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Introduction to Radiation Shielding, Design Goals and Regulatory Requirements-

Many medical apparatus use ionising radiation (including, but not limited to, x-rays) for diagnostic or therapeutic purposes. However, exposure to ionising radiation has been linked to a number of negative health effects. Different types of ionising radiation (such as X-Rays, Neutrons and Heavy particles) produce these health effects to differing degrees for a given dose recieved (amount of energy deposited). A system of weighting factors is used to account for the different rates of biological damage caused by the different types of radiation, allowing an 'equivalent dose' to be calculated. The SI-derived unit* of equivalent dose is the Sievert (Sv), and it is equivalent dose that regulatory authorities use when specifying dose-limits, in order to limit the potential negative effects of the use of such equipment.

**SI is the modern form of the metric system and the most commonly used system of measurements. There are a number of different units used to describe equivalent dose, Sievert is the most commonly used by regulatory authorities.*

The relevant regulatory authorities specify the maximum equivalent dose that individuals can receive per year from artificial sources of radiation, excluding medically justified procedures. Particularly relevant to this project are the dose-rate limitations set by the Office of Environment and Heritage (NSW EPA) which includes the equivalent dose limit for members of the public of 1mSv/yr. To put this in perspective, the typical Australian receives an equivalent dose of approximately 1 to 2 mSv per year from naturally occurring 'background' radiation. The shielding for radiation facilities is designed to ensure no member of the public will receive an annual equivalent dose in excess of 1mSv.

As the equivalent dose-rate limitations are for people, rather than for areas, it is accepted practice when designing radiation shielding to take into account the expected 'occupancy' of the area. The occupancy factor is defined as the fraction of the workload of the radiation room that the person who is likely to receive the greatest dose in that area is likely to occupy that area. In this way, an area can be constantly occupied, but if no one individual spends a large amount of time in that area, the area can be considered to have a low 'occupancy factor', as no individual is likely to receive a dose that approaches the prescribed dose limit. An area with a low occupancy factor will not require the same level of shielding as an area that has a high occupancy factor. Assumptions of occupancy factors are generally made very conservatively, and should take into consideration future uses of the surrounding areas (including public areas nearby).

POW CCBDC – Stage I

The areas of Stage 1 which will require radiation shielding assessment include:

- 4 x Linear Accelerator Bunkers
- 1 x Orthovoltage Room

- 1 x Hot Laboratory

The linear accelerators and orthovoltage unit are artificial x-ray sources, and only generate ionising radiation (predominantly x-rays) while in operation.

The Hot Laboratory will be used to store and dispense short-lived radioisotopes intended for medical uses. As these will be stored in appropriately shielded containers which will allow the lab itself to be occupied, the dose-rates to the external areas from sources within the hot-lab will be negligible.

Radiation Shielding Design Methodology

The radiation shielding barrier requirement calculations are based on the methods described in *NCRP Report No. 151,* and the primary beam and leakage transmission data from *Varian Document 12004, 'Shielding against Primary and Leakage X-Rays'.*

Radiation Shielding Design Assumptions for this Project -

Design Goals (Dose-Limits)

The requirements of the Office of Environment and Heritage will be met by the radiation shielding design for the project. The shielding design for barriers to uncontrolled areas is based on an occupancy-adjusted design goal of 10 µSv/wk (equivalent to 0.5 mSv/yr). This is half the allowable dose-rate for members of the public* – This allows for construction tolerances, as well as adding a general level of conservatism to the design. The shielding design for barriers to controlled areas **(if the designation of areas as controlled is agreed to by the client)) is based on a design goal of 40 µSv/wk (equivalent to 2 mSv/yr), and assume full occupancy. This value is significantly less than the 100µSv/wk from all sources for occupationally exposed individuals[1], again allowing for construction tolerances, but also allowing for dose to be received from other sources.

** *Controlled areas are areas within the building where public access is limited. They are predominately occupied by radiation workers.*

	EPA Prescribed Dose-Limit*	Project Design Goal**
Members of the Public	20 µSv/wk	10 µSv/wk
Occupationally Exposed Persons (Controlled Areas)	100 µSv/wk	40 µSv/wk

* Limits from Section 1.5 of *Radiation Guideline 7, published by the NSW Department of Environment, Climate Change and Water (2009)*
** Please Note- The figures used for design goals are partially to take into account construction tolerances

Occupancy Factors

Where applicable, occupancy factors chosen are very conservative, and in no cases less than the recommendations of *NCRP Report No. 151*[2]. In particular, the outdoor area above the bunkers is assumed, for the purposes of the shielding design calculations, to have an occupancy factor of 100%. This allows for flexibility in terms of future uses of the areas above the bunkers.

Design Workload

The design workload for the linear accelerator bunkers is 500Gy/wk at isocentre, all performed at 18MV. This value is the recommendation of *NCRP Report No. 151*[2] for clinical linear accelerator bunkers as a conservatively high workload if the true workload is not known. It is assumed that each primary barrier (floor, ceiling and both primary walls) has a use factor of 0.25, plus an additional factor applied to those walls designated as to be used for TBI.

IMRT Considerations

Many modern radiation oncology facilities perform *Intensity Modulated Radiation Therapy,* where a relatively high workload (measured in Monitor Units) per treatment is administered at relatively small field sizes. This is sufficiently different to conventional treatments that modifications are made to the workload assumptions to account for IMRT use.

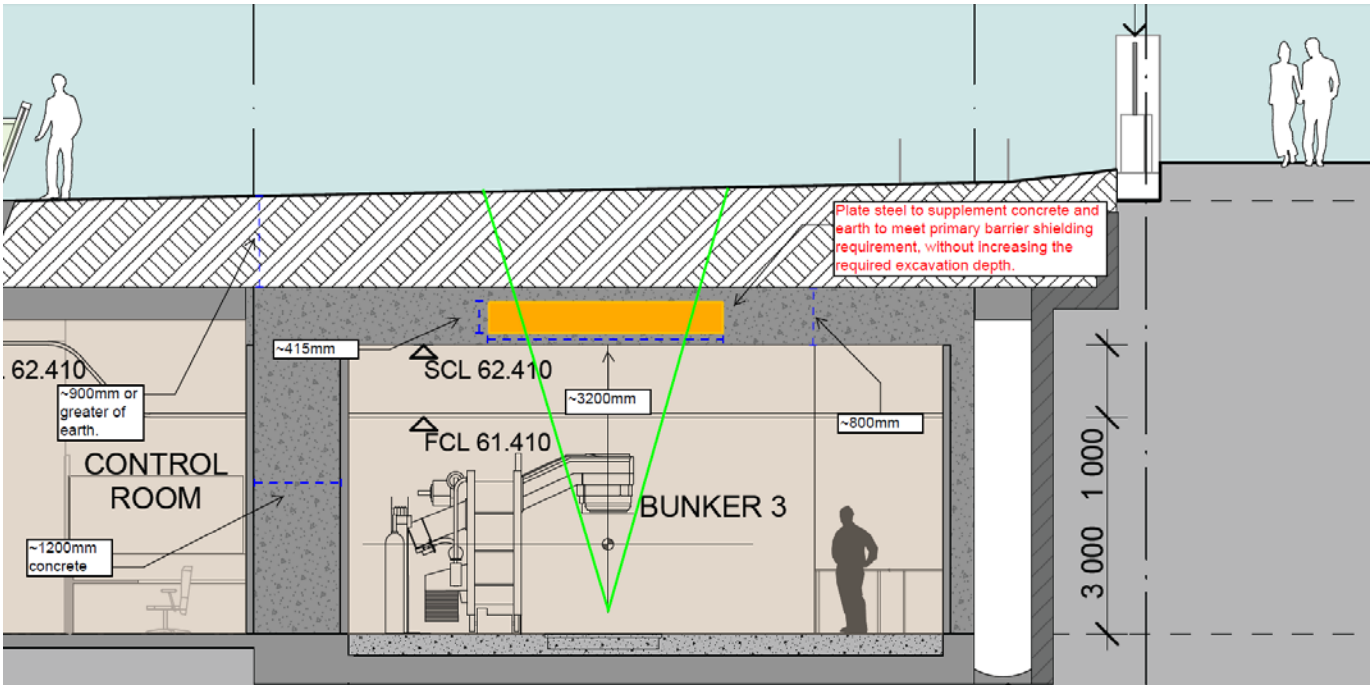
NCRP Report No. 151[2] suggests that a factor be assigned for the use of IMRT, which will allow for the greater number of monitor units (dose as measured by the accelerator ion chambers) required for the delivery of a given isocentre dose during IMRT procedures. The primary radiation component used for the design is unchanged (due to the extremely restricted field size used for IMRT. The machine leakage component of the radiation is then multiplied by this factor for use in shielding estimates. For the purpose of this design, an extremely conservative factor of 5 is used, and all IMRT is assumed to be performed using the high energy mode of the accelerator. Normally this is not the case, with the majority of IMRT treatments employing the lower energy beam.

TBI Considerations

The use of some bunkers for total body irradiation treatments (TBI) will require those barriers which are designated as for TBI use to have a higher workload assumed. When calculating the dose-rate contribution from patient scatter, the patient location during TBI treatments will be taken into account.

Shielding Materials

For the linear accelerator bunkers and orthovoltage room, concrete construction is generally the preferred material for new facilities, and will likely form the majority of the shielding barriers for this project. Depending on a number of factors, but particularly speed of construction, this concrete will either be poured in-situ or pre-cast. Either is an acceptable form of construction, and the choice between the two will be determined by non-shielding related factors. Steel will be used strategically to reduce the space consumed by the bunker shielding, particularly to reduce the height of the primary shielding barriers and therefore reduce the required excavation depth.



Bunker Layout and Door Requirements

The layout selected for the bunkers includes only a single-turn maze. This better suits the requirements of the users, though a lead-lined scatter door will be required in the maze for Linear Accelerators up to 10MV, and a neutron door for higher energy use.

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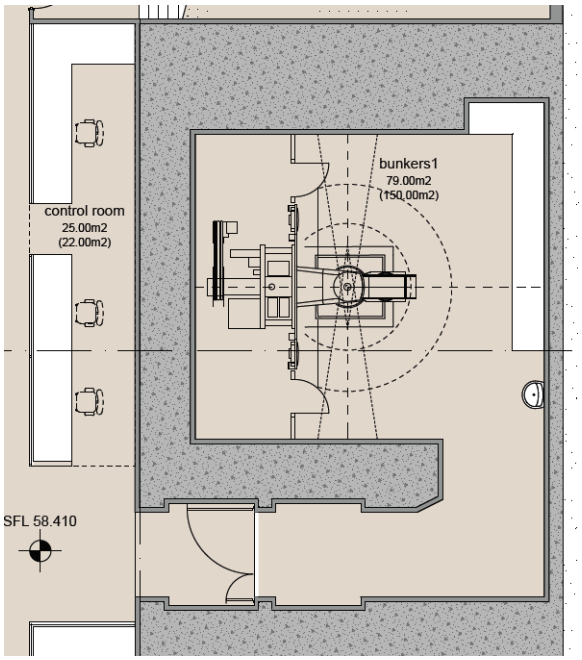


Future Proofing

Clinical linear accelerator bunkers generally house a number of different linear accelerators during their useful life. It is therefore prudent to, within reason, make some allowances for variations in the linear accelerator specification from that originally planned.

Linear accelerator bunkers will have structural shielding to cater for 18MV linear accelerators, although 18MV linear accelerators may not be installed initially. The increase in barrier thicknesses for an 18MV linear accelerator over an otherwise identical 10MV bunker is of the order of 10%, but will potentially save the significant cost (and down-time) of retrofitting additional shielding into an existing facility in the future. Should the bunkers have 18MV linear accelerators installed in the future, the only shielding modification required will be to install a neutron door system in the maze. Allowances in the design to ensure the optimal integration of neutron door systems into the bunkers include:

- leaving recesses in the maze-walls for the door frame and open door.
- placing a set-down in the floor of the maze at the location of the neutron door to allow for the installation of pressure-sensitive mats.
- installing a suitably sized concrete lintel in the maze (from the ceiling to the height of the top of the neutron door (~2500mm) so neutron shielding tanking is not required above the door.

Additionally, primary barriers will be designed to cater to a full 40 x 40cm square field size at isocentre. This is generally considered to be the worst-case scenario of all commercial clinical linear accelerators. While the accelerator initially selected may not be capable of this field size, it will allow for flexibility in linear accelerator choice in the future.

Radioactive Waste

There will be no radioactive waste generated by either the linear accelerators or the orthovoltage unit. These units generate x-rays by accelerating electrons into a target material, rather than by containing a radioisotopic source, and so do not contain radioactive material that will need to be disposed of at some time in the future.. While high-energy (>10MV) linear accelerators can produce very small amounts of activated (radioactive) materials , these are very short-lived (no appreciable dose-rate within the bunker from activated materials after 48hrs [2]) and there is no appreciable build-up of activity with time.

Storage of Radioactive Materials

The Hot Lab may be used to store radioactive materials. All materials will be stored in appropriately shielded containers, and suitable local shielding will be provided for the short times any materials are to be outside their shielded containers (such as for dispensing or source replacement). As neither the linear accelerator bunkers or orthovoltage rooms are likely to require the regular use of radioisotopes, the hot lab may not be fully utilised until stage 2 is complete.

Building Considerations (for poured concrete construction)

The shielding design is based on the assumption that normal concrete with density at least 2350kg/m^3 is used. Most aggregates use in Australia easily meet this requirement. Concrete is to be poured and vibrated to minimize voids. Small cracks due to shrinkage are of no consequence. Use of low heat of hydration mixes is recommended, as is leaving formwork in place until there is little thermal gradient to the atmosphere. Construction joints are, generally, not a problem if properly designed and keyed. It is, however, better if there are none. Placement of the machine set-down and laser cavities are critical and should be done with care and checked (preferably by the nominated equipment supplier) before concrete is poured. The walls of the maze to which the neutron door is to be fixed must be plumb and square.

Impact of the Development on the Surrounding Areas, including on future developments

All areas are adequately shielded for their immediate intended uses. The following points concern future developments in the vicinity of Stage 1.

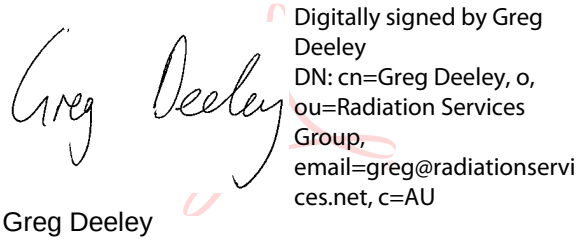
- As the surrounding earth is used to provide most of the shielding requirement of external barriers, development below ground within the site boundaries may require supplementary shielding, particularly if the development is within 5 metres of the linear accelerator bunkers.
- The outdoor area above the bunkers is assumed, for the purposes of the shielding design calculations, to have an occupancy factor of 100%. This will allow for the unrestricted development of all above-ground areas within the site-boundaries. However, the earth above the bunkers does contribute to the shielding provided above the bunkers, and if the areas above or surrounding the bunkers are excavated, sufficient additional shielding to compensate for the earth removed will be required.
- At the public boundary of the site (footpath and road), the dose-rates received will be sufficiently low that full occupancy by a member of the public would be acceptable, even assuming all 4 bunkers are operating at the maximum design workload. Therefore, the radiation from the facility will not limit any future development of these areas

References

1- *Radiation Guideline 7 – Radiation Shielding Design Assessment and Verification Requirements, (published by the Office of Environment and Heritage), Section 1.5*

2- NCRP Report No. 151, Structural Shielding Design and Evaluation for Megavoltage X-Ray and Gamma Ray Facilities, National Council on Radiation Protection and Measurements, *2005*

Signed this 29th March,



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