



SHIELDING INTEGRITY TESTING FOR IONISING RADIATION FACILITIES

Jill Reay, Robert Hill and Allan May (Aurora Health Physics Services Ltd) have developed a method of shielding integrity testing in order to assess the level of a facility's radiation protection

D **DO YOU KNOW WHAT'S IN YOUR WALLS?**

Installed radiation shielding is the primary means of restricting the exposure of persons in areas adjacent to facilities which house radiation sources. The radiation may be electrically generated, e.g. a diagnostic x-ray set or a linear accelerator, be derived from sealed or open radioactive sources or even originate from patients who have been administered with large activities of gamma-emitting radionuclides, e.g. persons undergoing thyroid treatment or persons awaiting PET scans. The shielding may be an integral part of the building structure itself, such as conventionally poured concrete walls and ceilings. Alternatively it may be comprised of an assembly of discrete parts, e.g. the use of modular concrete panels, steel plates, blocks or bespoke shielding bricks, or it may be attached to the facility as an external skin ready to take the final finish, e.g. lead-lined plasterboard. Apertures in the structure also need to conform

with the room's shielding requirements and provide the same level of radiation protection as adjacent walls, e.g. shielded windows, doors and architrave sets. In all cases, the integrity of the shielding is paramount to its ability to provide the intended level of protection. Even small weaknesses or defects can result in levels of radiation outside of the facility which are significantly higher than expected and quite possibly unacceptable.

In order to determine how best to test the integrity of the shielding provided, it is important to understand where the shielding design has come from. This will ensure that an appropriate radiation source is selected to perform the tests and that the levels of radiation outside of the facility can be confidently predicted to allow appropriate precautions to be taken to restrict the exposure of those involved with the testing and, where necessary, those present in adjacent areas. ►



◀ Night-time transmission measurements on bunker roof.



◀ Visible crack in concrete.

SHIELDING DESIGN

Shielding design depends on many factors, including the intended radiation source, its normal operation, potential accident scenarios, acceptable levels of radiation outside of the facility and the available footprint. The designer's work is not simply to define the level of shielding that is required, as there are many practical decisions to be made. These include what materials will be used ('normal' or high-density concrete, lead, steel, etc.) and how the chosen shielding options will be installed (poured, blocks, chevron bricks, plates, etc.). Where the shielding is not structural, it must either be self supporting or fixed to the structure in some way. This approach can act to reduce the available footprint within the facility and has the additional benefits of not impacting overall project timescales and being usefully employed for refitting existing facilities, space reductions notwithstanding. With any supported shielding there is always the risk of introducing weakness at joints and abutments, and the potential for future weaknesses due to structural movement. Penetrations in the structure must be designed to ensure leakage paths are not introduced resulting in unacceptable levels of radiation dose rate outside of the facility.

The responsibility for the various aspects of providing shielding may be shared among many different parties. Radiation protection advisers or medical physics experts may specify the level of shielding required and the position and size of any penetrations which are required. Staff will be concerned to ensure that good access for both personnel and patients (possibly on wheelchairs or beds) is provided for and that their use of facilities has not been unduly hindered by the use of slow-opening doors on heavily shielded facilities. The equipment installer may require a minimum footprint inside the room which will contain the radiation source but there may be a maximum external footprint for the facility set by the planning approval authority. The architect will be concerned with aesthetics, ergonomics, patient flow (in the hospital environment) and, specifically in relation to shielded facilities, the impact on adjacent areas of providing the space for the shielding structures. The requirements for shielding and the space it occupies often conflict with the allocation of space assigned. The structural engineer may specify which materials may be incorporated into the structure and which should be added once the

structure is in place. This may affect the integrity of the shielded facility as it may only be possible to complete the structure once the equipment is installed, dependent upon restrictions on access that may be imposed by the construction of other parts of the facility. The builder is concerned with implementing everyone's requirements as well as the provision of services into the facility. For example, there may be a requirement to run waste drains through a shielded floor/ceiling slab or there may be a steel beam in the middle of the space where a lead brick wall is being erected. The final provision of shielding is a compromise between all parties and good communication is absolutely key to ensuring the required level of shielding is provided – even if the way it is provided is different in the end to what was specified at the start when the facility was just a design on a drawing board or CAD package.

WHY IS SHIELDING INTEGRITY TESTING IMPORTANT DURING THE CONSTRUCTION PHASE?

As a result of the inevitable compromises (and we haven't even mentioned the cost of the different shielding materials or time which can be spent having to rework the design should changes need to be made during construction), it is always important to test the integrity of any shielding and confirm that the level of shielding which has been provided meets the initial design criteria. It is much more preferable to establish that this requirement has been satisfied prior to the handover and fitting out of the facility rather than waiting until the facility is essentially operational with the clinical source *in situ*. In a new or refurbished/extended facility this should therefore be done as soon as the shielding structure is complete and before the final surface finishes have been applied. Identification of any shielding weaknesses or installation errors at this stage can be incorporated into the normal construction work and would not be expected to add significantly to the project programme or costs. The reparation of any weaknesses detected at this early stage also minimises any potential impact on meeting key dates, such as facility handover, and ultimately ensures that patient services are not affected. ▶

Using an independent source of radiation will also ensure that the shielding provided can be tested quantitatively. Shielding is usually designed to ensure that the level of radiation outside of the facility during normal operation is as low as reasonably practicable. In practice, this will often mean that the radiation levels outside of the facility during normal operation are so low that they cannot be reliably measured. In this instance, tests performed as part of the clinical acceptance of the new facility will confirm that the shielding present is providing the required level of protection for the installed equipment. However, the results obtained will not be sufficient to state confidently that the facility has been built according to the design. This may cause significant problems when the radiation source and/or equipment is replaced, as only at this point may problems with the shielding be identified. For this reason it is also important to test the integrity of shielding with an independent source prior to any change of use of a facility. Even if reliable information is available regarding the construction of a facility, unless detailed records have been kept it is possible that changes will have been made to the structure over time which could affect the adequacy of the shielding provided.

SHIELDING INTEGRITY TESTING

Radiation Protection Advisers (RPAs) at Aurora Health Physics Services have developed a robust method for performing independent shielding integrity testing (SIT) using a variety of radiation sources, e.g. 5–100 GBq ⁷⁵Se, 100–1000 GBq ¹⁹²Ir, x-ray sets, 6 MV Betatron (portable linear accelerator). With these sources, shielding ranging from 1 mm of lead up to around 2 m of normal density (2.35 g.cm⁻³) concrete can be tested. The sources used for the testing are subject to the requirements of their respective mobile source registration conditions (or permit conditions under the Environmental Permitting Regulations 2010); they are also usually high activity sealed sources (HASS) and hence security conditions apply to any facility used for the temporary storage of sources if storage is required. Where it may be beneficial for the sources to be

stored on site, this is done under the source's mobile registration and does not require the site to obtain any new Permit. Sources are transported in approved transport containers in accordance with the relevant transport legislation. The Health & Safety Executive is usually notified as a matter of courtesy of the work which will be performed, although there is no strict legal requirement as SIT is not classed as industrial radiography.

The purpose of SIT is to assess the level of shielding provided by the built structure and compare this with the design specification. A fundamental aspect of successfully carrying out work of this nature is detailed, logical and comprehensive planning. There are several key issues that are addressed in the planning process, namely:

- the safety of the staff carrying out the work, site staff, persons who may be occupying adjacent premises and members of the public;
- the adequacy of the testing regimes to give confidence that shielding is as expected and all areas where shielding has been provided have been assessed;
- compliance with all regulatory requirements, Ionising Radiations Regulations 1999 (IRR99), the Environmental Permitting Regulations 2010, etc.;
- the logistics of carrying out the work, including control of work areas, access and egress control, secure storage of equipment, signage and warning (audible and visual) systems;
- risk assessments, contingency planning and method statements;
- liaison with all relevant parties including building contractors, on-site facility management, security, etc.

The process is usually split into three phases: preparatory work, on-site testing and interpretation of results. Good communication with all parties at all stages is vitally important. A summary of the aspects covered in each part is given in table 1.

For new buildings, SIT is usually performed out of normal working hours, either overnight or at the weekend, so as to minimise disruption and the likelihood of unauthorised individuals entering the testing area during SIT. Where SIT is performed in existing facilities, it may not be possible to evacuate all of the

“ The purpose of SIT is to assess the level of shielding provided by the built structure ”

areas adjacent to the facility under test. In this instance special attention must be paid to the choice of radiation source and the measurement protocol to ensure dose levels in adjacent areas are kept to an acceptable level, and disruption to individuals present in those areas is kept to a minimum.

Although detailed protocols are prepared for the testing, it is sometimes necessary to make changes during SIT. The first part of the SIT process involves the use of a radiation source to assess the general level of shielding provided and identify any potential gross weaknesses, e.g. missing shielding or holes, or differences to the expected level of shielding. This either gives confidence that there are no significant weaknesses or defects which would cause higher than expected dose levels during SIT, or allows testing protocols to be amended to take account of any identified weaknesses. In the second part of the process, point transmission measurements are taken and the shielding present assessed quantitatively. During this part, additional qualitative measurements are also taken to give the maximum opportunity for detecting weaknesses or defects in the structure.

WHAT DO YOU FIND WHEN YOU DO SIT?

To date we have performed SIT in a number of hospital and research facilities including PET and nuclear medicine suites, radiotherapy centres and diagnostic radiology departments. The types of room/facilities we have tested include linear accelerator bunkers, CT simulator rooms, high dose rate and superficial radiotherapy treatment rooms, cyclotron bunkers, hot cells, interventional radiotherapy suites, radiopharmacy and gamma camera rooms and shielded glove boxes. We have found defects in over half of the facilities we have tested.

Shielding integrity testing has been found to be very effective in identifying defects in shielding such as: inadequate shielding depth, missing or incorrectly installed shielding, defects due to penetrations, damage during construction, improper positioning of shielding and joint defects. Some specific examples of the problems we have found are indicated in table 2. Similar problems have also been found by others,¹ particularly those relating to poorly installed lead-lined plasterboard.

As indicated above, the costs associated with remediating the defects found at this stage are much lower than those which would be incurred if the problems were not identified until the commissioning phase of the facility. In particular, performing SIT early in the construction phase can usually prevent any project delays, ensuring that patient services are not disrupted by problems being identified only during the commissioning phase, i.e. during the critical examination or acceptance testing of the new facility.

In all of the cases we have been involved with, remedial action would have been significantly more costly (in terms of both monetary value and patient service disruption) had the problems we found not been identified until the clinical equipment was in place.

In most cases the discussions which followed the issue of the SIT results indicated that the missing shielding was just down to human error. However, for some cases, it appeared that the builder was aware that the level of shielding indicated on the drawings hadn't been provided (in one instance because when they came to build the wall there just wasn't space and instead of querying this, they just built it thinner). It is important to ensure the architect, builder and others associated with the practical implementation of shielding design understand the implications of making changes to that design.

We have also performed SIT in a brachytherapy room where cracks were visible in the concrete structure (and water was leaking into the room). In this particular instance although the water ingress was a problem, and there was an increase in accessible radiation levels very locally, the visible defect did not cause any significant reduction in the level of shielding provided by the structure due to the random nature of the crack path line through concrete.

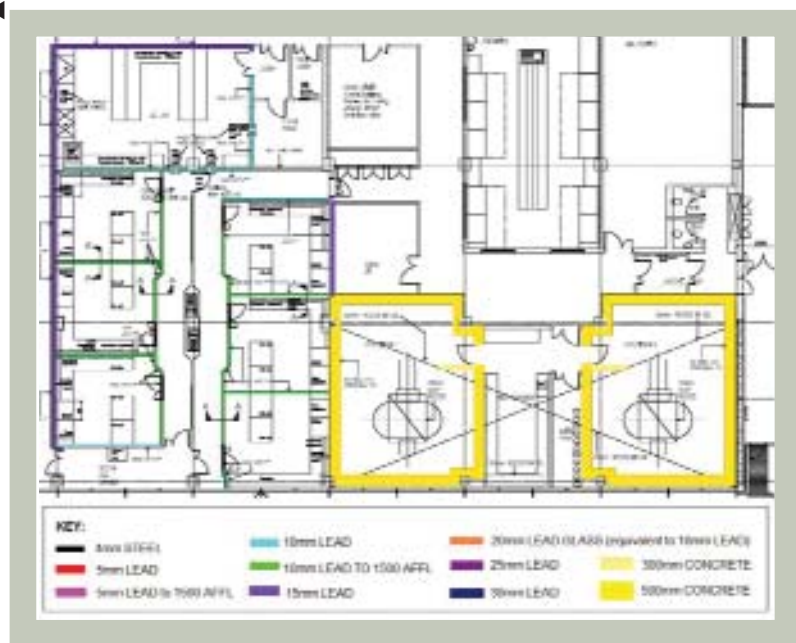
However, although SIT provides confidence that the facilities generally meet the design criteria with no significant weaknesses, it does not replace the requirement for the testing of the facility using clinical equipment. In addition to being a legal requirement (installers of equipment which incorporates a

► **TABLE 1.** Summary of the shielding integrity testing (SIT) methodology.

TABLE 1	
Phases	Activities
Before SIT	<ul style="list-style-type: none"> Initial site visit to discuss proposed testing (including site access, stage of build, current issues) and determine any particular areas of interest or potential difficulties Preparation of prior risk assessments and method statements Preparation of detailed testing protocols, including sources of radiation to be used, areas to be tested and how results will demonstrate compliance with design Pre-SIT site visit to ensure area(s) ready for testing, resolve any practical issues, agree (and if possible mark) testing points
During SIT	<ul style="list-style-type: none"> Evacuate test and adjacent areas (if possible) and establish access control Establish radiologically controlled area and set up equipment, including ensuring emergency equipment for source retrieval available (if appropriate) Perform SIT Physically mark position(s) of weakness(es) if possible Make safe all sources and equipment and remove area designation Make initial report regarding testing, if appropriate
After SIT	<ul style="list-style-type: none"> Perform initial interpretation of results and report to client Taking site specifics into consideration, provide a detailed results report indicating the level of shielding present and any actual or potential weaknesses or defects

► **TABLE 2.** Typical defects found during SIT.

TABLE 2	
Room type	Problem
Linear accelerator bunker	<ul style="list-style-type: none"> Air gaps around structural supports Gaps under shielded doors Non-overlapping brickwork in secondary walls Misplaced steel sheet embedded in primary poured concrete wall Incorrect positioning of 'top hat' Shield walls not inset into adjacent walls but abutted leading to leakage path
Radiographic/fluoroscopy/CT room	<ul style="list-style-type: none"> Joins in lead-lined plasterboard sections not protected – missing batons Missing protection behind electrical sockets and control panels Insufficient protection in doors/windows No shielding present – lead-lined plasterboard missing
High dose rate radiotherapy room	<ul style="list-style-type: none"> Waste water penetrations made through ceiling slab not shielded Concrete tie bars removed but not filled with concrete
Iodine patient ward	<ul style="list-style-type: none"> Thinner than expected concrete walls Penetrations for plumbing through floor not shielded
Cyclotron/PET facility	<ul style="list-style-type: none"> Significant leakage from hot cells Missing protection in external walls



◀ Variety of shielding encountered on a single floor of a new hospital.

source of ionising radiation are required to carry out a critical examination of that equipment which includes the assessment of any shielding which has been provided to restrict individuals exposure^{2,3}) this remains important as it is unlikely that the radiation sources used for earlier tests will have been able to fully mimic the clinical radiation field (it is particularly difficult to simulate the scatter which may be generated by the patient). For this reason, tests using the clinical source may identify localised weakness in the shielding which were not apparent during SIT. For example, it is possible that overlapping protection in door frames will seem acceptable during construction phase testing but specific directional shielding weaknesses may be highlighted using the clinical source in its position of use. It is also possible, due to the time lapse between SIT and the installation of clinical equipment, that changes will be made to the facility, such as the re-hanging of doors, which may change the protection afforded. The significance of small diameter penetrations in thick shielding structures, such as the holes left by tie-bar rods in concrete structures, could also be missed. Unless the initial shielding test radiation source was directly in line with such a weakness it may not be apparent as the oblique path crossing the weakness may still provide sufficient shielding and hence indicate the structure meets design criteria. In our experience, the few weaknesses not detected by SIT have

been easy to remediate and have not had significant costs or delays to patient services associated with them.

To ensure that SIT is as effective as possible at detecting weaknesses and defects, it is therefore also important to understand how the facility will be used operationally. This ensures an appropriate radiation source can be selected to perform the testing and that during testing the source is placed at appropriate locations within the facility to test the shielding in conditions as close as possible to those anticipated during normal use.

INTERPRETATION OF THE RESULTS

SIT generates transmission data for the shielding under assessment and this data must be converted into material thickness using published (or, where possible, measured) factors to allow comparison with the design specification. Where the composition of the shielding is known, the results are presented for the material(s) present. Where the composition is not known (or where the design requirement is in terms of millimetres of lead or concrete) the result is presented in lead or concrete equivalence. There are a number of errors associated with the results, including: inherent accuracy of the measurement equipment, use of reference data, variation in source output and positioning errors. Consideration of all the quantifiable errors suggests that the results gained are accurate to within at least ± 10 per cent and usually ± 5 per cent.

Errors can be reduced by consideration of the shielding construction and careful selection of radiation source and measurement equipment. For example, if simple brick construction has been used, it is better to test with a non-collimated source to reduce the possibility of directing a collimated beam at the weaker joints. Where there are known penetrations in the room, e.g. a rat hole for equipment cables, care must be taken not to align the source (or the first scatter from a collimated source) with the penetration. Scatter through joints in shielding sections which have not been properly overlapped can cause transmission measurements to become meaningless.

SO, DO YOU KNOW WHAT'S IN YOUR WALLS? (AND CEILINGS, FLOORS, DOORS ...)

The only reliable method for determining the level and integrity of shielding provided in a facility is by testing it. This is best done using an independent radiation source which can be placed at any point in the facility, i.e. is not constrained to normal operational parameters and generates measurable radiation dose levels outside of the facility. Shielding integrity testing is particularly important for new facilities and those where a change of use is planned. Our experience has shown that any additional costs associated with SIT are likely to be trivial in comparison with project costs and will easily be offset by the potential savings associated with identifying problems before clinical commissioning commences. ■

REFERENCES

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- 2 Ionising Radiations Regulations. 1999; SI1999/3232.
- 3 Work with ionising radiation. *The Ionising Radiations Regulations 1999. Approved Code of Practice and Guidance L121*. HSE Books: 2000.