diamond Light source, U.K**

Particle accelerators and their uses

- Industry
- Medicine
- Agriculture
- Environment
- Food Processing
- Basic and applied research
- Spallation Neutron Sources
- Accelerator Driven System

Radiation environment of accelerators

Electron accelerators

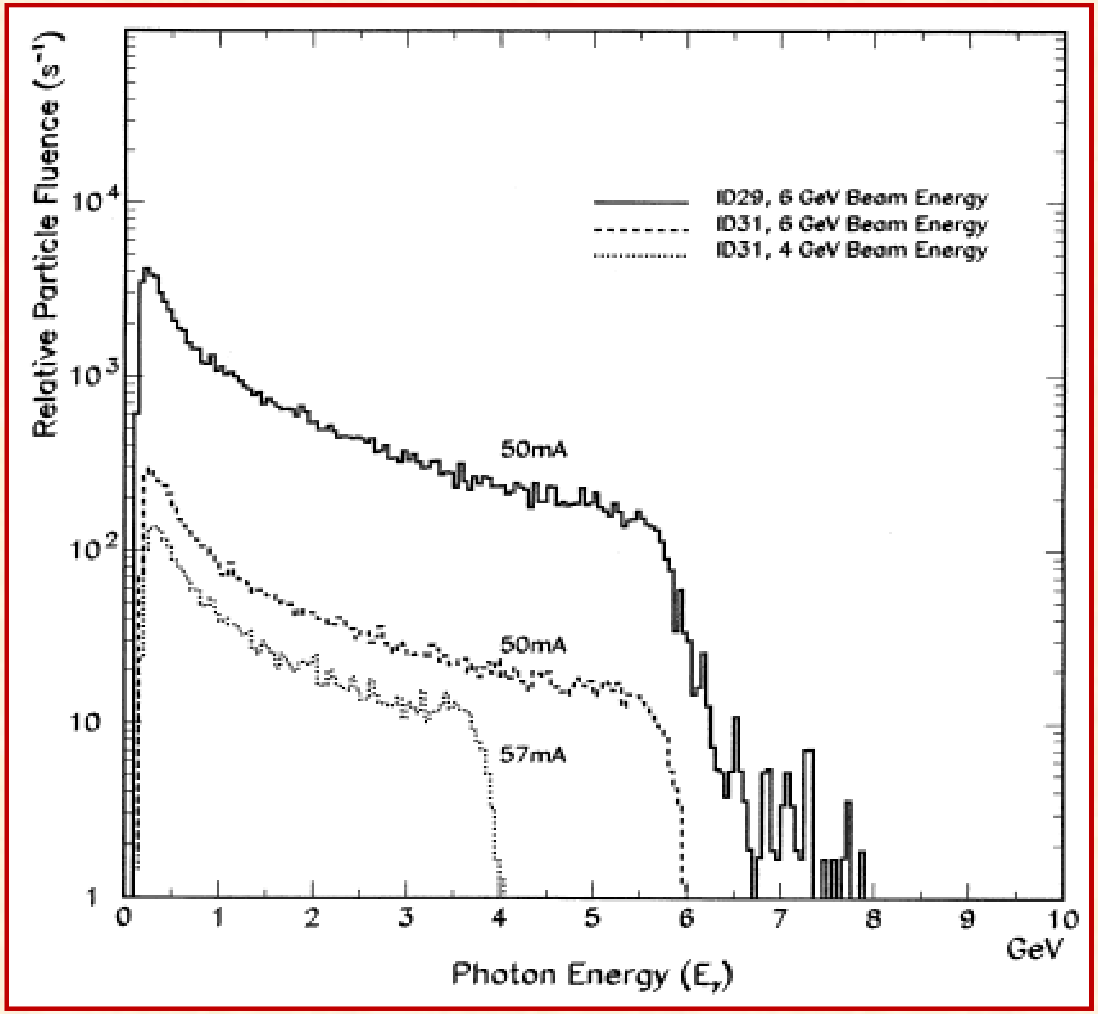
- Bremsstrahlung X-rays
- Photo-neutrons
- Induced activity negligible

Proton / Heavy ion accelerators

- Neutrons
- Mixed field of pions, muons, bremsstrahlung x-rays etc.
- Induced activity very significant (structural materials, air, cooling water etc) –
  (Beam loss to be well controlled)

Bremsstrahlung X-ray Spectra

measured at ESRF synchrotron beam lines



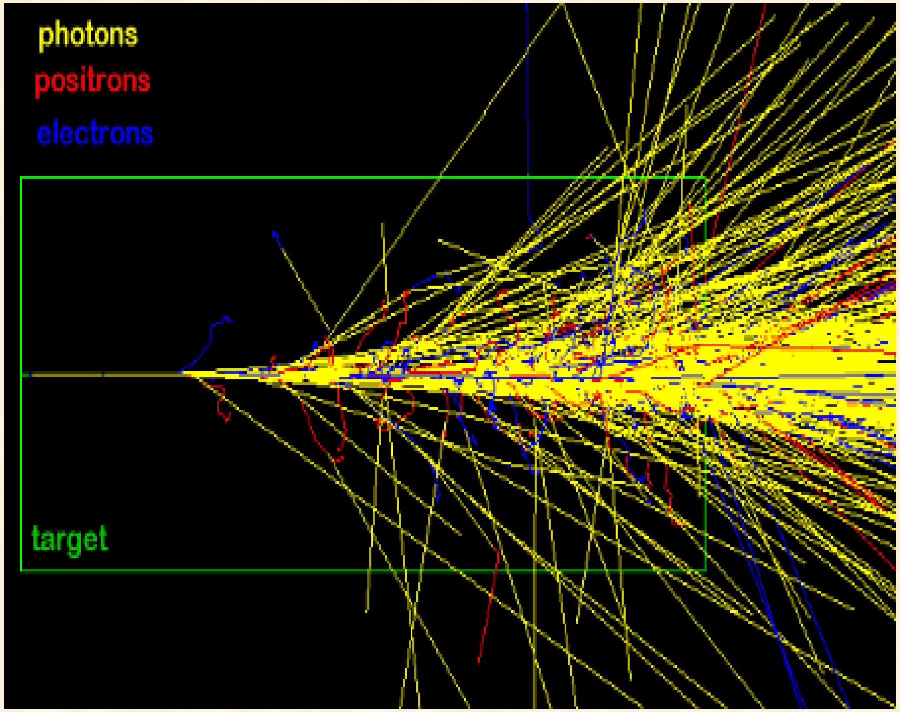
The energy of bremsstrahlung photons extends up to the energy of incident electrons.

Rad. Phy. & Chem. 59, 459-466 (2000)

Electro-magnetic cascade

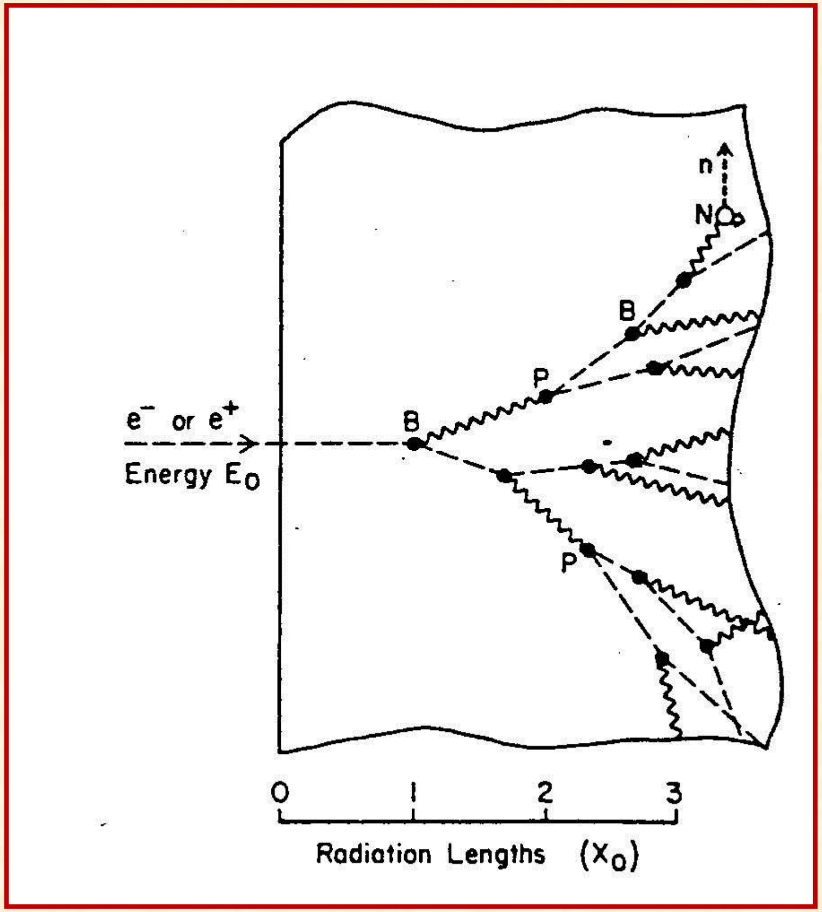
High energy bremsstrahlung photons when produced on electron interaction with structural materials or gas molecules interacts through (e+, e-) pair production. They in turn emit bremsstrahlung photons further produces (e+, e-) pair. This process keeps repeating resulting in electro-magnetic cascade.

Radiation environment at electron accelerators is the manifestation of electro-magnetic cascade.



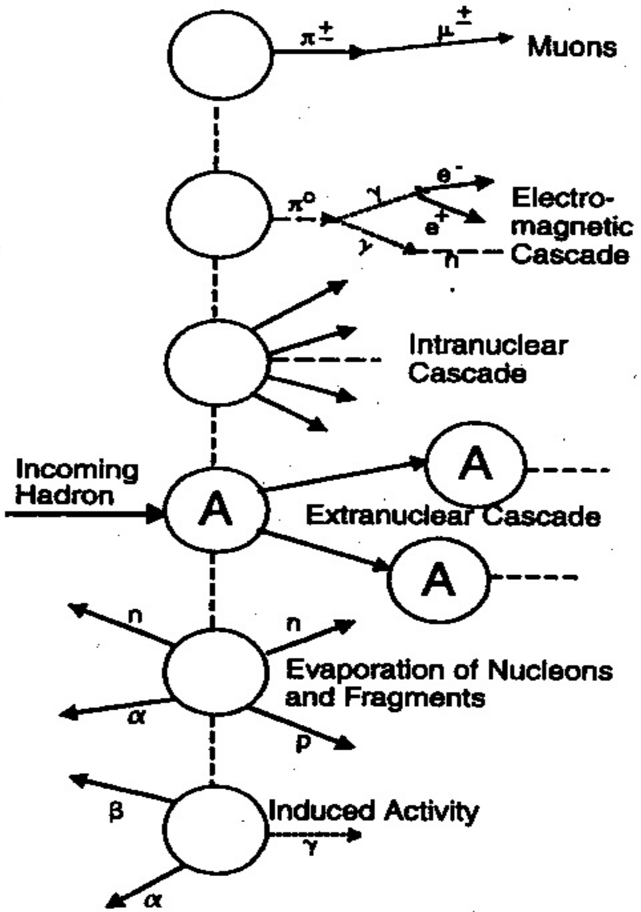
Massive shower developed in tungsten on 10 GeV electron incidence _EGS4

http://rcwww.kek.jp/research/egs/egs4_source.html



IAEA Tech. Report Series.188 (1979)

Hadronic cascade



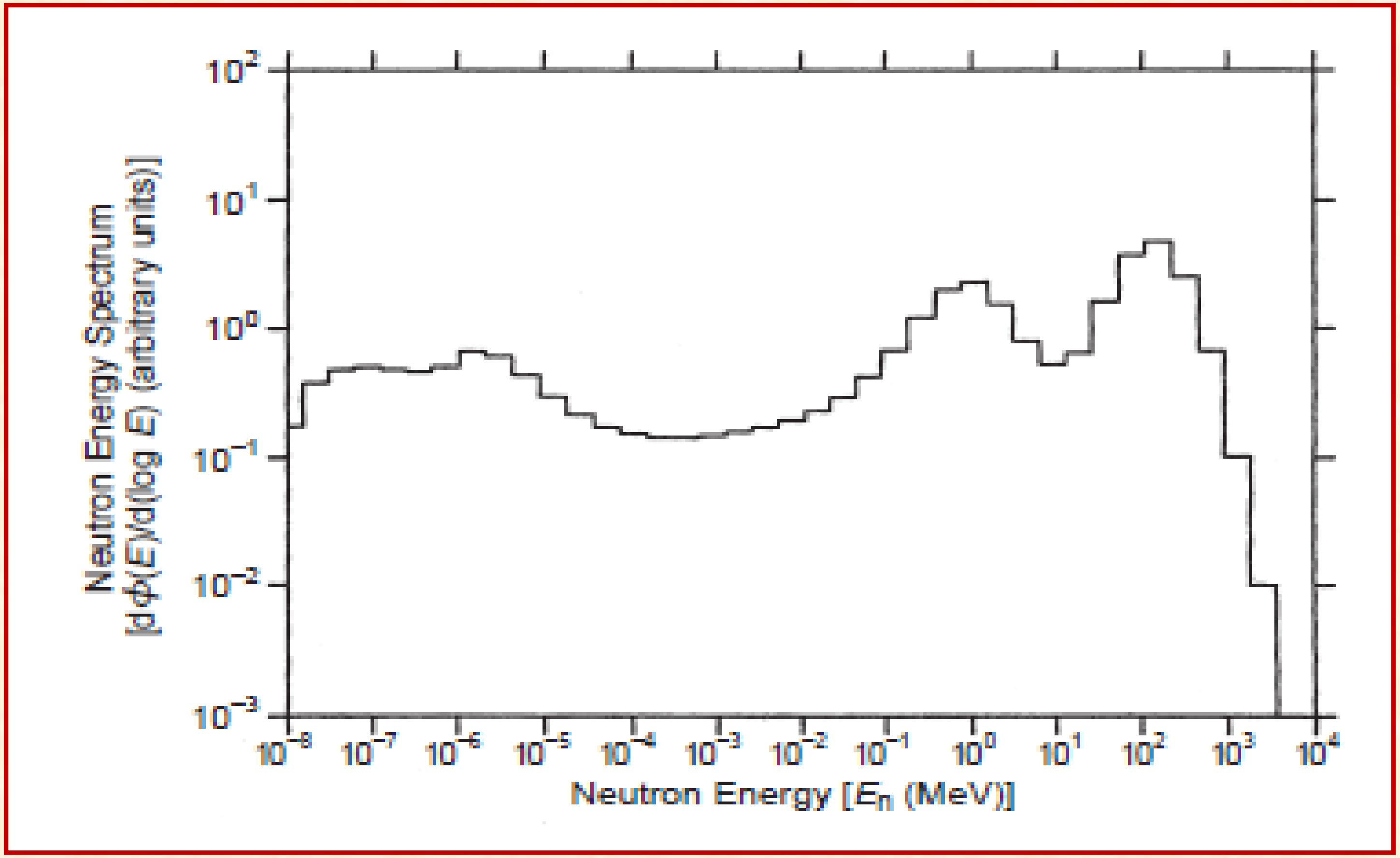
Most Numerous Participants	Time Scale (s)	Typical Energy per Particle (MeV)	Percent of Energy Deposition
$\pi, K \rightarrow \mu$	10^{-8}	any	10
$\pi^0 \rightarrow e, \gamma$	10^{-16}	any	20
p, n, π, K	10^{-22}	<200	30
p, n, π, K	10^{-23}	>200	30
p, n, d, α	10^{-19}	<30	10
α, β, γ	seconds to years	<10	<1

Hadronic cascade produces a mixed filed of particles like secondary protons, neutrons, pions, muons, x-rays, photo-neutrons etc.

Major challenge in high energy proton accelerators in terms of detection and quantification of dose equivalent.

ICRU Report No.28, 1978

Neutron spectrum around high energy accelerators _typical

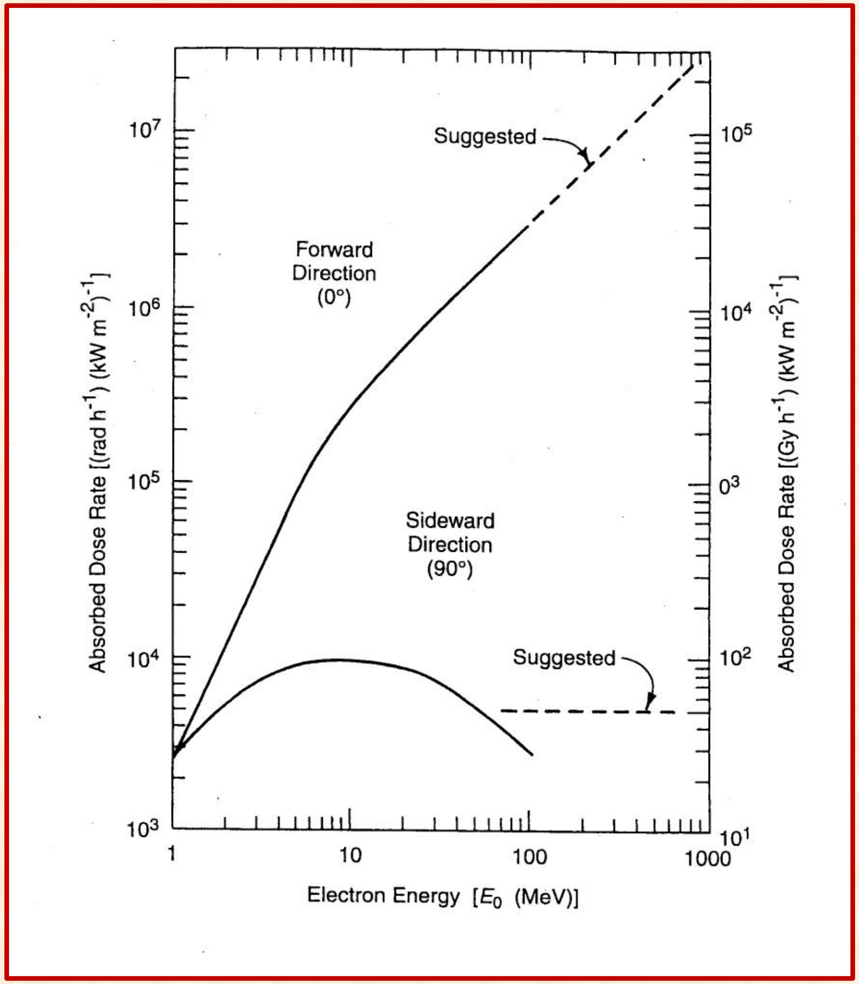


Measured spectrum outside thick shielding from 12 GeV proton synchrotron using bonner sphere technique. Reproduced from NCRP Report 144 (2003).
The energy extends nearly up to 1 GeV !

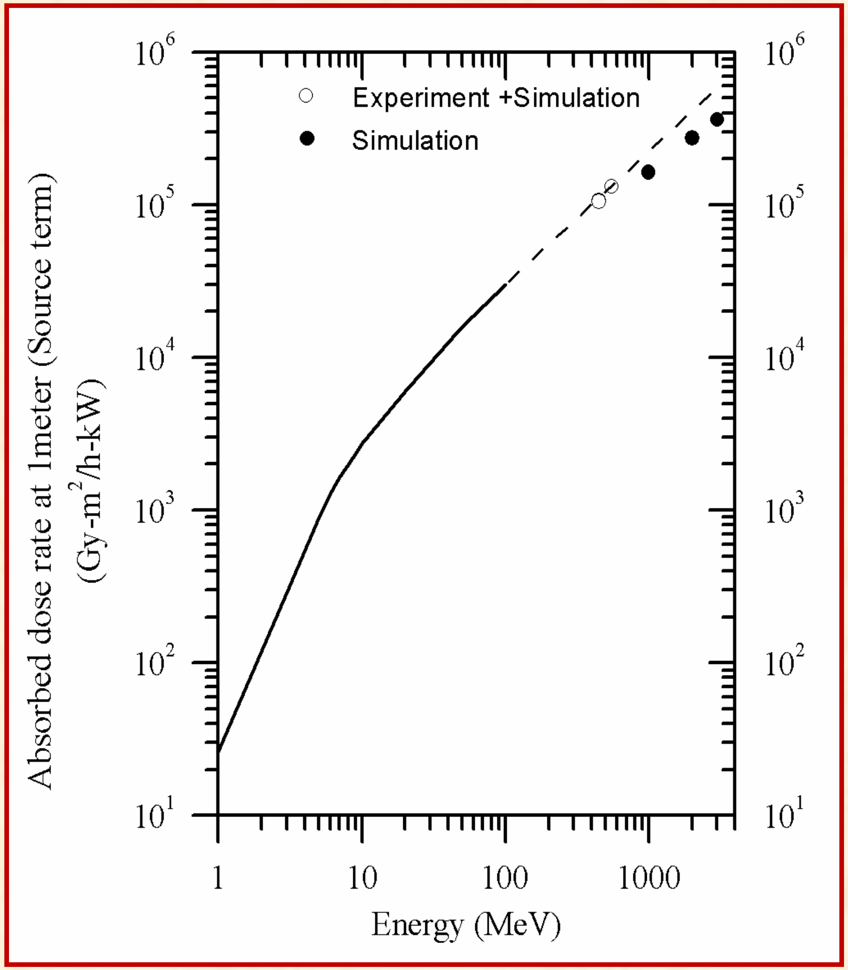
Challenges

- Dynamic nature of the radiation level due to change in beam loss scenario
- Lack of systematic data on source term
- Underestimation of personal and ambient dose equivalent
- Detectors /personal dosimeters may miss the highly forward peaked radiation (bremsstrahlung x-rays & synchrotron rdn)
- Evaluation of dose during accidental beam loss
- Radio-Frequency (RF) interference
- Enforcing regulatory recommendations and radiation protection procedures

Lack of experimental data on source term



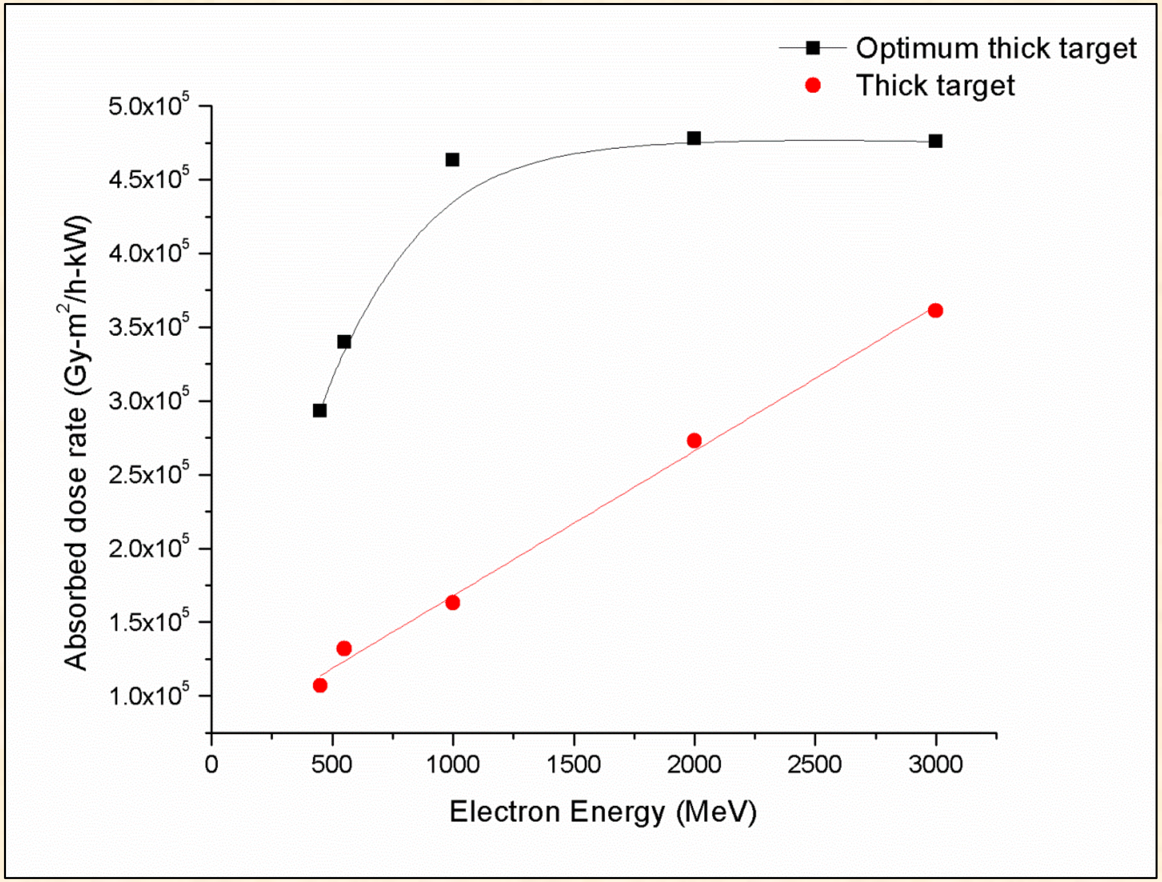
W.P.Swanson, IAEA Tech.Rep. 188, (1979), NCRP 144, (2003)



M.K.Nayak, Haridas.G, communicated to Radiation Measurements (2014)

The present study indicates a deviation from the suggested trend at higher energies. Needs more experimental data to be generated at high energies.

Investigation of source terms



M.K.Nayak , Haridas.G (2014), Manuscript under preparation

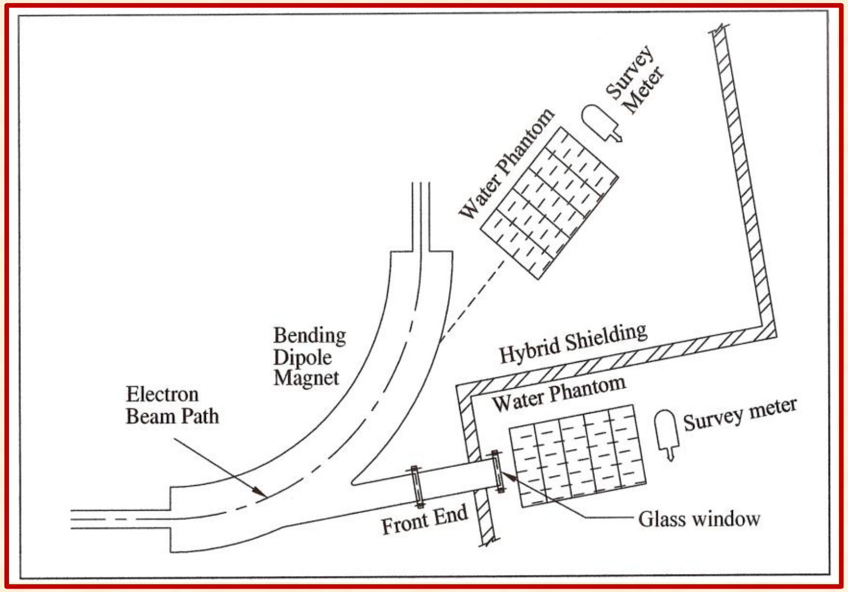
Usually radiation source term is evaluated from high Z thick target.

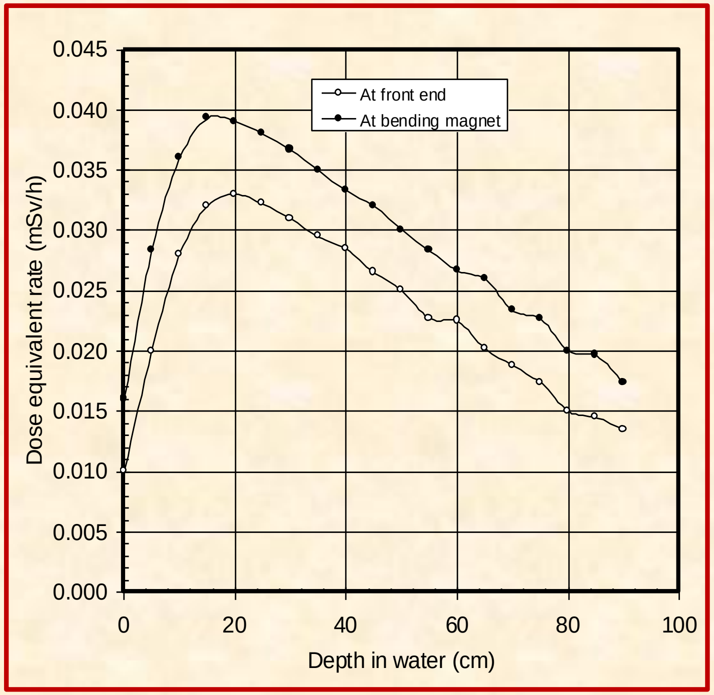
However, in reality accelerated beam in a vacuum chamber encounters a thin / optimum target where the source term would be higher.

This is an area of concern.

Underestimation of dose equivalent in high energy radiation

- Commercially available area radiation monitors, survey meters and personal dosimeters have limited energy response, up to few MeV
- They are expected to underestimate the dose equivalent in high energy radiation fields.
- The underestimation in high energy is mainly due to **electromagnetic cascade generation** and high **collimated nature** of radiation





H_p(10) & *H*(10)* is not valid in this case !

Rad.Prot.Dosim. 118 (3) 233-237, 2006

Effect of pulsed radiation in survey instruments

Instrument	Detector	Expected response (µSv/h)	*Observed response (µSv/h)
Radiation survey meter 451P, (Victoreen, USA)	Ion Chamber	180	185
Beta-gamma exposure rate meter(ECIL, India)	Ion Chamber	180	180
Area radiation monitor (Electronics Dvn. BARC)	Ion chamber	180	170
Teletector, Sonde 6150 Adt (BEFIC, Germany)	GM tube	180	190
Radiation survey meter MR121D, (ECIL, India)	GM tube	180	190

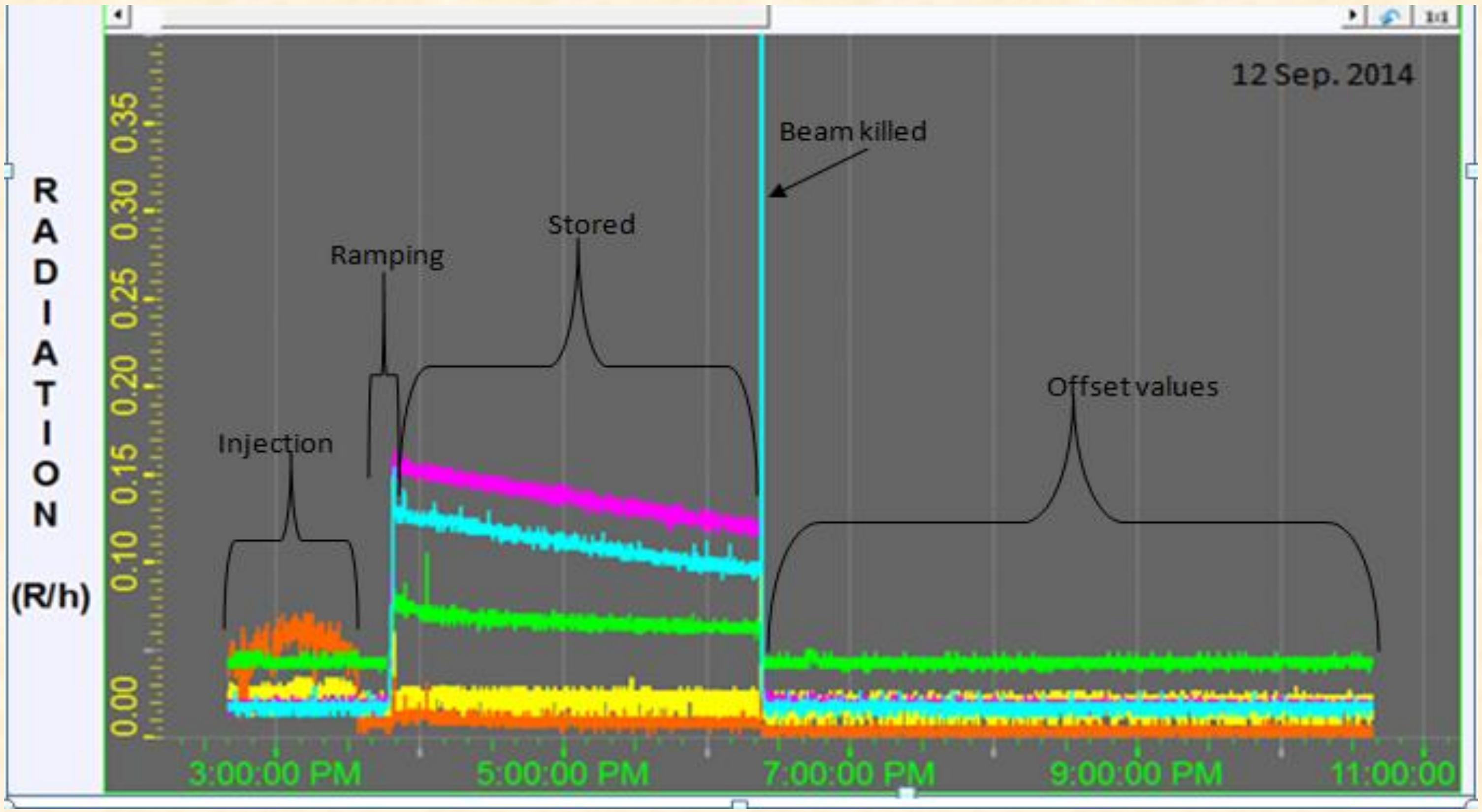
Steady radiation from Co-60

Instrument	Detector type	Response (µSv/h) w.r.t Duty cycle			
		10^{-9}	$\geq 10^{-9}$	10^{-6}	10^{-1}
Radiation survey meter 451P (Victoreen,USA)	Ion chamber	30	100	270	0.6
β-γ exposure rate meter (ECIL, India)	Ion chamber	30	100	250	--
Teletector, Sonde 6150 Adt (BEFIC, Germany)	GM tube	0.5	2.0	0.5	1.0
Radiation survey meter MR 121D (ECIL, India)	GM tube	0.4	1.0	0.4	1.1

Pulsed radiation from electron accelerator

At low duty cycle response of GM based monitors are found to show very low dose equivalent rate! Should not use n pulsed fields.

Accidental loss of accelerated beam during acceleration



Radiation level in a storage ring tunnel area (2.5 GeV Synchrotron radiation source) from ion chamber detectors placed around the ring during various operating modes.

A sudden rise in radiation level at one location can be seen due to accidental beam loss.

Quantification of the dose during accidental beam loss needs special detection techniques.

RF Interference in Radiation Monitors

Location	Instrument	Instrument response (µSv/h)		RF power density meter (mW/cm²)*	
		Bare	With RF shielding	Bare	With RF shielding
30 cm from magnetron	Radiation survey meter 451P, (victoreen, USA)	1.7×10^4	4.0	>20	2.0
1 m from magnetron	Radiation survey meter 451P (Victoreen , USA)	2×10^3	2. 8	15	0.7

Note: Operating condition: Magnetron operating voltage- 42kV,RF frequency -2998MHz, pulse current - 100A, pulse duration - 4μs and pulse repletion rate - 250Hz.

RF power density measurements were carried out with power density meter (Radiation Hazard Meter, RHM, model 495), General Microwave Corporation, USA. Frequency range of the probe: 200 kHz – 40 GHz.

Erroneous reading is reduced drastically when leakage RF power density level was reduced.

Enforcing regulatory recommendations

- Due to the non-routine nature of the work of the researchers, enforcing regulatory recommendations and radiation protection procedures often becomes a challenging task.

- Broad guidelines listing procedures to be followed in research accelerator facilities needs to be evolved which form a basis for implementing them by regulators and radiation protection professionals.

Conclusions

- Accelerators in terms energy, intensity and technology are growing at a rapid pace, which are driven by the need of industry, research & development in basic and applied science, medicine, agriculture etc.
- Due to the technological advancement in the field of accelerators, in terms of energy and intensity many challenges are faced by radiation protection professionals.
- Development of area monitors and survey meters suitable for monitoring high, low energy, pulsed radiation with RF shielding need to be undertaken by the manufactures.
- Due to uncertainties in dose estimation prevailing in these peculiar radiation environments, one has to give importance to engineered, redundant radiation safety systems like various interlocks, shielding (with safety margin), zoning, access control and strict adherence to training and operational procedures.
- Also efforts shall be made in standardizing radiation safety systems for accelerator facilities and evolving a policy for ensuring their effectiveness.

Thank you

for

Patience

and

Support