Ref: Accep/Comm of linac accelerator -> TG45 (code of practice for radiotherapy accelerators)
Benchmark test/verification of TPS -> TG23
Commission of TPS -> TG53
Commission equipment and procedure -> TG106
IEC 976/977 "accelerator functional performance characteristics and guidelines

TG-35: Linac safety
TG-40: Linac QA
TG-142 Linac QA (new)

TG-50 MLC
AAPM report 82 IMRT
TG-119 commission of IMRT

TG-29 TBI
TG-30 TSEI
TG-58 MV portal image
TG-104 In-room KV

TG-65 Inhomogeneity

General procedures:

- Evaluation of clinical needs and linac selection
- Review/generation of specification and purchase agreement
- Machine installation, Preliminary test as soon as machine is capable of producing radiation beam including:
  - Safety checks: door interlock, emergency off, radiation light/warning
  - Preliminary calibration
  - Preliminary radiation survey
- Acceptance test
- Commission
- Report and documentation
- Training
- Establish of baseline QA parameters and programs

Acceptance (Varian):

1. Radiation Safety
   a. Preliminary radiation survey (as soon as the installation has reached a stage when the beam can be generated, may need preliminary calibration)
   b. After completion of installation, formal radiation survey
      i. Collimator transmission (<0.5%) and header leakage (<0.1% of the intensity at ISO over an area of $100cm^2$ at 1m from the primary beam
      ii. interlocks, warning lights, emergency off and other safety
2. Mechanical tests
   - Gantry, collimator, couch, jaw size indicator/motion check
   - ODI indicator and all accessories check
   - Coincidence:
     a. Collimator axis, light beam axis, and cross-hair coincidence
     b. Light beam and radiation field coincidence
     c. asymmetric jaw and multiple beam alignment

- Collimator, gantry and couch rotational mechanical axis (use calibrated front point rods and graph paper)
- Radiation Isocenter test : (rotation spoke check and Wiston-Lutz check;)
  (Wiston-Lutz check-> link between mechanical and radiation centers)

3. Dosimetry
   a. Energy check (PDD)
   b. Beam uniformity (flatness and symmetry)
   c. Beam penumbra (by profile)
   d. MU/dose characteristics: dose reproducibility with time and gantry angle, linearity with MU and DR
4. MLC tests
5. Imager tests

Acceptance (per TG-45)

1. Preliminary checks
2. Mechanical system checks
   a. Alignment of collimator axis and collimator jaws
      (rode grasped by all four collimators jaws and rotate around a graph paper)
   b. Alignment of collimator axis, light axis and cross hair
      (with the graphic paper intact, remove rod and turn on field light, mark file edge and find intersection of the diagonal, which should coincide with cross hair and point marker on graph paper. Rotate 180 and check light field edge and cross-hair; if need adjustment, adjust light field prior to cross field
   c. Light and Radiation field coincidence
      i. Light, radiation field readout agreement and accuracy
      ii. Light and radiation field congruence and symmetry
      (symmetry: exposure two films with 180 rotation; congruence: performed as usual; need to perform @ different G angles)
   d. Mech isocenter location
      (use a calibrated collimator front point plus a short front point or graph paper on couch)
   e. Radiation isocenter location
      (use the calibrated collimator front point as reference to mark the mechanical isocenter on film. Perform start shots for collimator, couch and gantry; make sure jaws are symmetric relative to cross-hair!)
      Winston-lutz test

3. Other mechanical checks
   a. Patient support system (couch motion, speed, brakes)
   b. Anti-collision system
   c. Beam modifier system (wedge, tray, e- cone mechanical, distance)
4. Console system checks
   a. Mode selection
   b. Operational, safety, and dosimetric specifications
   c. Readout and RV system
5. Radiation systems and parameters
   a. Beam output/dose rate
      i. calibration stability (1 day, 1 week) ; timer
      ii. MU linearity and end effects (5% for <5MU, 2% for >=5MU)
      iii. Dose rate accuracy and dependency
      iv. Output with gantry angle

b. Beam uniformity, horn
c. Energy (photon: dmax, %dd; electron: dmax, 80%, 50%, Rp, bremstrunlung)
d. Collimator transmission; beam modify devices
e. Surface dose
(machine specific, depends on FS, SSD, beam modifier and angle of beam) Extrapolation chamber -> gold standard; p.p.l chamber over-response in the buildup region.

6. Interlock systems
7. MLC and ancillary equipment check

Commission (per TG-45):

1. dosimetric calibration
2. acquiring all beam data:
    a. Photon (PDD, profiles, S_c, S_{total}, Tray and wedge, MLC transmissions, wedge PDD and profiles)
    b. Electron (PDD, profiles, cone and cutout output factors)
    c. Special measurements for special procedures (TBI, TSEI, IMRT, SRS)
3. entry of beam data into RTP system and prepare dosimetric book
4. verification of RTP system
5. development of operational procedures (dosimetric, treatment planning, treatment procedures)
6. verify these procedures and develop QA procedures and devices
7. Training of all personals

Commission of TPS: (TG-53):

1. Verify the accuracy of the dose calculation algorithm through benchmark tests (part of acceptance test) [TG-23 bench mark, Vendor Golden data, publications] => [Test of open square field, irregular field, blocked field, wedge field, oblique field, inhomogeneity]
2. Nondosimetric commissioning
    - Patient immobilization
    - Imaging acquisition [image quality, CT density, geometric accuracy, registration..]
    - Structure definition
    - Beams properties [machine description, limits, display….]
    - Dose display and plan evaluation [DVH, composite plan…]
3. dosimetric commissioning
    - Acquire a self consistent data of machine
    - Input data into TPS system
    - Dose calculation algorithm parameters determination
    - Dosimetric comparison and verification
        - Characterization set (basic water scans)
        - Clinical case verification through phantom measurement
            - MU calculation
            - Inhomogeneity [dose proximal, within, distal, lateral to inhomo and at the interface]
            - Dose accuracy [Inside beam, penumbra, outside, build up]
            - Clinical cases tests
4. Development of operational procedures
5. Development of QA programs
6. Documentations and report

7. Training of all staffs

Survey treatment room:

- Equipments: G-M or Scintillator counter; ion-chamber survey meter (scale up to 50mGy/hr); neutron survey meter (proportional region) like Rem-Meters with moderator
- Head leakage:
  - Wrap linac head with films
  - Collimator closed
  - Localize hotspot and then integrated reading can be made with an integrating ion-chamber survey meter at 1m from source for the hotspot location
  - Measure 10x10cm open filed at isocenter, calculate ratio <0.1%
- Voids, cracks and defects:
  - Use largest FS and highest dose rate
  - G-M or Scintillator counter to identify
  - Ion-chamber to measure dose rate at that location
- Primary barriers:
  - Use max field size and No phantom
  - G = 0, 90, 180, and 270 and oblique angles (wall-floor, wall-ceiling intersections)
  - Ion-chamber survey meter and neutron survey meter make measurement 30cm from barrier
- Secondary barriers:
  - Max field size with phantom in beam
  - Repeated measurements
- Radiation Skyshine
- In-room survey
  Only passive detector for neutron in the room
  In primary beam, only activation detectors (Gold, indium foils) can be used for neutron detection
  Bubble detector can be used outside primary beam
  Solid state track detectors (CR-39 or TLD combination)

Dose calculation algorithms:

Radiation transport: primary photon, scatter photon, and scattered e-

1. Correction based
   - Primarily based on measured data obtained from water phantom
   - Various correction based on analytic functions or factors applied
   - The dose at any point usually analyzed into primary and scattered components, which computed separated and summed
   - Calculation and corrections assume CPE
   - Strong limitation in dose calculation for inhomogeneity in lung and tissue interface where e- equilibrium not fully established

2. Model based
   - Use physical model simulates the actual radiation transport and the distribution of energy subsequent to primary photon
   - More accurately predicate dose distribution under conditions of e- disequilibrium

- Measured data from water phantom used to fit the model parameters

Various models:

- Convolution method
    - Convolution kernel: a dose spread array (matrix) represents dose distribution deposited by scattered photons and electrons set in motion at the primary photon interaction site per unit Terma
    - Kernel obtained from MC simulation or direct measurement [Force a photon to interact with a point in medium and follow where the energy is deposited]
    - Require knowledge of photon energy spectrum
    - Convolution method accounts for the effects of scatters, but assume medium water equivalent, need to consider scatters in inhomogeneity

- Convolution-superposition method:
    - A convolution equation when modified for radiological path length (distance corrected for e- density relative to water) [per Khan]
    - Dose kernel can be calculated by using range scaling by electron density of the MC generated kernel in water according to O'Conner theorem [Doses at point A and B are equal if all linear dimensions are scaled by the medium density]

- Pencil beam convolution (PBC) algorithm
    - An approximation method -> pre-convolving in the depth dimension
    - PB can be calculated by MC or generated from measurement by de-convolution of broad beam
    - superposition of pencil beam in 2D
    - Heterogeneity handled only in longitudinal scaling (effective path length…)
    - Break down at interfaces and for small structure smaller than PB.

  Per Khan about PB for e- beam (PEB):
    - e- beam dose calculation method was developed based on Gaussian pencil beam distribution based on Fermi-Eyges multiple scattering theory
    - Assuming small-angle multiple scattering approximation, an elementary PEB penetrating a medium is scattered like Gaussian in its lateral spread at all depths. Large angle scattering events are considered to be small and ignored.
    - The Gaussian function is characterized by its lateral spread parameter σ.
    - The dose distribution in a PEB incident on a uniform phantom looks like a teardrop or onion. The lateral spread σ increases with depth until a max spread.
    - Beyond this depth, there is a precipitous loss of e- as their lateral excursion cause them to run out energy
    - Eyges predicted σ by extending the small-angle multiple scatter to slab geometry of any composition with mass angular stopping power and density in the equation.

        - The Fermi-Eyges equations only considers small-angle multiple scatter and predict σ increases with depth indefinitely. Practical implementation requires correction factors.

- AAA (Anisotropic Analytic Algorithm) and Collapsed Cone Convolution (CCC)
    - AAA adds scaling of spread of pencil beam on lateral direction
    - CCC also consider changes in lateral electron transport

3. Monte Carlo
    - Build based on the foundation of measured or calculated probability distributions
    - Have to have cross-section data reflecting the probability of interaction of a particular particle [the accuracy of MC depends on cross-section data accuracy]
    - Couples ray tracing and probability sampling algorithms
    - The method is microscopic, but can be used to obtain macroscopic quantities
    - Phase space file generation:
      It is like a "source" file containing ALL the information on all the photons and electrons, necessary to complete their trajectories (using MC), at some plane between the target and the patient. Usually the plane is right before the Jaws so that the particle trajectories from the target thru the the flattening filters, monitor chambers, etc. do not have to be calculated every time the jaws or the MLC are moved. This is a non-math explanation, of course.
      A phase-space file stores the information of a particle (i.e. position x,y,z ; angle of deflection and history - previous interactions it suffered). Such a particle is used to calculate the Dose Distributions in a patient. A phase-space file is actually the input to a user code (e.g. Electron Gamma Shower EGS4) for Beam/Dose calculations.
      To be more precise:
      - Monte Carlo generates a space-phase file of a hypotetical particle
      - A code like EGS for Dose calculation is using this file in computations (energy spectrum of a linac and dose distributions in tissue)

Inhomogeneity Correction:

- Key points:
    - As photon E ↑, more KE transfer to e- by Compton scatter
    - With ρ ↓, e- has longer range
    - So high E photon in lung will yield high energy e- and longer range
    - As d ↑, photon scatter ↑
    - As FS ↑, photon scatter ↑
    - As E ↑, photon scatter ↓, but e- has longer range

- Inhomogeneity correction algorithms (TG-65) :
    - Local energy deposition (no electron transport) (1D or 3D):
        - Effect attenuation coefficient (1D)
        - Ration of TAR (RTAR) (1D) => no consideration of position and size of Inhom

- Power law (Batho) (1D) => consider location of inhom, good for $\rho < 1$, overestimate for $\rho > 1$
- Equivalent TAR (ETAR) (3D)
- Differential SAR (dSAR), dTAR….. (3D)

- Non-local energy deposition (electron transport) (1D or 3D):
  - Convolution (1D density sampling)
  - FFT convolution (1D density sampling)
  - Convolution/Superposition (3D density sampling)
  - Monte Carlo (3D)