



Albira Si

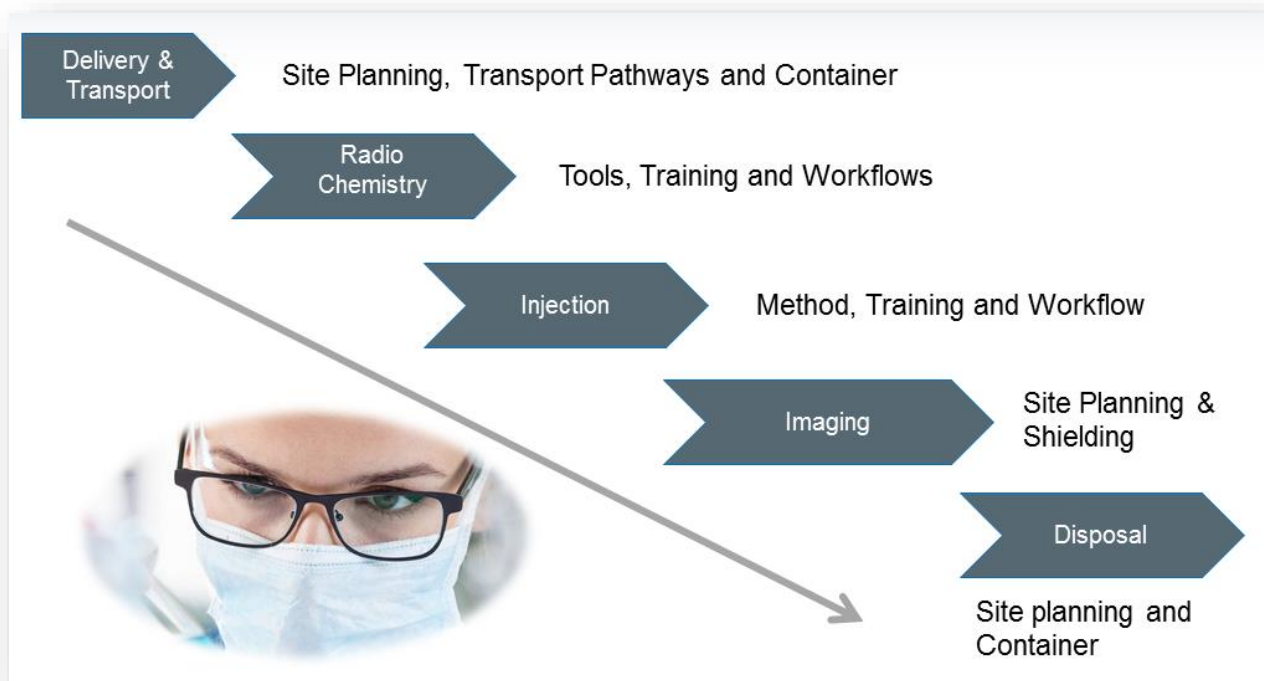
- Considerations on Radiation Safety:
Instrument Shielding



Prevention of Exposure to Radioactivity

The standard for the protection of laboratory staff against radiation exposure are commonly stated “As Low as Reasonably Achievable (ALARA) . ALARA can be achieved in part by considering concepts of time (decay), distance, and shielding. In order to implement these principles in laboratory workflow, it is essential to include all steps of handling radioactive tracer material, starting from the delivery of radioactive materials, its transport pathways and usage up to the final disposal of radioactive waste, materials and tools.

In this paper, we will provide guidelines for radiation emissions during typical PET and SPECT studies using the Albira PET/SPECT/CT preclinical scanner. In addition, example data of radioactive doses that were measured at an Albira Si research lab indicate the importance of the workflow analysis for minimizing the overall radioactive exposure to laboratory staff.





Radiation Shielding Analysis of the Albira Si

The radiation safety analysis includes radiation arising from X-ray and from the radioactive decay of PET and SPECT tracer materials.

- 10 keV – 140 keV Gamma emitted from X-ray sources and low energy SPECT tracer
- 511 keV Gamma emitted from PET Tracer
- Emissions from medium- and high-energy SPECT tracers are considered to be equal or below the exposure arising from 511 keV Gamma of PET tracers.

The exposure of laboratory staff to radiation arising from high energy SPECT tracers or from PET tracer were simulated and measured based on an assumed *in vivo* dose of 37 MBq (1000 μ Ci). This dose used in the evaluation is rather at the higher limit of what typical *in vivo* experiments require and therefore provides a conservative upper limit for the exposure. The real exposure depends on the actual used activities and can be scaled accordingly.

X-ray Shielding and Safety

- Gamma emission with energies in the range of up to 140 keV are considered
- Shielding is achieved by an integrated and fully enclosed X-ray shield of the Albira (1 mm lead and lead-shielding glass)
- The X-ray source can only be activated when all doors and covers of the instrument are closed.
- Every single instrument undergoes a quality control to test X-ray emission before it is released for installation and operation. An example of such a measurement of a production unit is given in the appendix A.

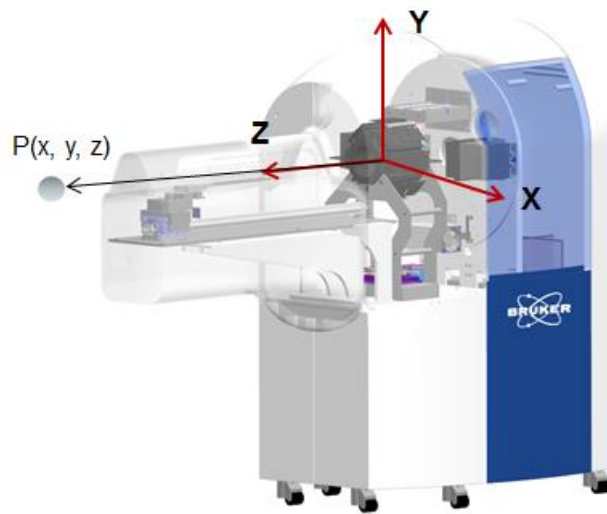
PET and SPECT Shielding

- Emission from low-energy SPECT tracers (< 140 keV) are considered to be fully absorbed by the lead shielding of the X-ray protection
- The Albira Si has no dedicated shielding against PET (511 keV) or high energy SPECT (> 140 keV) gamma rays. Inherent shielding is achieved by the gamma detector and its surrounding material.



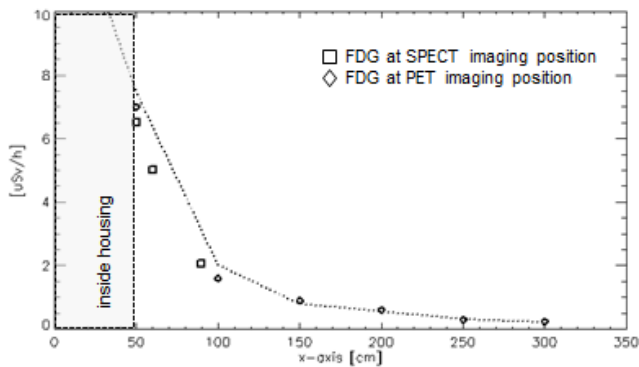
Shielding of PET tracer and high-energy SPECT tracer

The inherent shielding of the instrument and detectors was simulated and measured for different sample positions inside the scanner (PET imaging position, and SPECT imaging position) and the doses were calculated and measured at different distances from the radiation source.

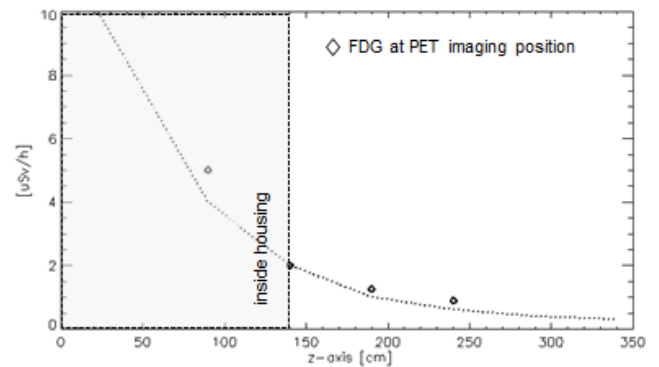


Definition of the coordinate system for the evaluation of shielding efficiency.

Shielding Effect @ 37 MBq along x-axis



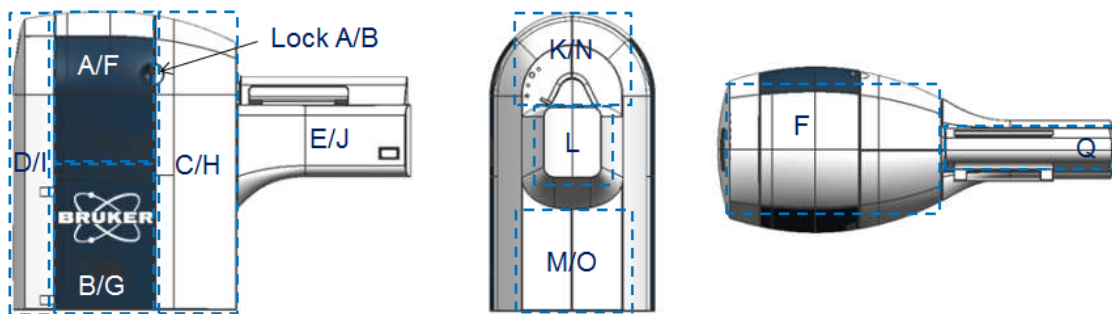
Shielding Effect @ 37 MBq along z-axis



Simulated (dotted line) and measured activity along the x (horizontal) and Z (axial) axis arising from 37 MBq FDG in the centre of the PET or SPECT detector.

Shielding of X-ray and low-energy SPECT tracer

Shielding from X-ray and low-energy SPECT tracer with energies up to 140 keV is achieved by a complete enclosure of the Albira Si with a 1 mm lead shield or 1 mm lead-shielding equivalent material. The quality of the shielding is verified with every produced unit and documented in a quality assurance protocol.



Test Results		
Minimum Value	0,09	μSv/h
Maximum Value	0,45	μSv/h

Sector	Max	Pos 1	Pos 2	Pos 3	Pos 4	Pos 5	Pos 6	Pos 7	Pos 8
A	0,13	0,10	0,13	0,12	0,10	0,13	0,09	0,10	0,05
B	0,16	0,09	0,13	0,09	0,10	0,09	0,12	0,16	0,11
C	0,15	0,08	0,15	0,10	0,13	0,13	0,10	0,15	0,09
D	0,13	0,09	0,13	0,08	0,12	0,11	0,11	0,12	0,11
E	0,18	0,11	0,14	0,14	0,18	0,09	0,13	0,12	0,14
F	0,41	0,28	0,41	0,35	0,39	0,20	0,34	0,30	0,26
G	0,40	0,30	0,28	0,30	0,38	0,30	0,36	0,27	0,40
H	0,45	0,27	0,27	0,44	0,26	0,25	0,45	0,22	0,26
I	0,40	0,23	0,24	0,22	0,40	0,22	0,23	0,20	0,20
J	0,26	0,26	0,18	0,23	0,26	0,22	0,22	0,18	0,20
K	0,30	0,30	0,19	0,14	0,15	0,24	0,21	0,23	0,24
L	0,35	0,35	0,16	0,11	0,12	0,21	0,20	0,24	0,22
M	0,10	0,10	0,11	0,15	0,12	0,14	0,12	0,10	0,12

Top: Definition of the measurement sections for X-ray certifications.
 Bottom: Example of the test results during factory acceptance.



Estimated Annual Exposures during PET/SPECT imaging studies

From the radiation safety analysis given above, a typical annual dose arising from SPECT and/or PET tracers and the instrument shielding capability can be estimated and compared to the national standard published by the world health organization. For that purpose, one might assume the following conditions for the routine operation of imaging studies using the Albira Si.

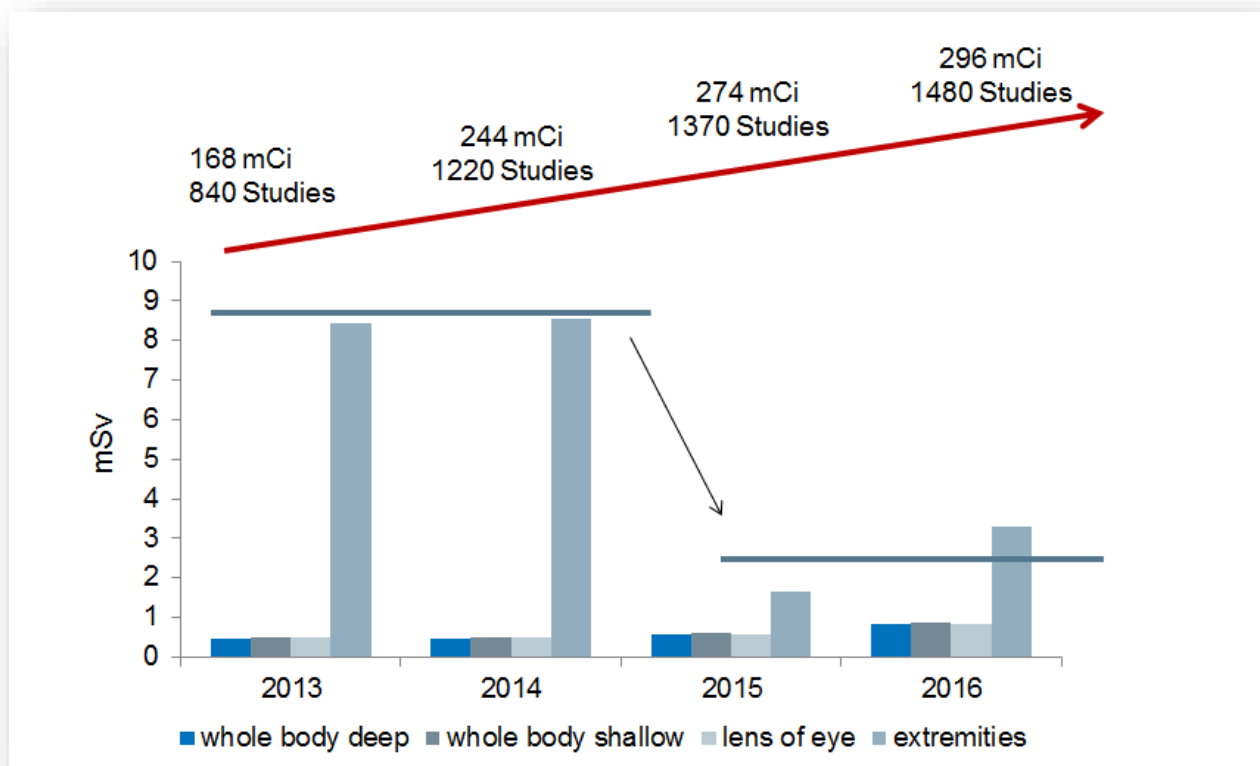
- The regulation applied in the more than ten European countries provides annual limits for safe doses: 1 mSv/year for general population and up to 20 mSv/year for professionals.
- The installation of the instrument is done in a way that the operators console is at a minimum distance of 1 meter, as measured from the housing of the instrument. At these distances, the hourly dose is 1 μ Sv/h.
- The daily operation by one individual person is 6 h, and the yearly working days are 230 days.
- Since the dose that is acquired during the preparation of the animal and the injection of the tracer depends not on the shielding of the instrument, those doses are not considered here, but are included in the real-life example further below.

With the assumptions above, which reflect the situation of the acquisition and reconstruction phases of imaging studies, one might conclude that the annual whole body dose that a single operator accumulates during the acquisition and reconstruction of PET/SPECT experiments is in the order of $230 \cdot 6 \cdot 1 = 1,38$ mSv/year. Since typical site planning suggests much higher distances between the operator workplace and the instrument as well for usual in vivo studies 1/10 to 1/5 of the here used doses are applicable, the real incorporation number can be expected to be a factor of 5-10 times lower, thus well below the recommended limit for the general population and by far below the annual dose for professionals.

For comparison, the estimated average annual cosmic radiation dose of civil flight personnel is in the order of 2,0 to 2,2 mSv (Feng et al, Estimated cosmic radiation doses for flight personnel, Space Med Eng. 15(4): 265-269 (2002), and Bottollier-et al, Assessing exposure to cosmic radiation during long-haul flights. Radiat Res 153(5 Pt. 1):526–532; (2000)).

Measured Annual Exposures During PET/SPECT Imaging Studies in Example Albira PET/SPECT/CT Laboratory

The influence and the importance of the workflow of animal preparation and injection on the annual radiation dose can be seen from the yearly dose evaluation of the staff members.



The upper part of the graph shows the absolute amount of radioactivity that was handled in total in the years 2013-2016 in the imaging lab [Notre Dame Imaging Lab, US]. Over the years, the total handled activity and the total number of performed PET experiments increased by almost a factor of 2.

The lower part of the graph shows the sum of the measured dose of the entire laboratory staff that was involved in handling the radioactivity and in performing the PET imaging experiments. There are a few aspects that are worth to note:

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- (i) By far the highest exposure is encountered at the extremities. The high exposure is related to the handling of radioactive materials during all phases of the daily laboratory workflow. In this lab and beginning of 2015, the tracer application protocol used in the lab has changed from tail vein injection (10-20 seconds) to retro-orbital injection in combination with additional shielding measures for tracer handling. By these changes and optimizations of the workflow, the exposure of extremities could be absolutely reduced by a factor of 2-3.
 - (ii) The measured total doses of the entire lab personal in the other regions, that are normally not probe to exposure due to sample preparation, the measured limits are clearly below the upper limit doses that we derived from the shielding effect of the instrument under worst case conditions.

Summary

In this paper, the instrumental shielding characteristics of the Albira Si imaging device with respect to low- and high-energy SPECT and PET tracers as well X-ray energies up to 140 keV are provided.

- at a distance of ~1m of the instrument, the maximum exposure arising from 37 MBq activity of PET/SPECT tracer with energies of up to 511 keV is in the order of 1 μ Sv/h.
- At a distance of 10 cm of the surface of the housing, the maximum exposure arising from X-ray or low-energy SPECT tracer with energies of up to 140 keV is very much below 1 μ Sv/h. The shielding capacity of every instrument is verified before delivery.
- As an example, actual annual radiation doses are presented from a preclinical imaging laboratory using the Albira for a period of four years. The sum of the total annual exposure of the entire lab personal for all locations except the extremities stay below 1 mSv.
- The annual exposure to the extremities is strongly influenced by the implemented workflow of tracer handling, from delivery to the application to the subject and disposal. Different application techniques have strong impact on the actual dose that could be observed. All doses stayed well below the European standard for lab personal of 50 mSv/year.