EGSnrc calculations of equivalent dose to skeletal soft tissues based on vertebral 3D-microCT images

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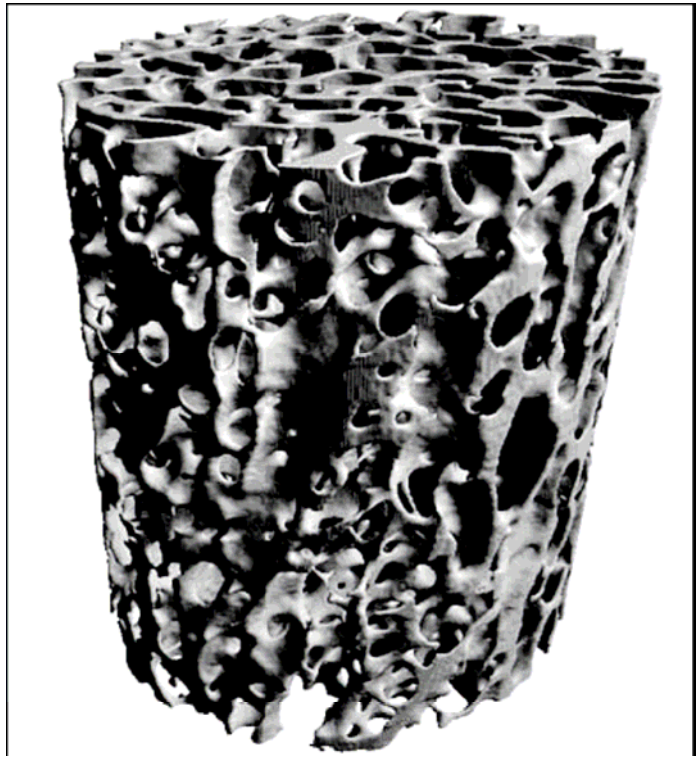
Two skeletal soft tissue at risk from exposure to ionising radiation:

The haematopietic stem cells of the marrow, called red bone marrow (RBM)

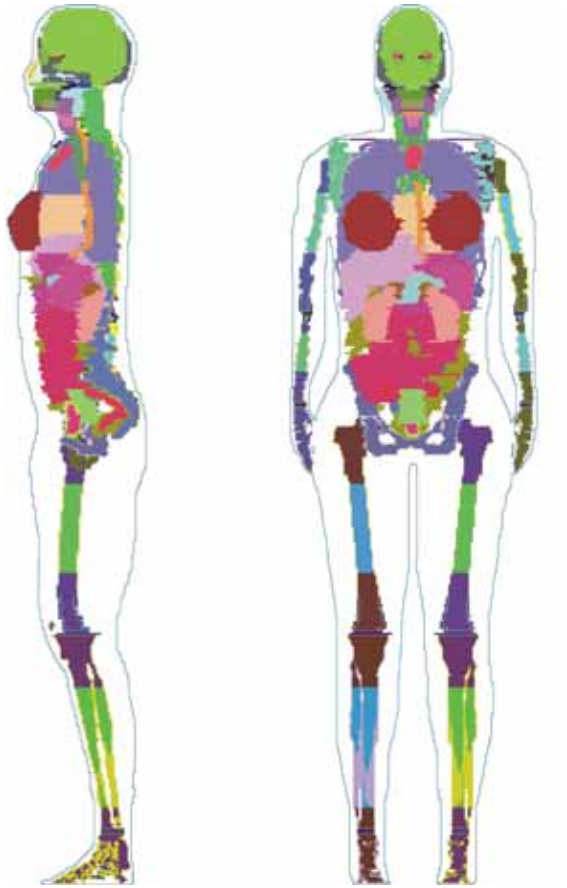
The osteogenic cells on the endosteal surfaces of trabecular bone, called bone surface cells (BSC)

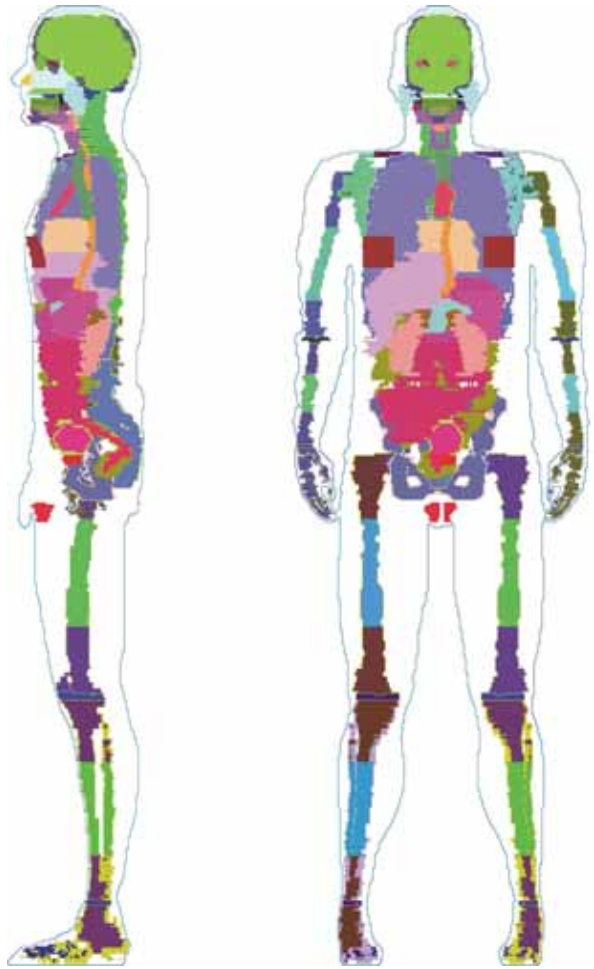
RBM and BSC are located in irregular cavities with diameters between 50 and 2000 micron. The thickness of the BSC layer is considered to be 10 micron



Trabecular bone specimen of a human femoral neck scanned at a resolution of 22 micron

Trabecular bone plus its supported soft tissue is sometimes also referred to as “spongiosa”

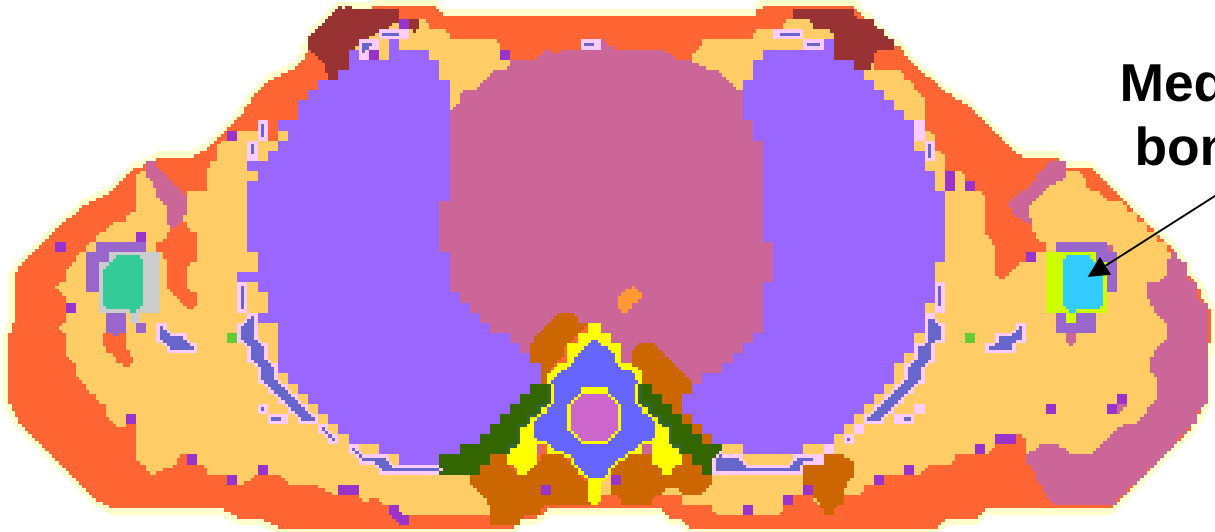


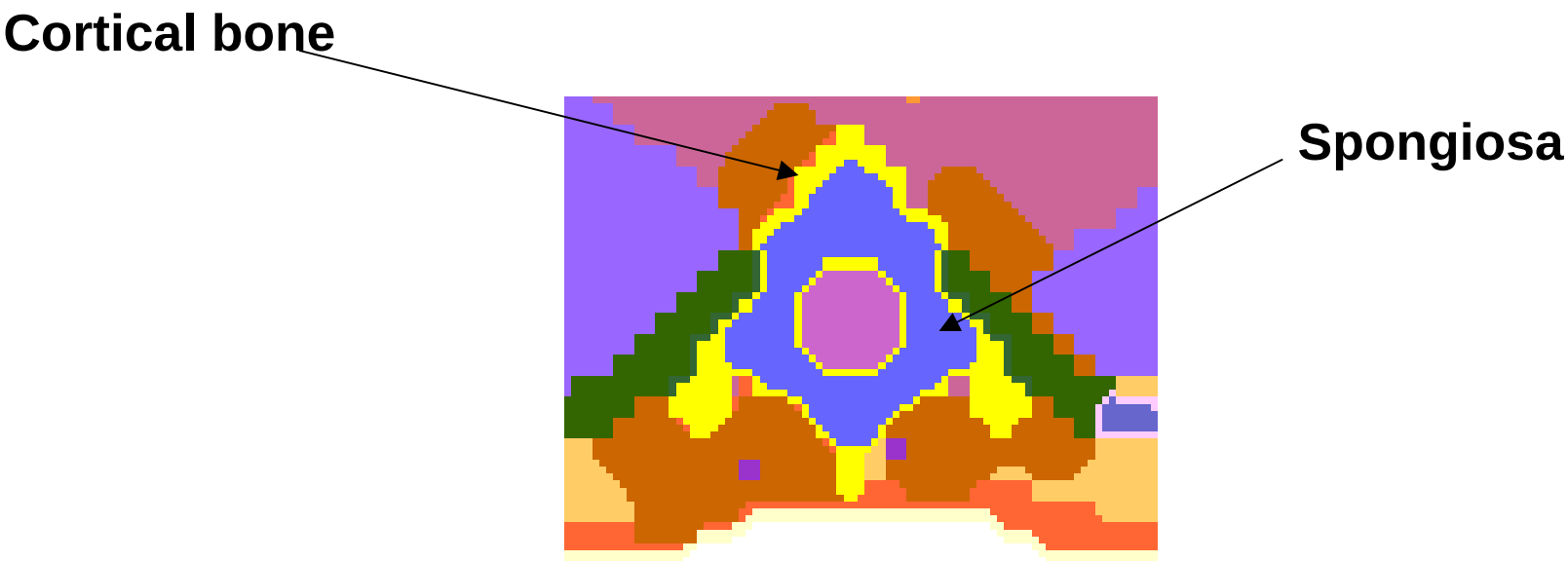


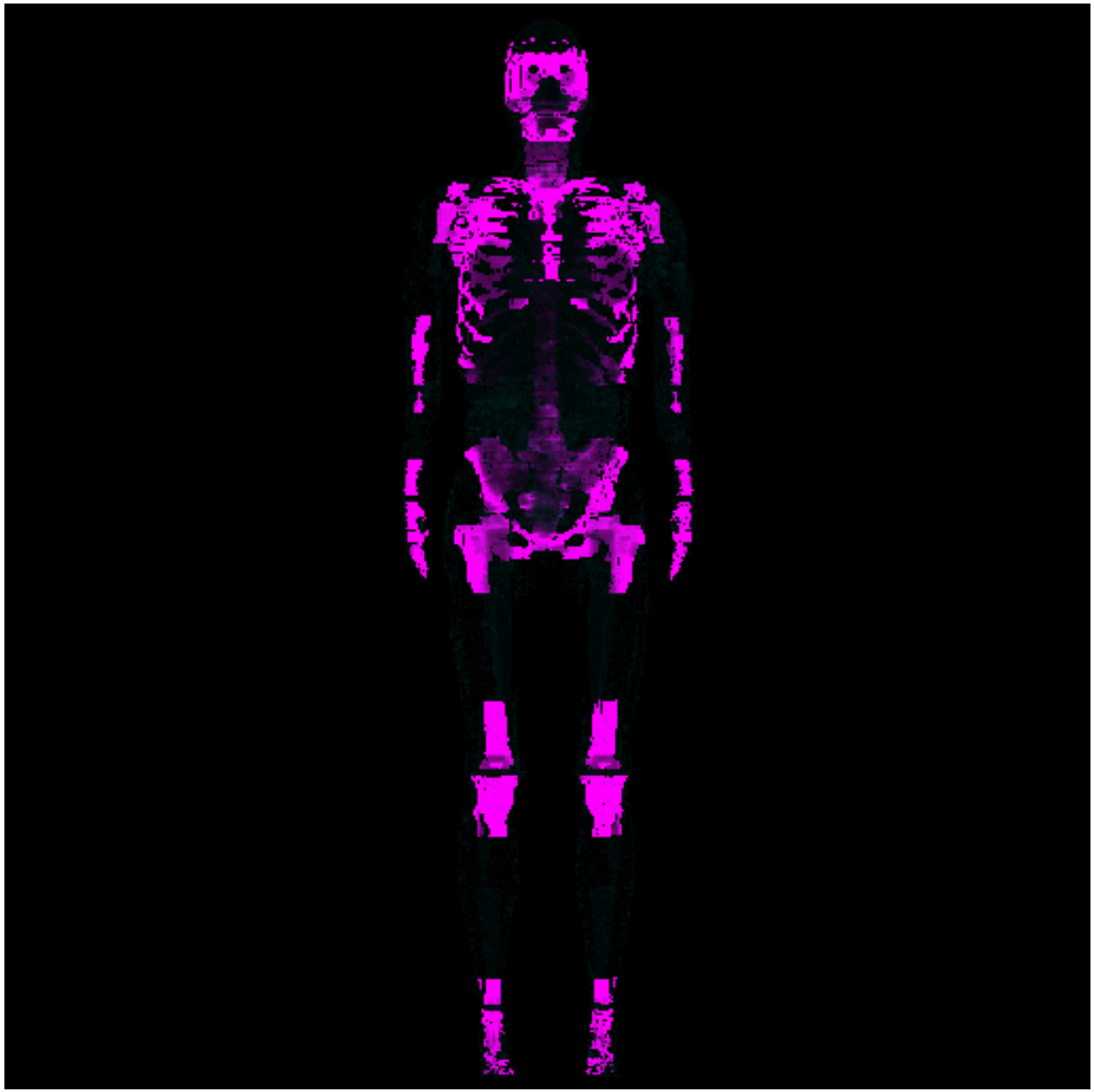
FAX06 **MAX06**

1.2 mm cubic voxels

FAX06







3D-microCT image-based particle transport in the MAX06 and the FAX06 phantoms

- Skeleton with segmented regions of cortical bone, spongiosa and medular yellow bone marrow

- 3D-microCT images of human spongiosa segmented into trabecular bone, BSC and marrow

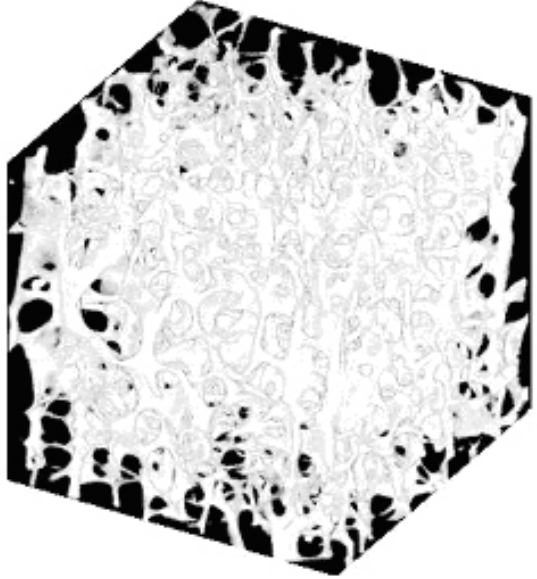
- Special method for particle transport in segmented 3D-microCT images in the spongiosa voxels of the skeleton with manageable memory requirements and reasonable execution times

Bone specimen	Gender	Age [y]	Height [cm]	Weight [kg]	Vertebra	Resolution [micron]	Image size mm^3
S0117					11. thorarcic	17.5	9.0 x 9.0 x 4.5
B1830	female	68	170	70	8. thorarcic	30	7.9 x 7.9 x 7.7
B0160	male	66	173	68	4. lumbar	60	12.0 x 12.9 x 8.7

Verterbral 3D-microCT images available for this study

Adult	trab. volume frac.
Skeletal region	%
Arm bones	15
Ribcage	10
Spine	12
Skull	55
Mandible	55
Pelvis	20
Leg bones	15

Trabecular bone volume fraction in spongiosa (ICRP70)



3D-microCT image of spongiosa

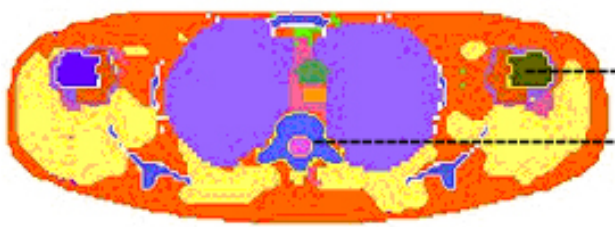
Resolution: 30 micron

Trabecular bone volume: 15%

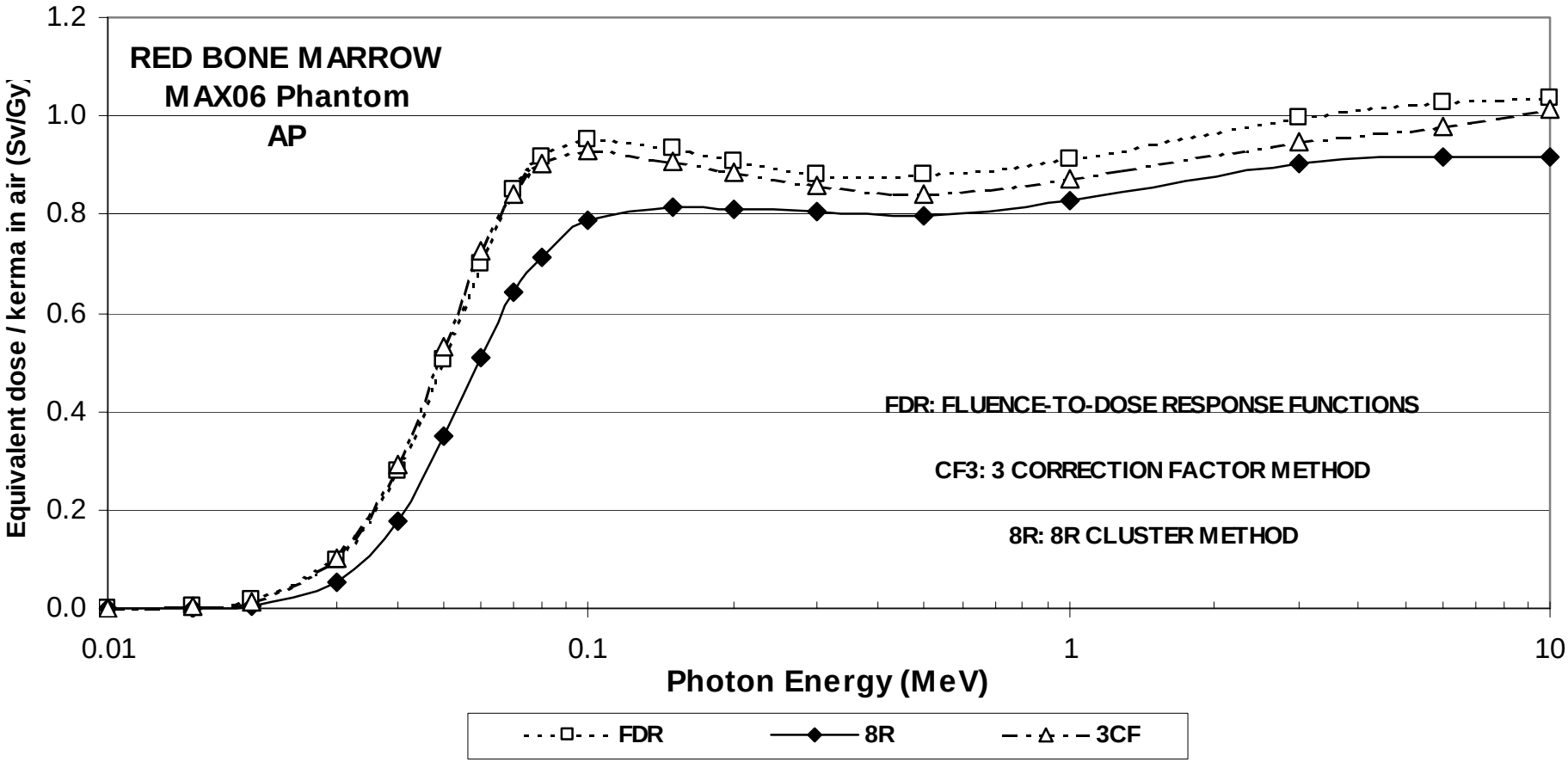
Size:
7.9mm x 7.9mm x 7.7mm

Cluster of 8 1.2mm cubic micro matrices with 15% trabecular bone volume extracted form the 3D-microCT image

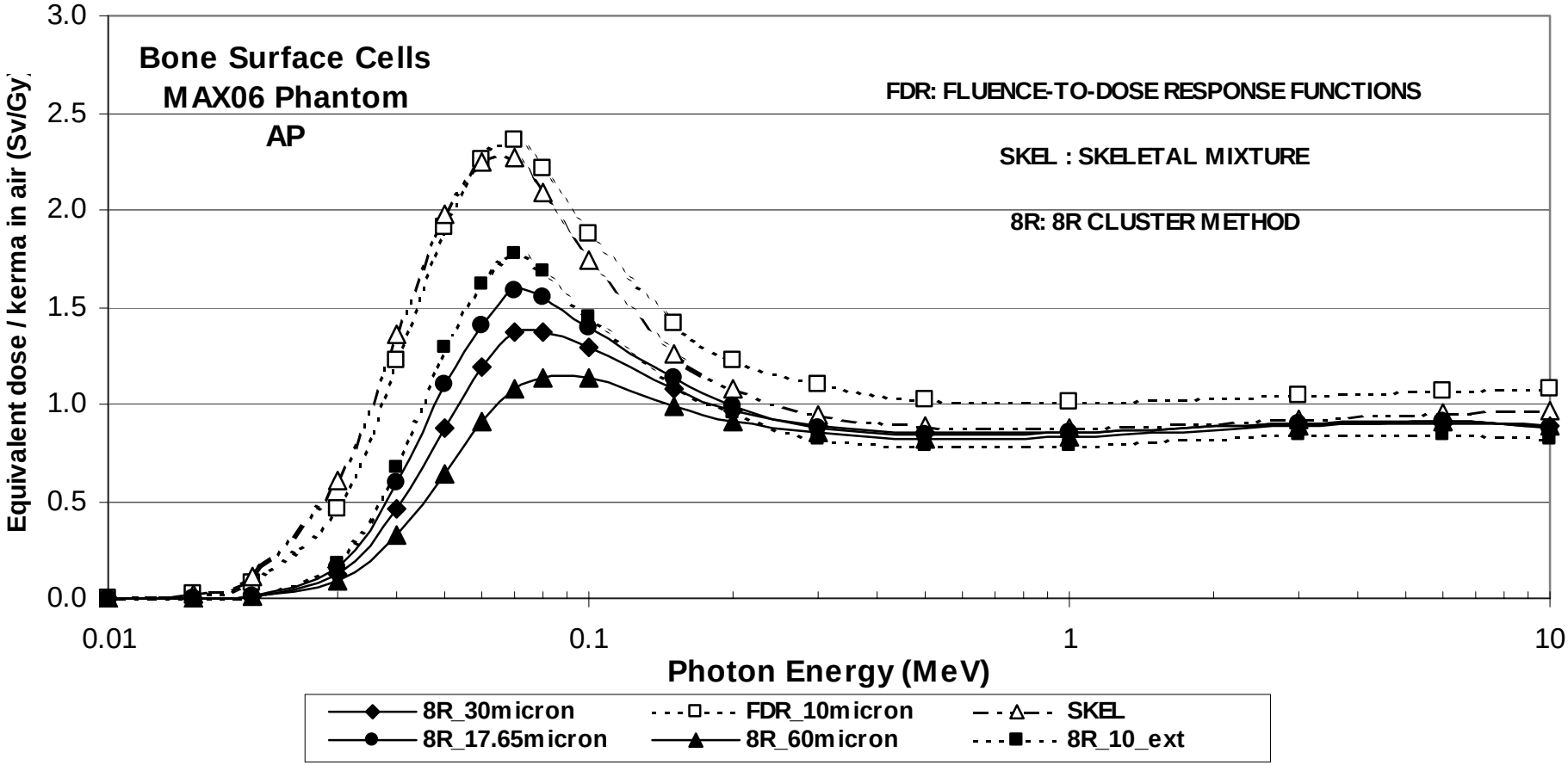
1 micro matrix randomly or systematically-periodically selected from the cluster at runtime to be used in a spongiosa voxel



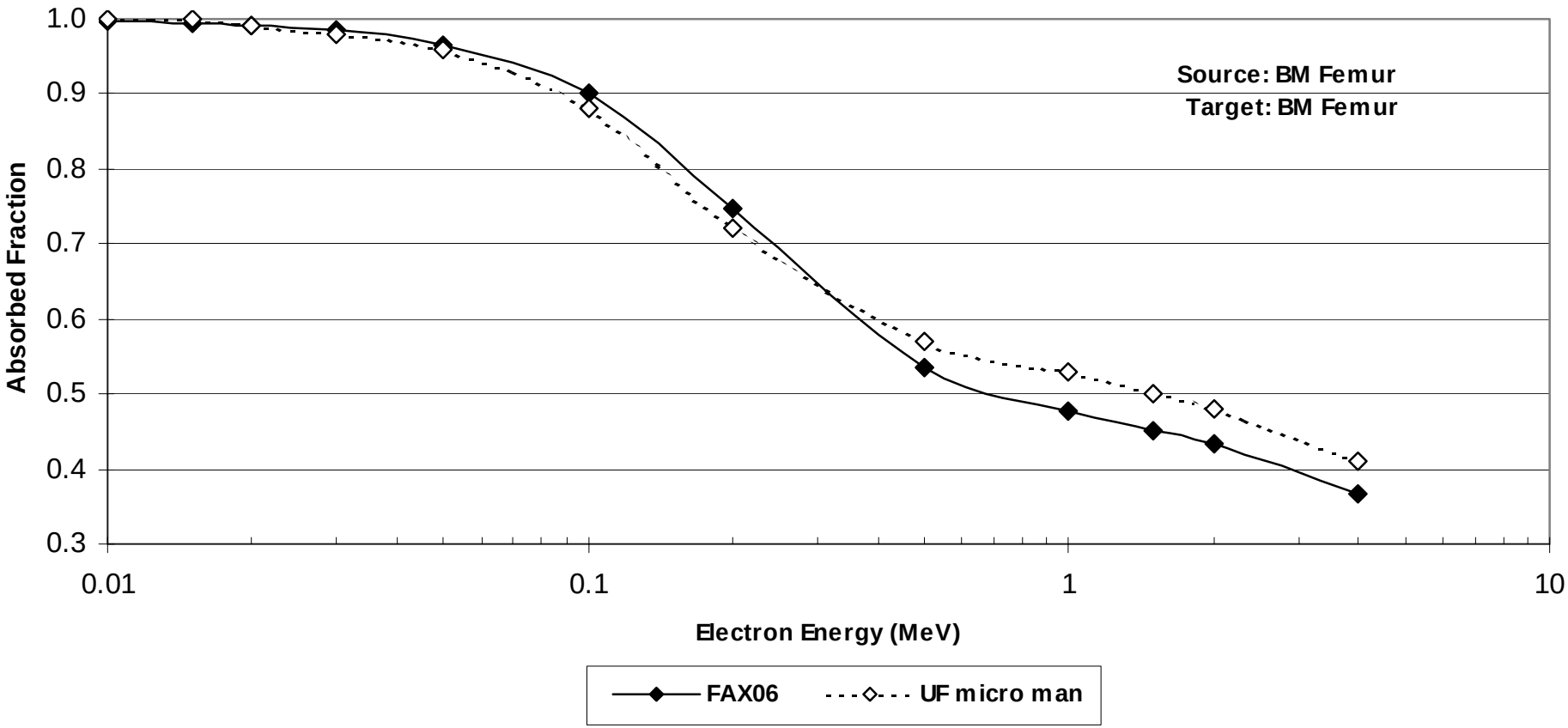
Skeletal dosimetry in spongiosa based a cluster of 8 micro matrices



RBM equivalent dose per air kerma free-in-air as a function of the photon energy for AP-incidence in the MAX06 phantom for different dosimetric methods



BSC equivalent dose per air kerma free-in-air as a function of the photon energy for AP-incidence in the MAX06 phantom for different dosimetric methods



Absorbed fractions for bone marrow from beta emitters uniformly distributed in bone marrow of the femurs of the FAX06 phantom and the femoral head of the "UF micro man" as a function of the electron energy.

Conclusion

This study has shown that RBM and BSC equivalent doses in the skeletons of the MAX06 and the FAX06 phantoms can be calculated using a cluster of only 8 micro matrices and RANDOM selection, for the time being for the three bone specimens used and the exposure conditions considered here.

The calculations have shown in particular that the results neither depend on gender, nor on the anatomical characteristics of the donor of the bone specimen, nor on the type of vertebra selected, and also not on the segmentation technique applied. For the equivalent doses to the RBM even the voxel resolution of the 3D-microCT images was not relevant, at least for the range up to 60 micron.

On the one hand the 3D-microCT images show that the irregular form and the complex spacial distribution of the bone trabeculae and of the soft tissue filled cavities are creating an extremely inhomogeneous environment for a particle crossing through a spongiosa voxel,

but on the other hand according to the results it seems, when many particles with different energies have crossed through only a few spongiosa voxels, that the trabecular micro structure appears very similar in all directions “from the particles’ point of view”, which allows for the random selection from a small cluster of micro matrices in order to get dosimetrically acurate results for equivalent dose quantities in the skeleton

References

- **Skeletal dosimetry in the MAX06 and the FAX06 phantoms for external exposure to photons based on vertebral 3D-microCT images**

  Physics in Medicine and Biology 51 (2006) 6265-6289

- **Skeletal dosimetry in the MAX06 and the FAX06 phantoms for internal exposure to photons and electrons based on vertebral 3D-microCT images**

  submitted to Physics in Medicine and Biology

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