Overview & Basis of Design for NCRP Report 151

Structural Shielding Design and Evaluation for Megavoltage x- and Gamma-ray Radiotherapy Facilities

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Learn

- Calculation methods
- W, U, T, IDR, TADR, RW, Rh,
- Dose at maze door
- Neutron, capture gamma at door
- Laminated primary barrier

New Issues since NCRP # 49

- New types of equipment,
- Some with energies above 10 MV,
- Many new uses for radiotherapy equipment,
- Dual energy machines,
- Room designs without mazes,
- Varied shielding materials including composites,
- More published data on empirical methods.
- Instantaneous Dose Rate interpretation problems

This Report was prepared through a joint effort of NCRP Scientific Committee 46-13 on Design of Facilities for Medical Radiation Therapy and AAPM Task Group 57.

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Increased data for:
• neutron production
• capture gamma rays
• scatter fractions
• scatter albedo
• activation
• laminated barriers
• IMRT factors

Public Dose Limits
for continuous exposure
- Annual limit of 1 mSv ED for man-made sources excluding background and exposures from personal medical care
- Unless can be documented otherwise, per site limit is 0.25 mSv

NCRP 116 (1993)

Public Dose Limits
0.25 mSv / yr per site

Annual background radiation doses in USA
3.6 mSv / yr

Rewrite of NCRP 49
Came to a stop
Until NCRP issued Statement 10

• Marty Weinhous
• Don Frey
• Richard Morin
• Bob Dixon
• …

Recent Applications of the NCRP
Public Dose Limit Recommendation for Ionizing Radiation

NCRP Statement No. 18, December 2004
Design Dose Limit for Public Area

- Statement 10 allows the annual Design Dose Limit to increase to 1 mSv
- But the conservative recommendations contained in NCRP Reports must be followed

NCRP Statement 10 (2004)

The quantity recommended in this Report for shielding design calculations when neutrons, as well as photons, are present is dose equivalent (H). Dose equivalent is defined as the product of the quality factor for a particular type of ionizing radiation and the absorbed dose (D) [in gray (Gy)] from that type of radiation at a point in tissue (ICRU, 1993). The units of dose equivalent are J kg\(^{-1}\) with the special name sievert (Sv).

The recommended radiation protection quantity for the limitation of exposure to people from sources of radiation is effective dose (E), defined as the sum of the weighted equivalent doses to specific organs or tissues (i.e., each equivalent dose is weighted by the corresponding tissue weighting factor for the organ or tissue) (ICRP, 1993).
Recommendation for Controlled Areas:
Shielding design goal ($P$) (in dose equivalent):
0.1 mSv week$^{-1}$ (5 mSv y$^{-1}$)

Recommendation for Uncontrolled Areas:
Shielding design goal ($P$) (in dose equivalent):
0.02 mSv week$^{-1}$ (1 mSv y$^{-1}$)

The required number ($n$) of TVLs is given by:

$$n = -\log(R_{\mu})$$

And the barrier thickness ($t_{\text{barrier}}$) is given by:

$$t_{\text{barrier}} = TVL_1 + (n - 1) TVL_e$$

Where the first and equilibrium TVLs are used to account for the spectral changes as the radiation penetrates the barrier.
The IMRT factor:
The ratio of the average monitor unit per unit prescribed absorbed dose needed for IMRT \((MU_{IMRT})\) and the monitor unit per unit absorbed dose for conventional treatment \((MU_{conv})\)

\[
C_1 = \frac{MU_{IMRT}}{MU_{conv}} \approx 2 - 10
\]

\[
MU_{IMRT} = \sum \frac{MU_i}{D_{refi}}
\]

\[
C_1 \text{ (CyberKnife)} = 15
\]
Weekly dose equivalent at the door due to neutron capture gamma rays:

\[ H_{nc} = W_{L} \left( K \frac{\phi_{n}}{10^{15}} \right) \]

\( K = \) ratio of the neutron capture gamma-ray dose equivalent (mrem) to the total neutron fluence at Location A in Figure 2.8 (an average value of \( 0.9 \times 10^{-6} \) Sv m\(^{-2}\) per unit neutron fluence was found for \( K \) based on measurements carried out at 22 accelerator facilities)

\( \phi_{n} = \) total neutron fluence (n/cm\(^2\)) at Location A per unit absorbed dose (gray) of x rays at the injector

\( d_{x} = \) distance from Location A to the door (meters)

\( TVD = \) tenth-value distance\(^{14} \) having a value of \( 8.4 \) m for x-ray beams in the range of 18 to 25 MV, and a value of \( 8.6 \) m for 35 MV x-ray beams

\[ \phi_{n} = \frac{B \omega}{4 \pi d_{x}^{2}} \frac{4 \beta}{2 \pi \lambda_{\text{min}}} \frac{1.3 \lambda_{\text{max}}}{2 \lambda_{\text{min}}} \]

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Weekly dose equivalent at the door due to neutrons:

Kersey's equation

\[ H_{n} = W_{L} \left( H_{0} \left( \frac{S_{d}}{S_{0}} \right) \left( \frac{d_{0}}{d_{L}} \right)^{2} \right) \left( \frac{1}{5} \right) \]

\( S_{d}/S_{0} = \) ratio of the inner maze entrance cross-sectional area to the cross-sectional area along the maze (Figure 2.8)

\( H_{0} \) at \( d_{0} = 1.41 \) m tabulated in Table B.9

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Modified Kersey's equation:

\[ H_{n} = W_{L} \left( \frac{2.4 \times 10^{-15} \phi_{n} S_{d}}{S_{0}^{2}} \left( 1.64 \times 10^{-5} \frac{d_{0}^{2}}{d_{L}^{2}} \right) \right) \]

\( S_{d}/S_{0} = \) ratio of the inner maze entrance cross-sectional area to the cross-sectional area along the maze (Figure 2.8)

\( TVD = \) tenth-value distance (meters) that varies as the square root of the cross-sectional area along the maze - \( S_{d} \) (m\(^{2}\)), t.e.:

\[ TVD = 2.06 \times \sqrt{S_{d}} \]

Wu and McGinley, 2003

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Smaller the better
Where for LOW ENERGY:

\[ H_{\text{Tot}} = \frac{WUTB_B B_n}{d^2} \quad \text{and} \quad H_{\text{cg}} = H_n = 0 \]

For HIGH ENERGY:

\[ H_{\text{Tot}} + H_{\text{cg}} = 2.7 \times \left( \frac{WUTB_B B_n}{d^2} \right) \]

\[ H_n = \frac{D_0 R F_{\max}}{t_0 + t_2 + 0.3} \left[ 10 - \left( \frac{t_1}{T_1} \right) \right] \left[ 10 - \left( \frac{t_2}{T_2} \right) \right] \]

McGinley (1992a) has reported on accelerators operated at 18 MV and measured neutron production coefficients (\( R \)) of 19 and 1.7 \( \mu \)Sv eGy\(^{-1}\) m\(^2\) for lead and steel, respectively; while \( R \) is decreased to around 0.5 \( \mu \)Sv eGy\(^{-1}\) m\(^2\) for lead at 15 MV.

**US Regulations**

Nuclear Regulatory Commission

Many State Regulations

2 mR (20 \( \mu \)Sv) in any one hour
20 \( \mu \text{Sv} \) (2 mR) in any one hour

This is not a measured doserate reading

not the same as 20 \( \mu \text{Sv} / \text{hr} \)

Measured IDR can be deceptive

Originally for Co-60 and the like

Linacs use pulsed beams

British Regulations
Approved Code of Practice – IRR (1999)

Public Area – where IDR \( \leq 7.5 \mu \text{Sv} / \text{hr} \)

As a result, user must reduce treatment doserate or increase shielding thickness

20 \( \mu \text{Sv} \) (2 mR) in any one hour

to assure adequate shielding if \( W \) is exceedingly low

Instantaneous Dose Rate (IDR) in NCRP 151:

- Unit in Sv week\(^{-1}\)
- Measured value depending on the absorbed-dose output rate of machine
- Specified at 30 cm beyond the barrier
- \( U = 1 \)
- For accelerator measurements it is averaged over 20 to 60 s depending on the instrument activation response time and the pulse cycle of the accelerator
  (In UK – averaged over 1 minute)
3.3 Time Averaged Dose-Equivalent Rates

When designing radiation shielding barriers it is usual to assume that the workload will be evenly distributed throughout the year. Therefore, it is reasonable to design a barrier to meet a weekly value equal to one-fiftieth of the annual shielding design goal (NCRP, 2004). However, further scaling the shielding design goal to shorter intervals is not appropriate and may be incompatible with the ALARA principle. Specifically, the use of a measured instantaneous dose-equivalent rate (IDR), with the accelerator operating at maximum output, does not properly represent the true operating conditions and radiation environment of the facility. It is more useful if the workload and use factor are considered together with the IDR when evaluating the adequacy of a barrier. For this purpose, the concept of time averaged dose-equivalent rate (TADR) is used in this Report along with the measured or calculated IDR. The TADR is the barrier attenuated dose-equivalent rate averaged over a specified time or period of operation. TADR is proportional to IDR, and depends on values of \( W \) and \( U \). There are two periods of operation of particular interest to radiation protection, the week and the hour.

**Weekly TADR**

\[
R_W = \frac{IDR \cdot W \cdot U}{\bar{D}_o}
\]

- \( R_W \) = TADR averaged over 40-hr week (Sv week\(^{-1}\))
- \( IDR \) = instantaneous dose-equivalent rate (Sv h\(^{-1}\)) measured at \( \bar{D}_o \)
- \( \bar{D}_o \) = absorbed-dose output rate at 1 m (Gy h\(^{-1}\))

If \( R_W \times T \) is less than \( P \), the barrier is adequate.

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The U.S. Nuclear Regulatory Commission (NRC) specifies that the dose equivalent in any unrestricted area from external sources not exceed 0.02 mSv in-any-one-hour (NRC, 2005a). \( R_h \) derives from the maximum number of patient treatments that could possibly be performed in-any-one-hour when the time for setup of the procedure is taken into account.

\[
R_h = \frac{N_{max}}{N_h} \bar{H}_{pt}
\]

- \( N_{max} \) = maximum number of patient treatments in-any-one-hour with due consideration to procedure set-up time
- \( \bar{H}_{pt} \) = average dose equivalent per patient treatment at 30 cm beyond the penetrated barrier
- \( N_h \) = the average number of patient treatments in an hour
- \( N_{max} \) is the maximum number of patient treatments in any hour
- \( R_h \) not to exceed 20 µSv-h\(^{-1}\) becomes the design goal if workload is exceedingly low

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NCRP 151 is just a report

How to translate this into regulations
Learned

- Calculation methods
- \( W, U, T, IDR, TADR, R_W, R_h, \)
- Dose at maze door
- Neutron, capture gamma at door
- Laminated primary barrier
British Regulations

Ionising Radiations Regulations

- Controlled Area - where workers are likely to get $> 6 \text{ mSv/yr}$ - e.g. inside treatment room
- Supervised Area - where people are likely to get $> 1 \text{ mSv/yr}$ - e.g. treatment console

IRR (1999)

British Regulations

Approved Code of Practice - IRR

- Supervised Area - where TADR is less than $7.5 \mu\text{Sv/hr}$ (ave over 8 h), and IDR $\leq 500 \mu\text{Sv/hr}$ (ave over 1 min)
- Public Area - where TADR is less than $0.5 \mu\text{Sv/hr}$, and IDR $\leq 7.5 \mu\text{Sv/hr}$

ACOP-IRR (2000)