UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF AIR QUALITY PLANNING AND STANDARDS
HEALTH AND ENVIRONMENTAL IMPACTS DIVISION
RESEARCH TRIANGLE PARK, NC 27711

January 26, 2007

TO: Lead NAAQS docket

FROM: Zachary Pekar (EPA OAQPS)

SUBJECT: Correction to Errors Identified in Leggett-Based Blood Lead Modeling Completed for the Pilot Analysis

EPA has identified an error in the Leggett blood lead modeling completed for the Pilot analysis (as documented in the First Draft Staff Paper and accompanying technical support documents). The attached memo, from the contractor supporting the lead NAAQS risk assessment, addresses those errors by (a) demonstrating that a "corrected" application of the Leggett model now in use by our team performs as expected given Leggett-based simulations presented in the literature (i.e., the error has been corrected) and (b) regenerating a subset of the blood lead level and IQ loss results originally presented in the Pilot using the new "corrected" application of the Leggett model. This memo also includes comparison of our IEUBK blood lead model setup used in the Pilot against trends in the literature involving IEUBK performance (this intending to support IEUBK-based portions of the Pilot risk assessment).

The errors identified in the original Leggett-based modeling completed for the Pilot mean that a number of the results tables presented in both the Staff Paper and the draft technical report ("Lead Human Exosure and Health Risk Assessments and Ecological Risk Assessment for Selected Areas", December 2006) are incorrect. These include, within the Staff Paper, Leggett-based results presented in: (a) Tables 4-7 through 4-9 (blood lead level estimates), (b) Table 4-12 (performance evaluation for the blood lead level modeling), (c) Tables 4-13 through 4-17 (IQ loss estimates for the three case studies) and (d) blood lead levels and IQ loss estimates discussed in Section 4.5 (summary findings for the Pilot analysis). With regard to the draft technical support document, Leggett-based results in the following exhibits are incorrect: (a) Exhibit 5-12 (model evaluation of blood lead levels), (b) Exhibits 5-15 through 5-17 (blood lead level results for the three case studies), (c) Exhibits 6-1, 6-2, 6-4, 6-5, and 6-7 (IQ loss estimates for the three case studies), (d) Exhibits 6-12 and 6-13 (sensitivity analysis results), (e) Exhibit 6-24 (summary of sensitivity analysis results) and (e) Exhibits J-1 through J-5 (detailed risk results tables). Note, that errors identified in the tables above only pertain to the Leggett-based results. All blood lead level and IQ loss estimates based on IEUBK are not effected by the identified error.

Rather than regenerating all of the Leggett-based blood lead level and IQ loss estimates presented in the Pilot analysis, we have opted for regenerating a subset of those results. Specifically, we have rerun the Leggett analysis for the Primary Lead Smelter case study and have updated the sensitivity analysis results to reflect the corrected application of the Leggett model. The trends now seen in Leggett performance for the Primary Lead Smelter case study (e.g., 2+ fold higher blood lead levels and IQ loss estimates compared with IEUBK) would be expected to hold for the other two case studies.

MEMORANDUM

To: Zach Pekar, EPA-OAQPS

From: Bill Mendez and Mark Lee, ICF International

Date: January 25, 2007

Re: Test Results for Fortran Leggett Model

1. INTRODUCTION

In the Pilot Risk Assessment (ICF 2006), ICF reported the results of blood lead (Pb) modeling performed using EPA's IEUBK model and our own adaptation of the "Leggett" ICRP model, programmed in Visual Basic® (VB). This adaptation of the Leggett model involved translation of the model's biokinetic code into VB (mostly cut-and-paste owing to the similarity of the languages), and the addition of multipathway intake and uptake modules. The intake and uptake modules were structured so that the input variables to the Leggett model would match, as closely as possible, the input variables used in the IEUBK, and, for a given set of exposure factors and exposure concentrations, Pb uptake (the amount of Pb entering the biokinetic compartments) would be the same in both models. All input variables (exposure concentrations, and exposure, intake, and uptake factors) were read from a standardized spreadsheet. Because the Leggett model would be used to estimate geometric mean blood Pb levels for many (more than 100) census blocks in both the primary Pb smelter and secondary Pb smelter case studies, we also added a batch facility which allowed the user to enter multiple sets of exposure concentrations, also from spreadsheets. Outputs from the model were likewise exported in a format could be used directly in the probabilistic IQ loss model.

While the adapted Leggett model initially appeared to function correctly and consistently, reviewers of the Pilot Risk Assessment noted that, in several previous comparisons of the IEUBK and Leggett models, the Leggett model consistently generated blood Pb predictions that were higher than those from the IEUBK for the same exposure scenarios. In contrast, the blood Pb distributions predicted by our adaptation of the Leggett model in the Pilot Risk Assessment were consistently lower than those obtained from the IEUBK model. Our initial belief was that the discrepancy from the previous analysis was due to differences in how we defined input parameters for the Leggett model. In an additional QA check performed in response to reviewers' comments, however, we found two coding errors in our version of the Leggett model which indeed resulted in significant and systematic errors toward low blood Pb predictions. When the errors were corrected, our VB version of the Leggett model predicted blood Pb levels similar to, but not exactly consistent, with previous model testing results.

To reduce uncertainty about the performance of the Leggett model application to the NAAQS risk assessment, OAQPS asked ICF to use the Fortran version of the Leggett model (Pounds 2000) to recreate, as closely as possible, several previous comparisons with the IEUBK and other blood Pb models. The remainder of this memo reports the results of this effort. We also illustrate how the Fortran version of the model may be applied to estimate the blood Pb distributions in one of the Pilot Risk Assessment case study scenarios.

2. TEST PROCEDURES

The Leggett model Fortran code was provided to ICF by Dr. Joel Pounds of Battelle Pacific Northwest Laboratories. The code (Pounds 2000) was imported into the Digital Visual Fortran® compiler and compiled into an .exe file that could be run from Windows®. The original input and output file formats

were preserved.

We also created a batch version of the model (also in Fortran) that repeatedly called the original model code as a subroutine, passing to it different sets of ingestion and inhalation Pb intake or uptake estimates for each age range. No additional features were added to the batch version of the model. In both Fortran versions, the assumption was maintained that all ingested Pb was absorbed with the same efficiency (i.e., there is only a single ingestion absorption fraction (AFI) value which applies to all ingested Pb). Therefore, to evaluate blood Pb impacts of multi-source scenarios (involving, for example, dietary, drinking water, and soil/dust exposures) it was necessary to calculate Pb uptake (input to the gastrointestinal (GI) tract or blood stream) external to the model, and provide a single "ingestion" intake or uptake value for each age interval that was evaluated.

For the sake of simplicity, age-specific Pb inputs to the Leggett model were specified in one of two ways, either as ingestion uptake values, assigning a constant value of 100 percent to the GI absorption fraction; or by using the "chronic" exposure pathway of the model, in which it is assumed that all of the uptake instantaneously enters the blood/extravascular fluid compartment.[1] Use of these two approaches gave nearly identical blood Pb estimates, except for the first few iterations after large changes in exposures, where the "chronic" pathway resulted in slightly more rapid increases in blood Pb levels compared to increases in other compartments. All of the biokinetic modeling parameters and age ranges were maintained exactly as in the default input file provided by Dr. Pounds. In all the tests that we performed, we found that our batch version of the Leggett model generated identical results to the off-the-shelf version (Pounds 2000).

To reproduce comparisons with the IEUBK results, we used EPA's IEUBKwin32 model Version 1.0©, build 261. We used both single-run and batch model results, with input parameter values specified as discussed below.

The "off-the-shelf" and batch versions of the Fortran Leggett model and IEUBKwin 32 (IEUBK) were applied to three previously reported test scenarios:

- ***Test 1***. The first test compared the predicted blood lead levels in 2 to 3 year-old children in response to a range of constant Pb uptakes from 0.1 to 100 µg/day. This test is described on page 4-122 and in Figure 4-32 of EPA's Air Quality Criteria Document for Lead (U.S. EPA 2006). The primary output measure from this test is the slope of the relationship between estimated blood Pb at age three and Pb uptake in the low-dose range (0-10 µg/day), where the model responses are very nearly linear. We also compared estimates of the daily lead uptake resulting in a predicted average blood Pb level of 10 µg/dL, and the predicted blood Pb level associated with 100 µg/day Pb uptake. This scenario provides a straightforward test of the biokinetic component of the model because it bypasses assumptions related to Pb absorption from different media. In the Leggett modeling, Pb uptake was assumed to directly enter the blood stream, as described above. In the IEUBK runs, lead uptake was "administered" through the ingestion pathway with an assumed AFI value of 1.0, or through the "Alternative" pathway, again with 100 percent absorption.

- ***Test 2***. The second test is also reported in the Criteria Document (p. 4-127, Figure 4-35). In the test scenario, a constant Pb uptake is assumed to begin at birth, resulting in a blood Pb level of 2.0 µg/dL at two years of age. At age two, Pb "exposure" (actually, oral intake) is increased by 100 µg/day for one year. Consistent with the description in the legend for Figure 4-32 of the Criteria Document, "default biaoavailability assumptions" were used, which we interpreted to mean the Leggett default age-specific ingestion absorption fraction (AFI) value for children from

1 We used Direct (injection) for the Leggett model, in addition to the oral route option, to make sure we had absolute control over the amount of lead entering the biokinetic algorithms in each time period.

birth through three years of age (45 percent from birth through age 100 days, falling linearly to 30 percent by one year of age, and remaining at 30 percent through childhood). For the IEUBK runs, the default absorption factor for soil and dust (30 percent) was also used (see below).

- ***Test 3***. Finally, we compared the performance of the Fortran-Leggett and IEUBK models on a multipathway exposure scenario described by Pounds and Leggett (1998). The exposure scenario was derived from the IEUBK default exposure concentration and exposure, uptake, intake factor values, as defined in EPA's 1994 Technical Support Document (USEPA 1994). In their study, Pounds and Leggett used the IEUBK default values to derive annual average Pb intake and uptake estimates for seven one-year age ranges beginning at birth. Exposure sources included diet, drinking water, soil, and household dust. Two sets of model inputs were developed for the Leggett model, one set being the Pb *intake* estimates derived from the IEUBK defaults, the other set being the Pb *uptake* estimates corresponding to the same set of exposures. In attempting to reproduce these two sets of estimates (see below), we assumed that the Pb uptake values were input to the Leggett models either directly into the blood stream, or by ingestion assuming 100 percent GI absorption. We also assumed that the age-specific Pb intakes were meant to be input to the model using the default age-specific AFI values described in Test 2. IEUBK model inputs were all maintained at their default values, except for house dust lead concentration, which was set to 200 µg/g, consistent with the value assumed by Pounds and Leggett.

As part of the testing process, we examined the effects of using different simulation time steps in the Leggett blood lead modeling. In all of the scenarios tested, we found that using time steps shorter than 0.1 day resulted in nearly identical results, except in the first few iterations of each run. The differences essentially disappeared for time steps of 0.01 days or less. We therefore used a constant iteration step of 0.01 days for all of the Leggett model testing. The default time step of four hours was used in all IEUBK runs.

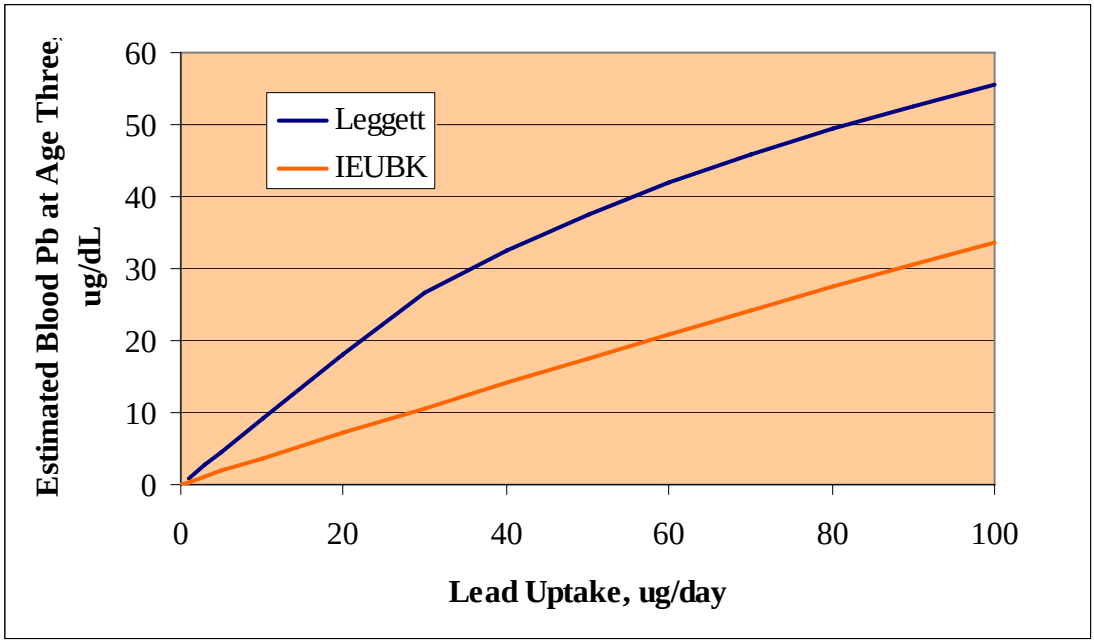
3. MODEL TEST RESULTS

Test 1. Change in Predicted Blood Pb With Increasing Pb Uptake

In examining the response of the Fortran version of the Leggett model to varying Pb uptake levels between 1.0 and 100 µg/dL, we found the results very similar to those presented in the Criteria Document (compare Figure 1, below, with the Figure 4-32 from the CD). In the uptake range from 0.1 to 10 µg/day, we estimated a blood Pb slope of 0.90 µg/dL per 1.0 µg/day increase in Pb uptake between the ages of two and three years. The corresponding Leggett slope reported in the Criteria Document is 0.88 µg/dL per µg/day increment in Pb uptake. The Criteria Document reported that a 10 ug/dL blood lead level would result from a 12 µg/day Pb uptake. Based on our Leggett modeling results, we calculated an analogous value of 11.1 µg/day. The blood Pb concentration associated with 100 µg/day Pb uptake in Figure 4-31 of the Criteria Document is around 55 µg/dl; our application of the Fortran version of the Leggett model gives a corresponding predicted blood Pb of 55.4 µg/dL.

We initially had difficulty getting our IEUBK results to match those presented in the Criteria Document. However, we found that we obtained similar blood lead predictions as reported in the Criteria Document if we bypassed the nonlinear uptake module in the IEUBK by setting the "Fraction Passive" input value to 1.0 (100 percent). This assumption appears to be consistent with the lack of curvature in the blood lead-lead uptake plot in the Criteria Document, Figure 4-32, which is reproduced by our results in Figure 1. In addition, when the nonlinear uptake module is bypassed, the IEUBK model outputs for annual lead uptake match the input values.

Figure 1. Predicted Blood Pb at Age 3 Years Versus Pb Intake



From our IEUBK runs, we estimated a blood lead-lead uptake slope of 0.36 µg/dL per ug/day uptake, which is identical to the value reported in the Criteria Document. We found that a lead uptake of 27 µg/day corresponded to an estimated blood lead level for a three-year old of 10 µg/dL, close to the value of 29 µg/day reported in the CD. Our IEUBK estimated blood Pb at 100 µg/day uptake was 33.7 µg/dL; the corresponding value from the Criteria Document, Figure 4-32 is approximately 33 µg/dL.

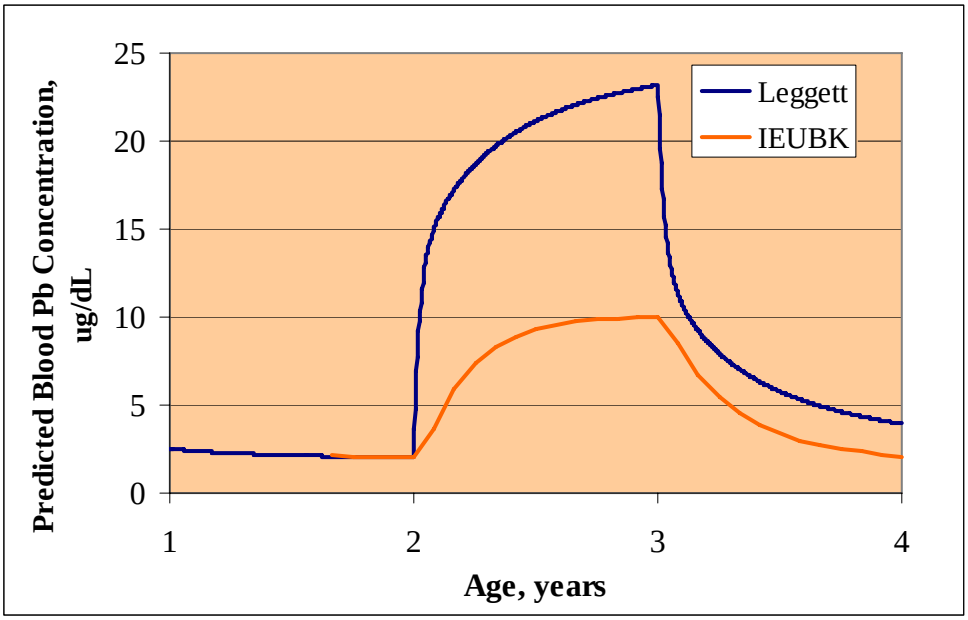
Our results are in close agreement with the results of the Leggett and IEUBK model comparisons reported in the Criteria Document. The reason for the small differences between our results and those in the Criteria Document are not clear, but they could include minor differences in the specification of model inputs, limitations in machine precision, or rounding error. As mentioned above, we obtained identical results with the off-the-shelf and batch versions of the Fortran Leggett model.

Test 2. Leggett and IEUBK Model Responses to Episodic High Exposure

As noted above, the second test examined the Leggett and IEUBK model response to a sudden increase in Pb exposure beginning at the age of two years. In this test, the initial Pb input to the models was a constant ingestion pathway Pb intake beginning at birth that resulted in a predicted blood Pb of 2.0 µg/dL at age two years. At age two, ingestion intake was increased by 100 µg/day for one year, resulting in a rapid increase in blood Pb. The predicted blood Pb level at age three is the primary test output. In the Leggett model runs, the default age-specific ingestion absorption fractions were used, as described above. For the IEUBK model, the default AFI value for Pb absorption from ingested soil (30 percent) was used for all model runs.

As shown in Figure 2, the result we obtained using the Fortran version of the Leggett model is indistinguishable from that obtained by EPA and summarized in Figure 4-32 of the Criteria Document. When EPA ran this scenario through the Leggett model, the peak blood Pb achieved at age three years was 23 µg/dL. When we ran the model, the peak blood Pb was 23.2 µg/dL. The maximum blood Pb predicted by the IEUBK model (10.0 µg/dL) also precisely matched the results presented in the Criteria Document.

Figure. 2. Fortran Leggett Model Predicted Blood Pb Response to a One-Year Increase in Pb Intake of 100 µg/day Beginning at Age Two



Test 3. IEUBK Default Multipathway Exposure Scenario

In order to compare results from the Leggett and IEUBK models, Pounds and Leggett (1998) constructed an exposure scenario for children age 0 to 7 based on the default input parameter values for the IEUBK model. For each age group, they estimated Pb intake (administered dose) and uptake (absorbed dose) based on the IEUBK default exposure concentrations, behavioral variables, and absorption fractions. The IEUBK model was run using the default values, and the estimated annual average blood lead for children from birth through age seven years served as the basis for comparison with the Leggett model predictions.

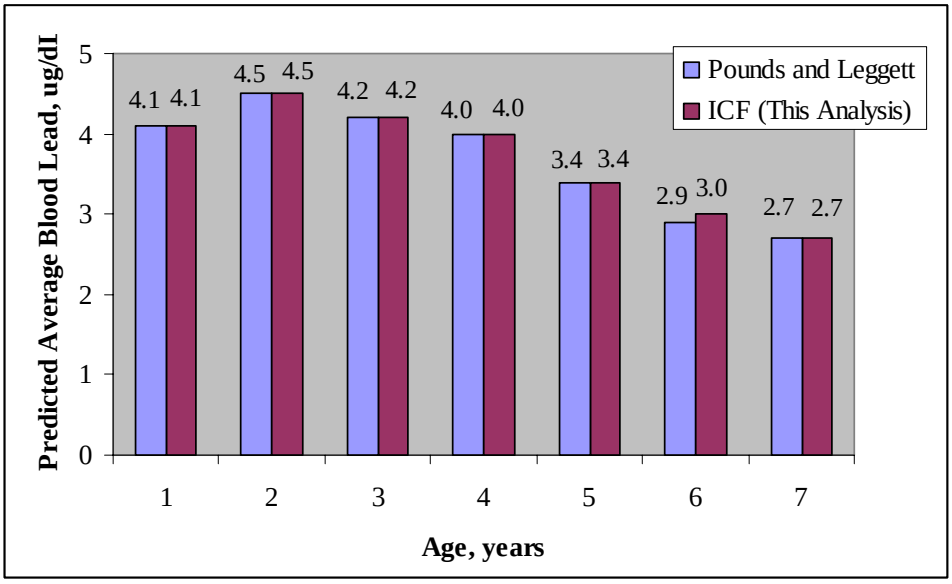
They ran the Leggett model using two different sets of intakes. First, ran it using the *uptake* values as direct inputs into the biokinetic algorithms. In addition, they also used the calculated Pb *intake* values as inputs, apparently applying the Leggett model default AFI values to the summed intakes. Table 1 (below) reproduces the intake and uptake estimates from Table 2 of Pounds and Leggett (1998).

We reproduced the Leggett and Pounds (1998) IEUBK blood Pb estimates by simply running the IEUBK with its default inputs, which have not changed since the 1994 Technical Support Document was issued. As noted above, the only input that was adjusted was the default house dust concentration which, in order to yield intake values consistent with Table 1, we adjusted to 200 µg/g (from 150). As shown in Figure 3, we obtained blood lead predictions that were essentially identical to those reported by Pounds and Leggett (1998.)

Table 1. Estimated Age-Specific Pb Uptake and Intakes Derived Based on the IEUBK Default Input Parameters (Reproduced from Pounds and Leggett, 1998)

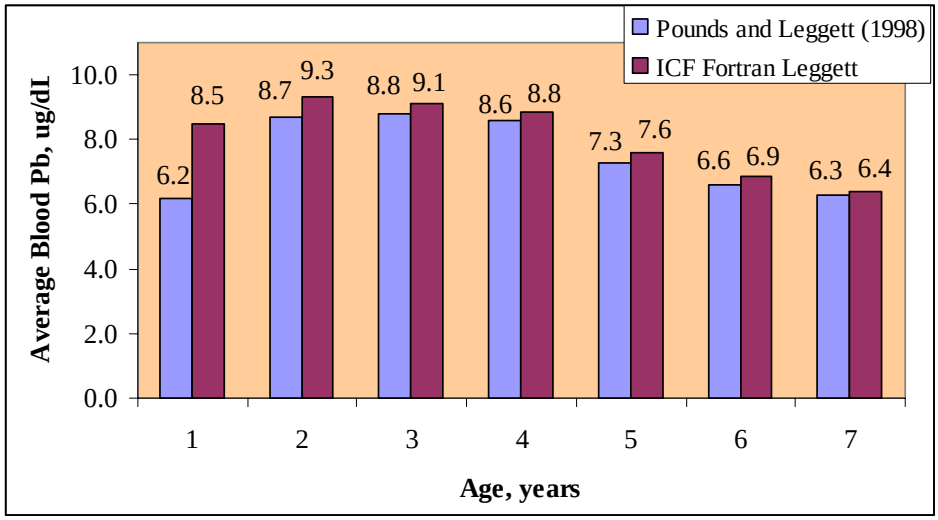
Age Range (months)	6 - 12	12 - 23	24 - 35	36 - 47	48 - 59	60 - 71	72 - 84
Default Intake, µg/day							
Air	0.07	0.11	0.19	0.21	0.21	0.29	0.29
Diet	5.53	5.78	6.49	6.24	6.01	6.34	7.00
Drinking Water	0.80	2.00	2.08	2.12	2.20	2.32	2.36
Soil	7.65	12.15	12.15	12.15	9.00	8.10	7.65
Dust	9.35	14.85	14.85	14.85	11.00	9.90	9.35
Paint	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Intake	23.40	34.89	35.76	35.57	28.42	26.95	26.65
Default Uptake , µg/day							
Diet	2.54	2.63	2.98	2.90	2.86	3.03	3.36
Water	0.37	0.91	0.96	0.99	1.04	1.11	1.13
Air	0.02	0.04	0.06	0.07	0.07	0.09	0.09
Soil + Dust	4.68	7.36	7.44	7.53	5.69	5.16	4.89
Paint	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Uptake	7.59	10.90	11.38	11.42	9.58	9.30	9.30

Figure 3. Comparison of IEUBK Blood Pb Predictions from the Leggett and Pounds (1998) Multi-Source Exposure Scenario with Results Obtained Using IEUBKwin32



When we used the Pb *intake* values from Table 1 as inputs to the Leggett model, the results we obtained were generally similar to those of Pounds and Leggett (Figure 4). Except for age "1" as defined by Pounds and Leggett (from birth to the first birthday), our results are very close to the values from the previous test. For infants less than one year old, our average blood Pb estimate is about 36 percent higher than the earlier estimate (8.5 versus 6.2 µg/dL). Possible explanations for this rather large difference may be differing assumptions about very early exposures patterns, and/or assumptions about when the averaging of blood Pb concentrations was initiated.

Figure 4. Comparison of Predicted Annual Average Blood Pb Concentrations Obtained Based on the IEUBK Default Pb *Intake* Estimates with the Results of Pounds and Leggett (1998)



For older children, our predicted blood Pb levels (based on intake) were very close to, but slightly higher than, the corresponding values obtained by Pounds and Leggett. For age "2," our prediction is about seven percent higher than the earlier estimate, and the difference decreases with age until the difference for children seven years of age is less than two percent. Given the inherent uncertainty in blood Pb modeling and possibly numerous subtle differences in the way the model could have been run, we believe these results represent very good agreement.

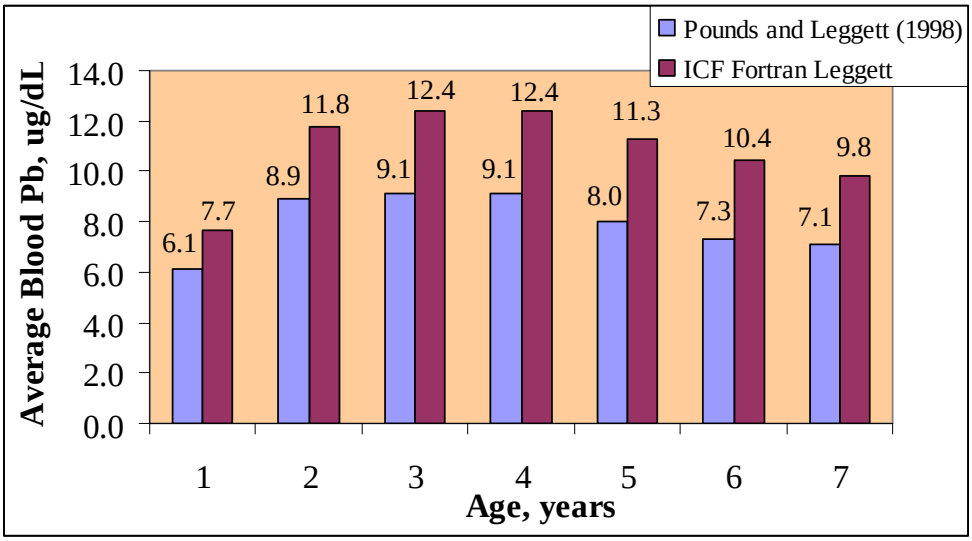
When we used the calculated Pb *uptake* values from Table 1 as model inputs, we obtained substantially different results from Pounds and Leggett when they (presumably) use the same assumptions (Figure 5). For all age groups, our predicted blood Pb levels are 26 to 43 percent higher than the Pounds and Leggett predictions. The reasons for these differences are not clear. However, in attempting to replicate the Pounds and Leggett analysis, we found that, while the age-specific Pb *intakes* we obtained were consistent with the default IEUBK input parameters, we were not able to reproduce the pathway-specific or total Pb *uptake* estimates in the bottom panel of Table 1 (Pounds and Leggett 1998, Table 2) using the default values from the 1994 Technical Support Document. To more completely understand the reasons for the differences in blood Pb predictions, we would need to obtain access to more complete documentation of the exact approaches used by Pounds and Leggett in deriving the intake and uptake estimates and in running the Leggett model. However, given the close agreement between the intake-based results, we believe that the differences are almost certainly due to differences in model inputs, rather than significant differences in model performance.

Summary of Model Comparisons

We found that we were able to almost exactly replicate the IEUBK results reported in previous model comparisons using the newest version of the model. The low-dose blood Pb slope estimated for three year-olds exactly matched the value reported in the Criteria Document, as did the maximum predicted blood lead response to episodic high exposure beginning at age two. Our IEUBK estimates of annual average blood lead estimates arising from the Leggett and Pounds (1998) multi-source scenario were also very close (within 0.1 ug/dL or less) to the previously reported values for all age groups. These results strongly suggest that the application of the IEUBK in the Pilot Risk Assessment was basically consistent with the approaches used previous model comparisons.

In two of the three tests that we conducted, our adaptation of the Fortran version of the Leggett model generated blood Pb predictions that were close or identical to the results obtained in previous calibration and comparison exercises. The low-dose blood Pb slope for three-year old children was within about two percent (0.90 versus 0.88 µg/dL per µg/day uptake) of the value reported in the Criteria Document. The maximum predicted blood Pb level in response to a sudden one-year high exposure beginning at age two (23.2 µg/dL), was identical to that (23 µg/dL) reported in the CD test. Thus, it appears that when the exposure scenarios and intake/uptake assumptions are precisely duplicated, the Fortran version of the Leggett model developed by ICF gives essentially the same results as the model in the hands of other investigators.

Figure 5. Comparison of Predicted Annual Average Blood Pb Concentrations Obtained Based on the IEUBK Default Pb *Uptake* Estimates with the Results of Pounds and Leggett (1998)



As noted above, given similar age patterns of total Pb intake, we were able to rather closely match (within seven percent, except for the youngest age group) the results obtained by Pounds and Leggett (1998) in their model comparison. Larger differences from the Pounds and Leggett results are seen when uptake estimates are used as the basis for blood Pb prediction. As explained above, we believe these differences are likely related to potential inconsistencies in the way Pb uptakes were calculated rather than to differences in model performance per se.

Based on the results presented above, we believe that both the off-the-shelf and ICF's batch version of the Leggett model reliably reproduce the performance of the Leggett model versions used in previous tests. Thus, they can play a useful role in the ongoing NAAQS risk assessment, whether in providing "primary" risk estimates, or as part of the uncertainty analysis supporting the IEUBK-based blood Pb predictions.

4. Estimation of Blood Pb and IQ Loss Distributions for Primary Smelter Current Conditions Scenario Using Fortran Version of Leggett Model

To illustrate the application of the Fortran version of the Leggett model in the NAAQS risk assessment, we applied the model to estimate updated blood Pb distributions and IQ losses for the primary Pb smelter case study current conditions scenario. This scenario is described in detail in Sections 3.1 and 4.1 of the Pilot Phase Risk Assessment Technical Report (ICF 2006). To summarize briefly, air-related exposure concentrations in ambient air, soil and house dust were estimated for each of 137 census blocks and block groups near the primary Pb smelter facility. Exposures were estimated assuming "current conditions," which are derived from recent monitoring data, and by fate and transport modeling based on recent emissions estimates. Exposure concentrations (air, soil, and house dust) for the individual census blocks and block groups are provided in Appendix F of the Technical Report.

To apply the Fortran version of the Leggett model to the primary Pb smelter case study, total ingestion pathway Pb uptake estimates were derived for children in each one-year age group in each census block or block group. In addition to the air-related exposures, "background" Pb intakes from diet and drinking water (assumed to be constant across the census blocks) were calculated for children from birth through age seven. Pb uptake was calculated by combining the ingestion pathway inputs using the exposure, uptake, and intake parameter values shown in Exhibit 5-11 of the Technical Report. Inhalation uptakes were calculated using estimated time-weighted average ambient air concentrations, along with the same age-specific respiratory volumes and inhalation absorption fraction used in the pilot phase risk assessment.

Ingestion and inhalation uptake estimates for each age group and each census block and block group were input into the batch version of the Fortran Leggett model. The daily blood Pb profiles for children in each block or block group generated by the Leggett model were used to calculate lifetime (birth through age seven) and "concurrent" (age 6 to 7) average blood Pb concentrations, as in the Pilot Risk Assessment. The estimated blood Pb levels for the census blocks and block groups were then used as inputs to the probabilistic IQ model described in Sections 5.1.3.4 and 6.1 of the Technical Report, serving as estimates of the geometric mean blood Pb levels.

The results of applying the batch Fortran Leggett model to the primary Pb smelter current conditions scenario are summarized in Table 2. The table is analogous to Table 6-1 in the Technical Report; the predicted blood Pb and IQ changes in the left-hand panel, derived using the IEUBK, have not changed. The right-hand panel of the table displays the blood Pb and IQ loss estimates derived using the batch Fortran Leggett model.

Table2. Comparison of Blood Pb and IQ Loss Distributions Predicted for the Primary Smelter Current Conditions by the IEUBK Model and the Fortran Version of the Leggett Model

Statistic (Percentile Estimate)	IEUBK Model				Leggett Model			
	Concurrent Blood Pb		Lifetime Blood Pb		Concurrent Blood Pb		Lifetime Blood Pb	
	Total Blood Pb (µg/dL)	IQ Loss (Log-Linear Model)	Total Blood Pb (µg/dL)	IQ Loss (Log-Linear Model)	Total Blood Pb (µg/dL)	Loss (Log-Linear Model)	Total Blood Pb (µg/dL)	IQ Loss (Log-Linear Model)
99.9th	21.9	6.0	28.6	4.7	73.6	9.3	83	8.0
99.5th	12.4	4.4	16.9	3.1	41.6	7.6	48	6.2
99th	7.4	3.0	10.6	1.7	29.1	6.8	34	5.3
95th	3.7	1.2	5.3	--	14.2	4.8	17	3.1
90th	2.9	<1	4.1	--	10.9	4.1	13	2.2
75th	2.0	--	2.7	--	7.4	3.0	8.5	<1
Median	1.3	--	1.8	--	5.0	2.0	5.7	--
25th	0.9	--	1.2	--	3.5	<1	3.9	--
1st	0.4	--	0.5	--	1.5	--	1.6	--

Blood lead percentiles predicted by the Leggett model in the revised version of the table are much greater than the corresponding estimates from the IEUBK model, as expected. Similarly, estimates of IQ changes derived from the Leggett blood lead estimates are higher than derived from the IEUBK estimates, and IQ changes are predicted for a larger percentage of the population. The Leggett model predicts that a substantially larger proportion of the population will have concurrent and lifetime average blood lead estimates exceeding the blood lead-IQ model cutoff values.

Table 3 provides a detailed summary of the differences in the population concurrent blood lead percentiles predicted by the IEUBK and Leggett models. This table is analogous to Table 6-12 in the sensitivity analysis section of the Technical Report, except that the last column is now expressed as a ratio of the Leggett to IEUBK percentile blood Pb estimates, rather than a percent difference, to facilitate comparisons with previous analyses (see below). The main contrast with the earlier version of the table is, of course, that the Leggett blood lead percentile predictions are now much greater than the corresponding IEUBK predictions. The ratios for individual percentile values range from about 3.4 to 4.0, with values for more stable percentile estimates below the 99th all being on the order of 3.7 to 3.8.

Table 3. Comparison of Primary Smelter Current Conditions Blood Lead Distributions from the IEUBK and Leggett Models

Percentile	Blood Pb Model		Leggett/ IEUBK
	Leggett (1993) Model	Baseline (IEUBK)	
99.9th	73.6	21.9	3.4
99.5th	41.6	12.4	3.4
99th	29.1	7.4	4.0
95th	14.2	3.7	3.8
90th	10.9	2.9	3.7
75th	7.4	2.0	3.8
Median	5.0	1.3	3.8
25th	3.5	0.9	3.7
1st	1.5	0.4	3.7

The differences we found between the blood Pb levels predicted by the Leggett and IEUBK models are similar to those reported in previous comparisons, although somewhat larger. In the Criteria Document, the low-dose blood Pb slope (Test 1, above) is reported to be 0.36 µg/dL per µg/day uptake, approximately 2.4-fold lower than the 0.88 value calculated for the IEUBK model. Similarly, the maximum blood Pb achieved by the Leggett model in Test 2 (23 µg/dL), is 2.3-fold higher than the corresponding result from the IEUBK model (10 µg/dL). Pounds and Leggett (1998) report that the IEUBK blood Pb predictions for the default scenario as being about 2-fold lower than the results from the Leggett model.

Based on the results of Test 1 reported in the Criteria Document, it would appear that the inherent differences in biokinetic components account for a slightly greater than two-fold difference between blood Pb predictions from the Leggett and the IEUBK models. The fact that we found somewhat larger differences is likely a result of the approach that we employed in estimating ingestion pathway Pb uptake, particularly for the "background" pathways. In contrast to the Leggett model default AFI assumptions, which assume that GI uptake decreases from 45 percent at birth to 30 percent at one year of age, we assumed a constant GI absorption fraction of 0.5 (50 percent) for dietary and drinking water intake for all age groups (zero to seven years). In addition, we employed a constant childhood GI uptake fraction for soil (0.48, based on site-specific data) that was considerably higher than the Leggett AFI values.

When the Fortran Leggett model is run using the primary Pb smelter current conditions exposure concentration inputs and the Leggett default AFI values, the predicted blood Pb levels for the individual census blocks were decreased, as expected. When these values were used as inputs to the probabilistic model, the average ratio of the Fortran Leggett concurrent blood lead percentile estimates to the corresponding IEUBK percentiles was reduced to about 2.6. The average ratio of the lifetime blood Pb

percentiles generated by the two models was approximately 2.3. These results are quite consistent with the relative performance of the IEUBK and Leggett models reported (albeit for different exposure scenarios) in the Criteria Document.

Table 4 is an updated version of Table 6-13 from the Technical Report, which compares the predicted distributions of IQ changes for the Primary Smelter concurrent conditions exposure scenario derived from blood lead distributions obtained using the IEUBK, Leggett, and Lanphear (1998) empirical models.2 As noted above, the Leggett model predicts non-zero IQ changes for the bulk of the exposed population (down to the 25th percentile). In contrast, the other two models predict IQ losses will occur only in about the top 10 percent of the exposed children. As expected, for the percentile values where both models predict IQ losses, the predictions based on the Leggett blood lead distribution are much higher than those based on the IEUBK and Lanphear (1998) models.

Table 4. Comparison of Primary Smelter Current Conditions IQ Change Distributions Based on the IEUBK, Leggett, and Lanphear (1998) Blood Pb Models

Percentile	Blood Pb Model			Change versus Baseline	
	IQ Change Based on Leggett (1993) Model	IQ Change Based on IEUBK Blood Pb Estimates (Baseline)	IQ Change Based on Lanphear et al. (1998) Empirical Model	Effect of Using Leggett Model Blood Pb	Effect of Using Lanphear et al. (1998) Model Blood Pb
99.9th	9.3	6.0	5.1	56%	-15%
99.5th	7.6	4.4	3.7	72%	-16%
99th	6.8	3.0	2.9	124%	-4%
95th	4.8	1.2	1.4	302%	17%
90th	4.1	0.5	0.8	690%	54%
75th	3.0	--	--	--	--
Median	2.0	--	--	--	--
25th	0.7	--	--	--	--
1st	--	--	--	--	--

5. Implications for Use of the Leggett Model in the NAAQS Risk Assessment

The comparisons discussed above make it clear that if the Leggett model is used as part of the ongoing NAAQS risk assessment, it is very likely to generate blood lead and IQ change estimates that are substantially greater than those generated based on the IEUBK model. For a given set of exposures, the tests and sensitivity analyses described above indicate that the Leggett model will likely generate individual blood lead estimates that are about two to three-fold higher, and population blood lead percentile distributions about three to four-fold higher, than the corresponding IEUBK estimates. The bulk of these differences is apparently due to inherent differences in the biokinetic components of the two models, with variations in specifications of absorption factors and other intake, uptake, and exposure factors (within the range we examined) contributing only a small proportion to the observed variations in model predictions.

2 It should be recalled that, unlike the IEUBK and Leggett models, the Lanphear (1998) model estimates "peak" blood lead levels for 16 month-old children. Thus, blood lead-IQ change cutoff values and slope factors used for the Lanphear model are different from those used for the other models, and the Lanphear model IQ loss distributions is not directly comparable to those based on Leggett and IEUBK.

Use of the Leggett model predictions as the basis for IQ change estimates will likewise result in much higher estimates of the proportion of the population affected by exposures (that is, the proportion of the population above blood lead-IQ model cutoff values). Owing to the nonlinearities in the most plausible ("log-linear") blood lead-IQ model, the differences in IQ loss estimates predicted based on Leggett and IEUBK at higher blood lead levels will be considerably less than the corresponding ratios of the predicted blood lead levels. It thus appears that use of the Leggett model would have most impact on relative risk (IQ change) estimates compared to the IEUBK in populations that experience moderate levels of exposure, where predicted blood lead levels are above IQ model cutoffs, but below values where the blood lead-IQ model "flattens out" significantly.

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