RADIATION SAFETY AROUND THE ESRF BEAMLINES

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INTRODUCTION

Today, over 20 beamlines have been put into operation at the ESRF. The record-breaking power of these beamlines, as well as their high critical energy (above 30 keV for some of the wigglers) made it necessary to design new ways of building X-ray hutches. No practical computer code existed, which would have allowed the calculation of the required shielding thickness, so a new computer code had to be developed. Finally, because of the large number of hutches at the ESRF (by the end of this year, more than 80 hutches will be installed) radiation tests have to be carried out in a very systematic and rigorous way. This paper describes these three aspects.

1 SHIELDING CALCULATIONS

The required shield wall thicknesses are calculated using a computer code written in C++ by P.Berkvens. The principle of these calculations is shown below. The dose equivalent rate behind a shield wall due to the scattering of an X-ray beam on a target is given by:

$$\frac{dH}{dt}[\mu Sv/h] =$$

$$\int_0^X dx \int_0^\infty c(E') \times B(E',\theta,t) e^{-\mu_{tot}(E')\frac{t}{\sin\theta}} \times \frac{d\mu_{cs}(E,\theta)}{d\Omega}\frac{1}{s^2} \times e^{-\mu_{tot}(E') l(x,\theta)} \times e^{-\mu_{tot}(E)x} n(E) dE$$

where :

$$E' = \frac{E}{1 + \frac{E}{m_0 c^2}(1-\cos\theta)}$$

$c(E')$: fluence to dose equivalent conversion factor

$$\left[\mu Sv/h \times \left(photons \cdot cm^{-2} \cdot s^{-1}\right)^{-1}\right]$$

$B(E',\theta,t)$: photon build - up factor

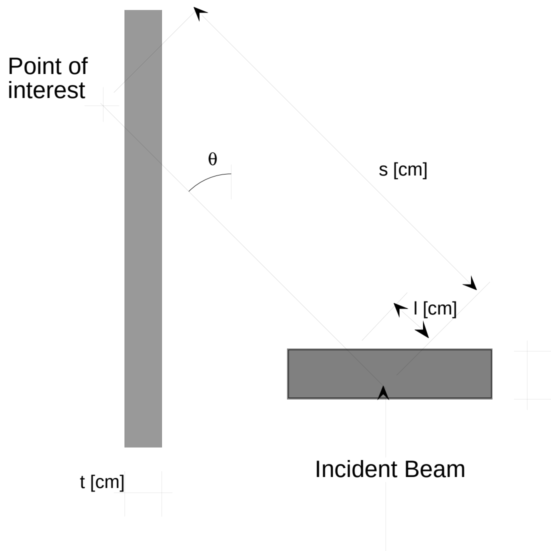
μ_{tot} : total attenuation factor

(Photo - electric + Compton) $[cm^{-1}]$

$\frac{d\mu_{cs}(E,\theta)}{d\Omega}$: differential Compton attenuation factor

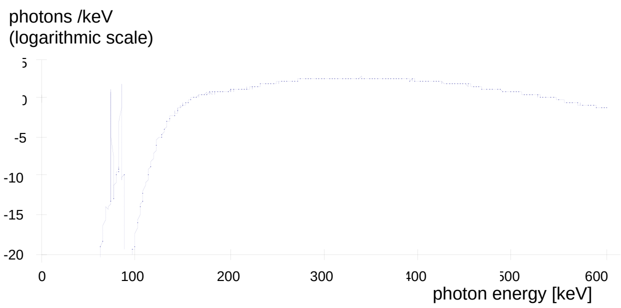
$[cm^{-1} \cdot steradians]$

$n(E)$: synchrotron radiation spectrum $[photons / dE / s]$



The required thicknesses are obtained for worst-case conditions, i.e. the full beam power incident on a thick low-Z scatterer, with small self-shielding. For a given wall thickness, the highest dose is obtained for angles around 45 degrees. For smaller angles, the effective wall thickness will gradually reduce the dose rates, whereas for larger angles the increasing Compton shift results in a more efficient shielding.

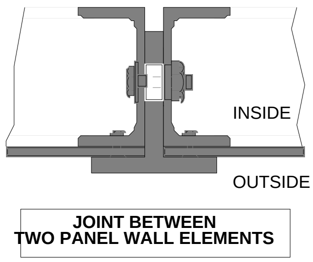
The programme also allows the calculation of the energy spectrum of radiation leaking through a shield wall, for a given geometry. An example of a calculated spectrum is shown below. This spectrum was calculated for a 1.6 T, 150 mm period wiggler, and shows the radiation scattered from a copper target, under 45 degrees, behind a 15 mm shield wall.

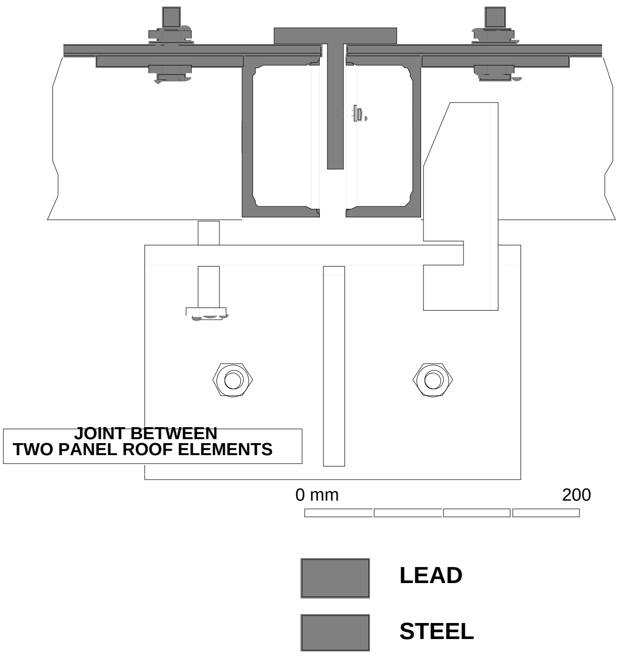


2 HUTCH DESIGN

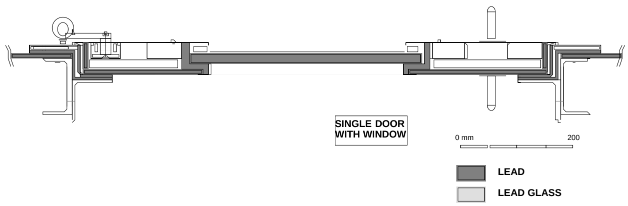
Once the wall thicknesses have been defined, the beamline hutches must be defined. The ESRF, together with the company Antitron Technomedirad, has developed a standard hutch design which is now systematically used for wall thicknesses of up to 12 mm lead, corresponding to white beam hutches for bending magnets, undulators and smaller wigglers, as well as all monochromatic hutches. For the more powerful wigglers, special designs are used. Wall thicknesses for the latter can be up to 35 mm lead.

The main characteristic of the standard hutch design is its modular principle. The hutches are built with standard full height, one meter wide panels. A few special panels are included to match the geometry of a given hutch. Because the panels are full height, only vertical cover profiles are used. The figure below shows the principle of these cover profiles:

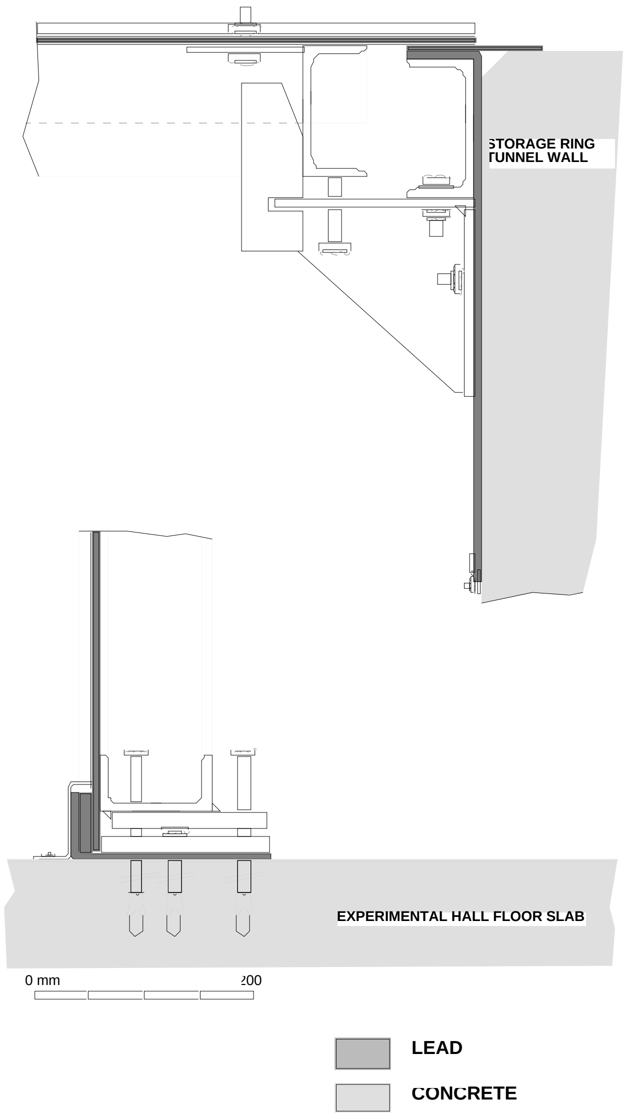




The cover profile design above illustrates a general principle. Since the ESRF hutches must shield against X-rays with energies where Compton scattering cross-sections become important with respect to photo-electric effect cross-sections, even for the heavier elements such as lead, junctions between hutch elements will always be based on at least a single chicane, rather than on a simple overlapping. This principle is applied for various hutch elements, such as doors, windows, services entries, etc. The standard design for a single door with window is shown below:



Finally, great care is taken with the junction between the lead panels of the hutch and the concrete, both for the floor slab and for the storage ring tunnel. A minimum lead width is always foreseen to avoid higher energy leaking through the concrete. As an example, the junction between the roof of an optics hutch and the storage ring tunnel is shown below.



The roofs of the hutches are removable, to allow the installation of heavy beamline equipment using the Experimental Hall overhead cranes. The door sills can be dismounted also, so that one can always roll in equipment via the doors.

Full thickness, double chicanes are welded on the panels to provide the necessary service entries, for fluids, cables, air inlet and outlet, liquid nitrogen. Special small cable chicanes have been designed with hinged doors to allow the Beamline Scientist to pull temporary cables easiliy into the hutch.

The standard design uses panels made of steel - soft lead sandwiches. The lead is glued on the steel, which is spot-welded to the steel structure. Heavier hutches, built for more powerful wigglers, use self-supporting, full height, hard lead panels (6 % Antimony). Special cover profiles are used to provide extra chicaning between the panels and the cover profiles. For the doors special designs are used, providing triple chicaning between the door wings and the door frame. These special designs have been used for wall thicknesses up to 35 mm.

3 RADIATION TESTS

Initial radiation tests are carried out on every hutch before its delivery to the Beamline Scientists. The principle of these tests is the following. No beamline equipment is installed in the hutch, apart from a pre-pumping vessel and a Be-window. The full power is scattered on a water-cooled Cu-target, placed in the air. The entire wall and roof surface is systematically verified. The scatterer is placed at several points along the beam-axis to cover the entire hutch.

As portable survey monitors, fast-reacting Geiger-Müller counters are used. If a leak is detected, more accurate measurements are performed with ionisation survey monitors. If necessary, spectrum measurements are carried out with a portable Ge-detector. The interpretation of the measured X-ray spectrum usually allows a better understanding of the origin of a leak.

The initial radiation tests are carried out at full power, which means at nominal electron current and minimum gap in the case of an Insertion Device beamline. In case of a white beam hutch, these radiation tests are carried out during dedicated shifts, during which the Storage Ring current will be increased from typically 10 mA up to nominal current, to guarantee that possible significant radiation leaks will be discovered at small beam power. Monochromatic hutches are tested immediately at nominal power.

The radiation tightness of the hutch will again be checked on the occasion of the first beam delivery, with the beamline equipment installed, and whenever major changes in the optics occur. Finally, regular routine radiation checks are carried out.

Any measurable leak (i.e. typically $\geq$ 0.2-0.3 μSv/h) will be repaired and will be checked afterwards. This strict criterion allows us to abandon the Personal Dosimetry follow-up for external users working on the beamlines.