Application of Heavy Concretes to the Shielding Material of Synchrotron Radiation Beamlines

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(1) Buildup Effect & the Importance for SR Beamline Shielding.

(2) Buildup Effect of Heavy Concretes

(Ba & Fe contained Heavy Concretes in comparison with ordinary concrete).

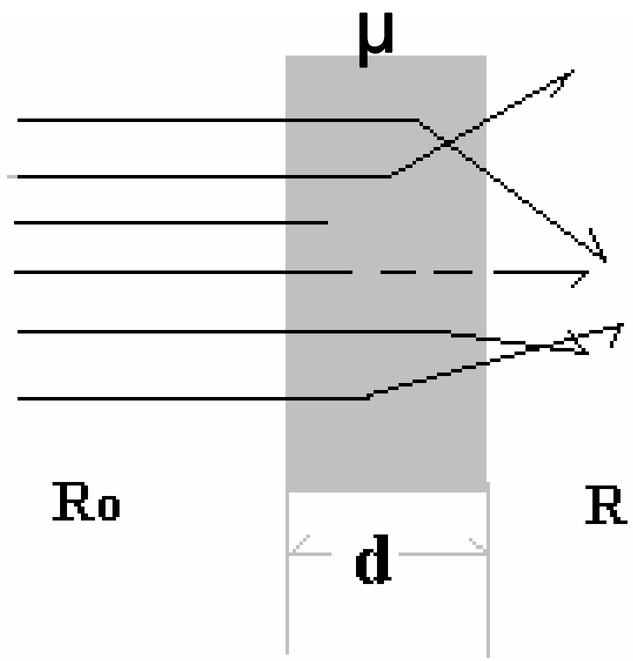
(3) Application to the 3 GeV & 8 GeV Class SR beamlines.

(4) Summary.

Buildup Effect & the Importance

- SR Beamline Shielding Design Calculations
- Strong Attenuation
- Demand of Quickness
- Conservative
- Advantages of Point Kernel Method
- & Importance of Buildup Effect

Buildup Effect



$$B(Eo, X) = R/(Ro * EXP(-X))$$

B; Build up factor

Eo: Incident Energy

X: thickness in the unit of mean free pass(μ^{-1})

(X=μ*d, μ:attenuation coefficient)

R & Ro responses with and without attenuation medium such as exposure, effective dose, ambient dose equivalent

Compositions of the ordinary and the heavy concretes

	Ordinary Concrete		Heavy Concrete	
	ANSI/ANS-6.4.3	Portland	HCON(Fe)	HCON(Ba)
Density (g/cm^3)	2.3	2.3	3.7	3.35
Composition(w/o)				
Hydrogen (H)	0.0056	0.01	0.004	0.0036
Carbon (C)	-	0.001	-	-
Oxygen (O)	0.4983	0.53	0.345	0.3116
Sodium (Na)	0.0171	0.016	-	-
Magnesium (Mg)	0.0024	-	0.019	0.0012
Aluminum (Al)	0.0456	0.036	0.010	0.0042
Silicon (Si)	0.3158	0.3367	0.069	0.0105
Fluorine (F)	-	-	-	0.1079
Sulfur (S)	0.0012	-	-	-
Potassium (K)	0.0192	-	-	-
Calcium (Ca)	0.0826	0.0564	0.048	0.0502
Iron (Fe)	0.0122	0.0139	0.505	0.0475
Barium (Ba)	-	-	-	0.4633

Portland:

NIST (http://physics.nist.gov/cgi-bin/Star/)

HCON(Fe):

Y.Asano & .Leuschner D3-120 DESY

HCON(Ba):

NIST Barite Concrete (http://physics.nist.gov/PhysicsRefData/)

Shield thickness corresponding to one mean free path

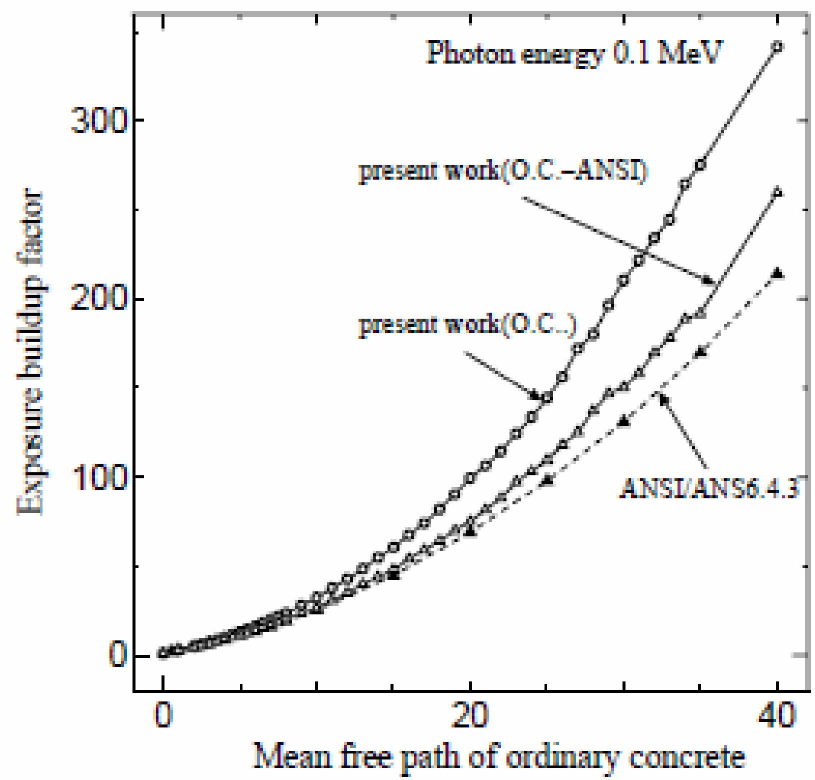
(unit:cm)

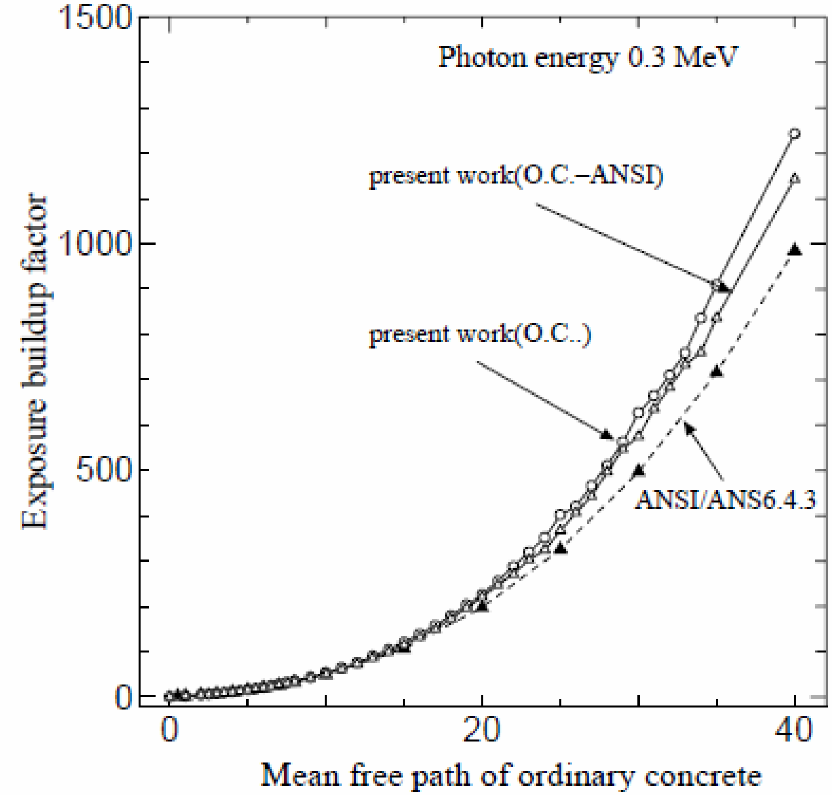
Photon Energy (MeV)	Ordinary Concrete		Heavy Concrete	
	ANSI/ANS-6.4.3	Portland	HCON (Fe)	HCON (Ba)
0.015	0.054	0.062	0.009	0.009
0.020	0.125	0.143	0.019	0.020
0.030	0.389	0.371	0.061	0.063
0.040	0.787	0.868	0.138	0.027
0.050	1.23	1.325	0.252	0.048
0.060	1.635	1.725	0.398	0.078
0.080	2.232	2.292	0.745	0.167
0.10	2.609	2.642	1.087	0.294
0.15	3.15	3.152	1.710	0.749
0.20	3.506	3.497	2.081	1.281
0.30	4.069	4.051	2.546	2.200
0.40	4.55	4.528	2.887	2.852
0.50	4.985	4.960	3.180	3.341
0.60	5.389	5.361	3.447	3.740
0.80	6.134	6.102	3.932	4.402
1.0	6.822	6.787	4.377	4.969
1.5	8.369	8.328	5.364	6.142
2.0	9.698	9.655	6.179	7.019
3.0	11.90	11.86	7.437	8.217
4.0	13.62	13.61	8.339	8.947
5.0	15.01	15.02	8.991	9.388
6.0	16.12	16.16	9.459	9.647
8.0	17.73	17.84	10.04	9.840
10.0	18.80	18.97	10.32	9.811
15.0	20.17	20.47	10.49	9.442

Calculation Methods

- Monte Carlo code **EGS4** with **PHOTX** data
- up to 40 mfp with considering Bremsstrahlung, fluorescence, coherent and incoherent scattering
- Isotropic irradiation and spherical geometry
- 10^6 history
- Radiation quantity → exposure,
- effective dose with AP geometry
- ambient dose equivalent

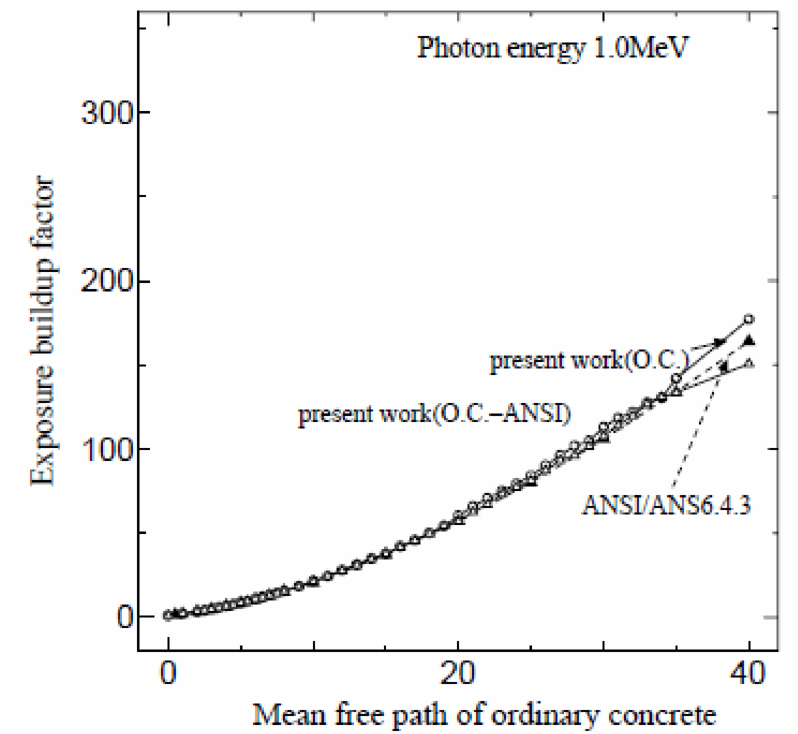
Buildup factor of ordinary concrete

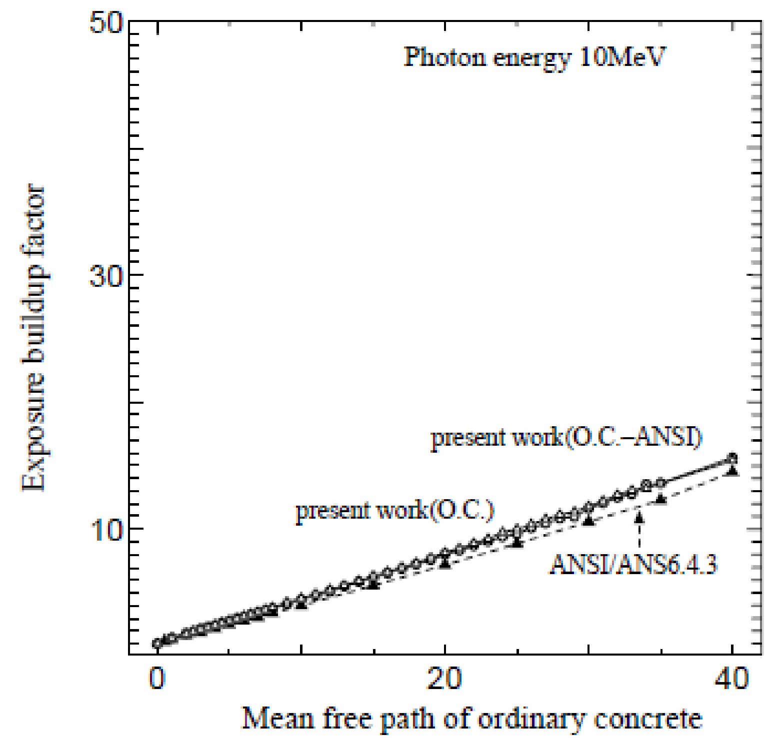




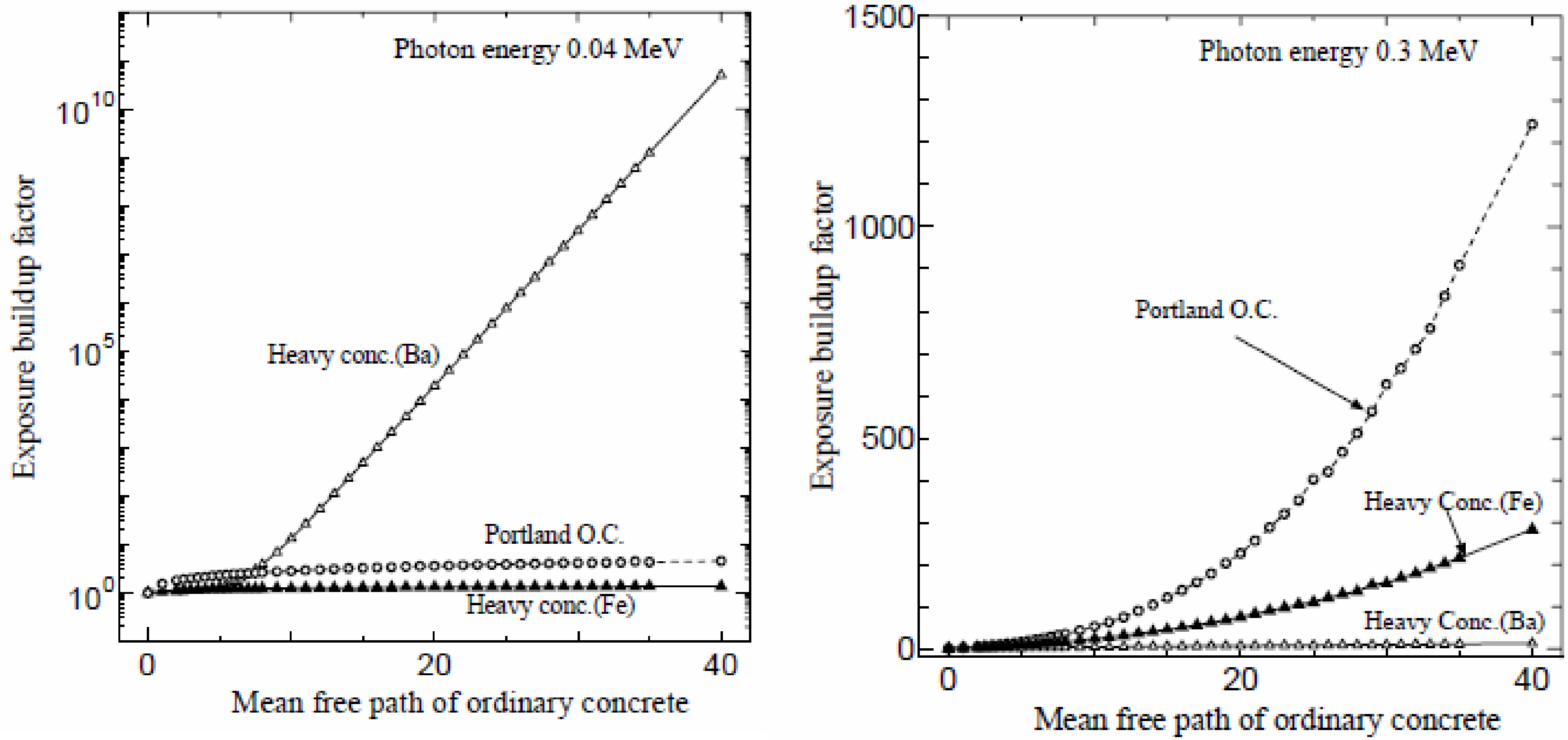
The ANSI/ANS data are based on the calculation result data with parallel beam source, and the present work is by using the Monte Carlo code, EGS4 with isotropic emission photons, and the development of the low energy photon treatments in EGS4 such as K-X ray, L-X ray and Bremsstrahlung. Besides, ANSI/ANS-6.4.3 data are without corrections for the neglect of coherent scattering.

Buildup factor of ordinary concrete



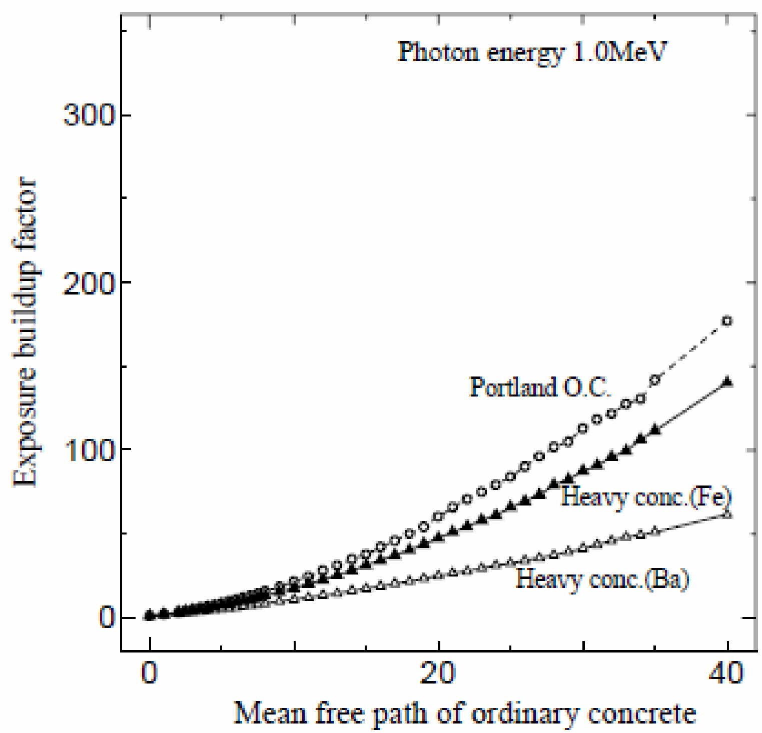


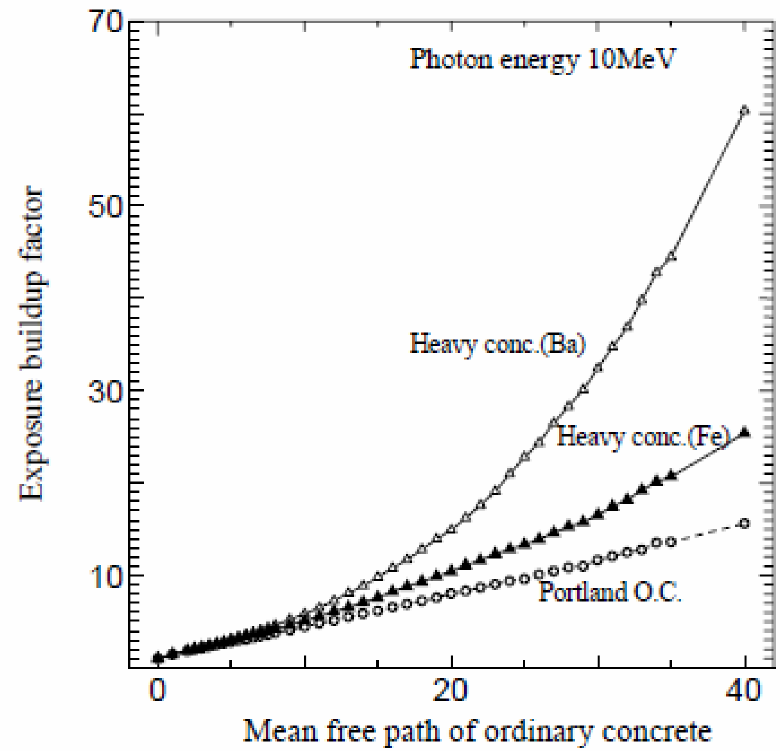
Buildup factor of heavy concrete



Figures show the buildup factors including data of the Portland cement ordinary concrete as a function of mean free path for the photon energy and as a function of photon energy for the exposure of radiation quantity, respectively. These calculations are performed with considering coherent and incoherent scattering.

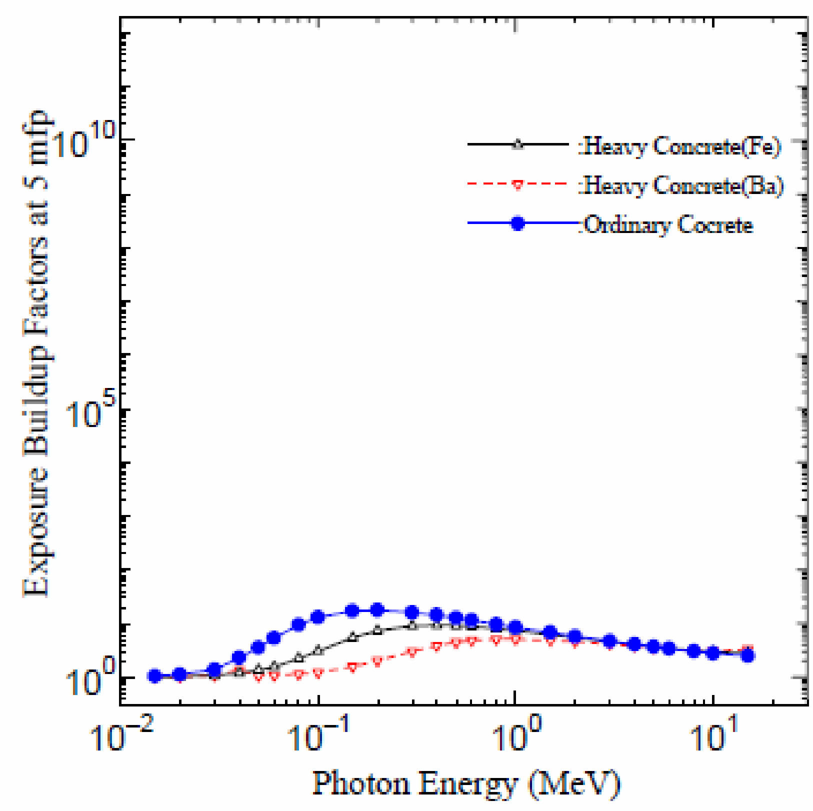
Buildup factor of heavy concrete

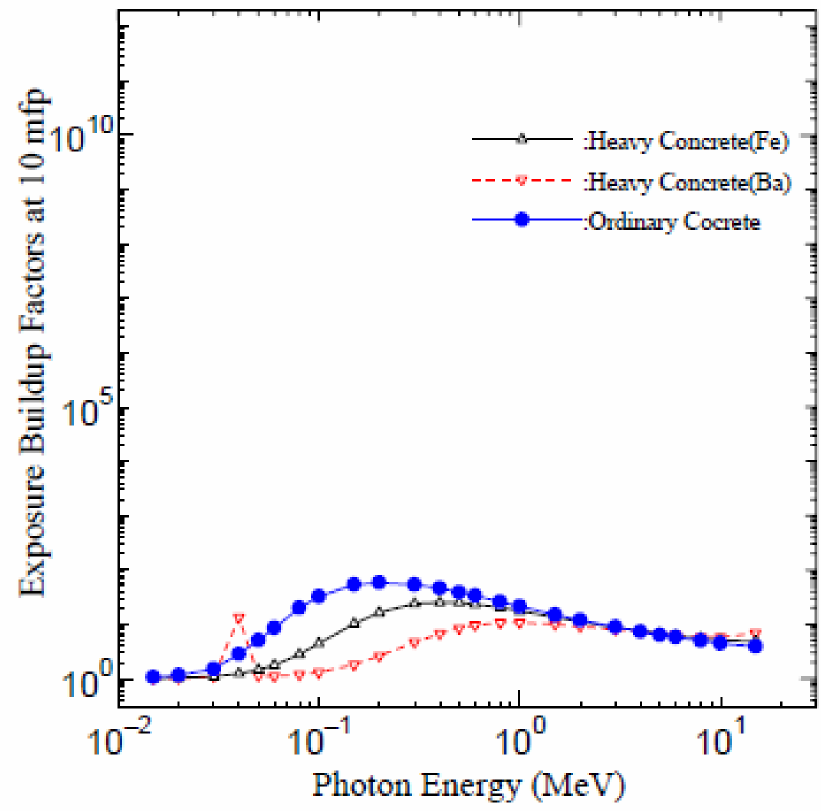




Exposure buildup factor of heavy concrete for 1.0 & 10 MeV photon

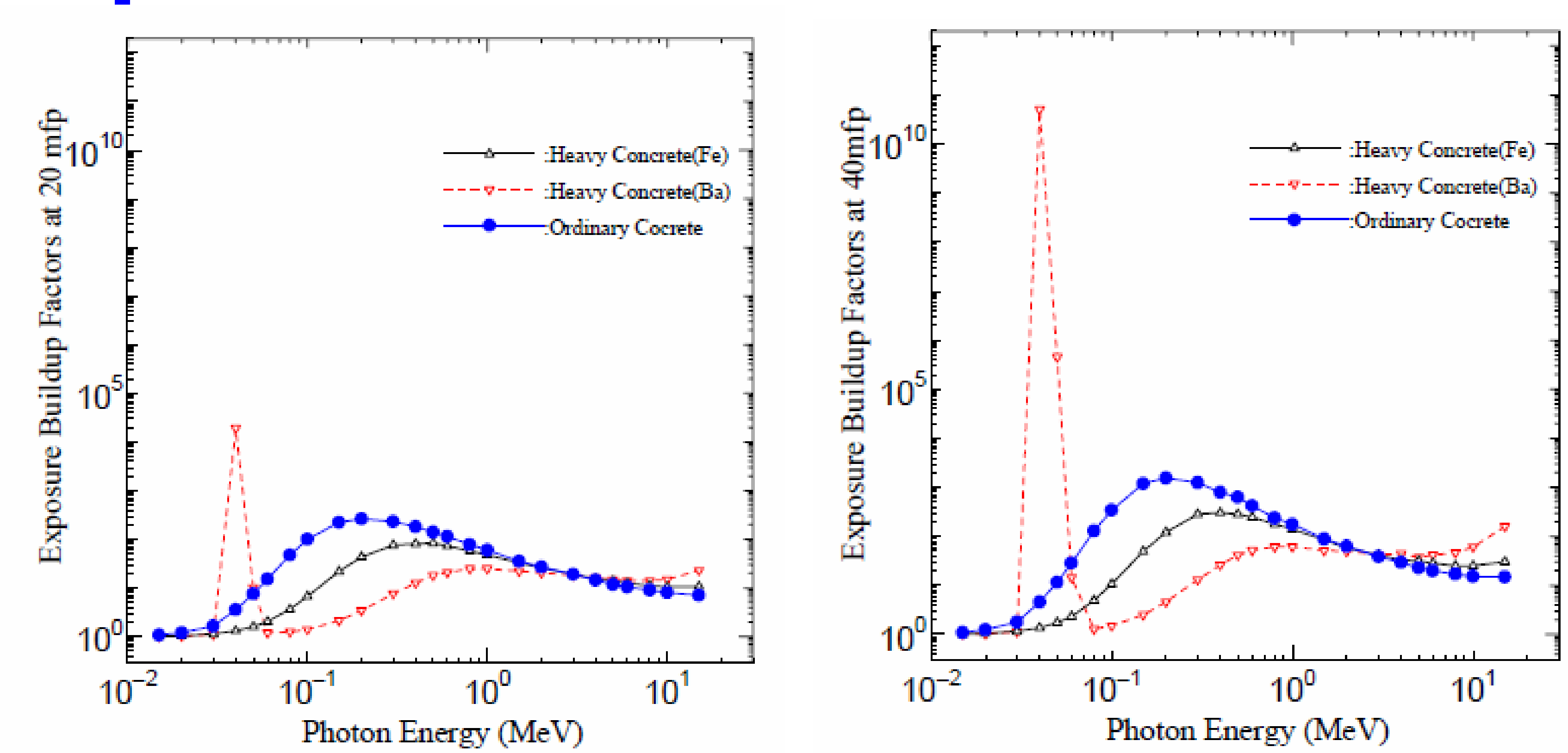
Exposure buildup factor





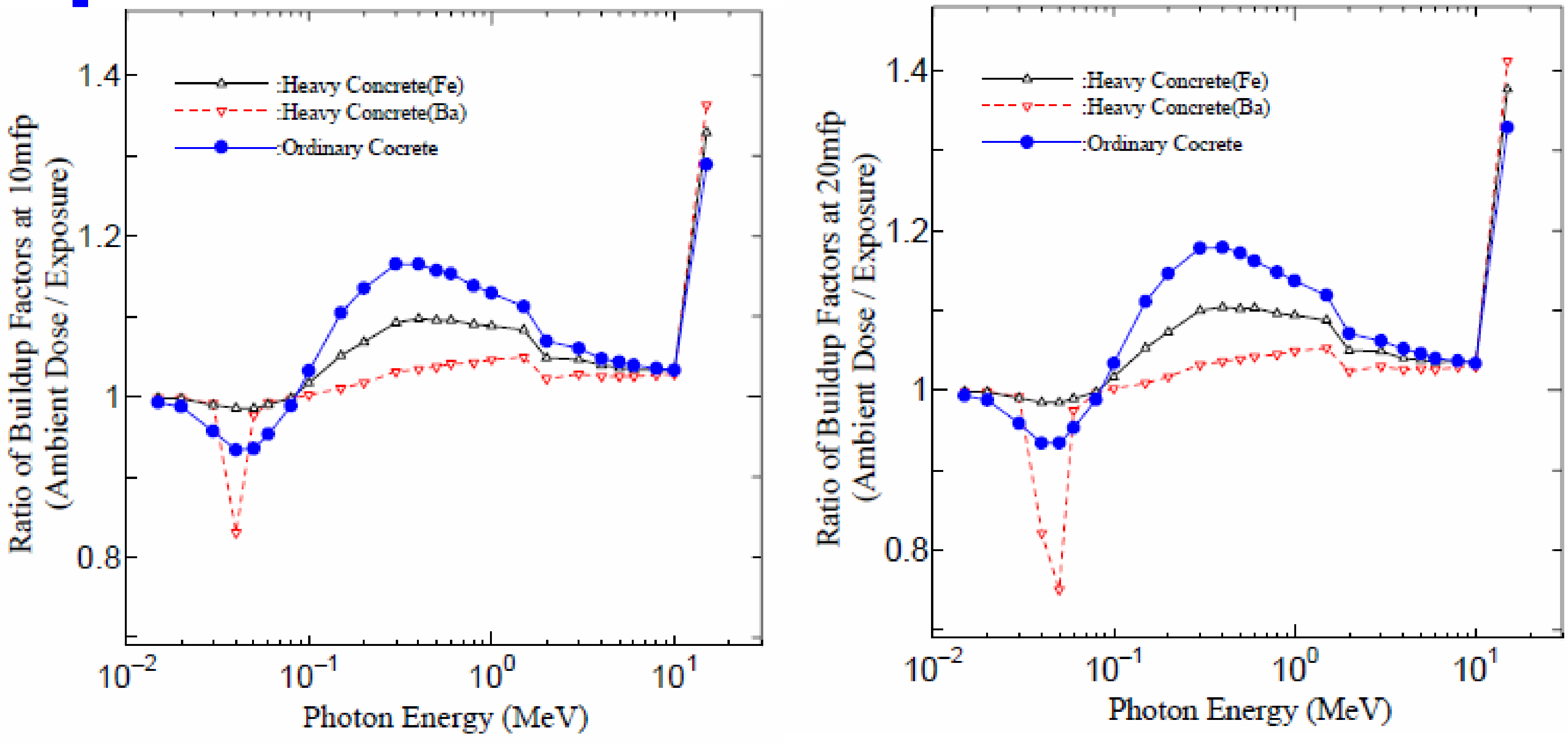
- **Exposure buildup factors of heavy concrete and Portland ordinary concrete for 5 & 10 mfp**

Exposure buildup factor



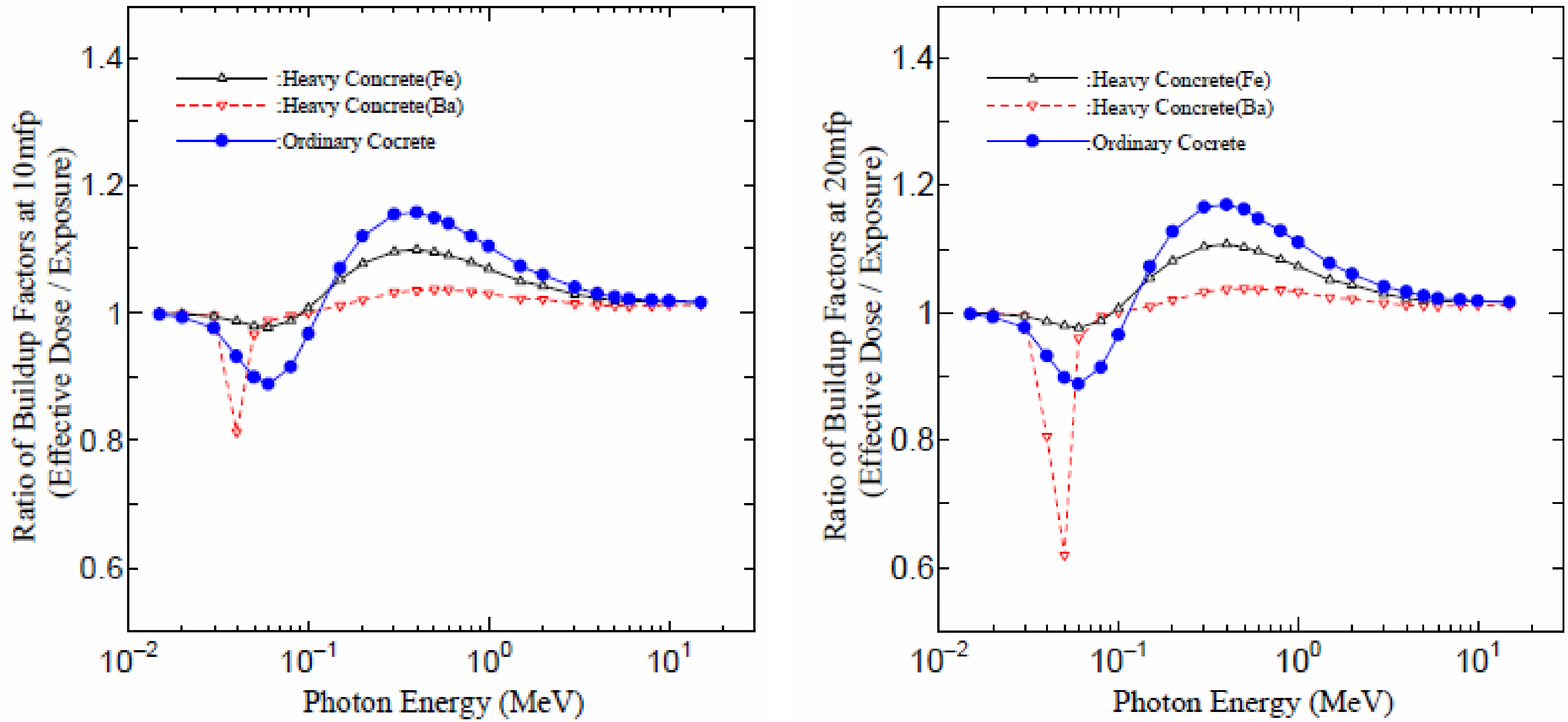
- **The specific features can be found at the energy of around 40 keV for the heavy concrete (Ba), and the buildup factors grow up more than 1010 at 40 mfp. The K-edge of photo-electric cross section of barium is 37.44 keV so that the specific features around 40 keV are recognized. On the other hand, the K edges of photo-electric cross section of iron and silicon are less than 10 keV so that the pointy-shaped features disappear in heavy concrete (Fe) and ordinary concrete.**

Buildup factor
(dependency of radiation quantity)



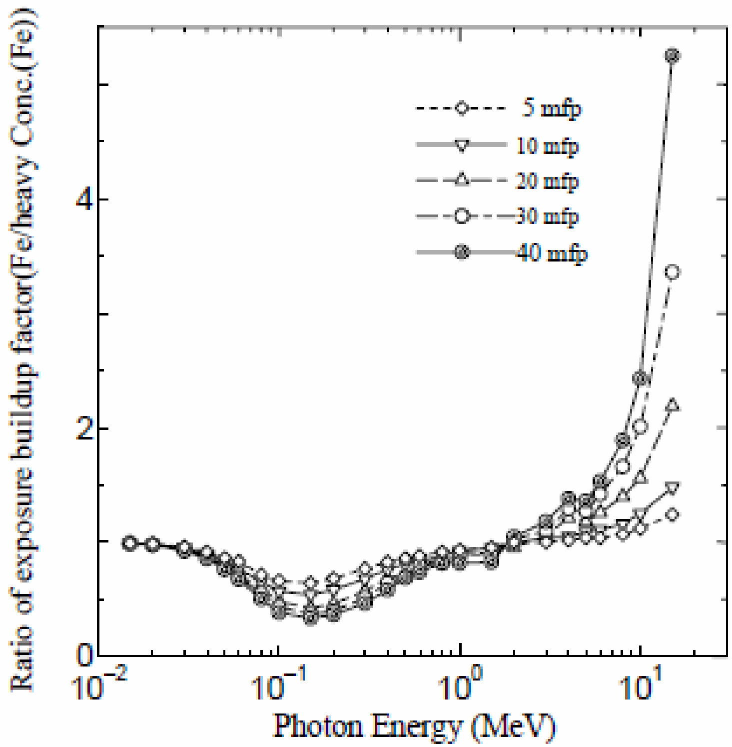
Figures show the ratios of the ambient dose equivalent to the exposure. In these calculation results except for 15 MeV photons, the ratios of the heavy concrete (Fe), the heavy concrete (Ba) and ordinary concrete are in ranging from about 1.0 to 1.1, 0.7 to 1.05, and 0.9 to 1.2, respectively. At 15 MeV, the ratios for each concrete are up to 1.4.

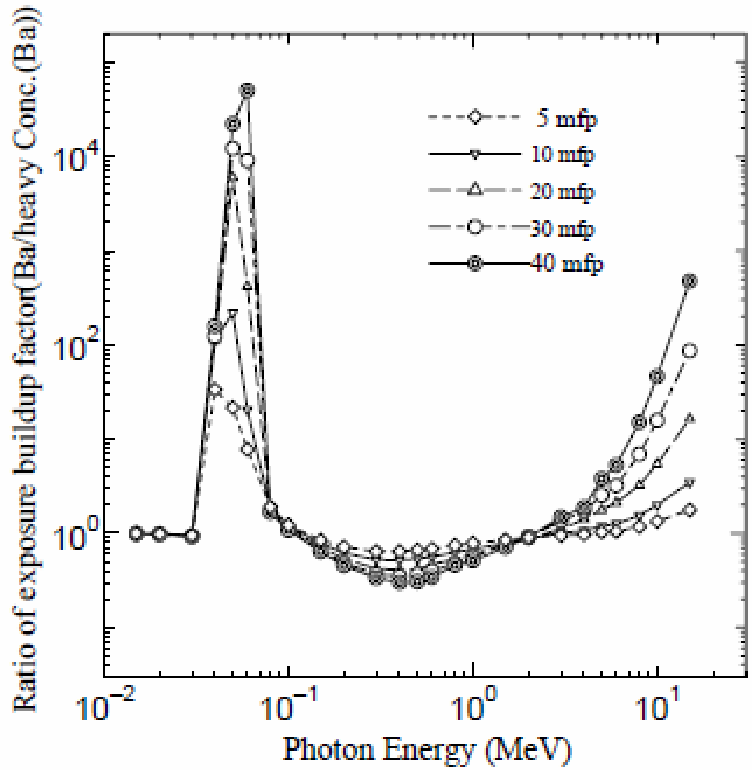
Buildup factor
(dependency of radiation quantity)



Figures show the ratios of the effective dose with AP geometry to that of the exposure. In the calculations, the ratios of the heavy concrete (Fe), the heavy concrete (Ba) and ordinary concrete are in ranging from about 1.0 to 1.1, 0.55 to 1.05, and 0.9 to 1.2, respectively. In both results of the ambient dose equivalent and the effective dose, the tendencies of the ratios to the exposure are not changed so much with the mean free path, except for the heavy concrete (Ba) with around 40 keV photon energy.

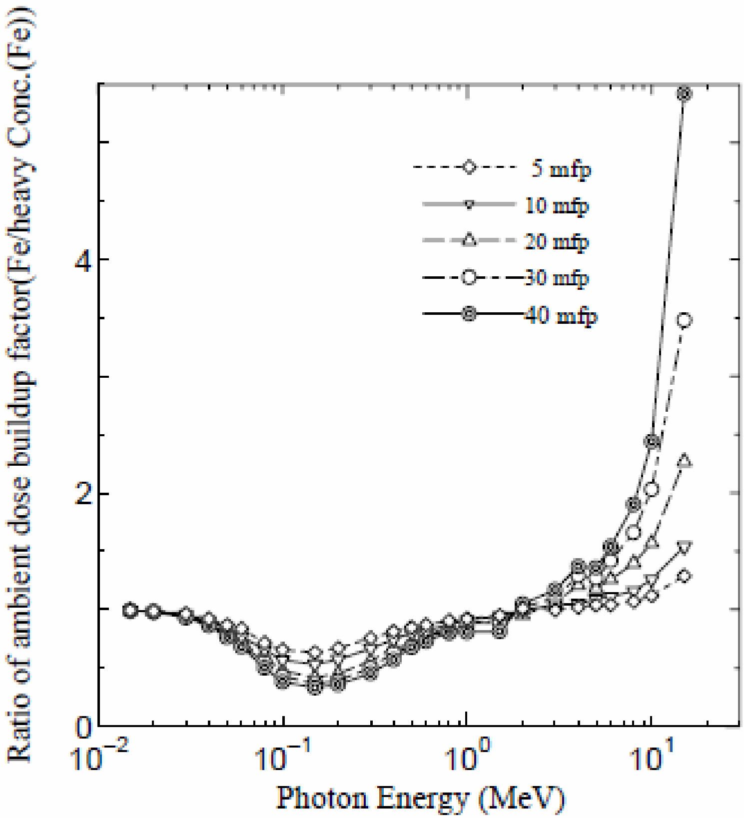
Exposure buildup factor (Mixed material dependence)

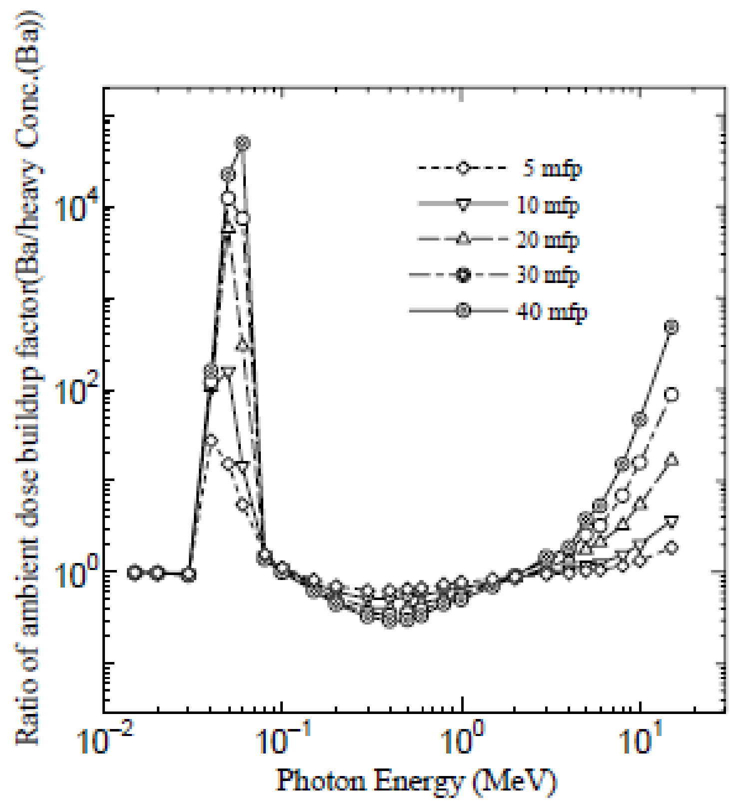




Figures are energy dependence of the ratio of exposure buildup factors between the Iron and Heavy Concrete (Fe) on the assumption of the fixed density, 3.7 g/cm3, and the Barium and Heavy Concrete (Ba) on the assumption of the fixed density, 3.35 g/cm3.

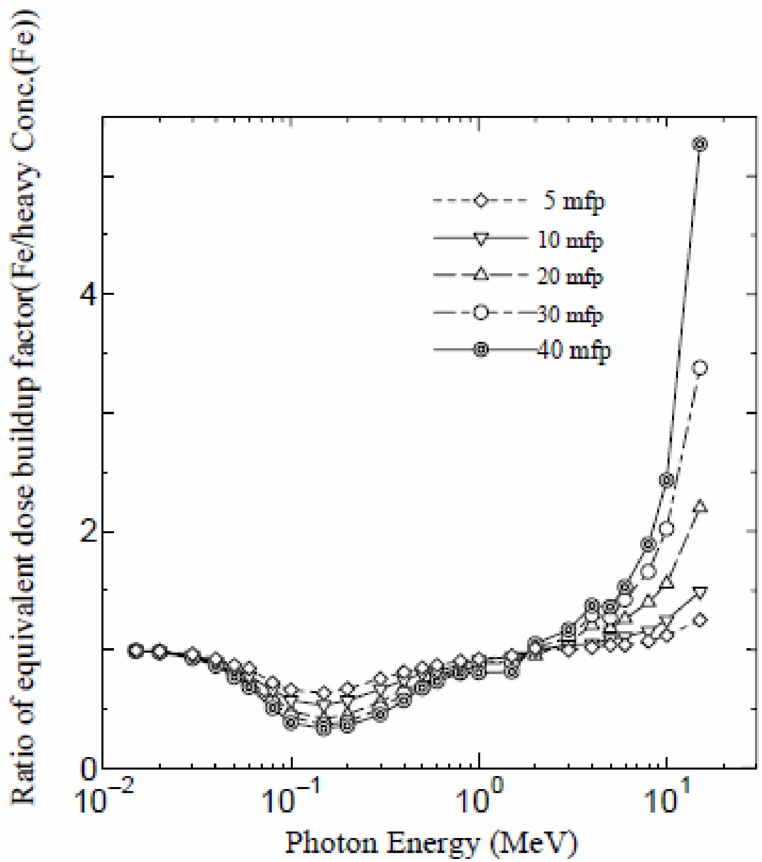
Ambient buildup factor (Mixed material dependence)

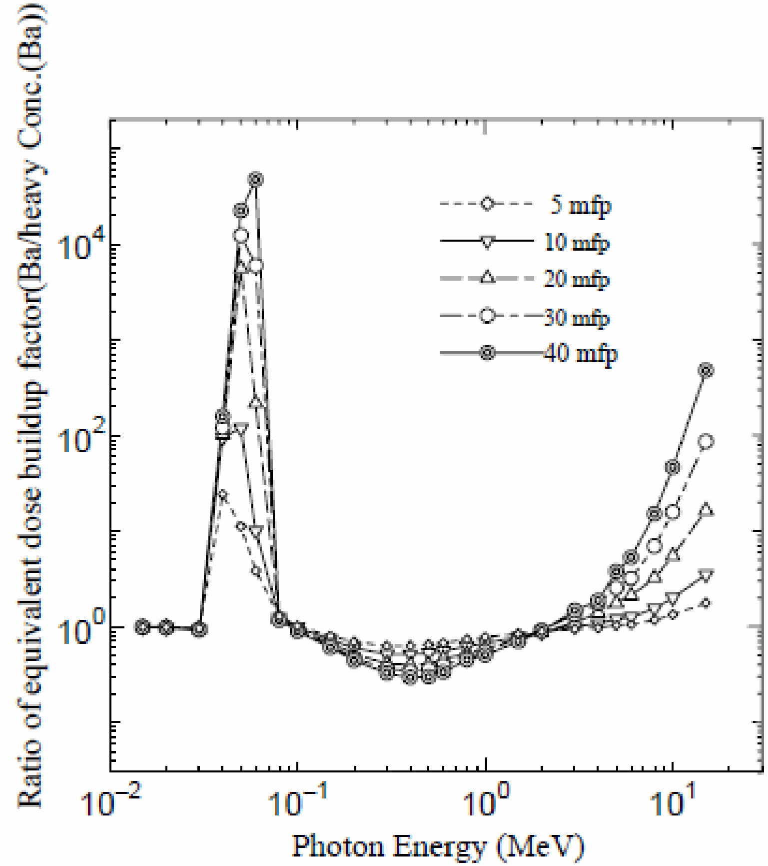




Figures are energy dependence of the ratio of ambient dose equivalent buildup factors between the Iron and Heavy Concrete (Fe) on the assumption of the fixed density, 3.7 g/cm3, and the Barium and Heavy Concrete (Ba) on the assumption of the fixed density, 3.35 g/cm3.

Effective dose buildup factor (Mixed material dependence)





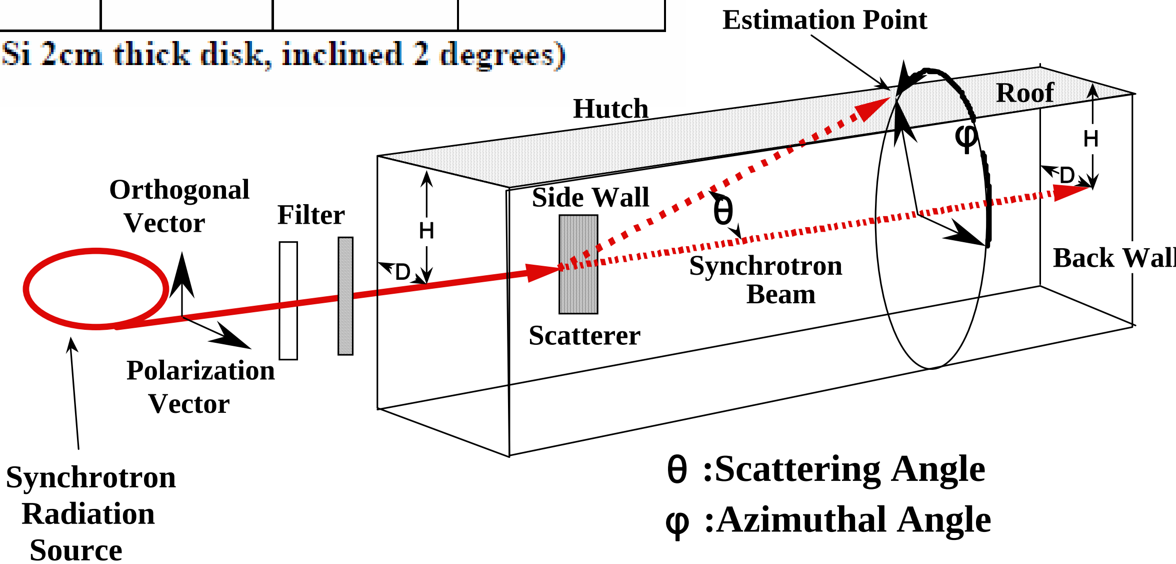
Figures are energy dependence of the ratio of equivalent dose buildup factors between the Iron and Heavy Concrete (Fe) on the assumption of the fixed density, 3.7 g/cm3, and the Barium and Heavy Concrete (Ba) on the assumption of the fixed density, 3.35 g/cm3.

Application of heavy concrete to shield material of synchrotron radiation beamlines

Key parameters for the typical light sources of SPring-8 and 3 GeV storage ring

Beamline	Light source	Period	Period length (cm)	Magnetic field (Tesla)	Critical energy (keV)	Distance (cm) tentative	Stored current (mA)
3 GeV class	Bending Magnet	(0.5)	785 (Bending radius)	1.2772	7.70	100	500
3GeV class	Wiggler	13	17.5	2.02	12.2	100	500
8 GeV class	Wiggler	37	12	1.0	42.66	100	100
8 GeV class	Undulator (In vacuum)	140	3.2	0.78	(33.27)	100	100

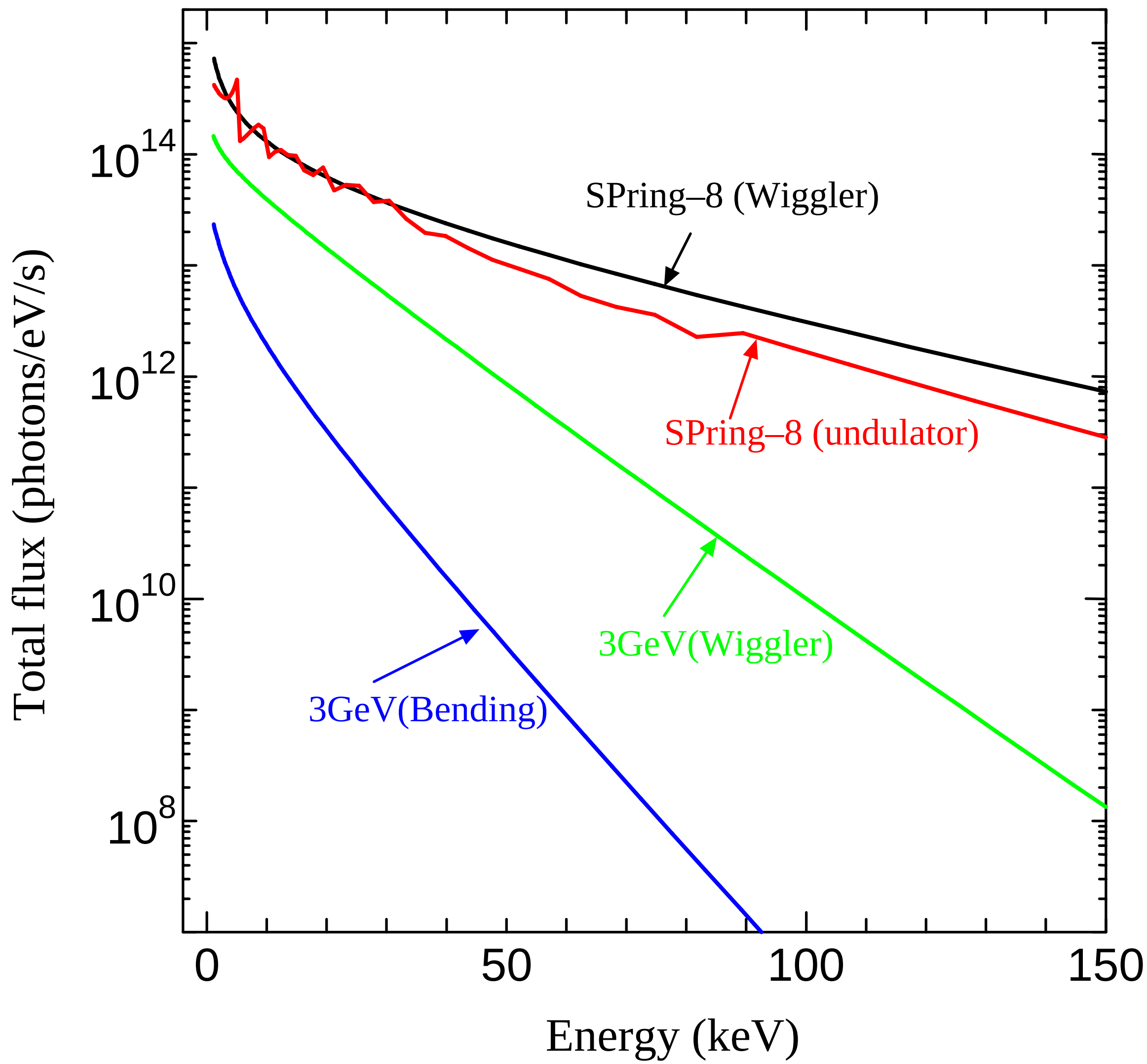
(Target of the scatterer-SPring-8: Cu 1cm disk; 3 GeV; Si 2cm thick disk, inclined 2 degrees)



θ :Scattering Angle

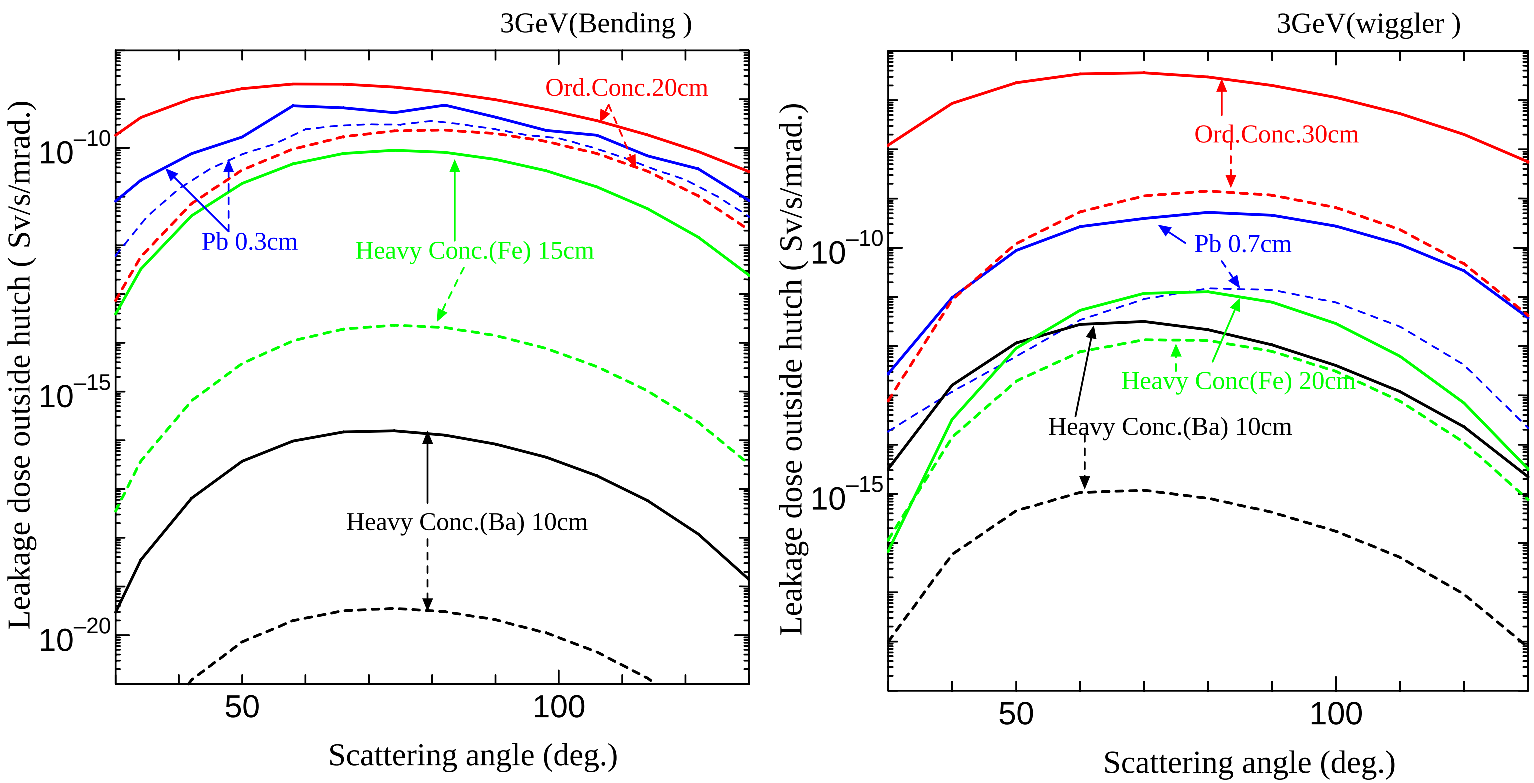
φ :Azimuthal Angle

Source spectrum of synchrotron radiation beamlines



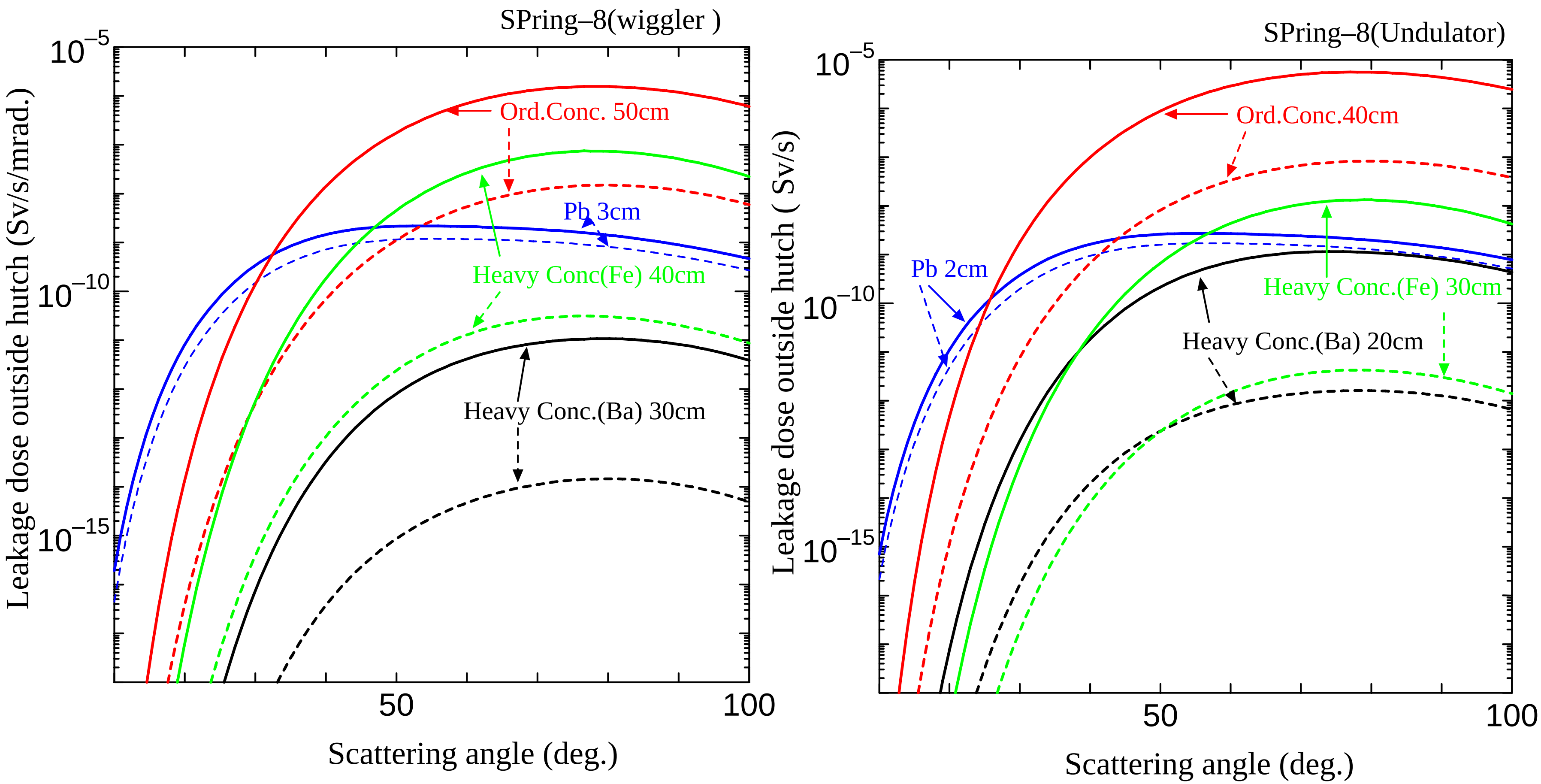
Synchrotron radiation spectra produced by typical 3 GeV and 8 GeV storage ring. The total fluxes of the wigglers and bending magnet are shown in the unit of the opening angle of 1mradian, and the angle integrated total flux is indicated for the undulator.

Application of heavy concrete to synchrotron radiation beamlines



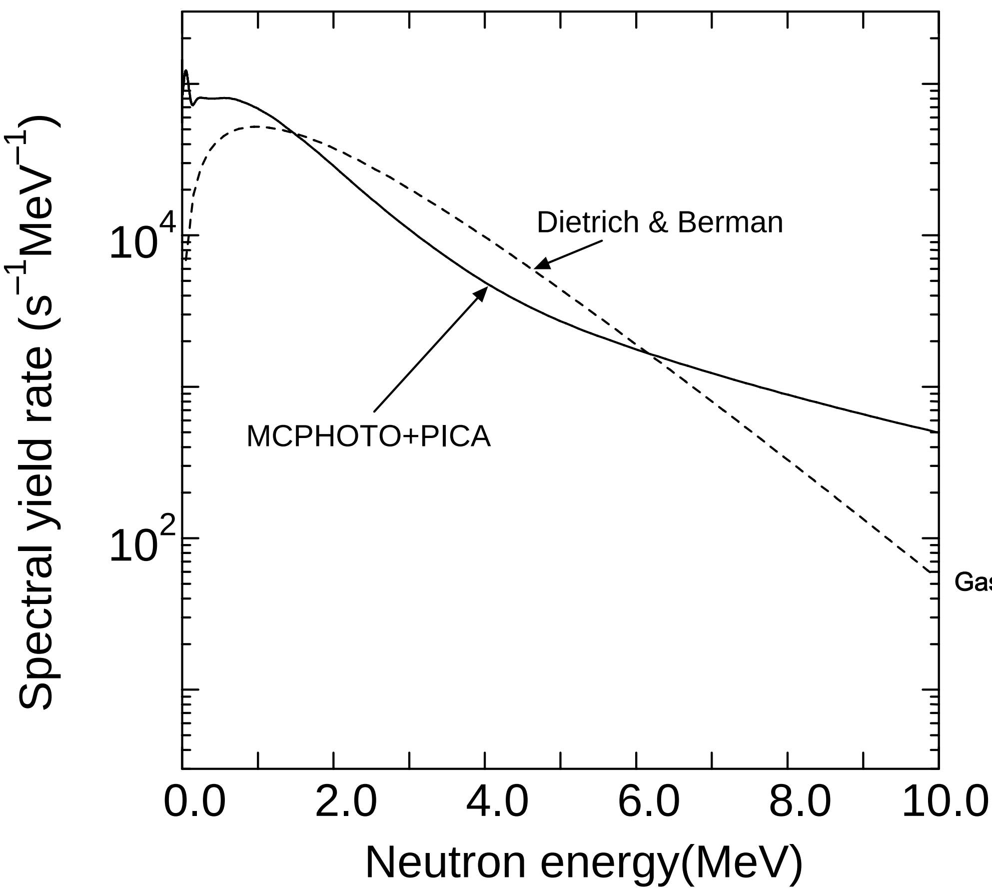
Leakage dose distributions depending on the scattering angle of the synchrotron radiation beam from the 3 GeV class beamline. Solid and dotted lines indicate the dose with and without considering the build-up effect. Black lines are the case of the heavy concrete (Ba) with 10cm in thickness, green lines are for the heavy concrete (Fe) with 15cm thick, red lines are for the ordinary concrete with 20cm thick, and blue lines are for lead shield wall with 0.3cm in thickness.

Application of heavy concrete to synchrotron radiation beamlines



Leakage dose distribution for the case of the SPring-8 undulator. Solid and dotted lines indicate the dose wit and without considering buildup effect. Black, green, red, and blue lines are for the heavy concrete (Ba), the heavy concrete (Fe), the ordinary concrete, and lead shield wall.

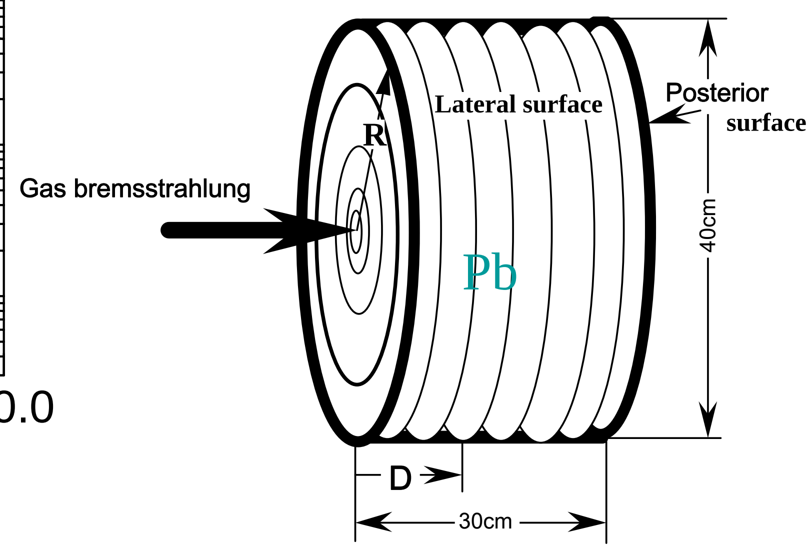
Photoneutron shielding



19m long straight section

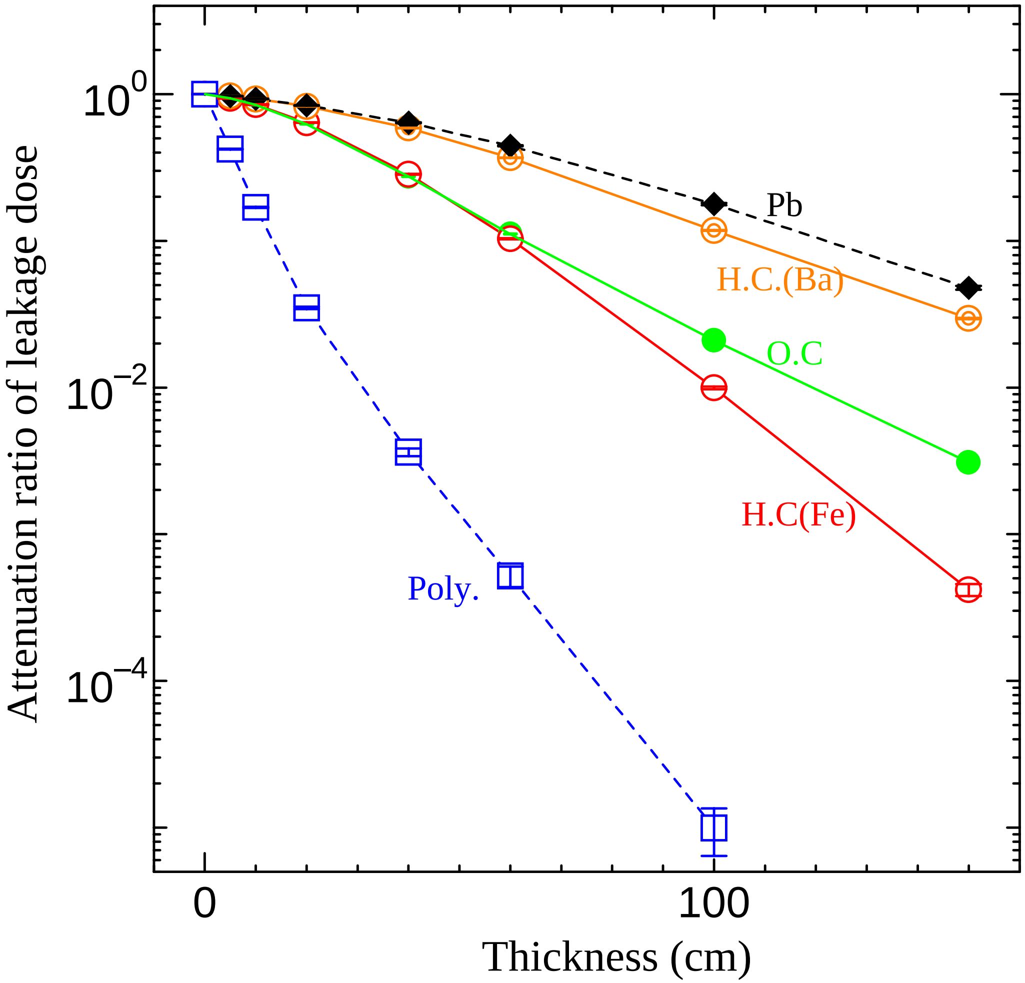
100mA stored current

133nPa residual gas pressure



R=30cm, D=30cm

Photoneutron shielding



MCNP5 with ENDF/b-VI

Spherical geometry

Neutron source (MCPHOTO+PICA)

Neutron leakage dose attenuation as a function of the thickness of the shield materials.

Summary

- The build up factors of two heavy concretes were evaluated by using the EGS4 code to improve the capability of the various materials for the shield wall of the synchrotron radiation beamline hutch.
- By using these data, leakage doses outside the hutch side wall of the synchrotron radiation Beamlines of the 3 GeV storage ring and the 8 GeV class ring were discussed. As the results, it was cleared that the build up effect has a strong influence on the leakage dose estimation outside the synchrotron radiation beamline hutch side walls of the heavy concretes as well as the ordinary concrete, and the effect infrequently comes up to two orders and more.
- For another radiation source, the Photoneutron due to gas bremsstrahlung at SPring-8 normal straight section, the leakage dose attenuation factors of the heavy concretes were improved in comparison with the ordinary concrete, lead, and polyethylene. As the results, the shield ability of the barium contained heavy concrete for the Photoneutron is almost the same as that of lead, and the iron contained heavy concrete is almost the same as that of the ordinary concrete.