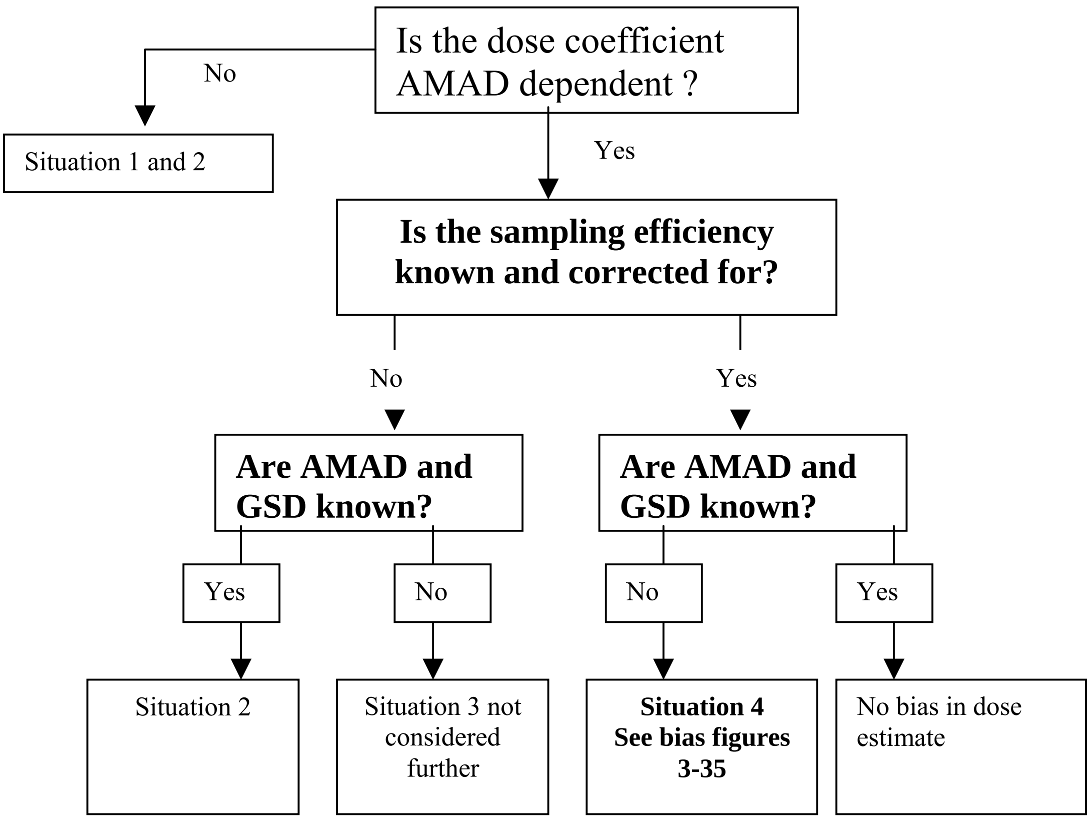
Annex 3, Appendix 3

Aerosol sampling and the bias produced between the true and estimated effective dose for the radionuclides of the ^{238}U and ^{232}Th natural decay chains

Aerosol sampling and bias in dose estimates

In Witschger 2002, four different aerosol sampling situations in the context of bias of dose estimation have been described [1]. These situations are described in the scheme below as far as they pertain to NORM nuclides for which the dose coefficients are AMAD dependent (situation 3 and 4). As is explained in Witschger 2002, the true Activity Median Aerodynamic Diameter (AMAD) and Geometric Standard Deviation (GSD) of an ambient aerosol are rarely well known. Therefore, default AMAD and GSD have to be assumed in the estimates of dose after correction for sampling efficiency to true ambient aerosol concentration. This introduces a bias in the dose estimate, relative to the true dose, the size of which will depend on the true AMAD and GSD values. The bias also depends on the absorption tType of the aerosol (Fast, Moderate or Slow) and on the aerosol sampling convention of the personal air sampler (PAS) on which the dose estimate is based. CEPN has extended the example calculations of relative bias in dose estimates in Witschger 2002 to all relevant NORM nuclides, for default AMADS of 1, 5, 10 and 20 µm; GSD 2.5 and 1.5; and inhalable, thoracic and respirable sampling conventions. This has been done for situation 3 and 4. From the results, those for situation 4 have been reproduced here in figures 1to– 35, assuming that sampling efficiency will always be corrected for. The figures have been limited to GSD 2.5 as this value is recommended by ICRP [2] for AMAD values ≥ 1µm.



To illustrate the results, the situation with respect to several commonly encountered NORM radionuclides and chains is summarised below.

Pb-210, absorption Type Slow

A Pb-210 particle of absorption Type S is sampled as an aerosol with a PAS according to the **inhalable** convention. The true AMAD and GSD of the ambient aerosol are not known. Default AMAD of 5 µm and GSD 2.5 are assumed. The sampling correction factor to true ambient aerosol concentration is 1.2 (main text WP4, Table 5). Figure 33 shows that if the true AMAD of the ambient aerosol is between 1µm and 5 µm the negative bias introduced by sampling in the dose estimate is less than 20%. If the true AMAD is 20 µm the positive bias (overestimate) is about 100%. **Thoracic sampling would have introduced virtually no bias (less than ±11%), independent of the true AMAD** of the ambient aerosol. Respirable sampling would have required a correction factor to true ambient aerosol of 2.5 (main text WP4, Table 5) and would have underestimated the dose by 64% at a true AMAD of 20 µm and overestimated the dose by 83% at a true AMAD of 1 µm.

Pb-210, absorption Type Moderate

A Pb-210 containing particle of absorption Type M is sampled as an aerosol with a PAS according to the **inhalable** convention. The true AMAD and GSD of the ambient aerosol are not known. Default AMAD of 5 µm and GSD 2.5 are assumed. The sampling correction factor to true ambient aerosol concentration is 1.2 (main text WP4, Table 5). Figure 34 shows that if the true AMAD of the ambient aerosol is between 1 and 5 µm , the negative bias in the dose estimate is less than 18%. If the true AMAD is 20 µm the positive bias (overestimate) is about 100%. **Thoracic sampling would have introduced virtually no bias (less than ±11%), independent of the true AMAD** of the ambient aerosol. Respirable sampling would have required a correction factor to true ambient aerosol of 2.5 (main text WP4, Table 5) and would have underestimated the dose by about 60% at a true AMAD of 20 µm and overestimated the dose by about 60% at a true AMAD of 1 µm.

Pb-210, absorption Type Fast

A Pb-210 containing particle of absorption Type F is sampled as an aerosol with a PAS according to the **inhalable** convention. The true AMAD and GSD of the ambient aerosol are not known. Default AMAD of 5 µm and GSD 2.5 are assumed. The sampling correction factor to true ambient aerosol concentration is 1.2 (main text WP4, Table 5). Figure 35 shows that if the true AMAD of the ambient aerosol is 1µm , the positive bias in the dose estimate is about 40%. **Inhalable sampling introduces virtually no bias (positive bias less than 18%), independent of the true AMAD of the ambient aerosol above 2 µm**. Respirable sampling would have required a correction factor to true ambient aerosol of 2.5 (main text WP4, Table 5) and would have underestimated the dose by about 80% at a true AMAD of 20 µm and overestimated the dose by about 175% at a true AMAD of 1 µm.

U-238sec, absorption Type Slow

A particle of absorption Type S containing U-238sec is sampled as an aerosol with a PAS according to the **thoracic** convention. The true AMAD and GSD of the ambient aerosol are not known. Default AMAD of 5 µm and GSD 2.5 are assumed. The sampling correction factor to true ambient aerosol concentration is 1.4 (main text WP4, Table 5). Figure 3 shows that **thoracic sampling introduces virtually no bias (less than ±11%), independent of the true AMAD of the ambient aerosol**. Respirable sampling would have required a correction factor to true ambient aerosol of 2.5 (main text WP4, Table 5) and would have underestimated the dose by 60% at a true AMAD of 20 µm and overestimated the dose by 60% at a true AMAD of about 1 µm. Inhalable sampling would have required a sampling correction factor of 1.2 (main text of WP4, Table 5) and would have overestimated the dose by 125% at a true AMAD of 20 µm and underestimated the dose only slightly (by 18%) at a true AMAD of 1 µm.

Th-232sec, absorption Type Slow

A particle of absorption Type S containing Th-232sec is sampled as an aerosol with a PAS according to the **thoracic** convention. The true AMAD and GSD of the ambient aerosol are not known. Default AMAD of 5 µm and GSD 2.5 are assumed. The sampling correction factor to true ambient aerosol concentration is 1.4 (main text WP4, Table 5). Figure 12 shows that **thoracic sampling introduces virtually no bias (less than ±11%), independent of the true AMAD of the ambient aerosol**. Respirable sampling would have required a correction factor to true ambient aerosol of 2.5 (main text WP4, Table 5) and would have underestimated the dose by 60% at a true AMAD of 20 µm and overestimated the dose by 60% at a true AMAD of about 1 µm. Inhalable sampling would have required a sampling correction factor of 1.2 (main text of WP4, Table 5) and would have overestimated the dose by 125% at a true AMAD of 20 µm and underestimated the dose only slightly (by 18%) at a true AMAD of 1 µm.

Recommended sampling fractions and default AMAD value

From these calculations it appears that:

- a thoracic sampler should be chosen to minimise the bias in effective dose assessment, whatever the true values of AMAD and GSD are, for naturally radioactive particles of slow and moderate absorption rate (type S and M);
- an inhalable sampler should be chosen to minimise the bias in effective dose assessment, whatever the true values of AMAD and GSD are, for naturally radioactive particles of fast absorption rate (Type F);
- a default AMAD value of 5µm (as recommended by ICRP [IC94], for workers) appears to reasonably minimise the bias in effective dose assessment, whatever the true values of AMAD and GSD, as illustrated in Figure 1 and summarised below for a default GSD value of 2.5.

Absorption Type Slow

The choice of a thoracic sampler as well as a 5 µm AMAD default value, together with the application of the appropriate sampling efficiency correction factors will ensure that, for an airborne aerosol with a 2.5 GSD, the derived effective dose of any naturally radioactive aerosol will be no more than 24% above, and no more than 29% below, the true effective dose, whatever the true AMAD of the airborne aerosol. If an inhalable (respirable) sampler was chosen, the bias would be significantly higher and the derived effective dose could be up to 178% (resp. 83%) above and 40% (resp. 64%) below the true effective dose, whatever the true AMAD of the airborne aerosol.

Absorption Type Moderate

The choice of a thoracic sampler as well as a 5 µm AMAD default value, together with the application of the appropriate sampling efficiency correction factors will ensure that, for an airborne aerosol with a 2.5 GSD, the derived effective dose of any naturally radioactive aerosol will be no more than 44% above, and no more than 13% below, the true effective dose, whatever the true AMAD of the airborne aerosol. If an inhalable (resp. respirable) sampler was chosen, the bias would be significantly higher and the derived effective dose would be up to 228% (resp. 65%) above and 27% (resp. 62%) below the true effective dose, whatever the true AMAD of the airborne aerosol.

Absorption Type Fast

The choice of an inhalable sampler as well as a 5 µm AMAD default value, together with the application of the appropriate collection efficiency correction factors will ensure that, for an airborne aerosol with a 2.5 GSD, the derived effective dose of any naturally radioactive aerosol will be no more than 39% above, and no more than 1% below, the true effective dose, whatever the AMAD of the airborne aerosol. If a thoracic (resp. respirable) sampler was chosen, the bias would be significantly higher and the derived effective dose would be up to

66% (resp. 173%) above and 48% (resp. 79%) below the true effective dose, whatever the AMAD of the airborne aerosol.

Small GSD aerosol

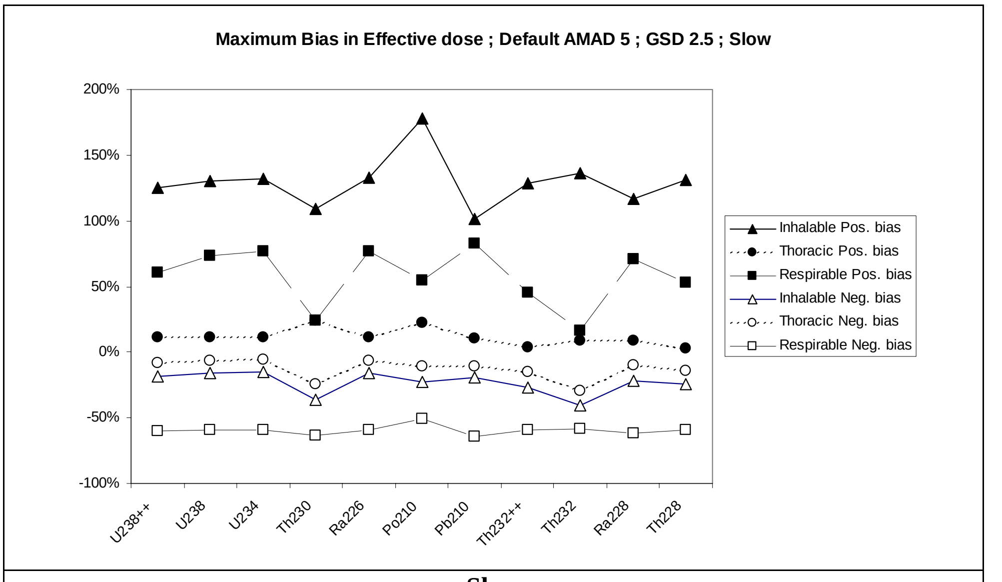
For an aerosol with a GSD value of 1.5, as can be seen in Figure 2, the same sampling fractions and default AMAD value are recommended. However, one can see clearly from this figure that while the recommended sampling fraction (as a function of the aerosol's absorption Type) and default AMAD value of 5µm still appear to reasonably minimise the bias in effective dose assessment whatever the true values of AMAD, the choice of a non-recommended sampling convention leads to much higher bias in effective dose assessment than in the case of an aerosol with a GSD value of 2.5. The choice of the "right" sampling fraction is thus all the more critical when the aerosol GSD is small.

References

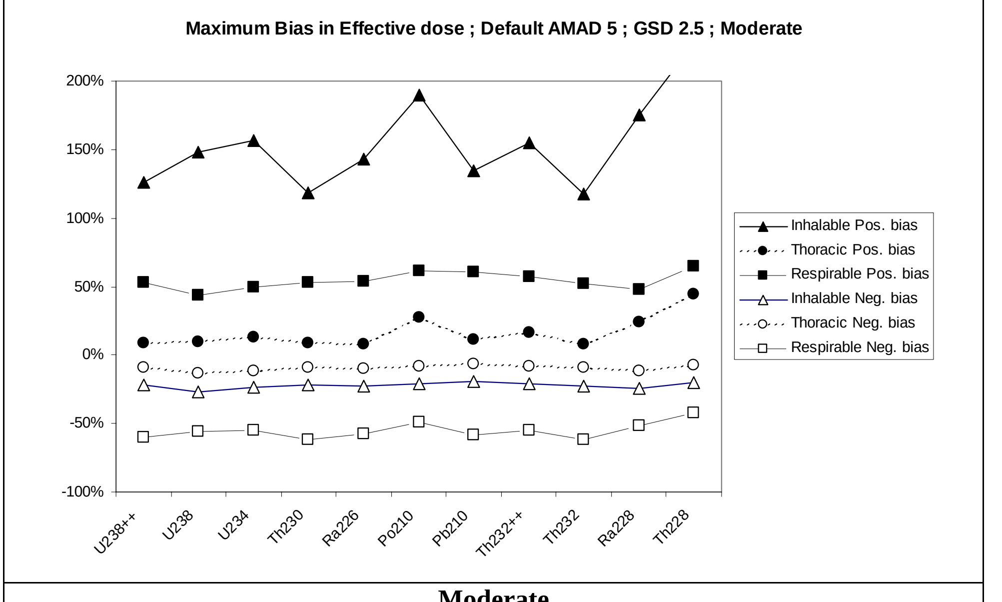
[1] I O. Witschger, Sampling for particulate airborne contaminants; Review and analysis of techniques. Report DPEA/SERAC/LPMA/02-18, IRSN/Département de Prevention et d'Ètude des Accidents – SERAC, September 2002 (See Appendix 1 in Annex 3 to the SMOPIE Rport)

[2] International Commission on Radiological Protection: Human respiratory tract model for radiological protection, ICRP publication 66, Annals of the ICRP Volume 24 Nos 1-3, Pergamon Press, Oxford. 1994

List of Figures



Slow



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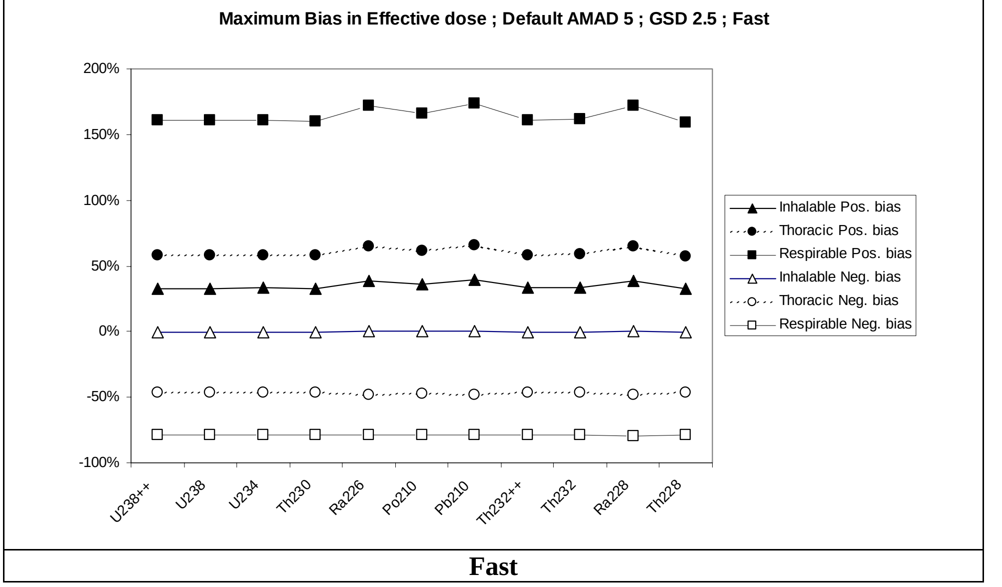
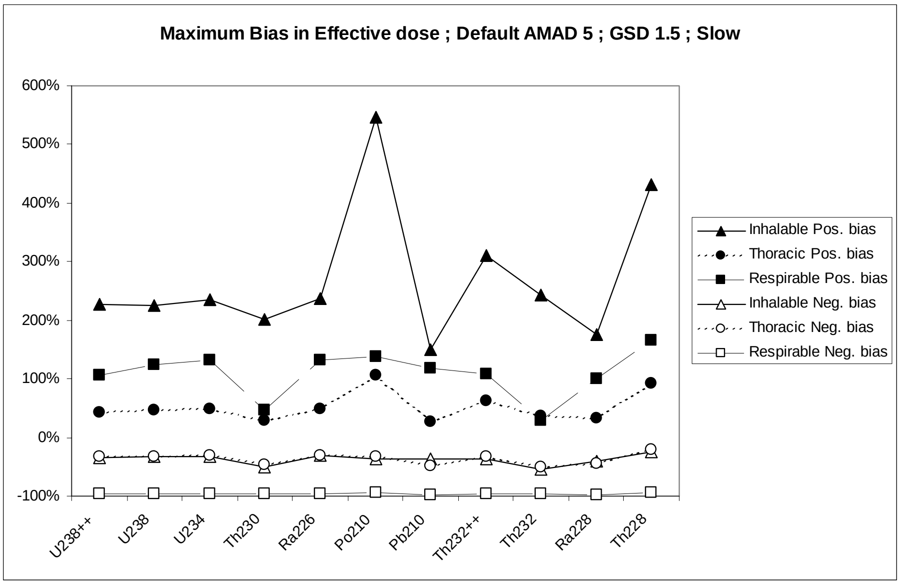
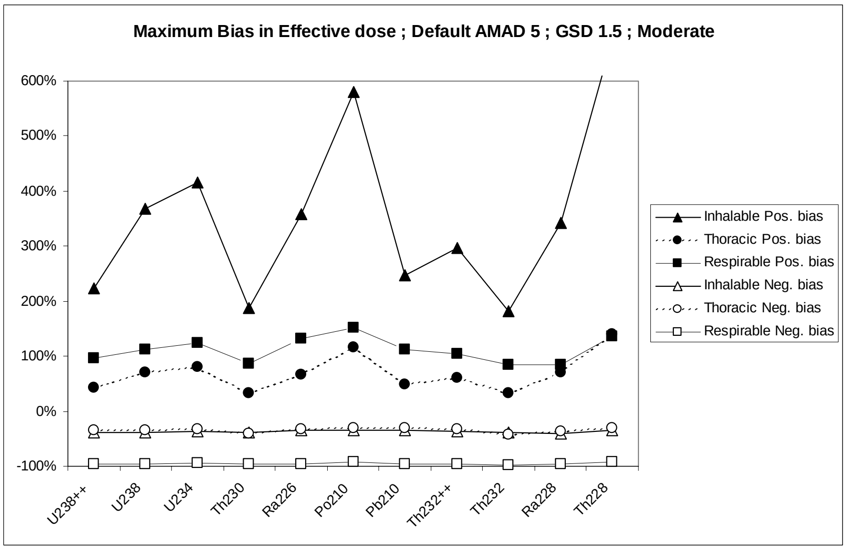


Fast

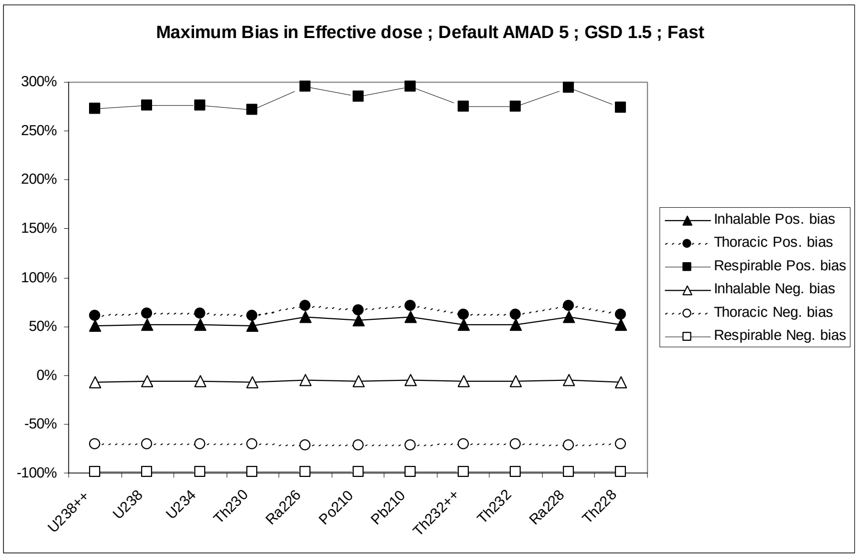
Figure 1: Maximum positive and negative bias (for a true AMAD between 1 and 20 µm) between the estimated and true effective dose, for a default AMAD value of 5 µm and GSD 2.5 (Situation 4)



Slow



Moderate



Fast

Figure 2: Maximum positive and negative bias (for a true AMAD between 1 and 20 µm) between the estimated and true effective dose, for a default AMAD value of 5 µm and GSD 1.5 (Situation 4)

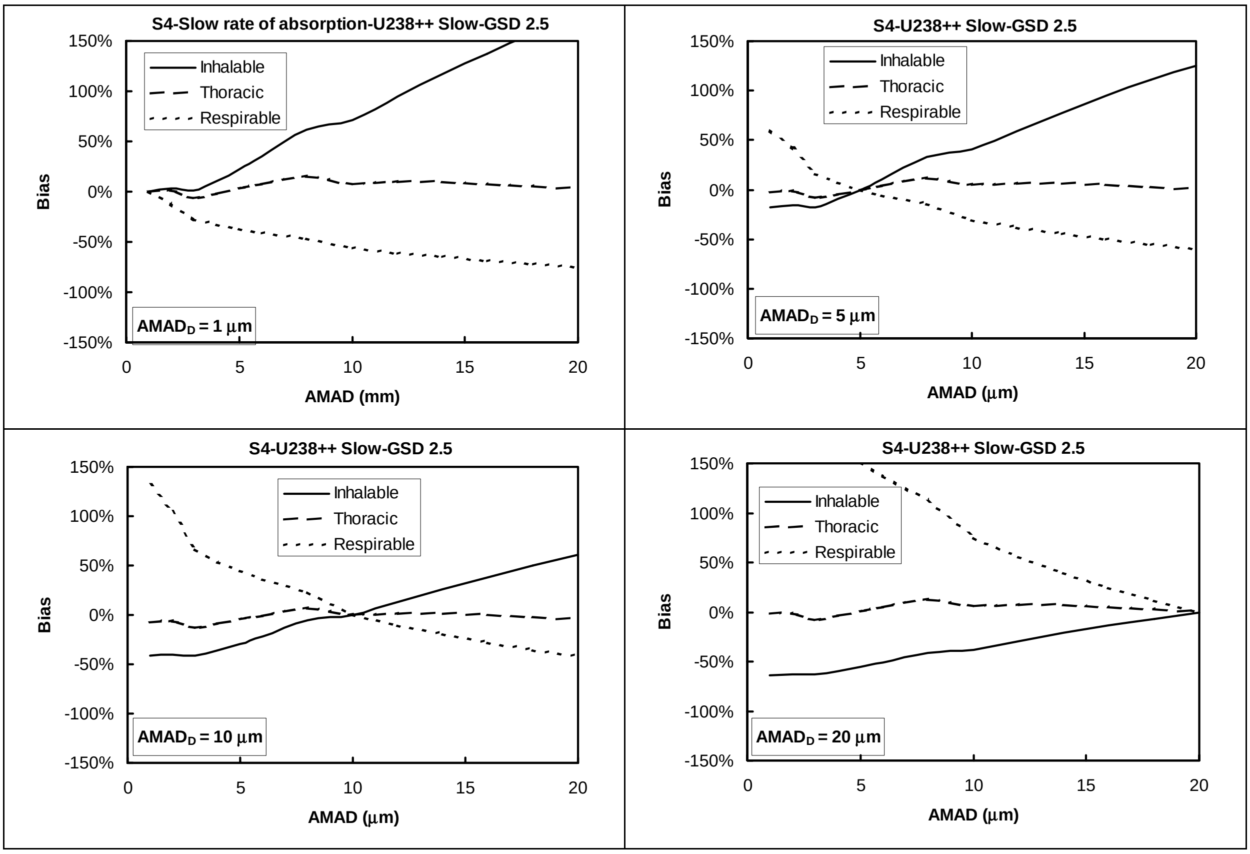


Figure 3: U-238 sec Slow ; Bias between the estimated and true effective dose (Situation 4)

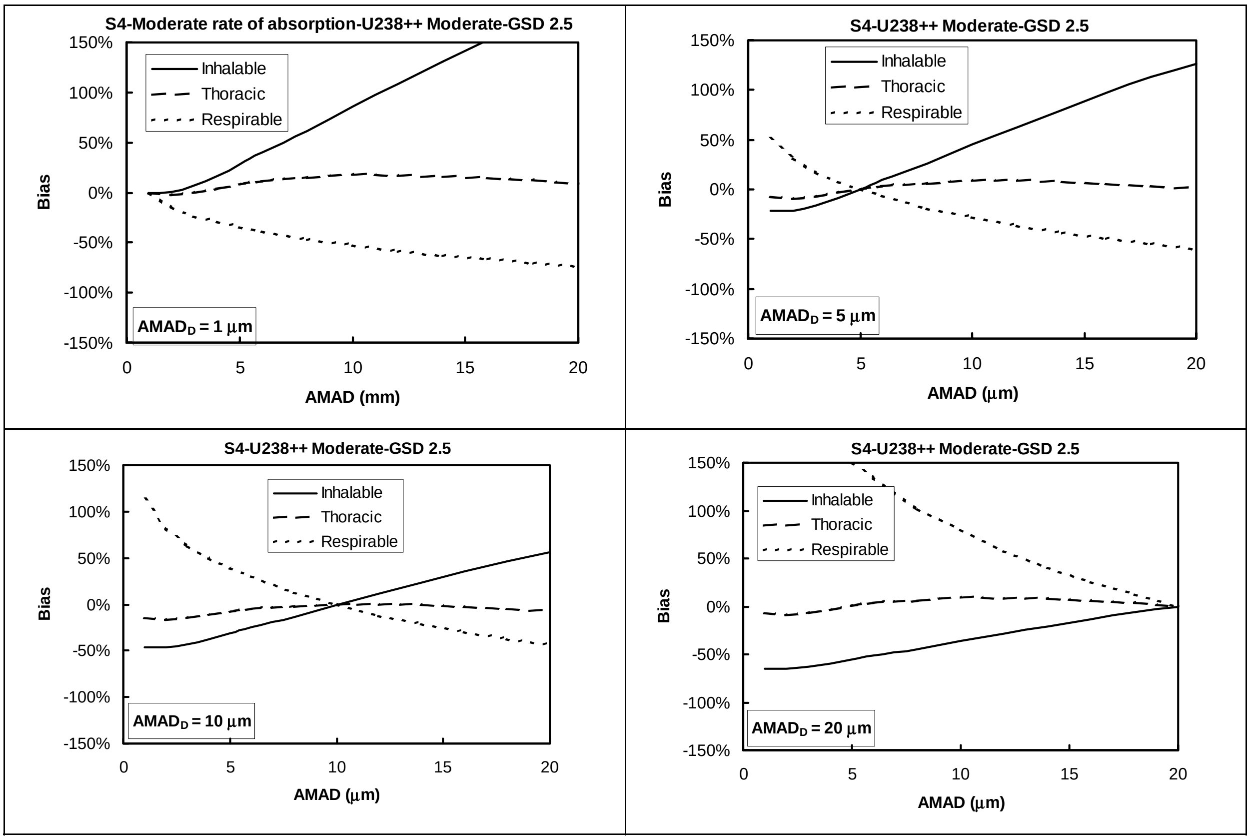


Figure 4: U-238 sec Moderate ; Bias between the estimated and true effective dose (Situation 4)

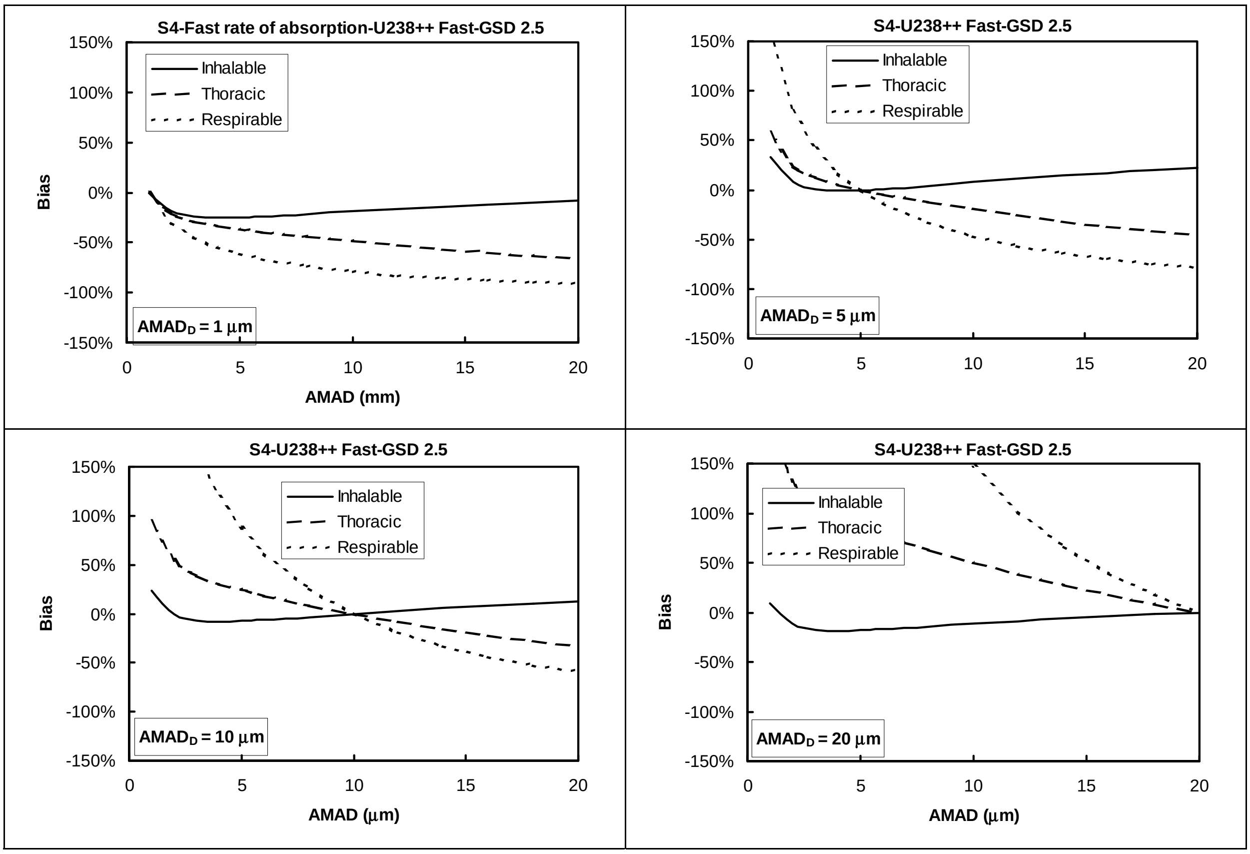


Figure 5: U-238 sec Fast ; Bias between the estimated and true effective dose (Situation 4)

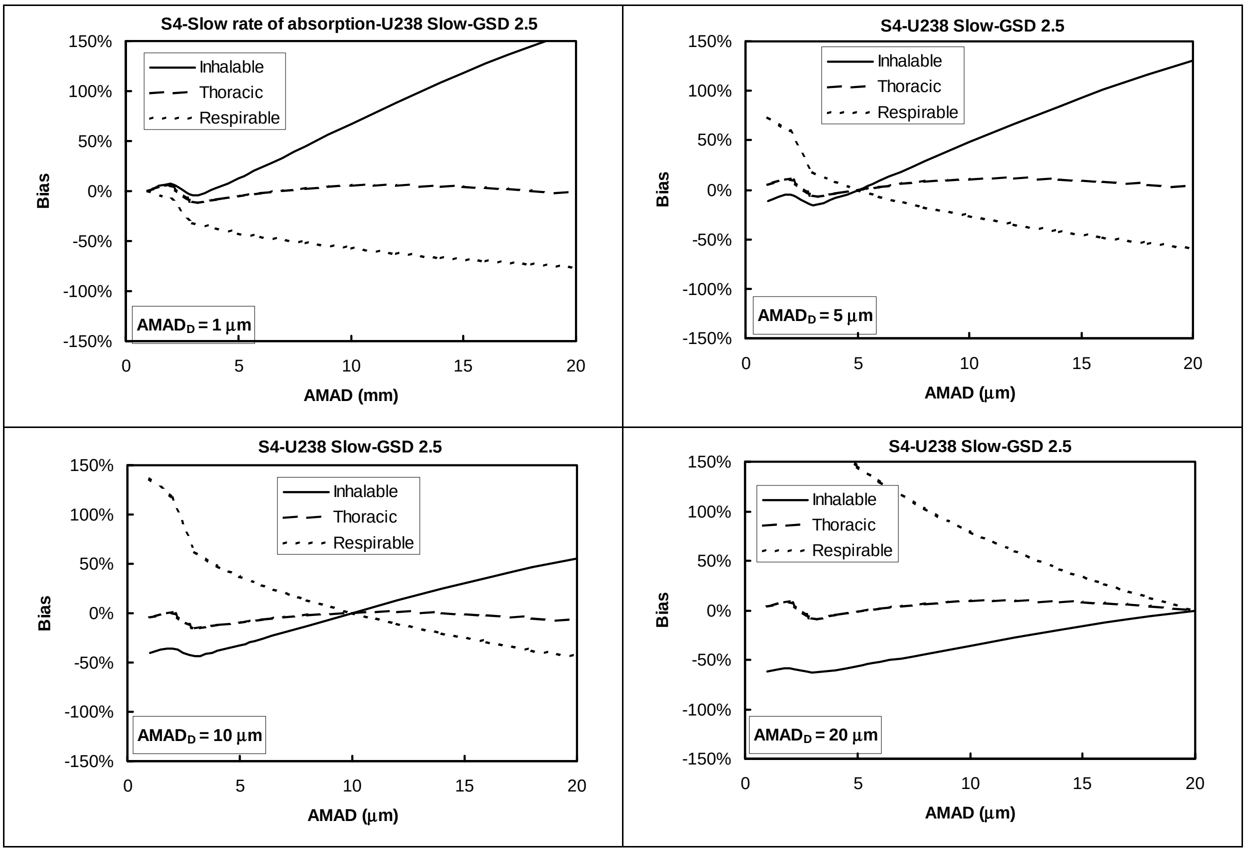


Figure 6: U-238 Slow ; Bias between the estimated and true effective dose (Situation 4)

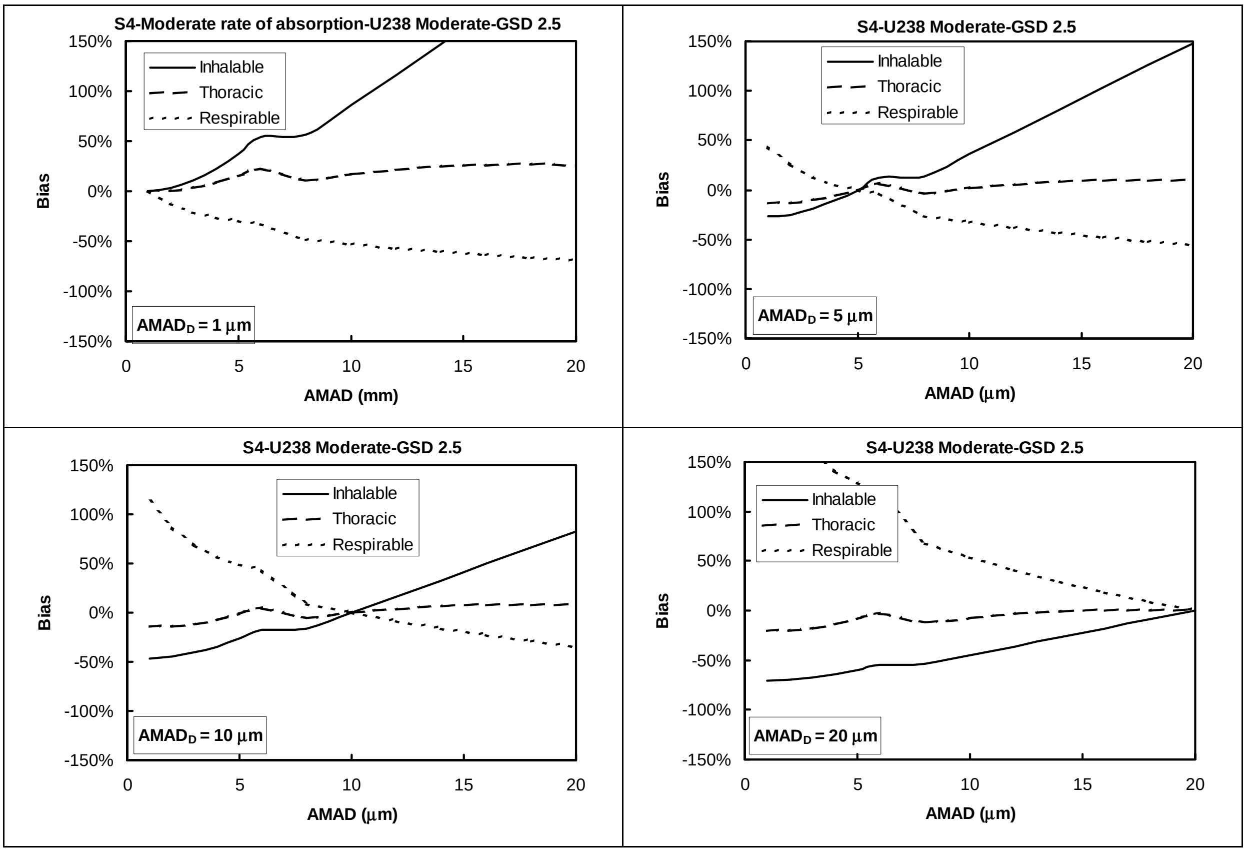


Figure 7: U-238 Moderate ; Bias between the estimated and true effective dose (Situation 4)

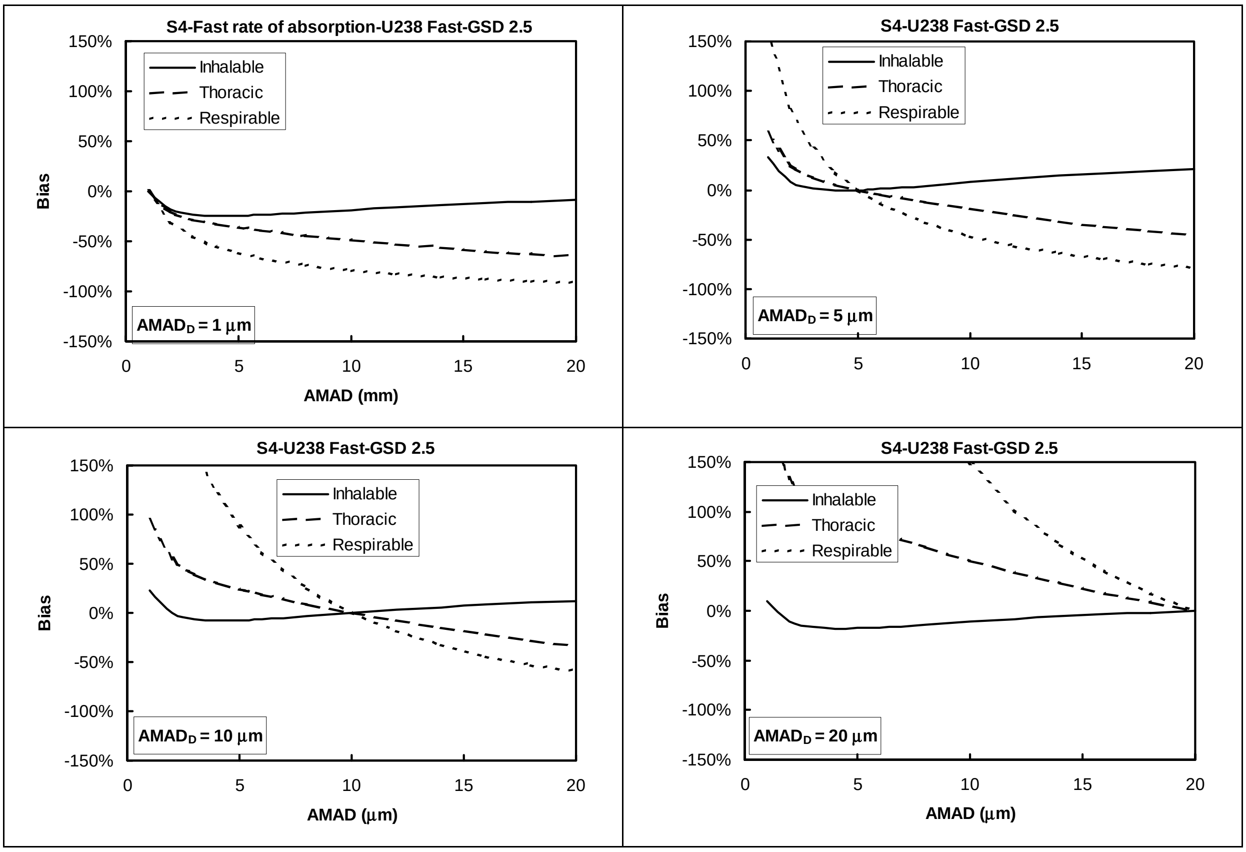


Figure 8: U-238 Fast ; Bias between the estimated and true effective dose (Situation 4)

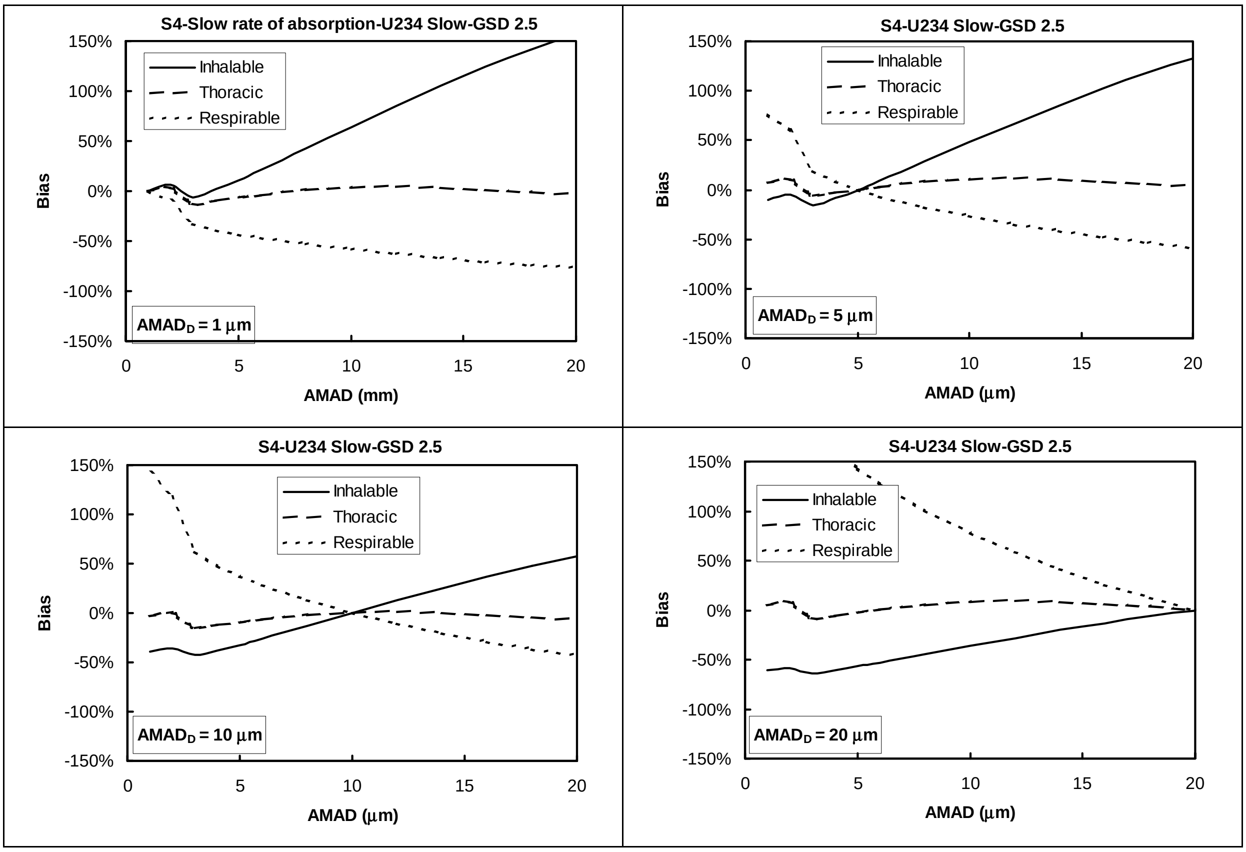


Figure 9: U-234 Slow ; Bias between the estimated and true effective dose (Situation 4)

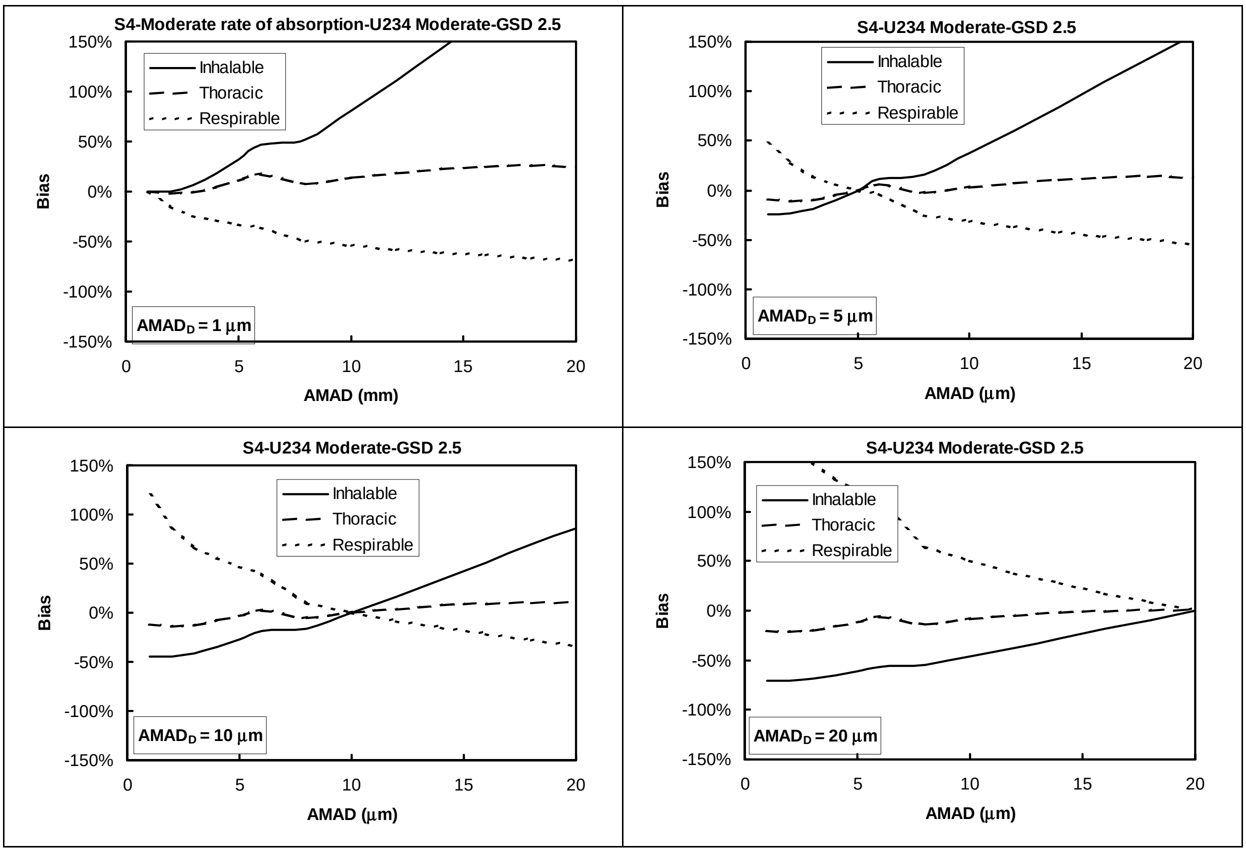


Figure 10: U-234 Moderate ; Bias between the estimated and true effective dose (Situation 4)

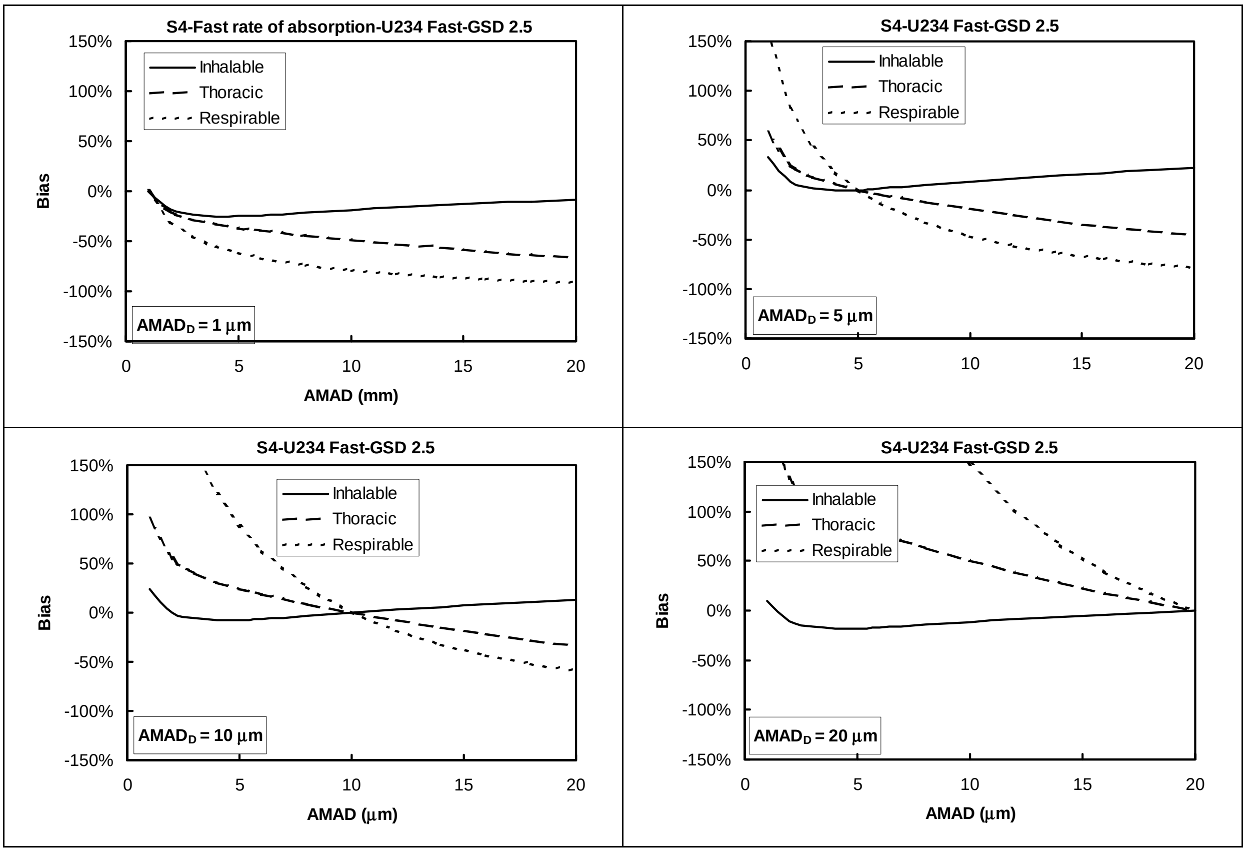


Figure 11: U-234 Fast ; Bias between the estimated and true effective dose (Situation 4)

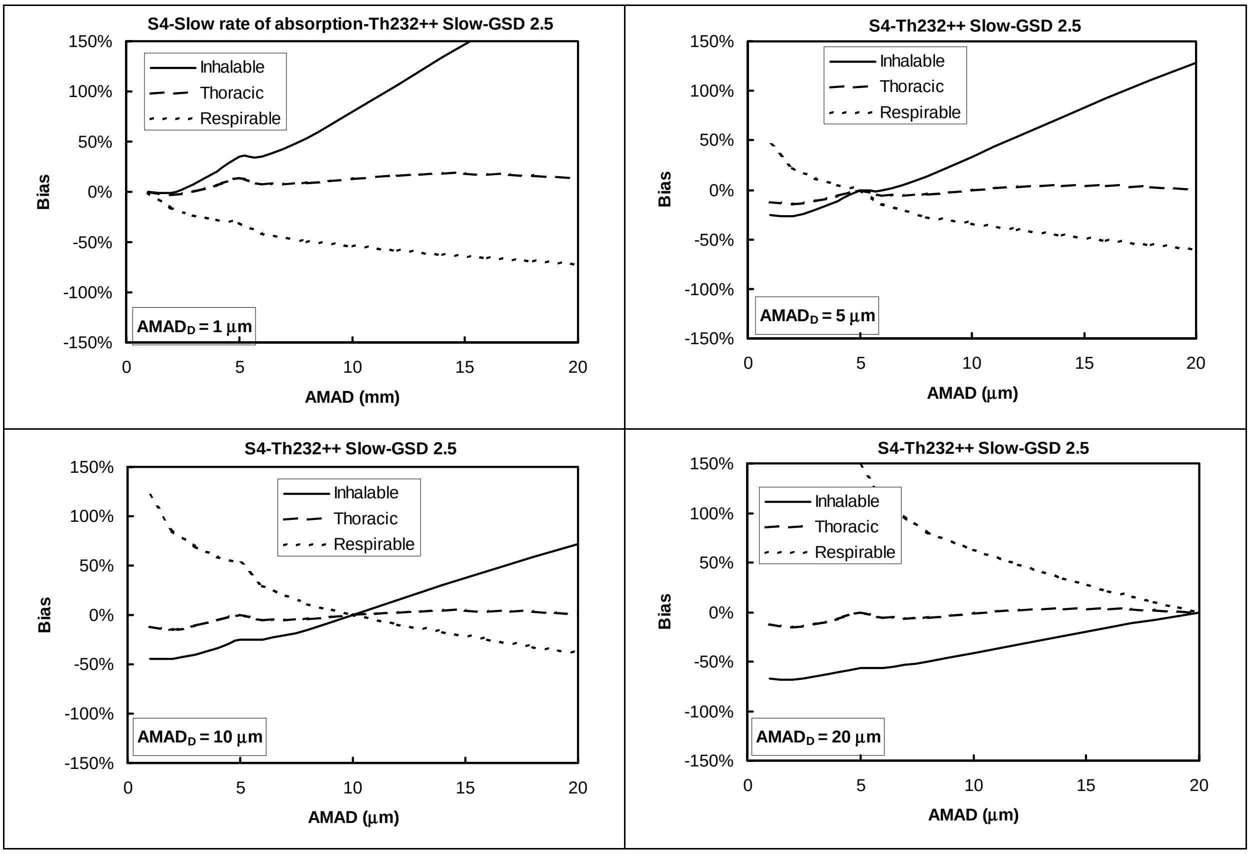


Figure 12: Th-232 sec Slow ; Bias between the estimated and true effective dose (Situation 4)

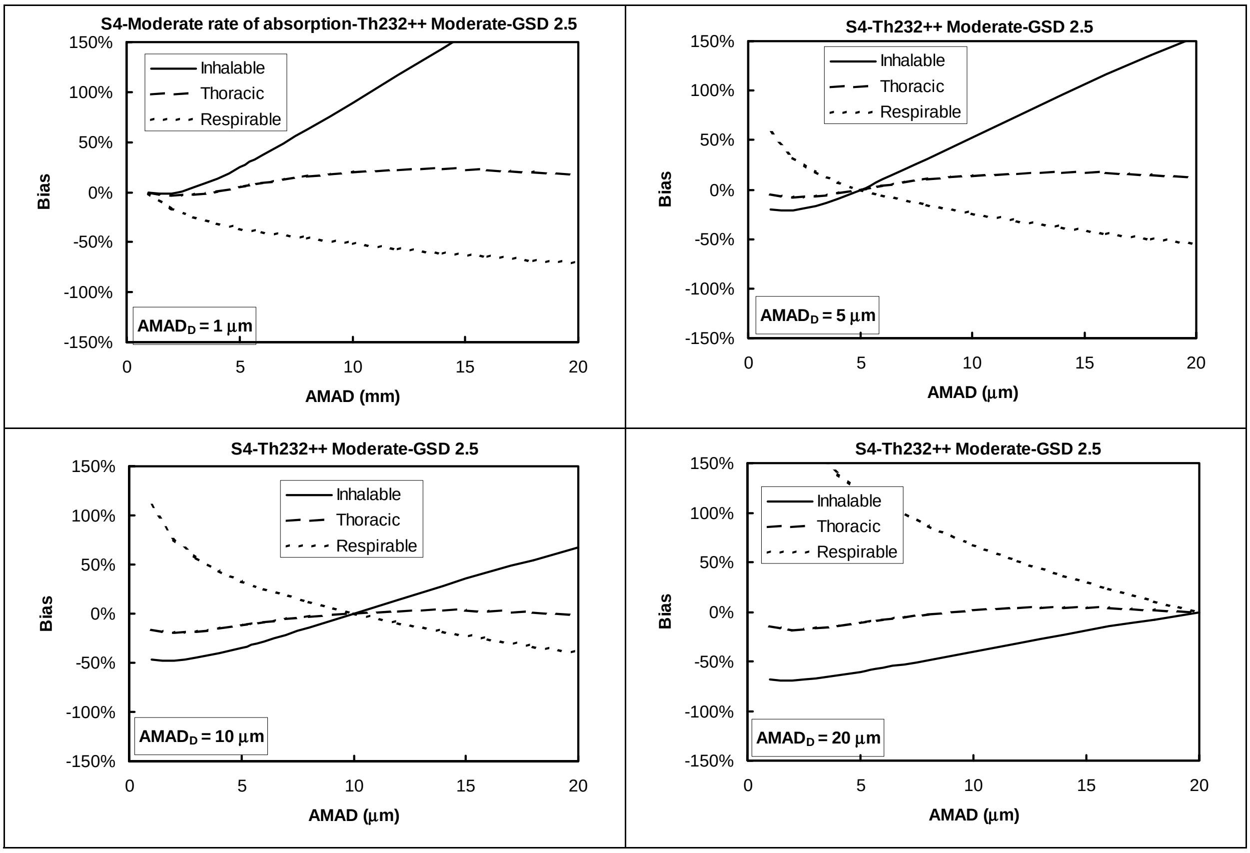


Figure 13: Th-232 sec Moderate ; Bias between the estimated and true effective dose (Situation 4)

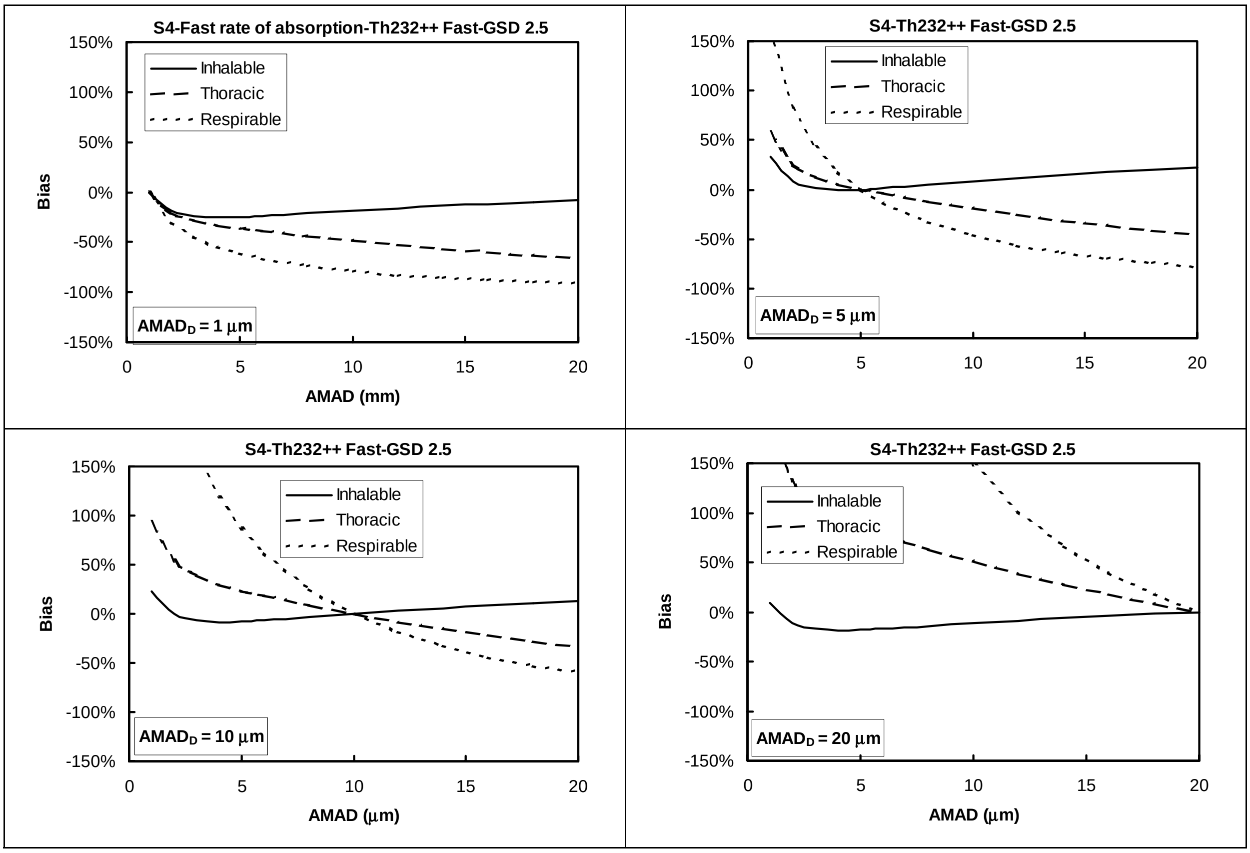


Figure 14: Th-232 sec Fast ; Bias between the estimated and true effective dose (Situation 4)

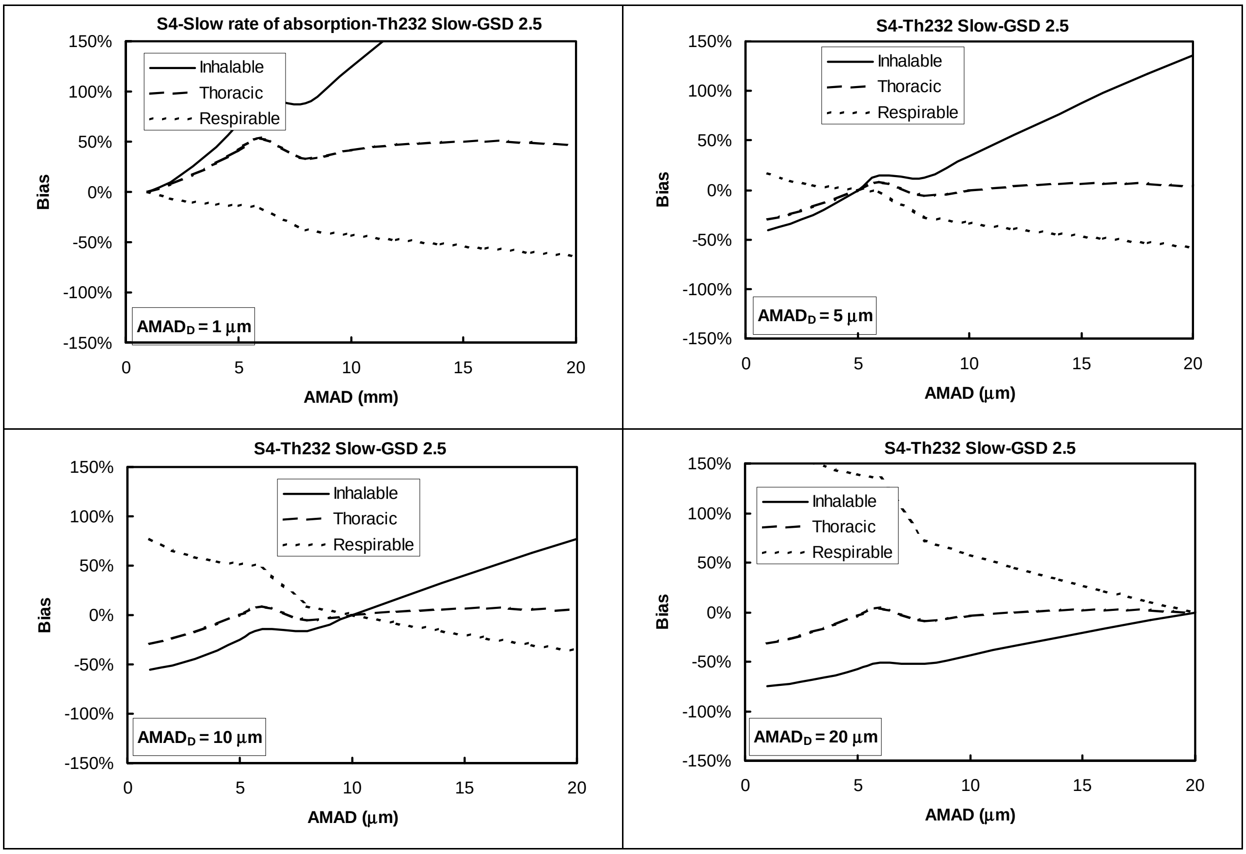


Figure 15: Th-232 Slow ; Bias between the estimated and true effective dose (Situation 4)

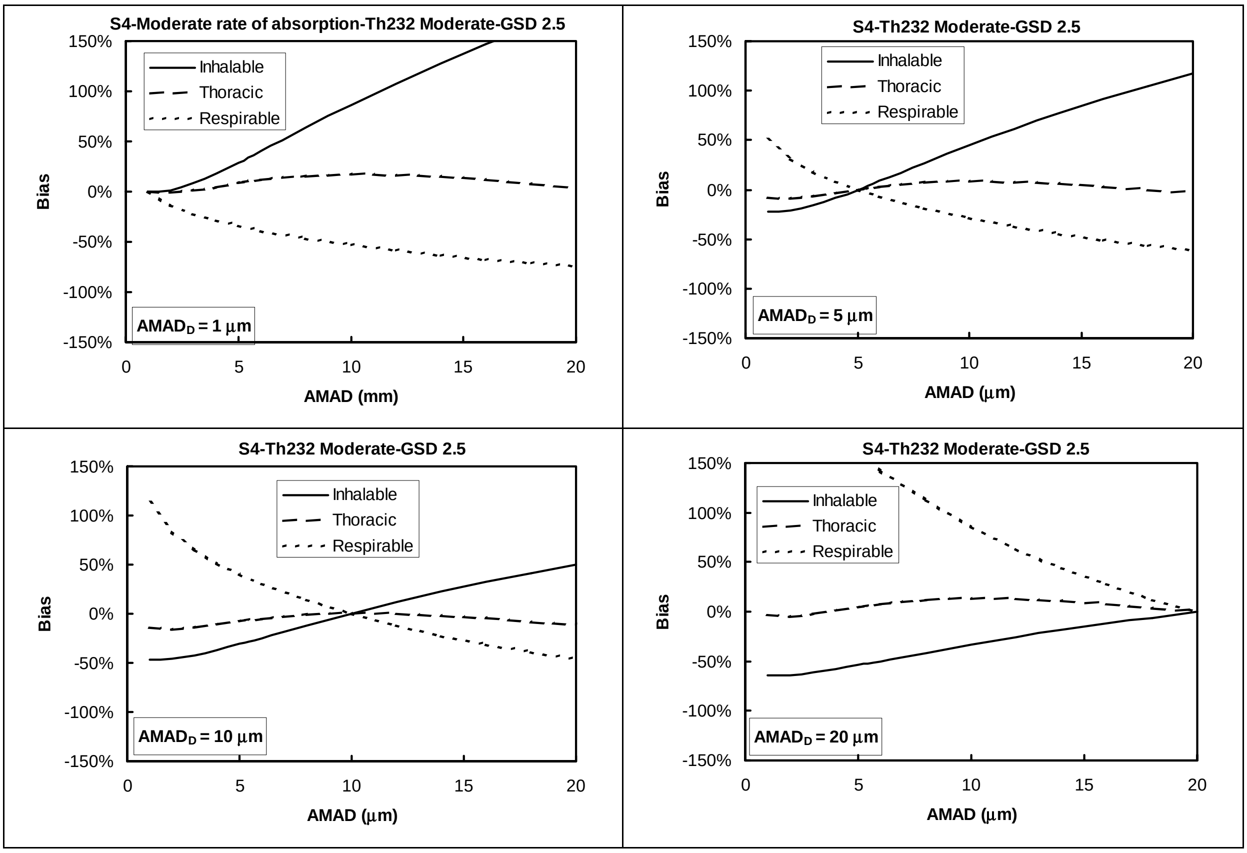


Figure 16: Th-232 Moderate ; Bias between the estimated and true effective dose (Situation 4)

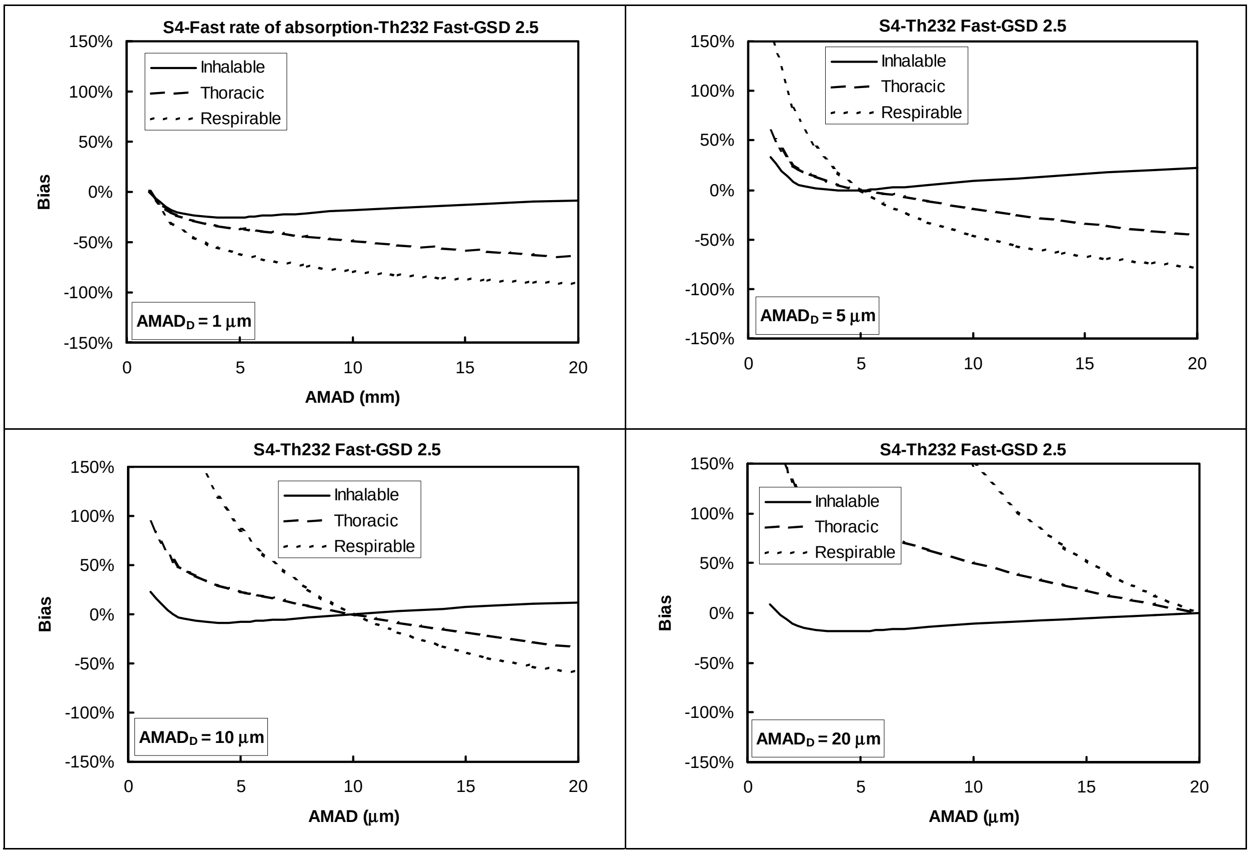
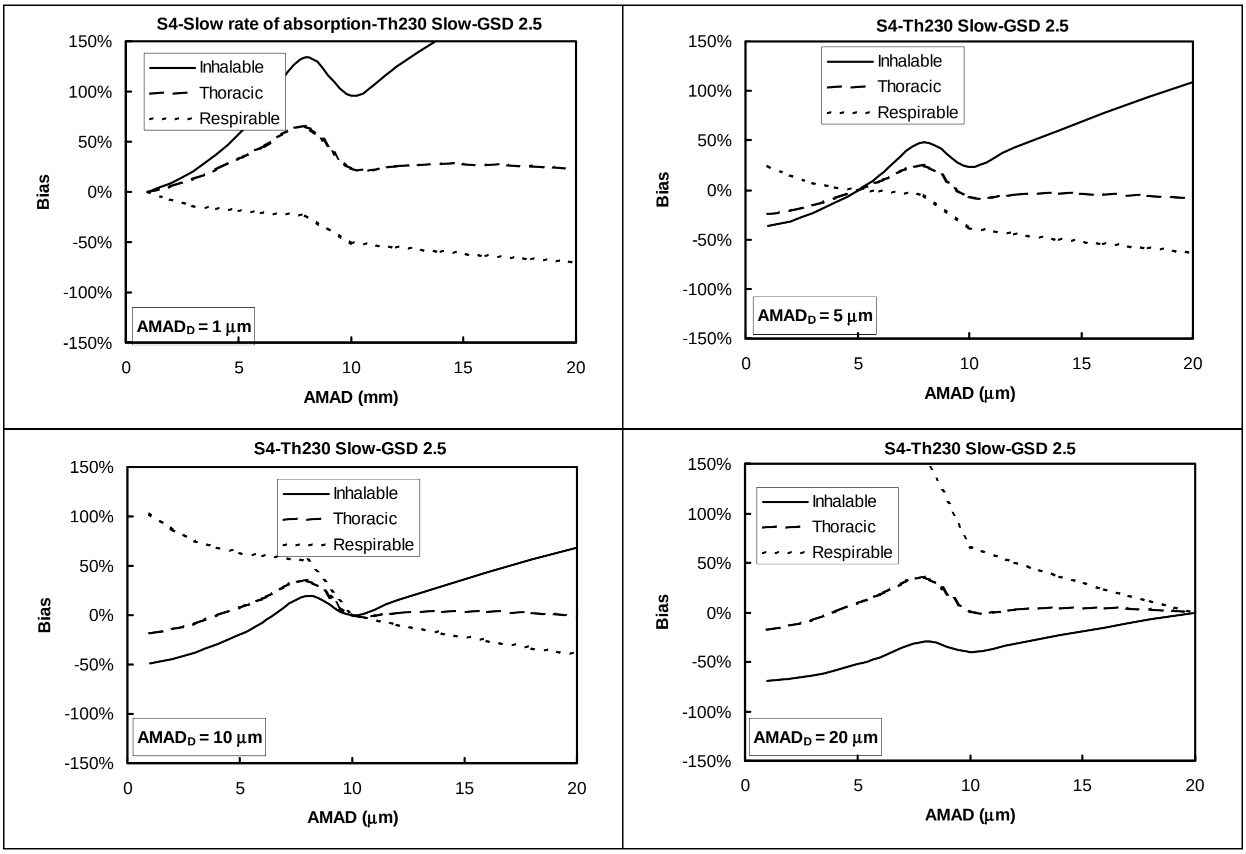


Figure 17: Th-232 Fast ; Bias between the estimated and true effective dose (Situation 4)



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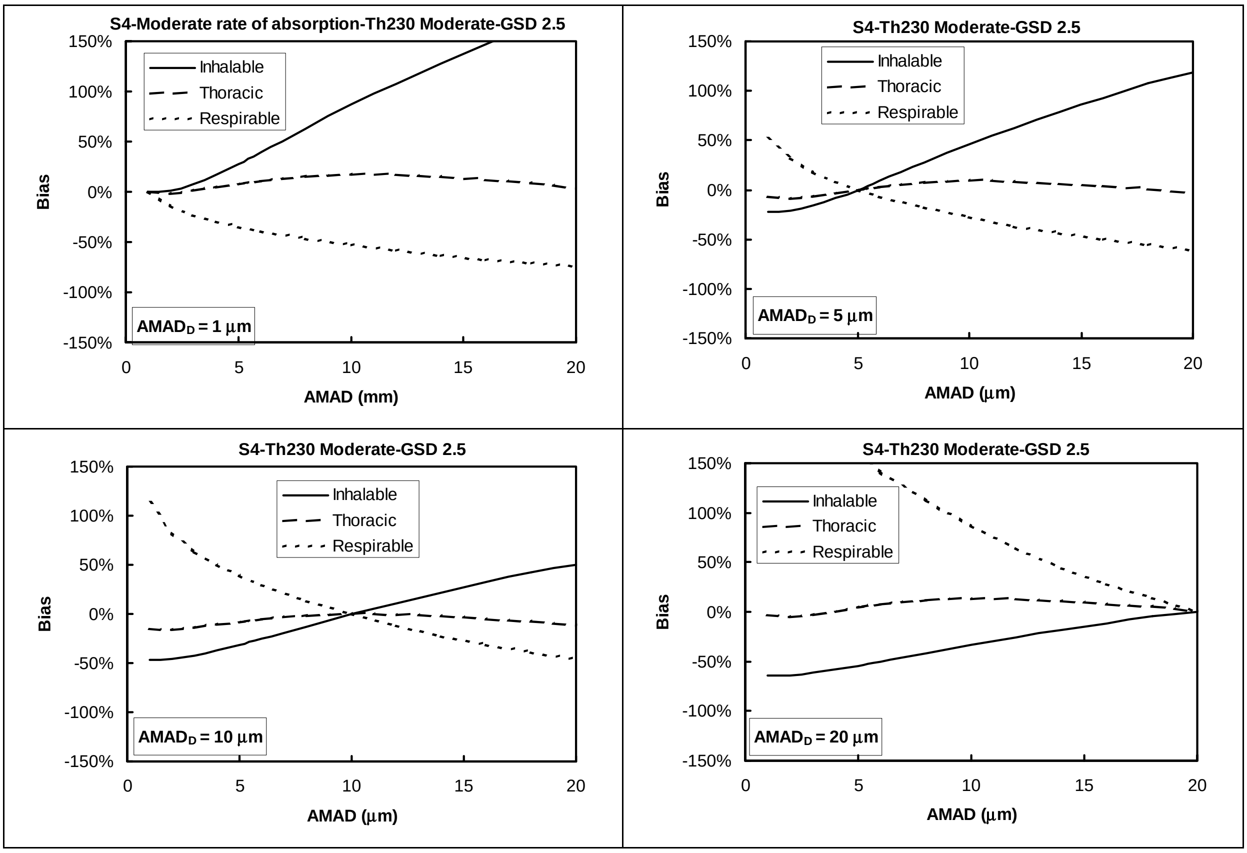


Figure 19: Th-230 Moderate ; Bias between the estimated and true effective dose (Situation 4)

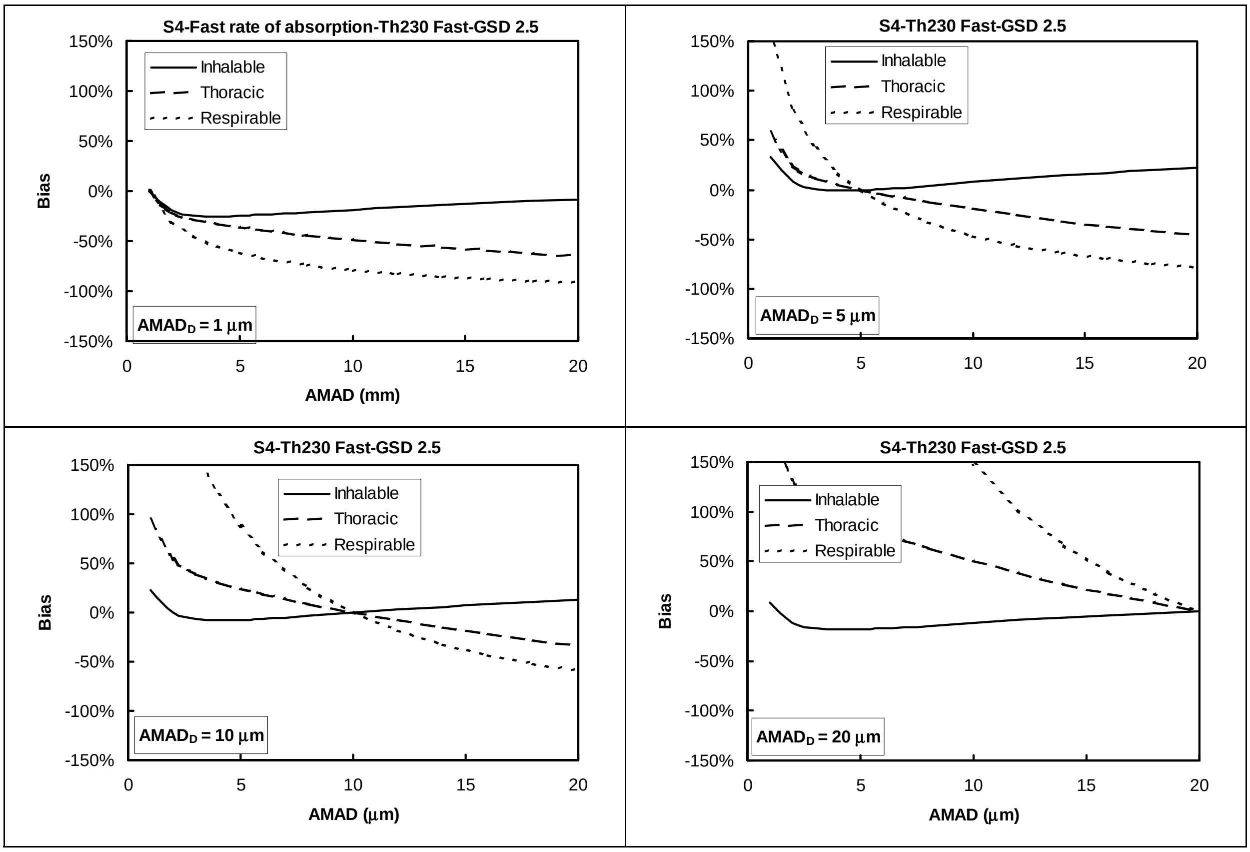


Figure 20: Th-230 Fast ; Bias between the estimated and true effective dose (Situation 4)

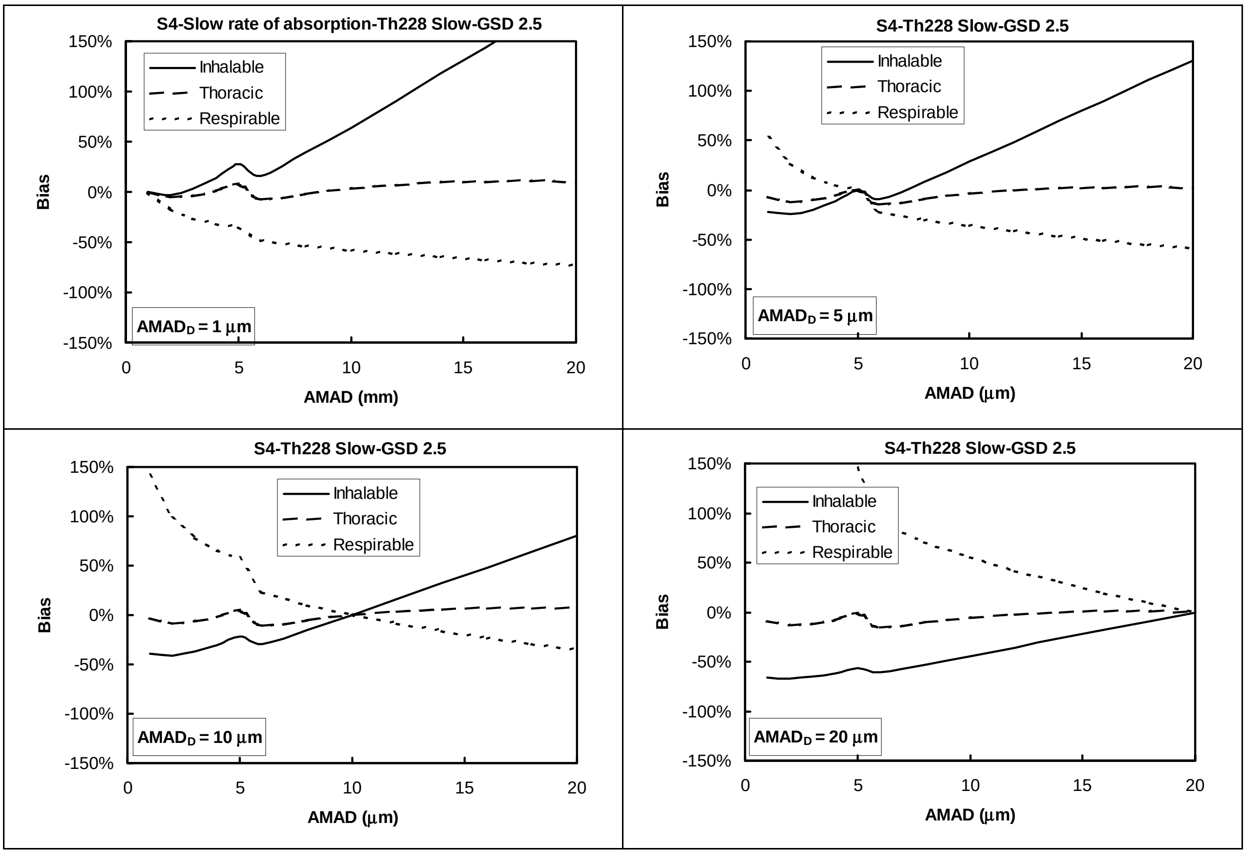


Figure 21: Th-228 Slow ; Bias between the estimated and true effective dose (Situation 4)

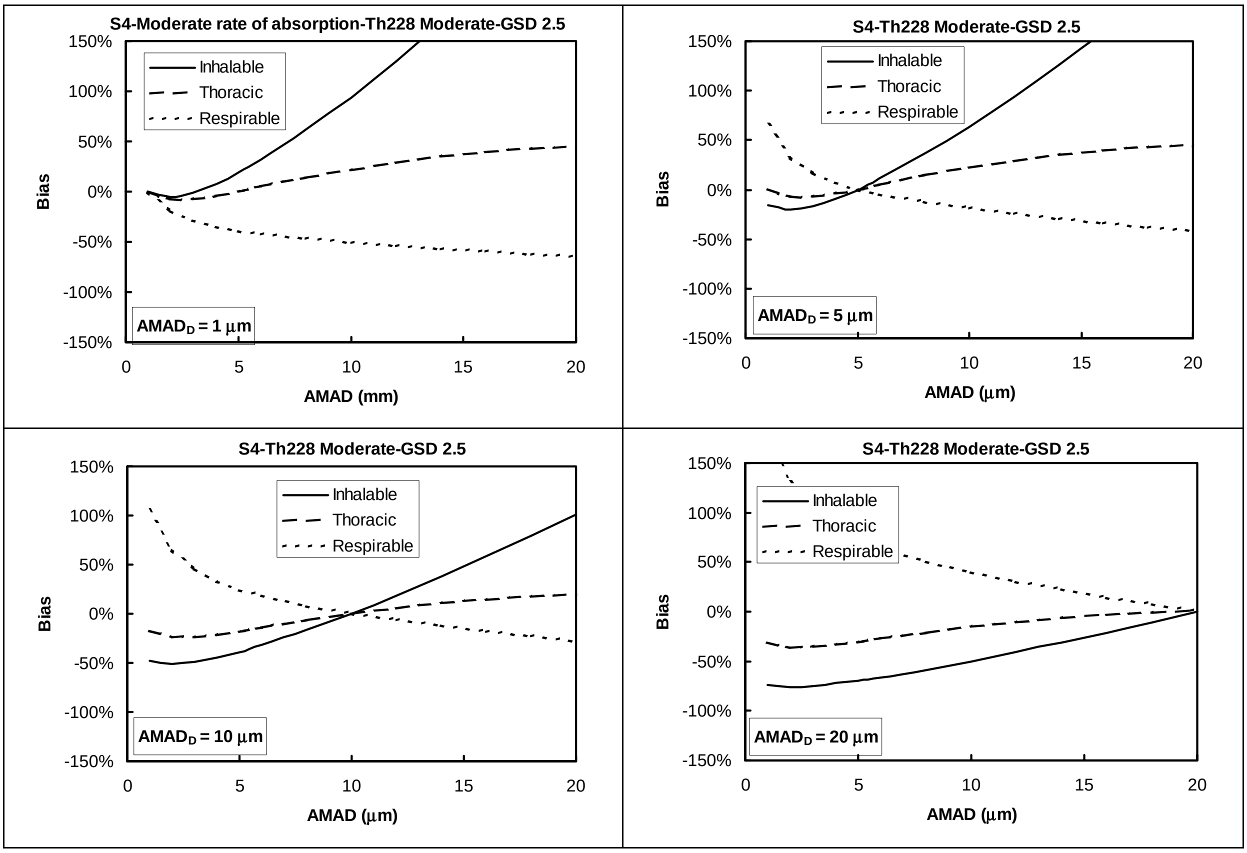


Figure 22: Th-228 Moderate ; Bias between the estimated and true effective dose (Situation 4)

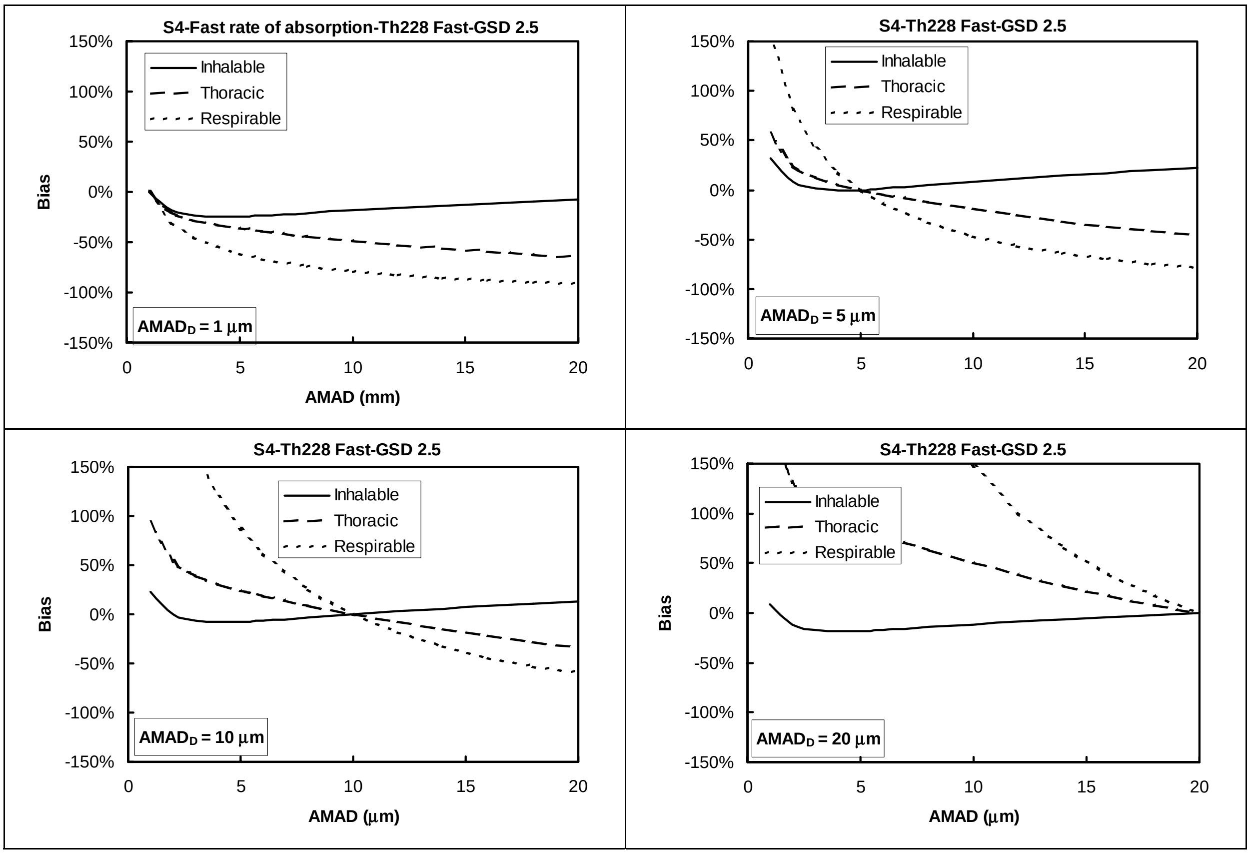


Figure 23: Th-228 Fast ; Bias between the estimated and true effective dose (Situation 4)

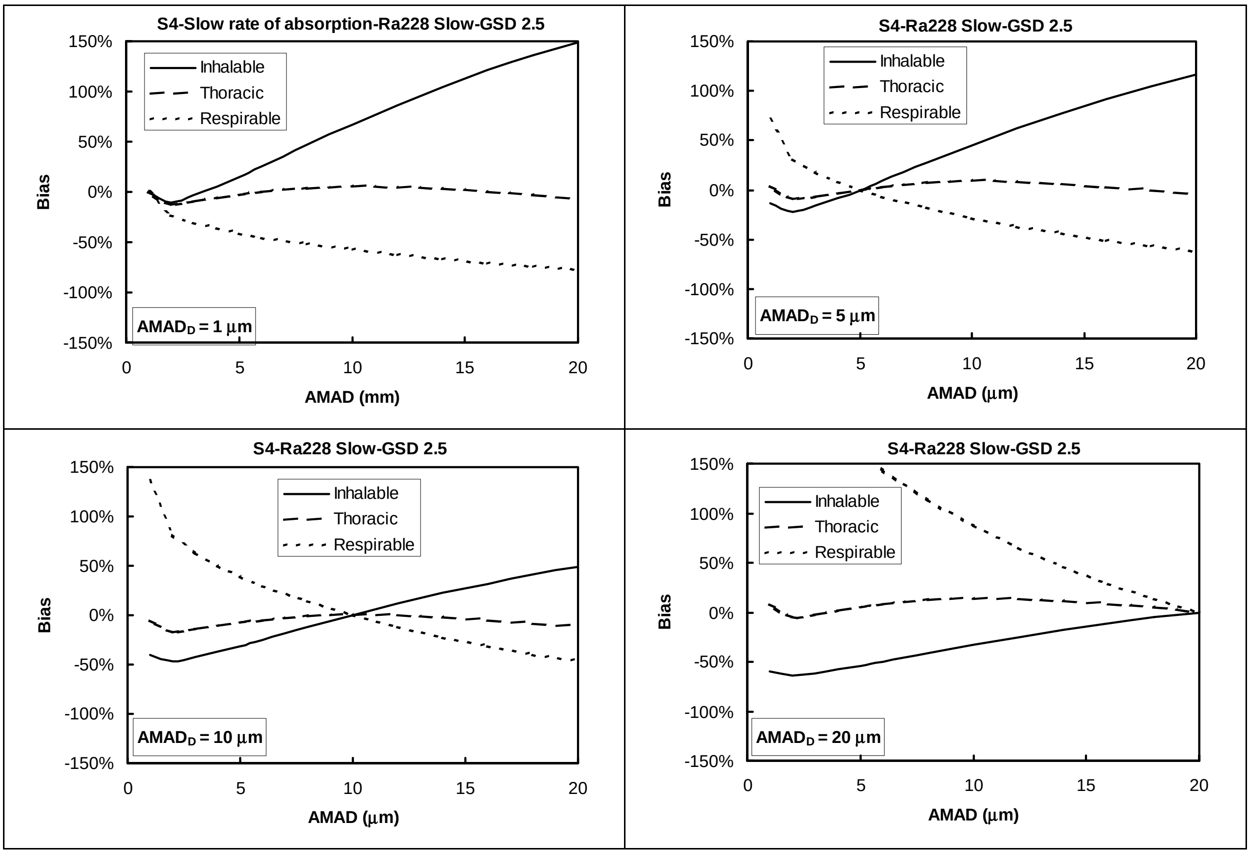


Figure 24: Ra-228 Slow ; Bias between the estimated and true effective dose (Situation 4)

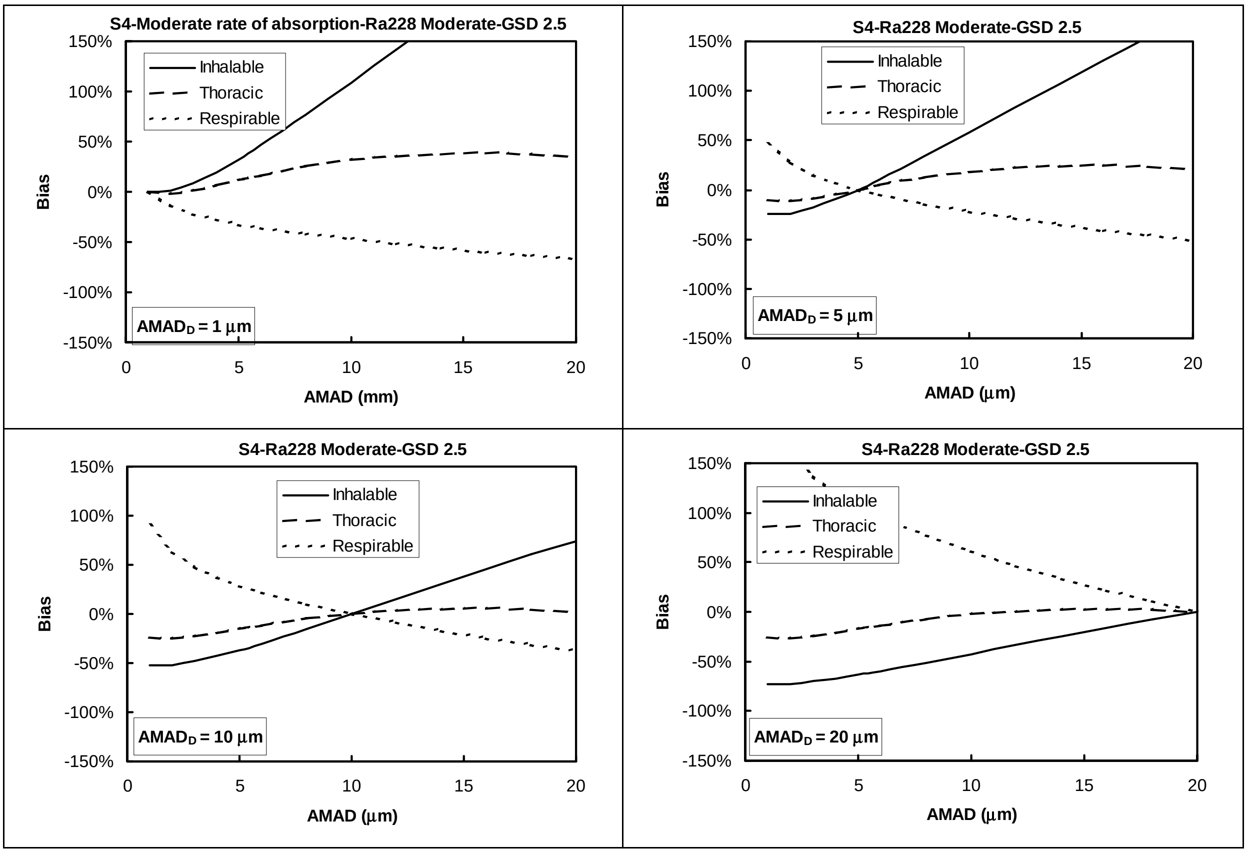


Figure 25: Ra-228 Moderate ; Bias between the estimated and true effective dose (Situation 4)

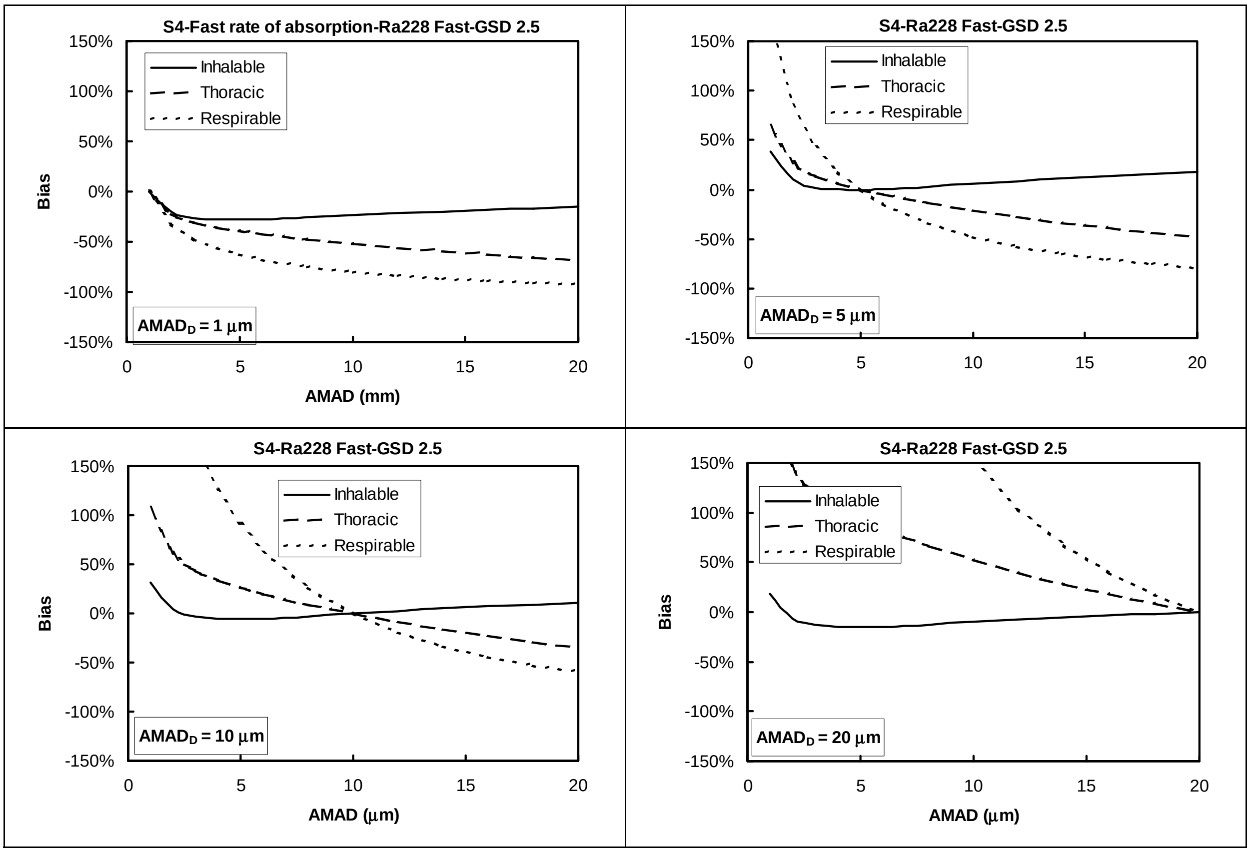
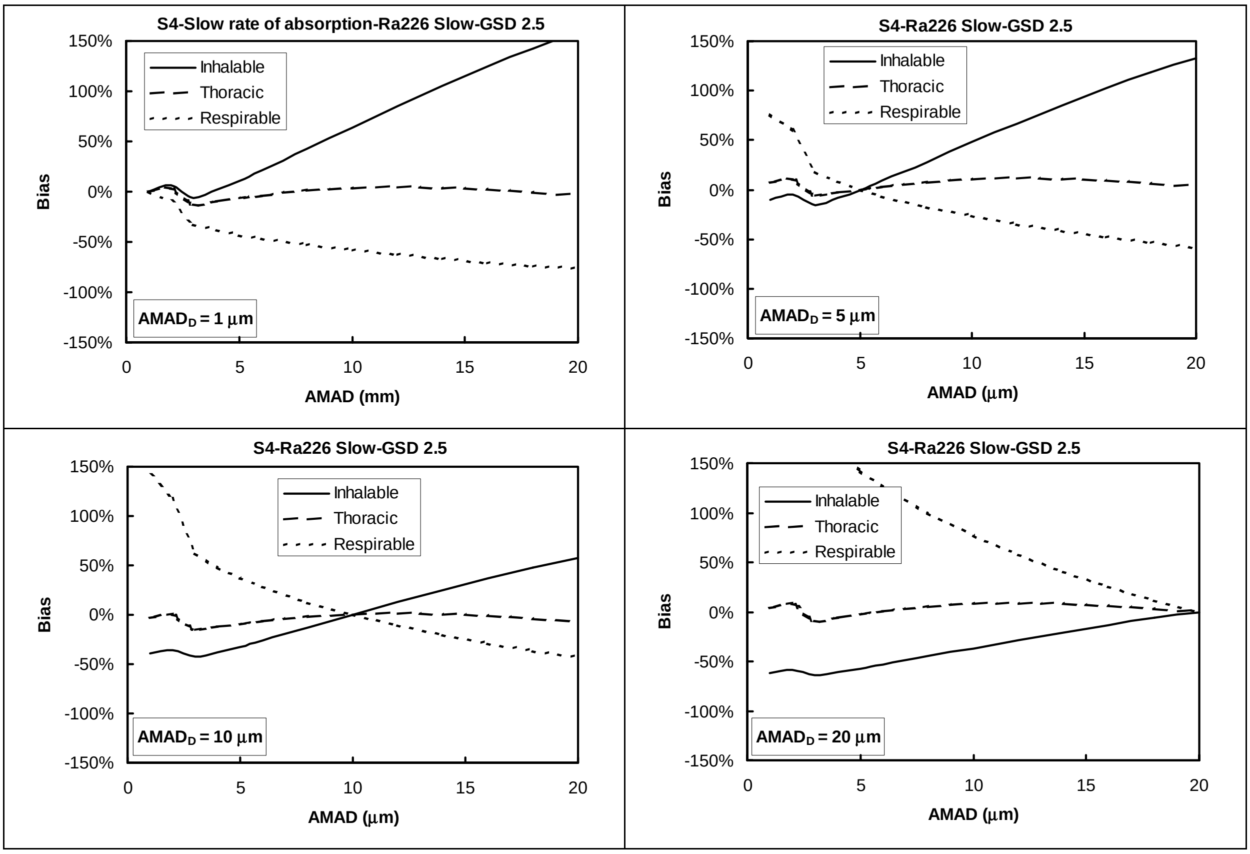


Figure 26: Ra-228 Fast ; Bias between the estimated and true effective dose (Situation 4)



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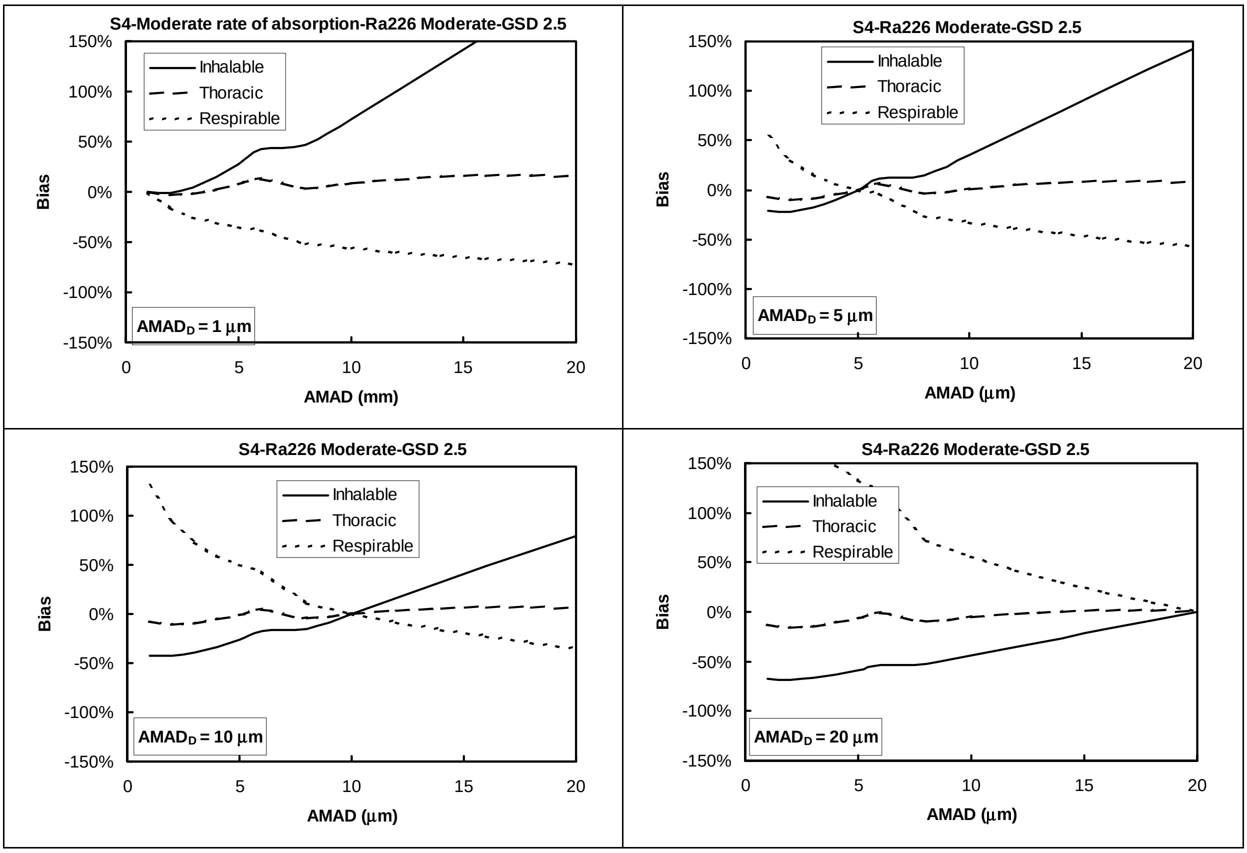

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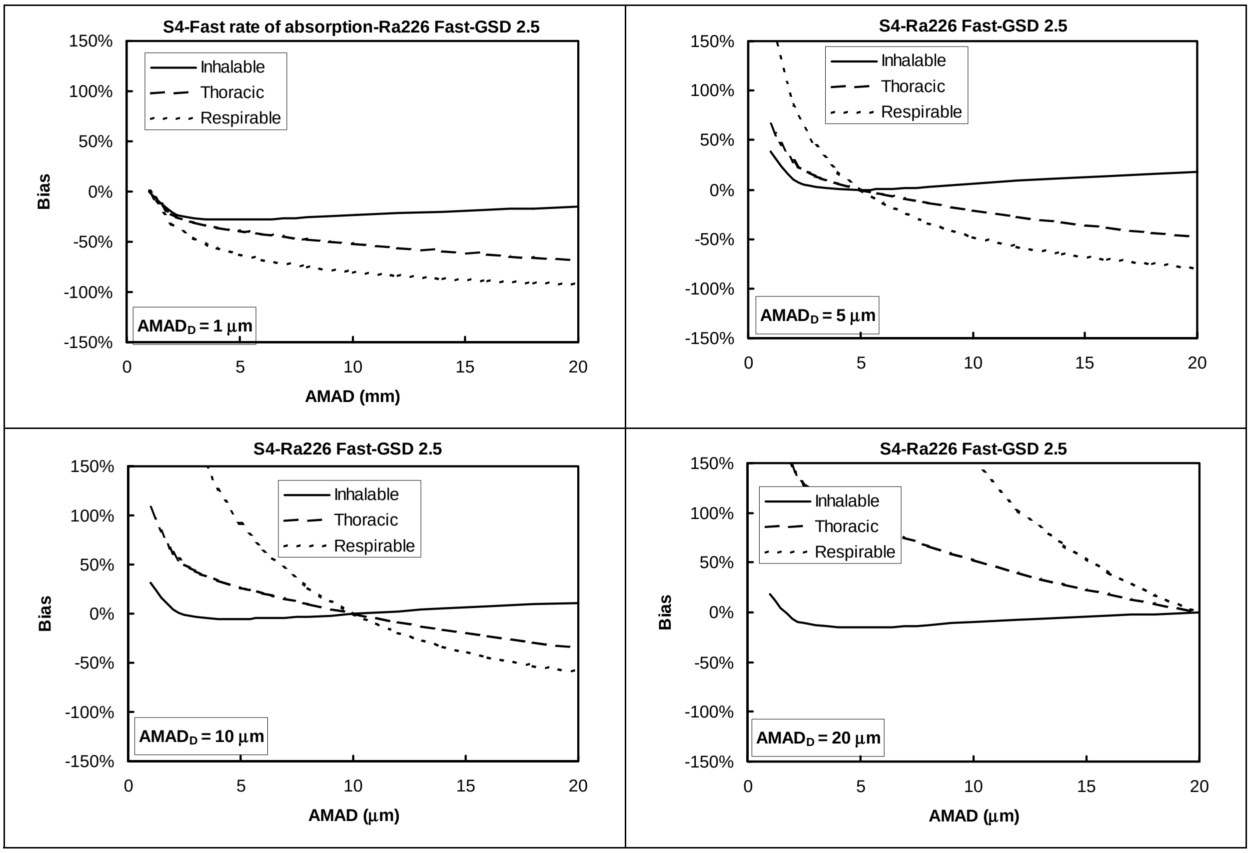

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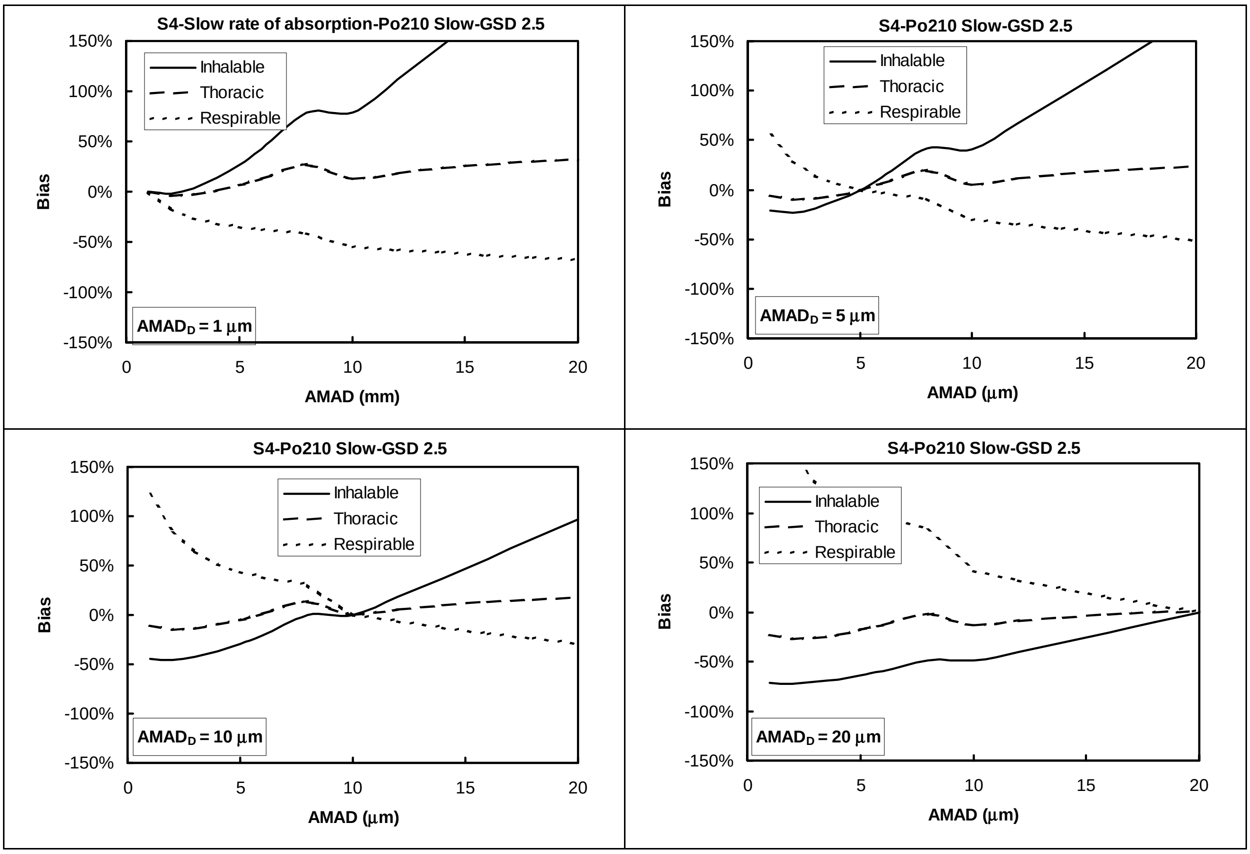

Figure 30: Po-210 Slow ; Bias between the estimated and true effective dose (Situation 4)

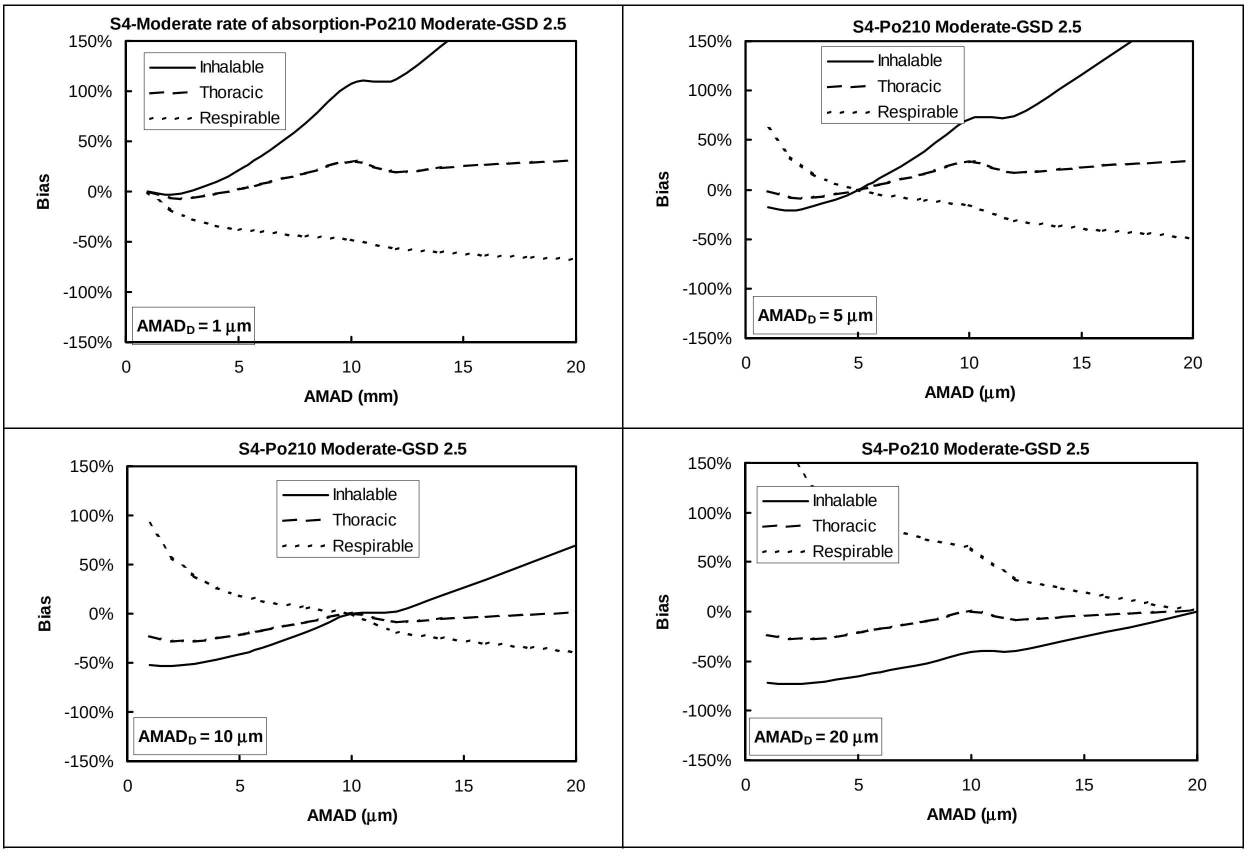

Figure 31 Po-210 Moderate ; Bias between the estimated and true effective dose (Situation 4)

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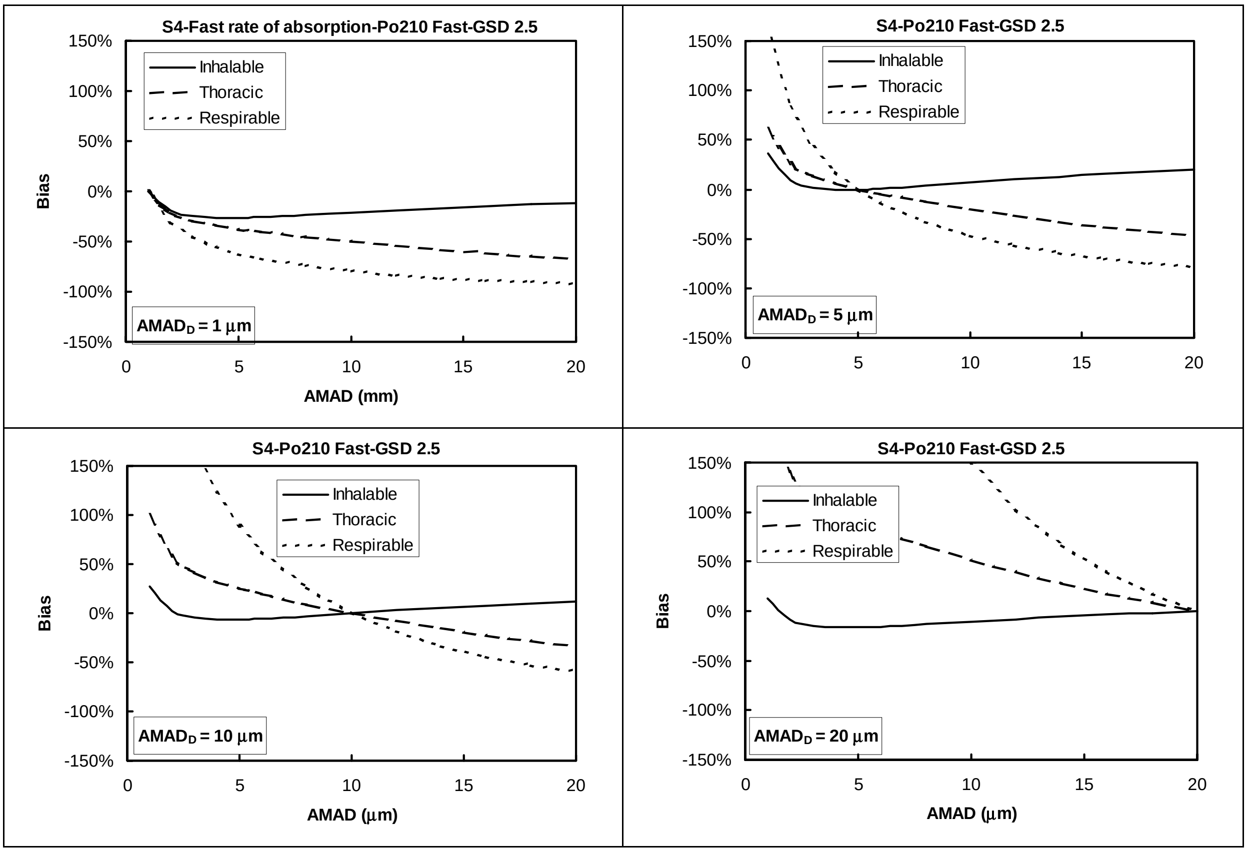


Figure 32: Po-210 Fast ; Bias between the estimated and true effective dose (Situation 4)

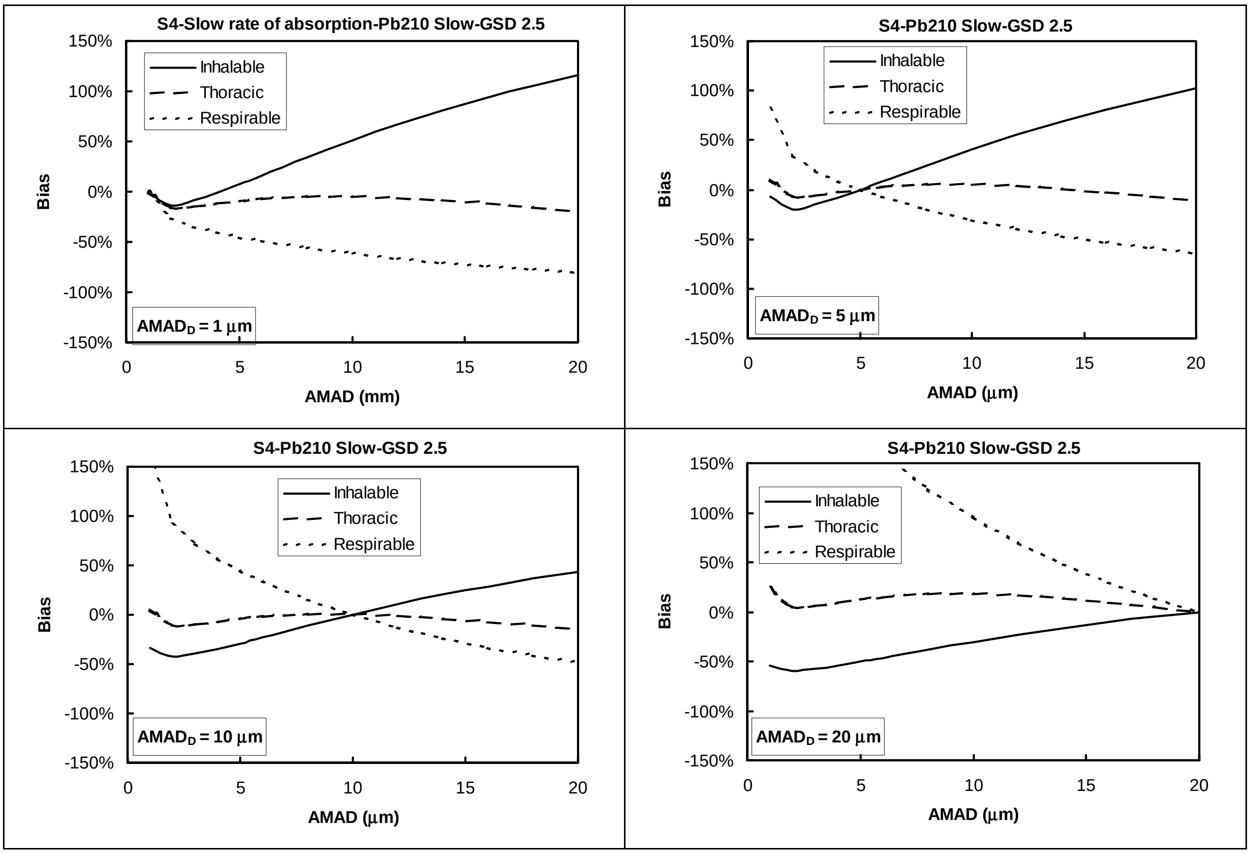


Figure 33: Pb-210 Slow ; Bias between the estimated and true effective dose (Situation 4)

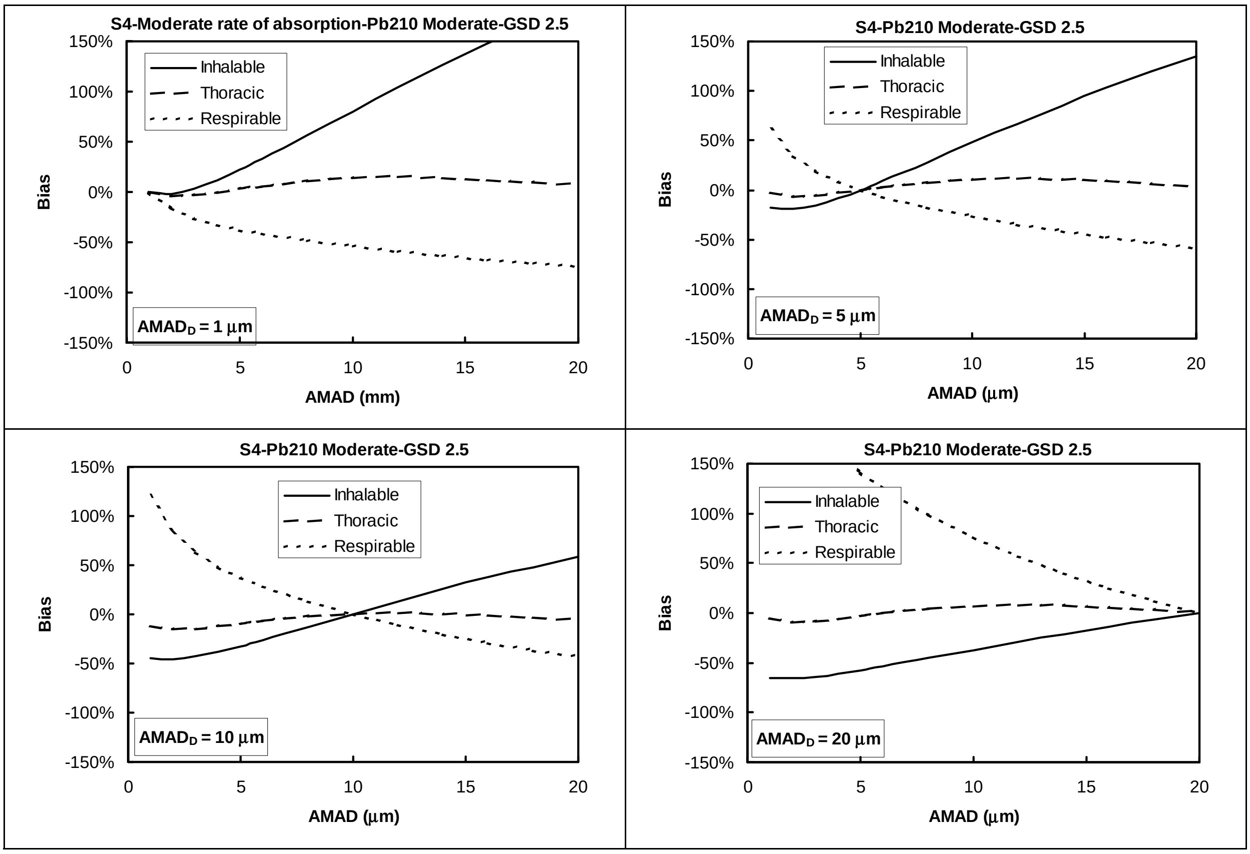
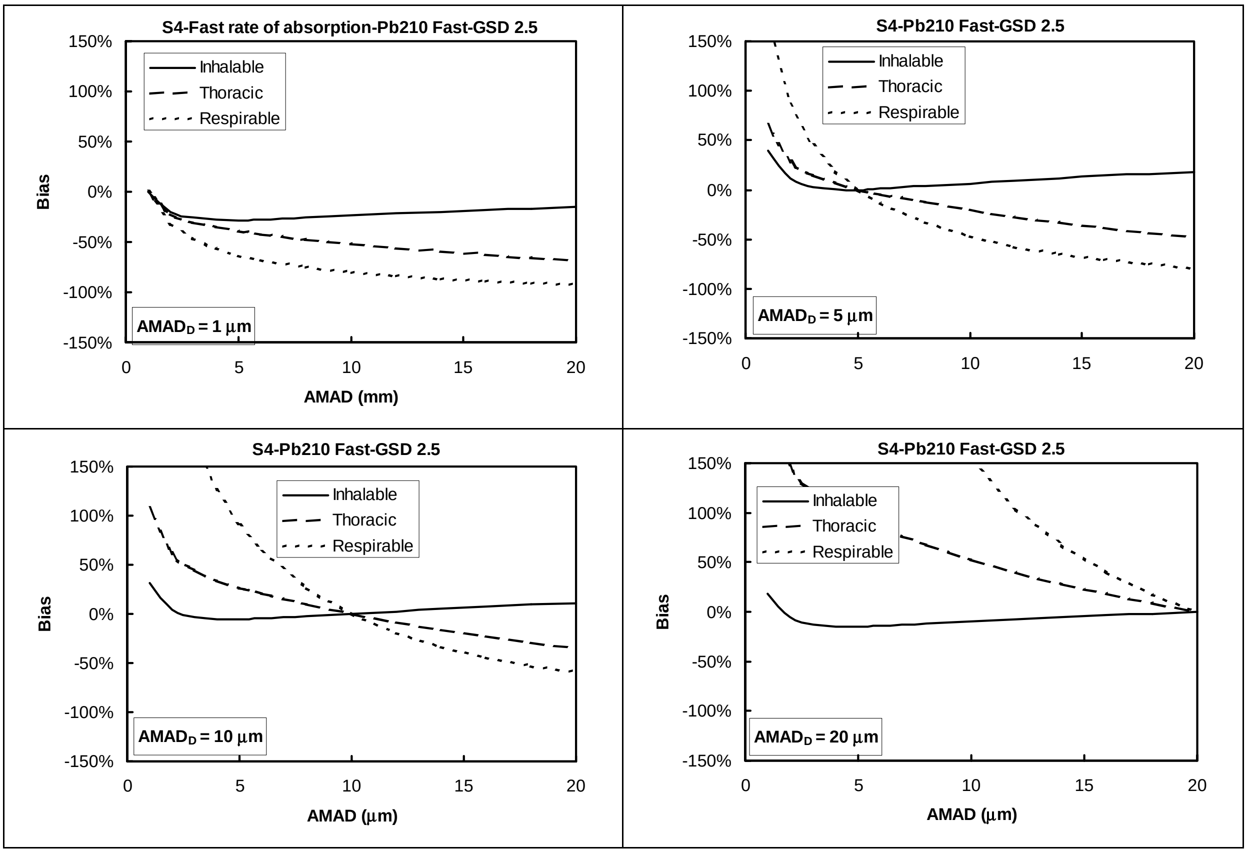


Figure 34: Pb-210 Moderate ; Bias between the estimated and true effective dose (Situation 4)



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