Inverse Adding-Doubling

(Version 3-15-0)

1. `iad` program.
Here is a relatively robust command-line utility that shows how the iad and ad subroutines might be called. It suffers because it is written in `CWEB` and I used the macro expansion feature instead of creating separate functions. Oh well.

I create an empty file `iad_main.h` to simplify the Makefile

⟨ `iad_main.h` 1 ⟩ ≡

2. All the actual output for this web file goes into `iad_main.c`

```
⟨ iad_main.c 2 ⟩ ≡
  ⟨ Include files for main 3 ⟩
  ⟨ print version function 18 ⟩
  ⟨ print usage function 19 ⟩
  ⟨ stringdup together function 25 ⟩
  ⟨ mystrtod function 26 ⟩
  ⟨ seconds elapsed function 27 ⟩
  ⟨ print error legend function 24 ⟩
  ⟨ print dot function 29 ⟩
  ⟨ calculate coefficients function 20 ⟩
  ⟨ parse string into array function 28 ⟩
  ⟨ print results header function 22 ⟩
  ⟨ Print results function 23 ⟩
  int main(int argc, char **argv)
  {
    ⟨ Declare variables for main 4 ⟩
    ⟨ Handle options 5 ⟩
    Initialize_Measure(&m);
    ⟨ Command-line changes to m 16 ⟩
    Initialize_Result(m, &r);
    ⟨ Command-line changes to r 13 ⟩
    if (cl_forward_calc ≠ UNINITIALIZED) {
      ⟨ Calculate and Print the Forward Calculation 6 ⟩
      exit(EXIT_SUCCESS);
    }
    ⟨ prepare file for reading 10 ⟩
    if (process_command_line) {
      ⟨ Count command-line measurements 17 ⟩
      ⟨ Calculate and write optical properties 11 ⟩
      exit(EXIT_SUCCESS);
    }
    if (Read_Header(stdin, &m, &params) ≡ 0) {
      start_time = clock( );
      while (Read_Data_Line(stdin, &m, params) ≡ 0) {
        ⟨ Command-line changes to m 16 ⟩
        ⟨ Calculate and write optical properties 11 ⟩
      }
    }
    if (cl_verbosity > 0) fprintf(stderr, "\n\n");
    if (any_error ∧ cl_verbosity > 1) print_error_legend( );
    exit(EXIT_SUCCESS);
  }
```

3. The first two defines are to stop Visual C++ from silly complaints

⟨ Include files for *main* 3 ⟩ ≡

```
#define _CRT_SECURE_NO_WARNINGS
#define _CRT_NONSTDC_NO_WARNINGS
#define NO_SLIDES 0
#define ONE_SLIDE_ON_TOP 1
#define TWO_IDENTICAL_SLIDES 2
#define ONE_SLIDE_ON_BOTTOM 3
#define ONE_SLIDE_NEAR_SPHERE 4
#define ONE_SLIDE_NOT_NEAR_SPHERE 5
#define MR_IS_ONLY_RD 1
#define MT_IS_ONLY_TD 2
#define NO_UNSCATTERED_LIGHT 3
#include <stdio.h>
#include <string.h>
#include <stdlib.h>
#include <unistd.h>
#include <time.h>
#include <math.h>
#include <ctype.h>
#include <errno.h>
#include "ad_globl.h"
#include "ad_prime.h"
#include "iad_type.h"
#include "iad_pub.h"
#include "iad_io.h"
#include "iad_calc.h"
#include "iad_util.h"
#include "version.h"
#include "mc_lost.h"
#include "ad_frsnl.h"
```

See also section 31.

This code is used in sections 2 and 30.

4. ⟨ Declare variables for *main* 4 ⟩ ≡

```
struct measure_type m;
struct invert_type r;
char *g_out_name = Λ;
int c;
long n_photons = 100000;
int MC_iterations = 19;
int any_error = 0;
int process_command_line = 0;
int params = 0;
int cl_quadrature_points = UNINITIALIZED;
int cl_verbosity = 2;
double cl_forward_calc = UNINITIALIZED;
double cl_default_a = UNINITIALIZED;
double cl_default_g = UNINITIALIZED;
double cl_default_b = UNINITIALIZED;
double cl_default_mua = UNINITIALIZED;
double cl_default_mus = UNINITIALIZED;
double cl_tolerance = UNINITIALIZED;
double cl_slide_OD = UNINITIALIZED;
double cl_cos_angle = UNINITIALIZED;
double cl_beam_d = UNINITIALIZED;
double cl_sample_d = UNINITIALIZED;
double cl_sample_n = UNINITIALIZED;
double cl_slide_d = UNINITIALIZED;
double cl_slide_n = UNINITIALIZED;
double cl_slides = UNINITIALIZED;
double cl_default_fr = UNINITIALIZED;
double cl_rstd_t = UNINITIALIZED;
double cl_rstd_r = UNINITIALIZED;
double cl_baffle_r = UNINITIALIZED;
double cl_baffle_t = UNINITIALIZED;
double cl_rc_fraction = UNINITIALIZED;
double cl_tc_fraction = UNINITIALIZED;
double cl_gain_type = UNINITIALIZED;
double cl_search = UNINITIALIZED;
double cl_mus0 = UNINITIALIZED;
double cl_musp0 = UNINITIALIZED;
double cl_mus0_pwr = UNINITIALIZED;
double cl_mus0_lambda = UNINITIALIZED;
double cl_UR1 = UNINITIALIZED;
double cl_UT1 = UNINITIALIZED;
double cl_Tc = UNINITIALIZED;
double cl_method = UNINITIALIZED;
int cl_num_spheres = UNINITIALIZED;
double cl_sphere_one[5] = {UNINITIALIZED, UNINITIALIZED, UNINITIALIZED, UNINITIALIZED,
    UNINITIALIZED};
double cl_sphere_two[5] = {UNINITIALIZED, UNINITIALIZED, UNINITIALIZED, UNINITIALIZED,
    UNINITIALIZED};
clock_t start_time = clock( );
char command_line_options[ ] = "1:2:a:A:b:B:c:C:d:D:e:E:f:F:g:G:hH:i:n:N:M:o:p:q:r:R:s:S:t:\
    T:u:vV:x:Xy:z";
```

See also section 32.

This code is used in sections 2 and 30.

5. use the *getopt*( ) to process options.

```
⟨ Handle options 5 ⟩ ≡
  while ((c = getopt(argc, argv, command_line_options)) ≠ EOF) {
    int n;
    char cc;
    char *tmp_str = Λ;
    switch (c) {
    case '1': tmp_str = strdup(optarg);
      parse_string_into_array(optarg, cl_sphere_one, 5);
      if (cl_sphere_one[4] ≡ UNINITIALIZED) {
        fprintf(stderr, "Error␣in␣command-line␣argument␣for␣-1\n");
        fprintf(stderr, "␣␣␣␣␣the␣current␣argument␣is␣'%s'␣but␣it␣must␣have␣5␣terms:␣", tmp_str);
        fprintf(stderr, "'d_sphere␣d_sample␣d_empty␣d_detector␣r_wall'\n");
        exit(EXIT_FAILURE);
      }
      break;
    case '2': tmp_str = strdup(optarg);
      parse_string_into_array(optarg, cl_sphere_two, 5);
      if (cl_sphere_two[4] ≡ UNINITIALIZED) {
        fprintf(stderr, "Error␣in␣command-line␣argument␣for␣-2\n");
        fprintf(stderr, "␣␣␣␣␣the␣current␣argument␣is␣'%s'␣but␣it␣must␣have␣5␣terms:␣", tmp_str);
        fprintf(stderr, "'d_sphere␣d_sample␣d_empty␣d_detector␣r_wall'\n");
        exit(EXIT_FAILURE);
      }
      break;
    case 'a': cl_default_a = my_strtod(optarg);
      if (cl_default_a < 0 ∨ cl_default_a > 1) {
        fprintf(stderr, "Error␣in␣command-line\n");
        fprintf(stderr, "␣␣␣␣␣albedo␣'-a␣%s'\n", optarg);
        exit(EXIT_FAILURE);
      }
      break;
    case 'A': cl_default_mua = my_strtod(optarg);
      if (cl_default_mua < 0) {
        fprintf(stderr, "Error␣in␣command-line\n");
        fprintf(stderr, "␣␣␣␣␣absorption␣'-A␣%s'\n", optarg);
        exit(EXIT_FAILURE);
      }
      break;
    case 'b': cl_default_b = my_strtod(optarg);
      if (cl_default_b < 0) {
        fprintf(stderr, "Error␣in␣command-line\n");
        fprintf(stderr, "␣␣␣␣␣optical␣thickness␣'-b␣%s'\n", optarg);
        exit(EXIT_FAILURE);
      }
      break;
    case 'B': cl_beam_d = my_strtod(optarg);
      if (cl_beam_d < 0) {
        fprintf(stderr, "Error␣in␣command-line\n");
        fprintf(stderr, "␣␣␣␣␣beam␣diameter␣'-B␣%s'\n", optarg);
        exit(EXIT_FAILURE);
      }
```

```
    break;
  case 'c': cl_rc_fraction = my_strtod(optarg);
    if (cl_rc_fraction < 0.0 ∨ cl_rc_fraction > 1.0) {
      fprintf(stderr, "Error␣in␣command-line\n");
      fprintf(stderr, "␣␣␣␣unscattered␣refl␣fraction␣'-c␣%s'\n", optarg);
      fprintf(stderr, "␣␣␣␣must␣be␣between␣0␣and␣1\n");
      exit(EXIT_SUCCESS);
    }
    break;
  case 'C': cl_tc_fraction = my_strtod(optarg);
    if (cl_tc_fraction < 0.0 ∨ cl_tc_fraction > 1.0) {
      fprintf(stderr, "Error␣in␣command-line\n");
      fprintf(stderr, "␣␣␣␣unscattered␣trans␣fraction␣'-C␣%s'\n", optarg);
      fprintf(stderr, "␣␣␣␣must␣be␣between␣0␣and␣1\n");
      exit(EXIT_SUCCESS);
    }
    break;
  case 'd': cl_sample_d = my_strtod(optarg);
    if (cl_sample_d < 0) {
      fprintf(stderr, "Error␣in␣command-line\n");
      fprintf(stderr, "␣␣␣␣sample␣thickness␣'-d␣%s'\n", optarg);
      exit(EXIT_FAILURE);
    }
    break;
  case 'D': cl_slide_d = my_strtod(optarg);
    if (cl_slide_d < 0) {
      fprintf(stderr, "Error␣in␣command-line\n");
      fprintf(stderr, "␣␣␣␣slide␣thickness␣'-D␣%s'\n", optarg);
      exit(EXIT_FAILURE);
    }
    break;
  case 'e': cl_tolerance = my_strtod(optarg);
    if (cl_tolerance < 0) {
      fprintf(stderr, "Error␣in␣command-line\n");
      fprintf(stderr, "␣␣␣␣error␣tolerance␣'-e␣%s'\n", optarg);
      exit(EXIT_FAILURE);
    }
    break;
  case 'E': cl_slide_OD = my_strtod(optarg);
    if (cl_slide_OD < 0) {
      fprintf(stderr, "Error␣in␣command-line\n");
      fprintf(stderr, "␣␣␣␣slide␣optical␣depth␣'-E␣%s'\n", optarg);
      exit(EXIT_FAILURE);
    }
    break;
  case 'f': cl_default_fr = my_strtod(optarg);
    if (cl_default_fr < 0.0 ∨ cl_default_fr > 1.0) {
      fprintf(stderr, "Error␣in␣command-line␣argument:␣");
      fprintf(stderr, "'-f␣%s'␣The␣argument␣must␣be␣between␣0␣and␣1.\n", optarg);
      exit(EXIT_SUCCESS);
    }
    break;
```

```
case 'F':      /* initial digit means this is mus is constant */
  if (isdigit(optarg[0])) {
    cl_default_mus = my_strtod(optarg);
    if (cl_default_mus < 0) {
      fprintf(stderr, "Error in command-line\n");
      fprintf(stderr, "    mus '-F %s'\n", optarg);
      exit(EXIT_FAILURE);
    }
    break;
  }     /* should be a string like 'R 1000 1.2 -1.8' */
  n = sscanf(optarg, "%c %lf %lf %lf", &cc, &cl_mus0_lambda, &cl_mus0, &cl_mus0_pwr);
  if (n ≠ 4 ∨ (cc ≠ 'P' ∧ cc ≠ 'R')) {
    fprintf(stderr, "Error in command-line\n");
    fprintf(stderr, "    bad -F option. '-F %s'\n", optarg);
    fprintf(stderr, "    -F 1.0                for mus=1.0\n");
    fprintf(stderr, "    -F 'P 500 1.0 -1.3' for mus=1.0*(lambda/500)^(-1.3)\n");
    fprintf(stderr, "    -F 'R 500 1.0 -1.3' for mus'=1.0*(lambda/500)^(-1.3)\n");
    exit(EXIT_FAILURE);
  }
  if (cc ≡ 'R' ∨ cc ≡ 'r') {
    cl_musp0 = cl_mus0;
    cl_mus0 = UNINITIALIZED;
  }
  break;
case 'g': cl_default_g = my_strtod(optarg);
  if (cl_default_g < -1 ∨ cl_default_g > 1) {
    fprintf(stderr, "Error in command-line\n");
    fprintf(stderr, "    anisotropy '-g %s'\n", optarg);
    exit(EXIT_FAILURE);
  }
  break;
case 'G':
  if (optarg[0] ≡ '0') cl_slides = NO_SLIDES;
  else if (optarg[0] ≡ '2') cl_slides = TWO_IDENTICAL_SLIDES;
  else if (optarg[0] ≡ 't' ∨ optarg[0] ≡ 'T') cl_slides = ONE_SLIDE_ON_TOP;
  else if (optarg[0] ≡ 'b' ∨ optarg[0] ≡ 'B') cl_slides = ONE_SLIDE_ON_BOTTOM;
  else if (optarg[0] ≡ 'n' ∨ optarg[0] ≡ 'N') cl_slides = ONE_SLIDE_NEAR_SPHERE;
  else if (optarg[0] ≡ 'f' ∨ optarg[0] ≡ 'F') cl_slides = ONE_SLIDE_NOT_NEAR_SPHERE;
  else {
    fprintf(stderr, "Error in command-line\n");
    fprintf(stderr, "    Argument for '-G %s' must be \n", optarg);
    fprintf(stderr, "    't' --- light always hits top slide first\n");
    fprintf(stderr, "    'b' --- light always hits bottom slide first\n");
    fprintf(stderr, "    'n' --- slide always closest to sphere\n");
    fprintf(stderr, "    'f' --- slide always farthest from sphere\n");
    exit(EXIT_FAILURE);
  }
  break;
case 'H':
  if (optarg[0] ≡ '0') {
    cl_baffle_r = 0;
    cl_baffle_t = 0;
```

```
    }
    else if (optarg[0] ≡ '1') {
      cl_baffle_r = 1;
      cl_baffle_t = 0;
    }
    else if (optarg[0] ≡ '2') {
      cl_baffle_r = 0;
      cl_baffle_t = 1;
    }
    else if (optarg[0] ≡ '3') {
      cl_baffle_r = 1;
      cl_baffle_t = 1;
    }
    else {
      fprintf(stderr, "Error␣in␣command-line␣-H␣argument\n");
      fprintf(stderr, "␣␣␣␣␣argument␣is␣'%s',␣but␣", optarg);
      fprintf(stderr, "must␣be␣0,␣1,␣2,␣or␣3\n");
      exit(EXIT_FAILURE);
    }
  case 'i': cl_cos_angle = my_strtod(optarg);
    if (cl_cos_angle < 0 ∨ cl_cos_angle > 90) {
      fprintf(stderr, "Error␣in␣command-line\n");
      fprintf(stderr, "␣␣␣␣␣incident␣angle␣'-i␣%s'\n", optarg);
      fprintf(stderr, "␣␣␣␣␣must␣be␣between␣0␣and␣90␣degrees\n");
      exit(EXIT_FAILURE);
    }
    cl_cos_angle = cos(cl_cos_angle ∗ M_PI/180.0);
    break;
  case 'M': MC_iterations = (int) my_strtod(optarg);
    if (MC_iterations < 0 ∨ MC_iterations > 50) {
      fprintf(stderr, "Error␣in␣command-line\n");
      fprintf(stderr, "␣␣␣␣␣MC␣iterations␣'-M␣%s'\n", optarg);
      exit(EXIT_FAILURE);
    }
    break;
  case 'n': cl_sample_n = my_strtod(optarg);
    if (cl_sample_n < 0.1 ∨ cl_sample_n > 10) {
      fprintf(stderr, "Error␣in␣command-line\n");
      fprintf(stderr, "␣␣␣␣␣slab␣index␣'-n␣%s'\n", optarg);
      exit(EXIT_FAILURE);
    }
    break;
  case 'N': cl_slide_n = my_strtod(optarg);
    if (cl_slide_n < 0.1 ∨ cl_slide_n > 10) {
      fprintf(stderr, "Error␣in␣command-line\n");
      fprintf(stderr, "␣␣␣␣␣slide␣index␣'-N␣%s'\n", optarg);
      exit(EXIT_FAILURE);
    }
    break;
  case 'o': g_out_name = strdup(optarg);
    break;
  case 'p': n_photons = (long) my_strtod(optarg);
```

```
    break;
  case 'q': cl_quadrature_points = (int) my_strtod(optarg);
    if (cl_quadrature_points % 4 ≠ 0) {
      fprintf(stderr, "Error␣in␣command-line\n");
      fprintf(stderr, "␣␣␣␣'-q␣%s'\n", optarg);
      fprintf(stderr, "␣␣␣␣Quadrature␣points␣must␣be␣a␣multiple␣of␣4\n");
      exit(EXIT_FAILURE);
    }
    if ((cl_cos_angle ≠ UNINITIALIZED) ∧ (cl_quadrature_points % 12 ≠ 0)) {
      fprintf(stderr, "Error␣in␣command-line\n");
      fprintf(stderr, "␣␣␣␣'-q␣%s'\n", optarg);
      fprintf(stderr,
          "␣␣␣␣Quadrature␣points␣must␣be␣multiple␣of␣12␣for␣oblique␣incidence\n");
      exit(EXIT_FAILURE);
    }
    break;
  case 'r': cl_UR1 = my_strtod(optarg);
    process_command_line = 1;
    if (cl_UR1 < 0 ∨ cl_UR1 > 1) {
      fprintf(stderr, "Error␣in␣command-line\n");
      fprintf(stderr, "␣␣␣␣UR1␣value␣'-r␣%s'\n", optarg);
      fprintf(stderr, "␣␣␣␣must␣be␣between␣0␣and␣1\n");
      exit(EXIT_FAILURE);
    }
    break;
  case 'R': cl_rstd_r = my_strtod(optarg);
    if (cl_rstd_r < 0 ∨ cl_rstd_r > 1) {
      fprintf(stderr, "Error␣in␣command-line\n");
      fprintf(stderr, "␣␣␣␣Rstd␣value␣'-R␣%s'\n", optarg);
      fprintf(stderr, "␣␣␣␣must␣be␣between␣0␣and␣1\n");
      exit(EXIT_FAILURE);
    }
    break;
  case 's': cl_search = (int) my_strtod(optarg);
    break;
  case 'S': cl_num_spheres = (int) my_strtod(optarg);
    if (cl_num_spheres ≠ 0 ∧ cl_num_spheres ≠ 1 ∧ cl_num_spheres ≠ 2) {
      fprintf(stderr, "Error␣in␣command-line\n");
      fprintf(stderr, "␣␣␣␣sphere␣number␣'-S␣%s'\n", optarg);
      fprintf(stderr, "␣␣␣␣must␣be␣0,␣1,␣or␣2\n");
      exit(EXIT_FAILURE);
    }
    break;
  case 't': cl_UT1 = my_strtod(optarg);
    if (cl_UT1 < 0 ∨ cl_UT1 > 1) {
      fprintf(stderr, "Error␣in␣command-line\n");
      fprintf(stderr, "␣␣␣␣UT1␣value␣'-t␣%s'\n", optarg);
      fprintf(stderr, "␣␣␣␣must␣be␣between␣0␣and␣1\n");
      exit(EXIT_FAILURE);
    }
    process_command_line = 1;
    break;
```

```
    case 'T': cl_rstd_t = my_strtod(optarg);
      if (cl_rstd_t < 0 ∨ cl_rstd_t > 1) {
        fprintf(stderr, "Error␣in␣command-line\n");
        fprintf(stderr, "␣␣␣␣␣transmission␣standard␣'-T␣%s'\n", optarg);
        fprintf(stderr, "␣␣␣␣␣must␣be␣between␣0␣and␣1\n");
        exit(EXIT_FAILURE);
      }
      break;
    case 'u': cl_Tc = my_strtod(optarg);
      if (cl_Tc < 0 ∨ cl_Tc > 1) {
        fprintf(stderr, "Error␣in␣command-line\n");
        fprintf(stderr, "␣␣␣␣␣unscattered␣transmission␣'-u␣%s'\n", optarg);
        fprintf(stderr, "␣␣␣␣␣must␣be␣between␣0␣and␣1\n");
        exit(EXIT_FAILURE);
      }
      process_command_line = 1;
      break;
    case 'v': print_version(cl_verbosity);
      exit(EXIT_SUCCESS);
      break;
    case 'V': cl_verbosity = my_strtod(optarg);
      break;
    case 'x': Set_Debugging((int) my_strtod(optarg));
      break;
    case 'X': cl_method = COMPARISON;
      break;
    case 'y': cl_gain_type = (int) my_strtod(optarg);
      break;
    case 'z': cl_forward_calc = 1;
      process_command_line = 1;
      break;
    default: fprintf(stderr, "unknown␣option␣'%c'\n", c);      /* fall through */
    case 'h': print_usage( );
      exit(EXIT_SUCCESS);
    }
  }
  argc -= optind;
  argv += optind;
```

This code is used in section 2.

6. We are doing a forward calculation. We still need to set the albedo and optical depth appropriately. Obviously when the -a switch is used then the albedo should be fixed as a constant equal to *cl_default_a*. The other cases are less clear. If scattering and absorption are both specified, then calculate the albedo using these values. If the scattering is not specified, then we assume that the sample is an unscattering sample and therefore the albedo is zero. On the other hand, if the scattering is specified and the absorption is not, then the albedo is set to one.

```
⟨ Calculate and Print the Forward Calculation 6 ⟩ ≡
  if (cl_default_a ≡ UNINITIALIZED) {
    if (cl_default_mus ≡ UNINITIALIZED) r.a = 0;
    else if (cl_default_mua ≡ UNINITIALIZED) r.a = 1;
    else r.a = cl_default_mus/(cl_default_mua + cl_default_mus);
  }
  else r.a = cl_default_a;
```

See also sections 7, 8, and 9.

This code is used in section 2.

7. This is slightly more tricky because there are four things that can affect the optical thickness — *cl_default_b*, the default mua, default mus and the thickness. If the sample thickness is unspecified, then the only reasonable thing to do is to assume that the sample is very thick. Otherwise, we use the sample thickness to calculate the optical thickness.

```
⟨ Calculate and Print the Forward Calculation 6 ⟩ +≡
  if (cl_default_b ≡ UNINITIALIZED) {
    if (cl_sample_d ≡ UNINITIALIZED) r.b = HUGE_VAL;
    else if (r.a ≡ 0) {
      if (cl_default_mua ≡ UNINITIALIZED) r.b = HUGE_VAL;
      else r.b = cl_default_mua ∗ cl_sample_d;
    }
    else {
      if (cl_default_mus ≡ UNINITIALIZED) r.b = HUGE_VAL;
      else r.b = cl_default_mus/r.a ∗ cl_sample_d;
    }
  }
  else r.b = cl_default_b;
```

8. The easiest case, use the default value or set it to zero

```
⟨ Calculate and Print the Forward Calculation 6 ⟩ +≡
  if (cl_default_g ≡ UNINITIALIZED) r.g = 0;
  else r.g = cl_default_g;
```

9. ⟨ Calculate and Print the Forward Calculation 6 ⟩ +≡

```
r.slab.a = r.a;
r.slab.b = r.b;
r.slab.g = r.g;
{
  double mu_sp, mu_a, m_r, m_t;
  Calculate_MR_MT(m, r, MC_iterations, &m_r, &m_t);
  Calculate_Mua_Musp(m, r, &mu_sp, &mu_a);
  if (cl_verbosity > 0) {
    Write_Header(m, r, -1);
    print_results_header(stdout);
  }
  print_optical_property_result(stdout, m, r, m_r, m_t, mu_a, mu_sp, 0, 0);
}
```

10. Make sure that the file is not named '-' and warn about too many files

⟨ prepare file for reading 10 ⟩ ≡

```
if (argc > 1) {
  fprintf(stderr, "Only␣a␣single␣file␣can␣be␣processed␣at␣a␣time\n");
  fprintf(stderr, "try␣'apply␣iad␣file1␣file2␣...␣fileN'\n");
  exit(EXIT_FAILURE);
}
if (argc ≡ 1 ∧ strcmp(argv[0], "-") ≠ 0) {      /* filename exists and != "-" */
  int n;
  char *base_name, *rt_name;
  base_name = strdup(argv[0]);
  n = (int)(strlen(base_name) − strlen(".rxt"));
  if (n > 0 ∧ strstr(base_name + n, ".rxt") ≠ Λ) base_name[n] = '\0';
  rt_name = strdup_together(base_name, ".rxt");
  if (freopen(argv[0], "r", stdin) ≡ Λ ∧ freopen(rt_name, "r", stdin) ≡ Λ) {
    fprintf(stderr, "Could␣not␣open␣either␣'%s'␣or␣'%s'\n", argv[0], rt_name);
    exit(EXIT_FAILURE);
  }
  if (g_out_name ≡ Λ) g_out_name = strdup_together(base_name, ".txt");
  free(rt_name);
  free(base_name);
  process_command_line = 0;
}
if (g_out_name ≠ Λ) {
  if (freopen(g_out_name, "w", stdout) ≡ Λ) {
    fprintf(stderr, "Could␣not␣open␣file␣'%s'␣for␣output\n", g_out_name);
    exit(EXIT_FAILURE);
  }
}
```

This code is used in section 2.

11. Need to explicitly reset *r.search* each time through the loop, because it will get altered by the calculation process. We want to be able to let different lines have different constraints. In particular consider the file `newton.tst`. In that file the first two rows contain three real measurements and the last two have the collimated transmission explicitly set to zero — in other words there are really only two measurements.

```
⟨ Calculate and write optical properties 11 ⟩ ≡
  {
    ⟨ Local Variables for Calculation 12 ⟩
    if (Debug(DEBUG_ANY)) {
      fprintf(stderr, "\n--------------------NEXT␣DATA␣POINT---------------------\n");
      if (m.lambda ≠ 0) fprintf(stderr, "lambda=%6.1f␣", m.lambda);
      fprintf(stderr, "MR=%8.5f␣MT=%8.5f\n\n", m.m_r, m.m_t);
    }
    Initialize_Result(m, &r);
    ⟨ Command-line changes to r 13 ⟩
    if (cl_method ≡ COMPARISON ∧ m.d_sphere_r ≠ 0 ∧ m.as_r ≡ 0) {
      fprintf(stderr, "A␣dual-beam␣measurement␣is␣specified,␣but␣no␣port␣sizes.\n");
      fprintf(stderr, "You␣might␣forsake␣the␣-X␣option␣and␣use␣zero␣spheres␣(which␣gives\n");
      fprintf(stderr, "the␣same␣result␣except␣lost␣light␣is␣not␣taken␣into␣account).\n");
      fprintf(stderr, "Alternatively,␣bite␣the␣bullet␣and␣enter␣your␣sphere␣parameters,\n");
      fprintf(stderr, "with␣the␣knowledge␣that␣only␣the␣beam␣diameter␣and␣sample␣port\n");
      fprintf(stderr, "diameter␣will␣be␣used␣to␣estimate␣lost␣light␣from␣the␣edges.\n");
      exit(EXIT_SUCCESS);
    }
    if (cl_method ≡ COMPARISON ∧ m.num_spheres ≡ 2) {
      fprintf(stderr, "A␣dual-beam␣measurement␣is␣specified,␣but␣a␣two␣sphere␣experiment\n");
      fprintf(stderr, "is␣specified.␣Since␣this␣seems␣impossible,␣I␣will␣make␣it\n");
      fprintf(stderr, "impossible␣for␣you␣unless␣you␣specify␣0␣or␣1␣sphere.\n");
      exit(EXIT_SUCCESS);
    }
    ⟨ Write Header 14 ⟩
    Inverse_RT(m, &r);
    if (r.error ≡ IAD_NO_ERROR) {
      calculate_coefficients(m, r, &LR, &LT, &mu_sp, &mu_a);
      ⟨ Improve result using Monte Carlo 15 ⟩
    }
    print_optical_property_result(stdout, m, r, LR, LT, mu_a, mu_sp, mc_iter, rt_total);
    if (Debug(DEBUG_LOST_LIGHT)) fprintf(stderr, "\n");
    else print_dot(start_time, r.error, mc_total, rt_total, 99, cl_verbosity, &any_error);
  }
```

See also section 34.

This code is used in sections 2 and 30.

12.

⟨ Local Variables for Calculation 12 ⟩ ≡

```
static int rt_total = 0;
static int mc_total = 0;
int mc_iter = 0;
double ur1 = 0;
double ut1 = 0;
double uru = 0;
double utu = 0;
double mu_a = 0;
double mu_sp = 0;
double LR = 0;
double LT = 0;
rt_total++;
```

This code is used in section 11.

13. ⟨ Command-line changes to r 13 ⟩ ≡

```
if (cl_quadrature_points ≠ UNINITIALIZED) r.method.quad_pts = cl_quadrature_points;
else r.method.quad_pts = 8;
if (cl_default_a ≠ UNINITIALIZED) r.default_a = cl_default_a;
if (cl_default_mua ≠ UNINITIALIZED) {
  r.default_mua = cl_default_mua;
  if (cl_sample_d ≠ UNINITIALIZED) r.default_ba = cl_default_mua * cl_sample_d;
  else r.default_ba = cl_default_mua * m.slab_thickness;
}
if (cl_default_b ≠ UNINITIALIZED) r.default_b = cl_default_b;
if (cl_default_g ≠ UNINITIALIZED) r.default_g = cl_default_g;
if (cl_tolerance ≠ UNINITIALIZED) {
  r.tolerance = cl_tolerance;
  r.MC_tolerance = cl_tolerance;
}
if (cl_musp0 ≠ UNINITIALIZED)
  cl_mus0 = (r.default_g ≠ UNINITIALIZED) ? cl_musp0/(1 − r.default_g) : cl_musp0;
if (cl_mus0 ≠ UNINITIALIZED ∧ m.lambda ≠ 0)
  cl_default_mus = cl_mus0 * pow(m.lambda/cl_mus0_lambda, cl_mus0_pwr);
if (cl_default_mus ≠ UNINITIALIZED) {
  r.default_mus = cl_default_mus;
  if (cl_sample_d ≠ UNINITIALIZED) r.default_bs = cl_default_mus * cl_sample_d;
  else r.default_bs = cl_default_mus * m.slab_thickness;
}
if (cl_search ≠ UNINITIALIZED) r.search = cl_search;
```

This code is used in sections 2 and 11.

14. ⟨ Write Header 14 ⟩ ≡

```
if (rt_total ≡ 1 ∧ cl_verbosity > 0) {
  Write_Header(m, r, params);
  if (MC_iterations > 0) {
    if (n_photons ≥ 0)
      fprintf(stdout, "#␣␣Photons␣used␣to␣estimate␣lost␣light␣=␣␣␣%ld\n", n_photons);
    else fprintf(stdout, "#␣␣␣␣␣␣Time␣used␣to␣estimate␣lost␣light␣=␣␣␣%ld␣ms\n", −n_photons);
  }
  else fprintf(stdout, "#␣␣Photons␣used␣to␣estimate␣lost␣light␣=␣␣␣0\n");
  fprintf(stdout, "#\n");
  print_results_header(stdout);
}
```

This code is used in section 11.

15. Use Monte Carlo to figure out how much light leaks out. We use the sphere corrected values as the starting values and only do try Monte Carlo when spheres are used, the albedo unknown or non-zero, and there has been no error. The sphere parameters must be known because otherwise the beam size and the port size are unknown.

⟨ Improve result using Monte Carlo 15 ⟩ ≡

```
if (m.as_r ≠ 0 ∧ r.default_a ≠ 0 ∧ m.num_spheres > 0) {
  double mu_sp_last = mu_sp;
  double mu_a_last = mu_a;
  if (Debug(DEBUG_LOST_LIGHT)) {
    print_results_header(stderr);
    print_optical_property_result(stderr, m, r, LR, LT, mu_a, mu_sp, mc_iter, rt_total);
  }
  while (mc_iter < MC_iterations) {
    MC_Lost(m, r, n_photons, &ur1, &ut1, &uru, &utu, &m.ur1_lost, &m.ut1_lost, &m.uru_lost,
        &m.utu_lost);
    mc_total++;
    mc_iter++;
    Inverse_RT(m, &r);
    calculate_coefficients(m, r, &LR, &LT, &mu_sp, &mu_a);
    if (fabs(mu_a_last − mu_a)/(mu_a + 0.0001) < r.MC_tolerance ∧ fabs(mu_sp_last − mu_sp)/(mu_sp +
        0.0001) < r.MC_tolerance) break;
    mu_a_last = mu_a;
    mu_sp_last = mu_sp;
    if (Debug(DEBUG_LOST_LIGHT))
      print_optical_property_result(stderr, m, r, LR, LT, mu_a, mu_sp, mc_iter, rt_total);
    else print_dot(start_time, r.error, mc_total, rt_total, mc_iter, cl_verbosity, &any_error);
    if (r.error ≠ IAD_NO_ERROR) break;
  }
}
```

This code is used in section 11.

16. Stuff the command line arguments that should be constant over the entire inversion process into the measurement record and set up the result record to handle the arguments properly so that the optical properties can be determined.

```
⟨ Command-line changes to m 16 ⟩ ≡
  if (cl_cos_angle ≠ UNINITIALIZED) {
    m.slab_cos_angle = cl_cos_angle;
    if (cl_quadrature_points ≡ UNINITIALIZED) cl_quadrature_points = 12;
    if (cl_quadrature_points ≠ 12 * (cl_quadrature_points/12)) {
      fprintf(stderr,
          "If you use the -i option to specify an oblique incidence angle, then\n");
      fprintf(stderr, "the number of quadrature points must be a multiple of 12\n");
      exit(EXIT_SUCCESS);
    }
  }
  if (cl_sample_n ≠ UNINITIALIZED) m.slab_index = cl_sample_n;
  if (cl_slide_n ≠ UNINITIALIZED) {
    m.slab_bottom_slide_index = cl_slide_n;
    m.slab_top_slide_index = cl_slide_n;
  }
  if (cl_slide_OD ≠ UNINITIALIZED) {
    m.slab_bottom_slide_b = cl_slide_OD;
    m.slab_top_slide_b = cl_slide_OD;
  }
  if (cl_sample_d ≠ UNINITIALIZED) m.slab_thickness = cl_sample_d;
  if (cl_beam_d ≠ UNINITIALIZED) m.d_beam = cl_beam_d;
  if (cl_slide_d ≠ UNINITIALIZED) {
    m.slab_bottom_slide_thickness = cl_slide_d;
    m.slab_top_slide_thickness = cl_slide_d;
  }
  if (cl_slides ≡ NO_SLIDES) {
    m.slab_bottom_slide_index = 1.0;
    m.slab_bottom_slide_thickness = 0.0;
    m.slab_top_slide_index = 1.0;
    m.slab_top_slide_thickness = 0.0;
  }
  if (cl_slides ≡ ONE_SLIDE_ON_TOP ∨ cl_slides ≡ ONE_SLIDE_NEAR_SPHERE) {
    m.slab_bottom_slide_index = 1.0;
    m.slab_bottom_slide_thickness = 0.0;
  }
  if (cl_slides ≡ ONE_SLIDE_ON_BOTTOM ∨ cl_slides ≡ ONE_SLIDE_NOT_NEAR_SPHERE) {
    m.slab_top_slide_index = 1.0;
    m.slab_top_slide_thickness = 0.0;
  }
  if (cl_slides ≡ ONE_SLIDE_NEAR_SPHERE ∨ cl_slides ≡ ONE_SLIDE_NOT_NEAR_SPHERE) m.flip_sample = 1;
  else m.flip_sample = 0;
  if (cl_method ≠ UNINITIALIZED) m.method = (int) cl_method;
  if (cl_rstd_t ≠ UNINITIALIZED) m.rstd_t = cl_rstd_t;
  if (cl_rstd_r ≠ UNINITIALIZED) m.rstd_r = cl_rstd_r;
  if (cl_sphere_one[0] ≠ UNINITIALIZED) {
    double d_sample_r, d_empty_r, d_detector_r;
    m.d_sphere_r = cl_sphere_one[0];
    d_sample_r = cl_sphere_one[1];
```

```
    d_empty_r = cl_sphere_one[2];
    d_detector_r = cl_sphere_one[3];
    m.rw_r = cl_sphere_one[4];
    m.as_r = (d_sample_r/m.d_sphere_r/2) * (d_sample_r/m.d_sphere_r/2);
    m.ae_r = (d_empty_r/m.d_sphere_r/2) * (d_empty_r/m.d_sphere_r/2);
    m.ad_r = (d_detector_r/m.d_sphere_r/2) * (d_detector_r/m.d_sphere_r/2);
    m.aw_r = 1.0 - m.as_r - m.ae_r - m.ad_r;
    m.d_sphere_t = m.d_sphere_r;
    m.as_t = m.as_r;
    m.ae_t = m.ae_r;
    m.ad_t = m.ad_r;
    m.aw_t = m.aw_r;
    m.rw_t = m.rw_r;
    if (cl_num_spheres ≡ UNINITIALIZED) m.num_spheres = 1;
  }
  if (cl_sphere_two[0] ≠ UNINITIALIZED) {
    double d_sample_t, d_empty_t, d_detector_t;
    m.d_sphere_t = cl_sphere_two[0];
    d_sample_t = cl_sphere_two[1];
    d_empty_t = cl_sphere_two[2];
    d_detector_t = cl_sphere_two[3];
    m.rw_t = cl_sphere_two[4];
    m.as_t = (d_sample_t/m.d_sphere_t/2) * (d_sample_t/m.d_sphere_t/2);
    m.ae_t = (d_empty_t/m.d_sphere_t/2) * (d_empty_t/m.d_sphere_t/2);
    m.ad_t = (d_detector_t/m.d_sphere_t/2) * (d_detector_t/m.d_sphere_t/2);
    m.aw_t = 1.0 - m.as_t - m.ae_t - m.ad_t;
    if (cl_num_spheres ≡ UNINITIALIZED) m.num_spheres = 2;
  }
  if (cl_num_spheres ≠ UNINITIALIZED) {
    m.num_spheres = (int) cl_num_spheres;
    if (m.num_spheres > 0 ∧ m.method ≡ UNKNOWN) m.method = SUBSTITUTION;
  }
  if (cl_rc_fraction ≠ UNINITIALIZED) m.fraction_of_rc_in_mr = cl_rc_fraction;
  if (cl_tc_fraction ≠ UNINITIALIZED) m.fraction_of_tc_in_mt = cl_tc_fraction;
  if (cl_gain_type ≠ UNINITIALIZED) m.gain_type = cl_gain_type;
  if (cl_UR1 ≠ UNINITIALIZED) m.m_r = cl_UR1;
  if (cl_UT1 ≠ UNINITIALIZED) m.m_t = cl_UT1;
  if (cl_Tc ≠ UNINITIALIZED) m.m_u = cl_Tc;
  if (cl_default_fr ≠ UNINITIALIZED) m.f_r = cl_default_fr;
  if (cl_baffle_r ≠ UNINITIALIZED) m.baffle_r = cl_baffle_r;
  if (cl_baffle_t ≠ UNINITIALIZED) m.baffle_t = cl_baffle_t;
```

This code is used in section 2.

17. put the values for command line reflection and transmission into the measurement record.

```
⟨ Count command-line measurements 17 ⟩ ≡
  m.num_measures = 3;
  if (m.m_t ≡ 0) m.num_measures−−;
  if (m.m_u ≡ 0) m.num_measures−−;
  params = m.num_measures;
  if (m.num_measures ≡ 3) {      /* need to fill slab entries to calculate the optical thickness */
    struct AD_slab_type s;
    s.n_slab = m.slab_index;
    s.n_top_slide = m.slab_top_slide_index;
    s.n_bottom_slide = m.slab_bottom_slide_index;
    s.b_top_slide = m.slab_top_slide_b;
    s.b_bottom_slide = m.slab_bottom_slide_b;
    s.cos_angle = m.slab_cos_angle;
    cl_default_b = What_Is_B(s, m.m_u);
  }
```

This code is used in section 2.

18.

```
⟨ print version function 18 ⟩ ≡
  static void print_version(int verbosity)
  {
    if (verbosity ≡ 0) {
      fprintf(stdout, "%s", VersionShort);
    }
    else {
      fprintf(stdout, "iad␣%s\n", Version);
      fprintf(stdout, "Copyright␣1993-2024␣Scott␣Prahl,␣scott.prahl@oit.edu\n");
      fprintf(stdout, "␣␣␣␣␣␣␣␣␣␣(see␣Applied␣Optics,␣32:559-568,␣1993)\n\n");
      fprintf(stdout, "This␣is␣free␣software;␣see␣the␣source␣for␣copying␣conditions.\n");
      fprintf(stdout, "There␣is␣no␣warranty;␣not␣even␣for␣MERCHANTABILITY␣or␣FITNESS.\n");
      fprintf(stdout, "FOR␣A␣PARTICULAR␣PURPOSE.\n");
    }
  }
```

This code is used in section 2.

19. ⟨ print usage function 19 ⟩ ≡

```
static void print_usage(void)
{
  fprintf(stdout, "iad %s\n\n", Version);
  fprintf(stdout, "iad finds optical properties from measurements\n\n");
  fprintf(stdout, "Usage:  iad [options] input\n\n");
  fprintf(stdout, "Options:\n");
  fprintf(stdout, "  -1 '# # # # #'   reflection sphere parameters \n");
  fprintf(stdout, "                   'd_sphere d d_sample_port d_empty_port d\
      _detector_port r_wall'\n");
  fprintf(stdout, "  -2 '# # # # #'   transmission sphere parameters \n");
  fprintf(stdout, "                   'd_sphere d d_sample_port d_empty_port d\
      _detector_port r_wall'\n");
  fprintf(stdout, "  -a #             use this albedo \n");
  fprintf(stdout, "  -A #             use this absorption coefficient \n");
  fprintf(stdout, "  -b #             use this optical thickness \n");
  fprintf(stdout, "  -B #             beam diameter \n");
  fprintf(stdout, "  -c #             fraction of unscattered refl in MR\n");
  fprintf(stdout, "  -C #             fraction of unscattered trans in MT\n");
  fprintf(stdout, "  -d #             thickness of sample \n");
  fprintf(stdout, "  -D #             thickness of slide \n");
  fprintf(stdout, "  -e #             error tolerance (default 0.0001) \n");
  fprintf(stdout, "  -E #             optical depth (=mua*D) for slides\n");
  fprintf(stdout,
      "  -f #             allow a fraction 0.0-1.0 of light to hit sphere wall first\n");
  fprintf(stdout, "  -F #             constrain scattering coefficient \n");
  fprintf(stdout, "                   #  = constant: use constant scattering coefficient \n");
  fprintf(stdout, "                   #  = 'P lambda0 mus0 gamma' then mus=mus0\
      *(lambda/lambda0)^gamma\n");
  fprintf(stdout, "                   #  = 'R lambda0 musp0 gamma'  musp=musp0*\
      (lambda/lambda0)^gamma\n");
  fprintf(stdout, "  -g #             scattering anisotropy (default 0) \n");
  fprintf(stdout, "  -G #             type of boundary '0', '2', 't', 'b', 'n', 'f' \n");
  fprintf(stdout, "                   '0' or '2'             ---  number of slides\n");
  fprintf(stdout, "                   't' (top) or 'b' (bottom) ---  one slide \
      that is hit by light first\n");
  fprintf(stdout, "                   'n' (near) or 'f' (far)    ---  one slide \
      position relative to sphere\n");
  fprintf(stdout, "  -h               display help\n");
  fprintf(stdout, "  -H #             #  = 0, no baffles for R or T spheres\n");
  fprintf(stdout, "                   #  = 1, baffle for R but not for T sphere\n");
  fprintf(stdout, "                   #  = 2, baffle for T but not for R sphere\n");
  fprintf(stdout, "                   #  = 3, baffle for both R and T spheres (default)\n");
  fprintf(stdout, "  -i #             light is incident at this angle in degrees\n");
  fprintf(stdout, "  -M #             number of Monte Carlo iterations\n");
  fprintf(stdout, "  -n #             specify index of refraction of slab\n");
  fprintf(stdout, "  -N #             specify index of refraction of slides\n");
  fprintf(stdout, "  -o filename      explicitly specify filename for output\n");
  fprintf(stdout, "  -p #             # of Monte Carlo photons (default 100000)\n");
  fprintf(stdout, "                   a negative number is max MC time in milliseconds\n");
  fprintf(stdout, "  -q #             number of quadrature points (default=8)\n");
  fprintf(stdout, "  -r #             total reflection measurement\n");
```

```
fprintf(stdout,"␣␣-R␣#␣␣␣␣␣␣␣␣␣␣␣␣actual␣reflectance␣for␣100%%␣measurement␣\n");
fprintf(stdout,"␣␣-S␣#␣␣␣␣␣␣␣␣␣␣␣␣number␣of␣spheres␣used\n");
fprintf(stdout,"␣␣-t␣#␣␣␣␣␣␣␣␣␣␣␣␣total␣transmission␣measurement\n");
fprintf(stdout,"␣␣-T␣#␣␣␣␣␣␣␣␣␣␣␣␣actual␣transmission␣for␣100%%␣measurement␣\n");
fprintf(stdout,"␣␣-u␣#␣␣␣␣␣␣␣␣␣␣␣␣unscattered␣transmission␣measurement\n");
fprintf(stdout,"␣␣-v␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣version␣information\n");
fprintf(stdout,"␣␣-V␣0␣␣␣␣␣␣␣␣␣␣␣␣verbosity␣low␣---␣no␣output␣to␣stdout\n");
fprintf(stdout,"␣␣-V␣1␣␣␣␣␣␣␣␣␣␣␣␣verbosity␣moderate␣\n");
fprintf(stdout,"␣␣-V␣2␣␣␣␣␣␣␣␣␣␣␣␣verbosity␣high\n");
fprintf(stdout,"␣␣-x␣#␣␣␣␣␣␣␣␣␣␣␣␣set␣debugging␣level\n");
fprintf(stdout,"␣␣-X␣␣␣␣␣␣␣␣␣␣␣␣␣␣dual␣beam␣configuration\n");
fprintf(stdout,"␣␣-z␣␣␣␣␣␣␣␣␣␣␣␣␣␣do␣forward␣calculation\n");
fprintf(stdout,"Examples:\n");
fprintf(stdout,"␣␣iad␣file.rxt␣␣␣␣␣␣␣␣␣␣␣␣␣␣Results␣will␣be␣put␣in␣file.txt\n");
fprintf(stdout,"␣␣iad␣file␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣Same␣as␣above\n");
fprintf(stdout,"␣␣iad␣-c␣0.9␣file.rxt␣␣␣␣␣␣␣Assume␣M_R␣includes␣90%%␣of␣uns\
    cattered␣reflectance\n");
fprintf(stdout,"␣␣iad␣-C␣0.8␣file.rxt␣␣␣␣␣␣␣Assume␣M_T␣includes␣80%%␣of␣uns\
    cattered␣transmittance\n");
fprintf(stdout,"␣␣iad␣-e␣0.0001␣file.rxt␣␣␣␣Better␣convergence␣to␣R␣&␣T␣values\n");
fprintf(stdout,
    "␣␣iad␣-f␣1.0␣file.rxt␣␣␣␣␣␣␣All␣light␣hits␣reflectance␣sphere␣wall␣first\n");
fprintf(stdout,"␣␣iad␣-o␣out␣file.rxt␣␣␣␣␣␣␣Calculated␣values␣in␣out\n");
fprintf(stdout,"␣␣iad␣-r␣0.3␣␣␣␣␣␣␣␣␣␣␣␣␣␣R_total=0.3,␣b=inf,␣find␣albedo\n");
fprintf(stdout,"␣␣iad␣-r␣0.3␣-t␣0.4␣␣␣␣␣␣␣␣R_total=0.3,␣T_total=0.4,␣find␣a,b,g\n");
fprintf(stdout,"␣␣iad␣-r␣0.3␣-t␣0.4␣-n␣1.5␣␣R_total=0.3,␣T_total=0.4,␣n=1.5,␣find␣a,b\n");
fprintf(stdout,"␣␣iad␣-r␣0.3␣-t␣0.4␣␣␣␣␣␣␣␣R_total=0.3,␣T_total=0.4,␣find␣a,b\n");
fprintf(stdout,"␣␣iad␣-p␣1000␣file.rxt␣␣␣␣␣␣Only␣1000␣photons\n");
fprintf(stdout,"␣␣iad␣-p␣-100␣file.rxt␣␣␣␣␣␣Allow␣only␣100ms␣per␣iteration\n");
fprintf(stdout,"␣␣iad␣-q␣4␣file.rxt␣␣␣␣␣␣␣␣Four␣quadrature␣points\n");
fprintf(stdout,"␣␣iad␣-M␣0␣file.rxt␣␣␣␣␣␣␣␣No␣MC␣␣␣␣(iad)\n");
fprintf(stdout,"␣␣iad␣-M␣1␣file.rxt␣␣␣␣␣␣␣␣MC␣once␣␣(iad␣->␣MC␣->␣iad)\n");
fprintf(stdout,"␣␣iad␣-M␣2␣file.rxt␣␣␣␣␣␣␣␣MC␣twice␣(iad␣->␣MC␣->␣iad␣->␣MC␣->␣iad)\n");
fprintf(stdout,"␣␣iad␣-M␣0␣-q␣4␣file.rxt␣␣␣␣Fast␣and␣crude␣conversion\n");
fprintf(stdout,
    "␣␣iad␣-G␣t␣file.rxt␣␣␣␣␣␣␣␣One␣top␣slide␣with␣properties␣from␣file.rxt\n");
fprintf(stdout,
    "␣␣iad␣-G␣b␣-N␣1.5␣-D␣1␣file␣Use␣1␣bottom␣slide␣with␣n=1.5␣and␣thickness=1\n");
fprintf(stdout,"␣␣iad␣-x␣␣␣1␣file.rxt␣␣␣␣␣␣␣Show␣sphere␣and␣MC␣effects\n");
fprintf(stdout,"␣␣iad␣-x␣␣␣2␣file.rxt␣␣␣␣␣␣␣DEBUG_GRID\n");
fprintf(stdout,"␣␣iad␣-x␣␣␣4␣file.rxt␣␣␣␣␣␣␣DEBUG_ITERATIONS\n");
fprintf(stdout,"␣␣iad␣-x␣␣␣8␣file.rxt␣␣␣␣␣␣␣DEBUG_LOST_LIGHT\n");
fprintf(stdout,"␣␣iad␣-x␣␣16␣file.rxt␣␣␣␣␣␣␣DEBUG_SPHERE_EFFECTS\n");
fprintf(stdout,"␣␣iad␣-x␣␣32␣file.rxt␣␣␣␣␣␣␣DEBUG_BEST_GUESS\n");
fprintf(stdout,"␣␣iad␣-x␣␣64␣file.rxt␣␣␣␣␣␣␣DEBUG_EVERY_CALC\n");
fprintf(stdout,"␣␣iad␣-x␣128␣file.rxt␣␣␣␣␣␣␣DEBUG_SEARCH\n");
fprintf(stdout,"␣␣iad␣-x␣256␣file.rxt␣␣␣␣␣␣␣DEBUG_RD_ONLY\n");
fprintf(stdout,"␣␣iad␣-x␣512␣file.rxt␣␣␣␣␣␣␣DEBUG_GRID_CALC\n");
fprintf(stdout,"␣␣iad␣-x␣1023␣file.rxt␣␣␣␣␣␣All␣debugging␣output\n");
fprintf(stdout,
    "␣␣iad␣-X␣-i␣8␣file.rxt␣␣␣␣␣␣Dual␣beam␣spectrometer␣with␣8␣degree␣incidence\n\n");
```

```
  fprintf(stdout,
      "␣␣iad␣-z␣-a␣0.9␣-b␣1␣-i␣45␣␣Forward␣calc␣assuming␣45␣degree␣incidence\n\n");
  fprintf(stdout, "␣␣apply␣iad␣x.rxt␣y.rxt␣␣␣␣␣Process␣multiple␣files\n\n");
  fprintf(stdout, "Report␣bugs␣to␣<scott.prahl@oit.edu>\n\n");
}
```

This code is used in section 2.

20. Just figure out the damn scattering and absorption

```
⟨ calculate coefficients function 20 ⟩ ≡
static void Calculate_Mua_Musp(struct measure_type m, struct invert_type r, double
        *musp, double *mua)
{
  if (r.b ≡ HUGE_VAL) {
    if (r.a ≤ 1 · 10^−5) {
      *musp = 0.0;
      *mua = 1.0;
      return;
    }
    if (r.default_mus ≠ UNINITIALIZED) {
      *musp = r.default_mus * (1 − r.g);
      *mua = r.default_mus/r.a − r.default_mus;
      return;
    }
    if (r.default_mua ≠ UNINITIALIZED) {
      *musp = (r.default_mua/(1 − r.a) − r.default_mua) * (1 − r.g);
      *mua = r.default_mua;
      return;
    }
    *musp = 1.0 − r.g;
    *mua = (1.0 − r.a)/r.a;
    return;
  }
  *musp = r.a * r.b/m.slab_thickness * (1.0 − r.g);
  *mua = (1 − r.a) * r.b/m.slab_thickness;
}
```

See also section 21.

This code is used in section 2.

21. This can only be called immediately after *Inverse_RT* You have been warned! Notice that *Calculate_Distance* does not pass any slab properties.

```
⟨ calculate coefficients function 20 ⟩ +≡
static void calculate_coefficients(struct measure_type m, struct invert_type r, double *LR, double
        *LT, double *musp, double *mua)
{
  double delta;
  *LR = 0;
  *LT = 0;
  Calculate_Distance(LR, LT, &delta);
  Calculate_Mua_Musp(m, r, musp, mua);
}
```

22. ⟨ print results header function 22 ⟩ ≡

```
static void print_results_header(FILE *fp)
{
  fprintf(fp,"#␣␣␣␣␣\tMeasured␣\t␣␣␣M_R␣␣␣\tMeasured␣\t␣␣␣M_T␣␣␣\tEstimat\
      ed\tEstimated\tEstimated");
  if (Debug(DEBUG_LOST_LIGHT)) fprintf(fp,
      "\t␣␣Lost␣␣␣\t␣␣Lost␣␣␣\t␣␣Lost␣␣␣\t␣␣Lost␣␣␣\t␣␣␣MC␣␣␣␣\t␣␣␣IAD␣␣␣\t␣␣Error␣␣");
  fprintf(fp,"\n");
  fprintf(fp,"##wave\t␣␣␣M_R␣␣␣\t␣␣␣fit␣␣␣\t␣␣␣M_T␣␣␣\t␣␣␣fit␣␣␣\t␣␣mu_a␣\
      ␣␣\t␣␣mu_s'␣␣\t␣␣␣␣g␣␣␣␣");
  if (Debug(DEBUG_LOST_LIGHT)) fprintf(fp,
      "\t␣␣␣UR1␣␣␣\t␣␣␣URU␣␣␣\t␣␣␣UT1␣␣␣\t␣␣␣UTU␣␣␣\t␣␣␣␣#␣␣␣␣\t␣␣␣␣#␣␣␣␣\t␣␣State␣␣");
  fprintf(fp,"\n");
  fprintf(fp,"#␣[nm]\t␣␣[---]␣␣\t␣␣[---]␣␣\t␣␣[---]␣␣\t␣␣[---]␣␣\t␣␣1/mm␣\
      ␣␣\t␣␣1/mm␣␣␣\t␣␣[---]␣␣");
  if (Debug(DEBUG_LOST_LIGHT)) fprintf(fp,
      "\t␣␣[---]␣␣\t␣␣[---]␣␣\t␣␣[---]␣␣\t␣␣[---]␣␣\t␣␣[---]␣␣\t␣␣[---]␣␣\t␣␣[---]␣␣");
  fprintf(fp,"\n");
}
```

This code is used in section 2.

23. When debugging lost light, it is handy to see how each iteration changes the calculated values for the optical properties. We do that here if we are debugging, otherwise we just print a number or something to keep the user from wondering what is going on.

⟨ Print results function 23 ⟩ ≡

```
void print_optical_property_result(FILE *fp, struct measure_type m, struct invert_type r, double
    LR, double LT, double mu_a, double mu_sp, int mc_iter, int line)
{
  if (m.lambda ≠ 0) fprintf(fp,"%6.1f\t",m.lambda);
  else fprintf(fp,"%6d\t",line);
  if (mu_a ≥ 200) mu_a = 199.9999;
  if (mu_sp ≥ 1000) mu_sp = 999.9999;
  fprintf(fp,"%␣9.4f\t%␣9.4f\t",m.m_r,LR);
  fprintf(fp,"%␣9.4f\t%␣9.4f\t",m.m_t,LT);
  fprintf(fp,"%␣9.4f\t",mu_a);
  fprintf(fp,"%␣9.4f\t",mu_sp);
  fprintf(fp,"%␣9.4f\t",r.g);
  if (Debug(DEBUG_LOST_LIGHT)) {
    fprintf(fp,"%␣9.4f\t%␣9.4f\t",m.ur1_lost,m.uru_lost);
    fprintf(fp,"%␣9.4f\t%␣9.4f\t",m.ut1_lost,m.utu_lost);
    fprintf(fp,"␣%2d␣␣\t",mc_iter);
    fprintf(fp,"␣%4d\t",r.iterations);
  }
  fprintf(fp,"#␣%c␣\n",what_char(r.error));
  fflush(fp);
}
```

This code is used in section 2.

24. ⟨ print error legend function 24 ⟩ ≡

```
static void print_error_legend(void)
{
  fprintf(stderr, "-----------------␣Sorry,␣but␣...␣errors␣encountered␣---------------\n");
  fprintf(stderr, "␣␣␣*␣␣==>␣Success␣␣␣␣␣␣␣␣␣␣");
  fprintf(stderr, "␣␣0-9␣==>␣Monte␣Carlo␣Iteration\n");
  fprintf(stderr, "␣␣␣R␣␣==>␣M_R␣is␣too␣big␣␣␣");
  fprintf(stderr, "␣␣␣r␣␣==>␣M_R␣is␣too␣small\n");
  fprintf(stderr, "␣␣␣T␣␣==>␣M_T␣is␣too␣big␣␣␣");
  fprintf(stderr, "␣␣␣t␣␣==>␣M_T␣is␣too␣small\n");
  fprintf(stderr, "␣␣␣U␣␣==>␣M_U␣is␣too␣big␣␣␣");
  fprintf(stderr, "␣␣␣u␣␣==>␣M_U␣is␣too␣small\n");
  fprintf(stderr, "␣␣␣!␣␣==>␣M_R␣+␣M_T␣>␣1␣␣␣␣");
  fprintf(stderr, "␣␣␣+␣␣==>␣Did␣not␣converge\n\n");
}
```

This code is used in section 2.

25. returns a new string consisting of s+t

⟨ stringdup together function 25 ⟩ ≡

```
static char *strdup_together(char *s, char *t)
{
  char *both;
  if (s ≡ Λ) {
    if (t ≡ Λ) return Λ;
    return strdup(t);
  }
  if (t ≡ Λ) return strdup(s);
  both = malloc(strlen(s) + strlen(t) + 1);
  if (both ≡ Λ) fprintf(stderr, "Could␣not␣allocate␣memory␣for␣both␣strings.\n");
  strcpy(both, s);
  strcat(both, t);
  return both;
}
```

This code is used in section 2.

26. catch parsing errors in strtod

```
⟨ mystrtod function 26 ⟩ ≡
  static double my_strtod(const char *str)
  {
    char *endptr;
    errno = 0;
    double val = strtod(str, &endptr);
    if (endptr ≡ str) {      /* No digits were found */
      fprintf(stderr, "Error␣in␣command-line\n");
      fprintf(stderr, "␣␣␣␣No␣conversion␣could␣be␣performed␣for␣‘%s‘.\n", str);
      exit(EXIT_FAILURE);
    }
    if (*endptr ≠ '\0') {      /* String contains extra characters after the number */
      fprintf(stderr, "Error␣in␣command-line\n");
      fprintf(stderr, "␣␣␣␣Partial␣conversion␣of␣string␣=␣'%s'\n", str);
      exit(EXIT_FAILURE);
    }
    if (errno ≡ ERANGE) {
      /* The converted value is out of range of representable values by a double */
      fprintf(stderr, "Error␣in␣command-line\n");
      printf("␣␣␣␣The␣value␣'%s'␣is␣out␣of␣range␣of␣double.\n", str);
      exit(EXIT_FAILURE);
    }
    return val;
  }
```

This code is used in section 2.

27. assume that start time has already been set

```
⟨ seconds elapsed function 27 ⟩ ≡
  static double seconds_elapsed(clock_t start_time)
  {
    clock_t finish_time = clock( );
    return (double)(finish_time − start_time)/CLOCKS_PER_SEC;
  }
```

This code is used in section 2.

28. given a string and an array, this fills the array with numbers from the string. The numbers should be separated by spaces.

Returns 0 upon successfully filling n entries, returns 1 for any error.

```
⟨ parse string into array function 28 ⟩ ≡
  static int parse_string_into_array(char *s, double *a, int n)
  {
    char *t, *last, *r;
    int i = 0;
    t = s;
    last = s + strlen(s);
    while (t < last) {      /* a space should mark the end of number */
      r = t;
      while (*r ≠ ' ' ∧ *r ≠ '\0') r++;
      *r = '\0';      /* parse the number and save it */
      if (sscanf(t, "%lf", &(a[i])) ≡ 0) return 1;
      i++;      /* are we done ? */
      if (i ≡ n) {
        if (a[i − 1] ≤ 0 ∨ a[i − 1] > 1) {
          fprintf(stderr,
              "Sphere wall reflectivity (r_w=%g) must be a fraction less than one.\n",
              a[i − 1]);
          exit(EXIT_FAILURE);
        }
        return 0;
      }      /* move pointer just after last number */
      t = r + 1;
    }
    return 1;
  }
```

This code is used in section 2.

29. ⟨ print dot function 29 ⟩ ≡

```
static char what_char(int err)
{
  if (err ≡ IAD_NO_ERROR) return '*';
  if (err ≡ IAD_TOO_MANY_ITERATIONS) return '+';
  if (err ≡ IAD_MR_TOO_BIG) return 'R';
  if (err ≡ IAD_MR_TOO_SMALL) return 'r';
  if (err ≡ IAD_MT_TOO_BIG) return 'T';
  if (err ≡ IAD_MT_TOO_SMALL) return 't';
  if (err ≡ IAD_MU_TOO_BIG) return 'U';
  if (err ≡ IAD_MU_TOO_SMALL) return 'u';
  if (err ≡ IAD_TOO_MUCH_LIGHT) return '!';
  return '?';
}
static void print_dot(clock_t start_time, int err, int count, int points, int final, int verbosity, int
        *any_error)
{
  static int counter = 0;
  (void) count;
  counter++;
  if (err ≠ IAD_NO_ERROR) *any_error = err;
  if (verbosity ≡ 0) return;
  if (final ≡ 99) fprintf(stderr, "%c", what_char(err));
  else {
    counter--;
    fprintf(stderr, "%1d\b", final % 10);
  }
  if (final ≡ 99) {
    if (counter % 50 ≡ 0) {
      double rate = (seconds_elapsed(start_time)/points);
      fprintf(stderr, "␣␣%3d␣done␣(%5.2f␣s/pt)\n", points, rate);
    }
    else if (counter % 10 ≡ 0) fprintf(stderr, "␣");
  }
  fflush(stderr);
}
```

This code is used in section 2.

30. Simple command-line shell program.

Here is a quick skeleton that I put together to show how the inverse adding-doubling code works. I have only cursorily tested this. If you find obvious bugs, they are probably real but should not extend beyond this code snippet.

All the output for this web file goes into `iad_main.c`

```
⟨ iad_main_mus.c 30 ⟩ ≡
  ⟨ Include files for main 3 ⟩
  int main(int argc, char **argv)
  {
    ⟨ Declare variables for main 4 ⟩
    if (Read_Header(&m, &r) ≡ TRUE) {
      ⟨ Process the header 33 ⟩
      m.num_measures = 2;
      m.m_r = 0.0;
      m.slab_thickness = 0.1;
      while (fp ≠ EOF) {
        fp = scanf("%lf␣%lf␣%lf␣%lf", &lambda, &r.mu_a, &m.default_g, &m.m_t);
        fp = readln(&line);
        ⟨ Calculate and write optical properties 11 ⟩
      }
    }
    exit(EXIT_SUCCESS);
  }
```

31. ⟨ Include files for *main* 3 ⟩ +≡

```
#include <stdio.h>
#include <string.h>
#include <stdlib.h>
#include "ad_globl.h"
#include "iad_type.h"
#include "iad_pub.h"
#include "iad_io.h"
```

32. ⟨ Declare variables for *main* 4 ⟩ +≡

```
  struct measure_type m;
  struct invert_type r;
  int lines;
  char *format1 = "␣␣␣␣R␣␣␣␣\t␣␣␣␣T␣␣␣␣\t␣␣␣␣Tc␣␣␣␣\t␣␣␣␣␣a␣␣␣␣\t␣␣␣␣␣b␣␣␣␣\t␣\
      ␣␣␣␣g␣␣␣␣\t␣␣␣␣!/?\n";
  char *format2 = "␣%9.5f\t␣%9.5f\t␣%9.5f\t␣%9.5f\t␣%9.5f\t␣%9.5f\t␣%9c\n";
  char found = '?';
  int fp;
  double lambda;
  int line = 1;
```

33. ⟨ Process the header 33 ⟩ ≡

```
  m.slab_thickness = 1;
  Initialize_Result(m, &r);
  Write_Header(m, r);
  lines = 1;
  printf(format1, m.m_r, m.m_t, m.m_u, r.a, r.b, r.g);
```

This code is used in section 30.

34. ⟨ Calculate and write optical properties 11 ⟩ +≡

```
{
  r.search = FIND_mus;
  Inverse_RT(m, &r);
  if (r.found ≡ TRUE) found = '!';
  else found = '?';
  printf(format2, m.m_r, m.m_t, m.m_u, r.a, r.b, r.g, found);
  fflush(stdout);
}
```

35. IAD Types. This file has no routines. It is responsible for creating the header file `iad_type.h` and nothing else.

⟨ `iad_type.h` 35 ⟩ ≡
```
#undef FALSE
#undef TRUE
  ⟨ Preprocessor definitions ⟩
  ⟨ Structs to export from IAD Types 38 ⟩
```

36.
```
#define FIND_A 0
#define FIND_B 1
#define FIND_AB 2
#define FIND_AG 3
#define FIND_AUTO 4
#define FIND_BG 5
#define FIND_BaG 6
#define FIND_BsG 7
#define FIND_Ba 8
#define FIND_Bs 9
#define FIND_G 10
#define FIND_B_WITH_NO_ABSORPTION 11
#define FIND_B_WITH_NO_SCATTERING 12
#define RELATIVE 0
#define ABSOLUTE 1
#define COLLIMATED 0
#define DIFFUSE 1
#define FALSE 0
#define TRUE 1
#define IAD_MAX_ITERATIONS 500
```

37. Need error codes for this silly program

```
#define IAD_NO_ERROR 0
#define IAD_TOO_MANY_ITERATIONS 1
#define IAD_AS_NOT_VALID 16
#define IAD_AE_NOT_VALID 17
#define IAD_AD_NOT_VALID 18
#define IAD_RW_NOT_VALID 19
#define IAD_RD_NOT_VALID 20
#define IAD_RSTD_NOT_VALID 21
#define IAD_GAMMA_NOT_VALID 22
#define IAD_F_NOT_VALID 23
#define IAD_BAD_PHASE_FUNCTION 24
#define IAD_QUAD_PTS_NOT_VALID 25
#define IAD_BAD_G_VALUE 26
#define IAD_TOO_MANY_LAYERS 27
#define IAD_MEMORY_ERROR 28
#define IAD_FILE_ERROR 29
#define IAD_EXCESSIVE_LIGHT_LOSS 30
#define IAD_RT_LT_MINIMUM 31
#define IAD_MR_TOO_SMALL 32
#define IAD_MR_TOO_BIG 33
#define IAD_MT_TOO_SMALL 34
#define IAD_MT_TOO_BIG 35
#define IAD_MU_TOO_SMALL 36
#define IAD_MU_TOO_BIG 37
#define IAD_TOO_MUCH_LIGHT 38
#define IAD_TSTD_NOT_VALID 39
#define UNINITIALIZED -99
#define DEBUG_A_LITTLE 1
#define DEBUG_GRID 2
#define DEBUG_ITERATIONS 4
#define DEBUG_LOST_LIGHT 8
#define DEBUG_SPHERE_EFFECTS 16
#define DEBUG_BEST_GUESS 32
#define DEBUG_EVERY_CALC 64
#define DEBUG_SEARCH 128
#define DEBUG_RD_ONLY 256
#define DEBUG_GRID_CALC 512
#define DEBUG_ANY #FFFFFFFF
#define UNKNOWN 0
#define COMPARISON 1
#define SUBSTITUTION 2
```

38. The idea of the structure **measure_type** is collect all the information regarding a single measurement together in one spot. No information regarding how the inversion procedure is supposed to be done is contained in this structure, unlike in previous incarnations of this program.

⟨ Structs to export from IAD Types 38 ⟩ ≡

```
typedef struct measure_type {
  double slab_index;
  double slab_thickness;
  double slab_top_slide_index;
  double slab_top_slide_b;
  double slab_top_slide_thickness;
  double slab_bottom_slide_index;
  double slab_bottom_slide_b;
  double slab_bottom_slide_thickness;
  double slab_cos_angle;
  int num_spheres;
  int num_measures;
  int method;
  int flip_sample;
  int gain_type;
  int baffle_r, baffle_t;
  double d_beam;
  double fraction_of_rc_in_mr;
  double fraction_of_tc_in_mt;
  double m_r, m_t, m_u;
  double lambda;
  double as_r, ad_r, ae_r, aw_r, rd_r, rw_r, rstd_r, f_r;
  double as_t, ad_t, ae_t, aw_t, rd_t, rw_t, rstd_t, f_t;
  double ur1_lost, uru_lost, ut1_lost, utu_lost;
  double d_sphere_r, d_sphere_t;
} IAD_measure_type;
```

See also sections 39 and 40.

This code is used in section 35.

39. This describes how the inversion process should proceed and also contains the results of that inversion process.

```
⟨ Structs to export from IAD Types 38 ⟩ +≡
  typedef struct invert_type {
    double a;     /* the calculated albedo */
    double b;     /* the calculated optical depth */
    double g;     /* the calculated anisotropy */
    int found;
    int search;
    int metric;
    double tolerance;
    double MC_tolerance;
    double final_distance;
    int iterations;
    int error;
    struct AD_slab_type slab;
    struct AD_method_type method;
    double default_a;
    double default_b;
    double default_g;
    double default_ba;
    double default_bs;
    double default_mua;
    double default_mus;
  } IAD_invert_type;
```

40. A few types that used to be enum's are now int's.

```
⟨ Structs to export from IAD Types 38 ⟩ +≡
  typedef int search_type;
  typedef int boolean_type;
  typedef int illumination_type;
  typedef struct guess_t {
    double distance;
    double a;
    double b;
    double g;
  } guess_type;
  extern double FRACTION;
```

41. IAD Public.

This contains the routine *Inverse_RT* that should generally be the basic entry point into this whole mess. Call this routine with the proper values and true happiness is bound to be yours.

Altered accuracy of the standard method of root finding from 0.001 to 0.00001. Note, it really doesn't help to change the method from `ABSOLUTE` to `RELATIVE`, but I did anyway. (3/3/95)

⟨ `iad_pub.c` 41 ⟩ ≡

```
#include <stdio.h>
#include <math.h>
#include "nr_util.h"
#include "ad_globl.h"
#include "ad_frsnl.h"
#include "iad_type.h"
#include "iad_util.h"
#include "iad_calc.h"
#include "iad_find.h"
#include "iad_pub.h"
#include "iad_io.h"
#include "stdlib.h"
#include "mc_lost.h"
```

⟨ Definition for *Inverse_RT* 45 ⟩
⟨ Definition for *measure_OK* 50 ⟩
⟨ Definition for *determine_search* 57 ⟩
⟨ Definition for *Initialize_Result* 61 ⟩
⟨ Definition for *Initialize_Measure* 69 ⟩
⟨ Definition for *ez_Inverse_RT* 67 ⟩
⟨ Definition for *Spheres_Inverse_RT* 71 ⟩
⟨ Definition for *Spheres_Inverse_RT2* 84 ⟩
⟨ Definition for *Calculate_MR_MT* 78 ⟩
⟨ Definition for *MinMax_MR_MT* 82 ⟩
⟨ Definition for *Calculate_Minimum_MR* 80 ⟩

42. All the information that needs to be written to the header file `iad_pub.h`. This eliminates the need to maintain a set of header files as well.

⟨ `iad_pub.h` 42 ⟩ ≡

⟨ Prototype for *Inverse_RT* 44 ⟩;
⟨ Prototype for *measure_OK* 49 ⟩;
⟨ Prototype for *determine_search* 56 ⟩;
⟨ Prototype for *Initialize_Result* 60 ⟩;
⟨ Prototype for *ez_Inverse_RT* 66 ⟩;
⟨ Prototype for *Initialize_Measure* 68 ⟩;
⟨ Prototype for *Calculate_MR_MT* 77 ⟩;
⟨ Prototype for *MinMax_MR_MT* 81 ⟩;
⟨ Prototype for *Calculate_Minimum_MR* 79 ⟩;
⟨ Prototype for *Spheres_Inverse_RT2* 83 ⟩;

43. Here is the header file needed to access one interesting routine in the `libiad.so` library.

⟨ `lib_iad.h` 43 ⟩ ≡

⟨ Prototype for *ez_Inverse_RT* 66 ⟩;
⟨ Prototype for *Spheres_Inverse_RT* 70 ⟩;
⟨ Prototype for *Spheres_Inverse_RT2* 83 ⟩;

44. Inverse RT. *Inverse_RT* is the main function in this whole package. You pass the variable m containing your experimentally measured values to the function *Inverse_RT*. It hopefully returns the optical properties in r that are appropriate for your experiment.

```
⟨ Prototype for Inverse_RT 44 ⟩ ≡
  void Inverse_RT(struct measure_type m, struct invert_type *r)
```

This code is used in sections 42 and 45.

45.
```
⟨ Definition for Inverse_RT 45 ⟩ ≡
  ⟨ Prototype for Inverse_RT 44 ⟩
  {
    if (0 ∧ Debug(DEBUG_LOST_LIGHT)) {
      fprintf(stderr, "** Inverse_RT (%d spheres) **\n", m.num_spheres);
      fprintf(stderr, "    M_R       =%8.5f, MT       =%8.5f\n", m.m_r, m.m_t);
      fprintf(stderr, "    UR1 lost  =%8.5f, UT1 lost  =%8.5f\n", m.ur1_lost, m.ut1_lost);
    }
    r→found = FALSE;
    if (r→search ≡ FIND_AUTO) r→search = determine_search(m, *r);
    if (r→search ≡ FIND_B_WITH_NO_ABSORPTION) {
      r→default_a = 1;
      r→search = FIND_B;
    }
    if (r→search ≡ FIND_B_WITH_NO_SCATTERING) {
      r→default_a = 0;
      r→search = FIND_B;
    }
    ⟨ Exit with bad input data 46 ⟩
    ⟨ Find the optical properties 47 ⟩
    if (r→final_distance ≤ r→tolerance) r→found = TRUE;
  }
```

This code is used in section 41.

46. There is no sense going to all the trouble to try a multivariable minimization if the input data is bogus. So I wrote a single routine *measure_OK* to do just this.

```
⟨ Exit with bad input data 46 ⟩ ≡
  r→error = measure_OK(m, *r);
  if (r→method.quad_pts < 4) r→error = IAD_QUAD_PTS_NOT_VALID;
  if (r→error ≠ IAD_NO_ERROR) return;
```

This code is used in section 45.

47. Now I fob the real work off to the unconstrained minimization routines. Ultimately, I would like to replace all these by constrained minimization routines. Actually the first five already are constrained. The real work will be improving the last five because these are 2-D minimization routines.

```
⟨ Find the optical properties 47 ⟩ ≡
  switch (r→search) {
  case FIND_A: U_Find_A(m, r);
    break;
  case FIND_B: U_Find_B(m, r);
    break;
  case FIND_G: U_Find_G(m, r);
    break;
  case FIND_Ba: U_Find_Ba(m, r);
    break;
  case FIND_Bs: U_Find_Bs(m, r);
    break;
  case FIND_AB: U_Find_AB(m, r);
    break;
  case FIND_AG: U_Find_AG(m, r);
    break;
  case FIND_BG: U_Find_BG(m, r);
    break;
  case FIND_BsG: U_Find_BsG(m, r);
    break;
  case FIND_BaG: U_Find_BaG(m, r);
    break;
  }
  if (r→iterations ≡ IAD_MAX_ITERATIONS) r→error = IAD_TOO_MANY_ITERATIONS;
```

This code is used in section 45.

48. Validation.

49. Now the question is — just what is bad data? Here's the prototype.

⟨ Prototype for *measure_OK* 49 ⟩ ≡
```
int measure_OK(struct measure_type m, struct invert_type r)
```
This code is used in sections 42 and 50.

50. It would just be nice to stop computing with bad data. This does not work in practice because it turns out that there is often bogus data in a full wavelength scan. Often the reflectance is too low for short wavelengths and at long wavelengths the detector (photomultiplier tube) does not work worth a damn.

The two sphere checks are more complicated. For example, we can no longer categorically state that the transmittance is less than one or that the sum of the reflectance and transmittance is less than one. Instead we use the transmittance to bound the values for the reflectance — see the routine *MinMax_MR_MT* below.

⟨ Definition for *measure_OK* 50 ⟩ ≡
```
⟨ Prototype for measure_OK 49 ⟩
{
  double ru, tu;
  if (m.num_spheres ≠ 2) {
    ⟨ Check MT for zero or one spheres 52 ⟩
    ⟨ Check MR for zero or one spheres 51 ⟩
  }
  else {
    int error = MinMax_MR_MT(m, r);
    if (error ≠ IAD_NO_ERROR) return error;
  }
  ⟨ Check MU 53 ⟩
  if (m.num_spheres ≠ 0) {
    ⟨ Check sphere parameters 54 ⟩
  }
  return IAD_NO_ERROR;
}
```
This code is used in section 41.

51. The reflectance is constrained by the index of refraction of the material and the transmission. The upper bound for the reflectance is just one minus the transmittance. The specular (unscattered) reflectance from the boundaries imposes minimum for the reflectance. Obviously, the reflected light cannot be less than that from the first boundary. This might be calculated by assuming an infinite layer thickness. But we can do better.

There is a definite bound on the minimum reflectance from a sample. If you have a sample with a given transmittance m_t, the minimum reflectance possible is found by assuming that the sample does not scatter any light.

Knowledge of the indicies of refraction makes it a relatively simple matter to determine the optical thickness $b = mu\_a * d$ of the slab. The minimum reflection is obtained by including all the specular reflectances from all the surfaces.

If the default albedo has been specified as zero, then there is really no need to check `MR` because it is ignored.

```
⟨ Check MR for zero or one spheres 51 ⟩ ≡
  {
    double mr, mt;
    Calculate_Minimum_MR(m, r, &mr, &mt);
      /* one parameter search only needs one good measurement */
    if (r.search ≡ FIND_A ∨ r.search ≡ FIND_G ∨ r.search ≡ FIND_B ∨ r.search ≡ FIND_Bs ∨ r.search ≡
          FIND_Ba) {
      if (m.m_r < mr ∧ m.m_t ≤ 0) return IAD_MR_TOO_SMALL;
    }
    else {
      if (r.default_a ≡ UNINITIALIZED ∨ r.default_a > 0) {
        if (m.m_r < mr) return IAD_MR_TOO_SMALL;
      }
    }
  }
```

This code is used in section 50.

52. The transmittance is also constrained by the index of refraction of the material. The minimum transmittance is zero, but the maximum transmittance cannot exceed the total light passing through the sample when there is no scattering or absorption. This is calculated by assuming an infinitely thin (to eliminate any scattering or absorption effects).

There is a problem when spheres are present. The estimated values for the transmittance using *Sp_mu_RT* are not actually limiting cases. This will require a bit of fixing, but for now that test is omitted if the number of spheres is more than zero.

```
⟨ Check MT for zero or one spheres 52 ⟩ ≡
  if (m.m_t < 0) return IAD_MT_TOO_SMALL;
  Sp_mu_RT_Flip(m.flip_sample, r.slab.n_top_slide, r.slab.n_slab, r.slab.n_bottom_slide, r.slab.b_top_slide, 0,
      r.slab.b_bottom_slide, r.slab.cos_angle, &ru, &tu);
  if (m.num_spheres ≡ 0 ∧ m.m_t > tu) {
    fprintf(stderr, "ntop=%7.5f, nslab=%7.5f, nbottom=%7.5f\n", r.slab.n_top_slide, r.slab.n_slab,
        r.slab.n_bottom_slide);
    fprintf(stderr, "tu_max=%7.5f, m_t=%7.5f, t_std=%7.5f\n", tu, m.m_t, m.rstd_t);
    return IAD_MT_TOO_BIG;
  }
```

This code is used in section 50.

53. The unscattered transmission is now always included in the total transmittance. Therefore the unscattered transmittance must fall betwee zero and `M_T`

⟨ Check MU 53 ⟩ ≡
```
if (m.m_u < 0) return IAD_MU_TOO_SMALL;
if (m.m_u > m.m_t) return IAD_MU_TOO_BIG;
```
This code is used in section 50.

54. Make sure that reflection sphere parameters are reasonable

⟨ Check sphere parameters 54 ⟩ ≡
```
if (m.as_r < 0 ∨ m.as_r ≥ 0.2) return IAD_AS_NOT_VALID;
if (m.ad_r < 0 ∨ m.ad_r ≥ 0.2) return IAD_AD_NOT_VALID;
if (m.ae_r < 0 ∨ m.ae_r ≥ 0.2) return IAD_AE_NOT_VALID;
if (m.rw_r < 0 ∨ m.rw_r > 1.0) return IAD_RW_NOT_VALID;
if (m.rd_r < 0 ∨ m.rd_r > 1.0) return IAD_RD_NOT_VALID;
if (m.rstd_r < 0 ∨ m.rstd_r > 1.0) return IAD_RSTD_NOT_VALID;
if (m.rstd_t < 0 ∨ m.rstd_t > 1.0) return IAD_TSTD_NOT_VALID;
if (m.f_r < 0 ∨ m.f_r > 1) return IAD_F_NOT_VALID;
```
See also section 55.

This code is used in section 50.

55. Make sure that transmission sphere parameters are reasonable

⟨ Check sphere parameters 54 ⟩ +≡
```
if (m.as_t < 0 ∨ m.as_t ≥ 0.2) return IAD_AS_NOT_VALID;
if (m.ad_t < 0 ∨ m.ad_t ≥ 0.2) return IAD_AD_NOT_VALID;
if (m.ae_t < 0 ∨ m.ae_t ≥ 0.2) return IAD_AE_NOT_VALID;
if (m.rw_t < 0 ∨ m.rw_r > 1.0) return IAD_RW_NOT_VALID;
if (m.rd_t < 0 ∨ m.rd_t > 1.0) return IAD_RD_NOT_VALID;
if (m.rstd_t < 0 ∨ m.rstd_t > 1.0) return IAD_TSTD_NOT_VALID;
if (m.f_t < 0 ∨ m.f_t > 1) return IAD_F_NOT_VALID;
```

56. Searching Method.

The original idea was that this routine would automatically determine what optical parameters could be figured out from the input data. This worked fine for a long while, but I discovered that often it was convenient to constrain the optical properties in various ways. Consequently, this routine got more and more complicated.

What should be done is to figure out whether the search will be 1D or 2D and split this routine into two parts.

It would be nice to enable the user to constrain two parameters, but the infrastructure is missing at this point.

⟨ Prototype for *determine_search* 56 ⟩ ≡

search_type *determine_search*(**struct measure_type** m, **struct invert_type** r)

This code is used in sections 42 and 57.

57. This routine is responsible for selecting the appropriate optical properties to determine.

```
⟨ Definition for determine_search 57 ⟩ ≡
  ⟨ Prototype for determine_search 56 ⟩
  {
    double rt, tt, rd, td, tc, rc;
    int search = 0;
    int independent = m.num_measures;
    if (Debug(DEBUG_SEARCH)) {
      fprintf(stderr, "\n*** Determine_Search()\n");
      fprintf(stderr, "     starting with %d measurement(s)\n", m.num_measures);
      fprintf(stderr, "     m_r=%.5f\n", m.m_r);
      fprintf(stderr, "     m_t=%.5f\n", m.m_t);
    }
    Estimate_RT(m, r, &rt, &tt, &rd, &rc, &td, &tc);
    if (m.m_u ≡ 0 ∧ independent ≡ 3) {
      if (Debug(DEBUG_SEARCH)) fprintf(stderr, "     no information in tc\n");
      independent −−;
    }
    if (rd ≡ 0 ∧ independent ≡ 2) {
      if (Debug(DEBUG_SEARCH)) fprintf(stderr, "     no information in rd\n");
      independent −−;
    }
    if (td ≡ 0 ∧ independent ≡ 2) {
      if (Debug(DEBUG_SEARCH)) fprintf(stderr, "     no information in td\n");
      independent −−;
    }
    if (independent ≡ 1 ∨ independent ≡ −1) {
      ⟨ One parameter search 58 ⟩
    }
    else if (independent ≡ 2) {
      ⟨ Two parameter search 59 ⟩
    }     /* three real parameters with information! */
    else {
      search = FIND_AG;
    }
    if (Debug(DEBUG_SEARCH)) {
      fprintf(stderr, "     independent measurements = %3d\n", independent);
      fprintf(stderr, "     m_r=%8.5f m_t=%8.5f (rd = %8.5f td=%8.5f)\n", m.m_r, m.m_t, rd, td);
      if (search ≡ FIND_A) fprintf(stderr, "     search = FIND_A\n");
      if (search ≡ FIND_B) fprintf(stderr, "     search = FIND_B\n");
      if (search ≡ FIND_AB) fprintf(stderr, "     search = FIND_AB\n");
      if (search ≡ FIND_AG) fprintf(stderr, "     search = FIND_AG\n");
      if (search ≡ FIND_AUTO) fprintf(stderr, "     search = FIND_AUTO\n");
      if (search ≡ FIND_BG) fprintf(stderr, "     search = FIND_BG\n");
      if (search ≡ FIND_BaG) fprintf(stderr, "     search = FIND_BaG\n");
      if (search ≡ FIND_BsG) fprintf(stderr, "     search = FIND_BsG\n");
      if (search ≡ FIND_Ba) fprintf(stderr, "     search = FIND_Ba\n");
      if (search ≡ FIND_Bs) fprintf(stderr, "     search = FIND_Bs\n");
      if (search ≡ FIND_G) fprintf(stderr, "     search = FIND_G\n");
      if (search ≡ FIND_B_WITH_NO_ABSORPTION)
        fprintf(stderr, "     search = FIND_B_WITH_NO_ABSORPTION\n");
```

```
    if (search ≡ FIND_B_WITH_NO_SCATTERING)
      fprintf(stderr, "␣␣␣␣search␣=␣FIND_B_WITH_NO_SCATTERING\n");
  }
  return search;
}
```

This code is used in section 41.

58. The fastest inverse problems are those in which just one measurement is known. This corresponds to a simple one-dimensional minimization problem. The only complexity is deciding exactly what should be allowed to vary. The basic assumption is that the anisotropy has been specified or will be assumed to be zero.

If the anistropy is assumed known, then one other assumption will allow us to figure out the last parameter to solve for.

Ultimately, if no default values are given, then we look at the value of the total transmittance. If this is zero, then we assume that the optical thickness is infinite and solve for the albedo. Otherwise we will just make a stab at solving for the optical thickness assuming the albedo is one.

⟨ One parameter search 58 ⟩ ≡

```
if (r.default_a ≠ UNINITIALIZED) {
  if (r.default_a ≡ 0) search = FIND_B_WITH_NO_SCATTERING;
  else if (r.default_a ≡ 1) search = FIND_B_WITH_NO_ABSORPTION;
  else if (tt ≡ 0) search = FIND_G;
  else search = FIND_B;
}
else if (r.default_b ≠ UNINITIALIZED) search = FIND_A;
else if (r.default_bs ≠ UNINITIALIZED) search = FIND_Ba;
else if (r.default_ba ≠ UNINITIALIZED) search = FIND_Bs;
else if (td ≡ 0) search = FIND_A;
else if (rd ≡ 0) search = FIND_B_WITH_NO_SCATTERING;
else search = FIND_B_WITH_NO_ABSORPTION;
```

This code is used in section 57.

59. If the absorption depth $\mu_a d$ is constrained return *FIND_BsG*. Recall that I use the bizarre mnemonic $bs = \mu_s d$ here and so this means that the program will search over various values of $\mu_s d$ and g.

If there are just two measurements then I assume that the anisotropy is not of interest and the only thing to calculate is the reduced albedo and optical thickness based on an assumed anisotropy.

```
⟨ Two parameter search 59 ⟩ ≡
  if (r.default_a ≠ UNINITIALIZED) {
    if (r.default_a ≡ 0) search = FIND_B;
    else if (r.default_g ≠ UNINITIALIZED) search = FIND_B;
    else search = FIND_BG;
  }
  else if (r.default_b ≠ UNINITIALIZED) {
    if (r.default_g ≠ UNINITIALIZED) search = FIND_A;
    else search = FIND_AG;
  }
  else if (r.default_ba ≠ UNINITIALIZED) {
    if (r.default_g ≠ UNINITIALIZED) search = FIND_Bs;
    else search = FIND_BsG;
  }
  else if (r.default_bs ≠ UNINITIALIZED) {
    if (r.default_g ≠ UNINITIALIZED) search = FIND_Ba;
    else search = FIND_BaG;
  }
  else if (rt + tt > 1 ∧ 0 ∧ m.num_spheres ≠ 2) search = FIND_B_WITH_NO_ABSORPTION;
  else search = FIND_AB;
```

This code is used in section 57.

60. This little routine just stuffs reasonable values into the structure we use to return the solution. This does not replace the values for $r.default\_g$ nor for $r.method.quad\_pts$. Presumably these have been set correctly elsewhere.

```
⟨ Prototype for Initialize_Result 60 ⟩ ≡
  void Initialize_Result(struct measure_type m, struct invert_type *r)
```

This code is used in sections 42 and 61.

61.

```
⟨ Definition for Initialize_Result 61 ⟩ ≡
  ⟨ Prototype for Initialize_Result 60 ⟩
  {
    ⟨ Fill r with reasonable values 62 ⟩
  }
```

This code is used in section 41.

62. Start with the optical properties.

```
⟨ Fill r with reasonable values 62 ⟩ ≡
  r→a = 0.0;
  r→b = 0.0;
  r→g = 0.0;
```

See also sections 63, 64, and 65.

This code is used in section 61.

63. Continue with other useful stuff.

```
⟨ Fill r with reasonable values 62 ⟩ +≡
  r→found = FALSE;
  r→tolerance = 0.0001;
  r→MC_tolerance = 0.01;      /* percent */
  r→search = FIND_AUTO;
  r→metric = RELATIVE;
  r→final_distance = 10;
  r→iterations = 0;
  r→error = IAD_NO_ERROR;
```

64. The defaults might be handy

```
⟨ Fill r with reasonable values 62 ⟩ +≡
  r→default_a = UNINITIALIZED;
  r→default_b = UNINITIALIZED;
  r→default_g = UNINITIALIZED;
  r→default_ba = UNINITIALIZED;
  r→default_bs = UNINITIALIZED;
  r→default_mua = UNINITIALIZED;
  r→default_mus = UNINITIALIZED;
```

65. It is necessary to set up the slab correctly so, I stuff reasonable values into this record as well.

```
⟨ Fill r with reasonable values 62 ⟩ +≡
  r→slab.a = 0.5;
  r→slab.b = 1.0;
  r→slab.g = 0;
  r→slab.phase_function = HENYEY_GREENSTEIN;
  r→slab.n_slab = m.slab_index;
  r→slab.n_top_slide = m.slab_top_slide_index;
  r→slab.n_bottom_slide = m.slab_bottom_slide_index;
  r→slab.b_top_slide = m.slab_top_slide_b;
  r→slab.b_bottom_slide = m.slab_bottom_slide_b;
  r→slab.cos_angle = m.slab_cos_angle;
  r→method.a_calc = 0.5;
  r→method.b_calc = 1;
  r→method.g_calc = 0.5;
  r→method.quad_pts = 8;
  r→method.b_thinnest = 1.0/32.0;
```

66. EZ Inverse RT. *ez_Inverse_RT* is a simple interface to the main function *Inverse_RT* in this package. It eliminates the need for complicated data structures so that the command line interface (as well as those to Perl and Mathematica) will be simpler. This function assumes that the reflection and transmission include specular reflection and that the transmission also include unscattered transmission.

Other assumptions are that the top and bottom slides have the same index of refraction, that the illumination is collimated. Of course no sphere parameters are included.

⟨ Prototype for *ez_Inverse_RT* 66 ⟩ ≡

```
void ez_Inverse_RT(double n, double nslide, double UR1, double UT1, double Tc, double *a, double
    *b, double *g, int *error)
```

This code is used in sections 42, 43, and 67.

67. ⟨ Definition for *ez_Inverse_RT* 67 ⟩ ≡

```
⟨ Prototype for ez_Inverse_RT 66 ⟩
{
  struct measure_type m;
  struct invert_type r;
  *a = 0;
  *b = HUGE_VAL;
  *g = 0;
  Initialize_Measure(&m);
  m.slab_index = n;
  m.slab_top_slide_index = nslide;
  m.slab_bottom_slide_index = nslide;
  m.slab_cos_angle = 1.0;
  m.num_measures = 3;
  if (UT1 ≡ 0) m.num_measures--;
  if (Tc ≡ 0) m.num_measures--;
  m.m_r = UR1;
  m.m_t = UT1;
  m.m_u = Tc;
  Initialize_Result(m, &r);
  r.method.quad_pts = 8;
  Inverse_RT(m, &r);
  *error = r.error;
  if (r.error ≡ IAD_NO_ERROR) {
    *a = r.a;
    *b = r.b;
    *g = r.g;
  }
}
```

This code is used in section 41.

68. ⟨ Prototype for *Initialize_Measure* 68 ⟩ ≡

```
void Initialize_Measure(struct measure_type *m)
```

This code is used in sections 42 and 69.

69. ⟨ Definition for *Initialize_Measure* 69 ⟩ ≡

```
⟨ Prototype for Initialize_Measure 68 ⟩
{
  double default_sphere_d = 8.0 * 25.4;
  double default_sample_d = 1.0 * 25.4;
  double default_detector_d = 0.1 * 25.4;
  double default_entrance_d = 0.5 * 25.4;
  double sphere_area = M_PI * default_sphere_d * default_sphere_d;
  m→slab_index = 1.0;
  m→slab_top_slide_index = 1.0;
  m→slab_top_slide_b = 0.0;
  m→slab_top_slide_thickness = 0.0;
  m→slab_bottom_slide_index = 1.0;
  m→slab_bottom_slide_b = 0.0;
  m→slab_bottom_slide_thickness = 0.0;
  m→slab_thickness = 1.0;
  m→slab_cos_angle = 1.0;
  m→num_spheres = 0;
  m→num_measures = 1;
  m→method = UNKNOWN;
  m→fraction_of_rc_in_mr = 1.0;
  m→fraction_of_tc_in_mt = 1.0;
  m→baffle_r = 1;
  m→baffle_t = 1;
  m→flip_sample = 0;
  m→gain_type = 0;
  m→m_r = 0.0;
  m→m_t = 0.0;
  m→m_u = 0.0;
  m→d_sphere_r = default_sphere_d;
  m→as_r = (M_PI * default_sample_d * default_sample_d/4.0)/sphere_area;
  m→ad_r = (M_PI * default_detector_d * default_detector_d/4.0)/sphere_area;
  m→ae_r = (M_PI * default_entrance_d * default_entrance_d/4.0)/sphere_area;
  m→aw_r = 1.0 − m→as_r − m→ad_r − m→ae_r;
  m→rd_r = 0.0;
  m→rw_r = 1.0;
  m→rstd_r = 1.0;
  m→f_r = 0.0;
  m→d_sphere_t = default_sphere_d;
  m→as_t = m→as_r;
  m→ad_t = m→ad_r;
  m→ae_t = 0;
  m→aw_t = 1.0 − m→as_t − m→ad_t − m→ae_t;
  m→rd_t = 0.0;
  m→rw_t = 1.0;
  m→rstd_t = 1.0;
  m→f_t = 0.0;
  m→lambda = 0.0;
  m→d_beam = 0.0;
  m→ur1_lost = 0;
  m→uru_lost = 0;
  m→ut1_lost = 0;
```

```
    m→utu_lost = 0;
  }
```

This code is used in section 41.

70. To avoid interfacing with C-structures it is necessary to pass the information as arrays. Here I have divided the experiment into (1) setup, (2) reflection sphere coefficients, (3) transmission sphere coefficients, (4) measurements, and (5) results.

```
⟨ Prototype for Spheres_Inverse_RT 70 ⟩ ≡
  void Spheres_Inverse_RT(double *setup, double *analysis, double *sphere_r, double *sphere_t, double
      *measurements, double *results)
```

This code is used in sections 43 and 71.

71.

```
⟨ Definition for Spheres_Inverse_RT 71 ⟩ ≡
  ⟨ Prototype for Spheres_Inverse_RT 70 ⟩
  {
    struct measure_type m;
    struct invert_type r;
    long num_photons;
    double ur1, ut1, uru, utu;
    int i, mc_runs = 1;
    Initialize_Measure(&m);
    ⟨ handle setup 72 ⟩
    ⟨ handle reflection sphere 75 ⟩
    ⟨ handle transmission sphere 76 ⟩
    ⟨ handle measurement 74 ⟩
    Initialize_Result(m, &r);
    results[0] = 0;
    results[1] = 0;
    results[2] = 0;
    ⟨ handle analysis 73 ⟩
    Inverse_RT(m, &r);
    for (i = 0; i < mc_runs; i++) {
      MC_Lost(m, r, num_photons, &ur1, &ut1, &uru, &utu, &m.ur1_lost, &m.ut1_lost, &m.uru_lost,
          &m.utu_lost);
      Inverse_RT(m, &r);
    }
    if (r.error ≡ IAD_NO_ERROR) {
      results[0] = (1 − r.a) * r.b/m.slab_thickness;
      results[1] = (r.a) * r.b/m.slab_thickness;
      results[2] = r.g;
    }
    results[3] = r.error;
  }
```

This code is used in section 41.

72. These are in exactly the same order as the parameters in the .rxt header

⟨ handle setup 72 ⟩ ≡

```
{
  double d_sample_r, d_entrance_r, d_detector_r;
  double d_sample_t, d_entrance_t, d_detector_t;
  m.slab_index = setup[0];
  m.slab_top_slide_index = setup[1];
  m.slab_thickness = setup[2];
  m.slab_top_slide_thickness = setup[3];
  m.d_beam = setup[4];
  m.rstd_r = setup[5];
  m.num_spheres = (int) setup[6];
  m.d_sphere_r = setup[7];
  d_sample_r = setup[8];
  d_entrance_r = setup[9];
  d_detector_r = setup[10];
  m.rw_r = setup[11];
  m.d_sphere_t = setup[12];
  d_sample_t = setup[13];
  d_entrance_t = setup[14];
  d_detector_t = setup[15];
  m.rw_t = setup[16];
  r.default_g = setup[17];
  num_photons = (long) setup[18];
  m.as_r = (d_sample_r/m.d_sphere_r/2.0) * (d_sample_r/m.d_sphere_r/2.0);
  m.ae_r = (d_entrance_r/m.d_sphere_r/2.0) * (d_entrance_r/m.d_sphere_r/2.0);
  m.ad_r = (d_detector_r/m.d_sphere_r/2.0) * (d_detector_r/m.d_sphere_r/2.0);
  m.aw_r = 1.0 - m.as_r - m.ae_r - m.ad_r;
  m.as_t = (d_sample_t/m.d_sphere_t/2.0) * (d_sample_t/m.d_sphere_t/2.0);
  m.ae_t = (d_entrance_t/m.d_sphere_t/2.0) * (d_entrance_t/m.d_sphere_t/2.0);
  m.ad_t = (d_detector_t/m.d_sphere_t/2.0) * (d_detector_t/m.d_sphere_t/2.0);
  m.aw_t = 1.0 - m.as_t - m.ae_t - m.ad_t;
  m.slab_bottom_slide_index = m.slab_top_slide_index;
  m.slab_bottom_slide_thickness = m.slab_top_slide_thickness;
  fprintf(stderr, "**** executing FIXME ****/n");
  m.slab_cos_angle = 1.0;      /* FIXME */
}
```

This code is used in section 71.

73. ⟨ handle analysis 73 ⟩ ≡

```
r.method.quad_pts = (int) analysis[0];
mc_runs = (int) analysis[1];
```

This code is used in section 71.

74.

⟨ handle measurement 74 ⟩ ≡
```
m.m_r = measurements[0];
m.m_t = measurements[1];
m.m_u = measurements[2];
m.num_measures = 3;
if (m.m_t ≡ 0) m.num_measures −−;
if (m.m_u ≡ 0) m.num_measures −−;
```
This code is used in section 71.

75.

⟨ handle reflection sphere 75 ⟩ ≡
```
m.as_r = sphere_r[0];
m.ae_r = sphere_r[1];
m.ad_r = sphere_r[2];
m.rw_r = sphere_r[3];
m.rd_r = sphere_r[4];
m.rstd_r = sphere_r[5];
m.f_r = sphere_r[7];
```
This code is used in section 71.

76.

⟨ handle transmission sphere 76 ⟩ ≡
```
m.as_t = sphere_t[0];
m.ae_t = sphere_t[1];
m.ad_t = sphere_t[2];
m.rw_t = sphere_t[3];
m.rd_t = sphere_t[4];
m.rstd_t = sphere_t[5];
m.f_t = sphere_t[7];
```
This code is used in section 71.

77. I needed a routine that would calculate the values of `M_R` and `M_T` without doing the whole inversion process. It seems odd that this does not exist yet.

The values for the lost light *m.uru_lost* etc., should be calculated before calling this routine.

⟨ Prototype for *Calculate_MR_MT* 77 ⟩ ≡
```
void Calculate_MR_MT(struct measure_type m, struct invert_type r, int include_MC, double
    *M_R, double *M_T)
```
This code is used in sections 42 and 78.

78. ⟨ Definition for *Calculate_MR_MT* 78 ⟩ ≡
⟨ Prototype for *Calculate_MR_MT* 77 ⟩
{
double *distance*, *ur1*, *ut1*, *uru*, *utu*;
struct measure_type *old_mm*;
struct invert_type *old_rr*;
if (*include_MC* ∧ *m.num_spheres* > 0) *MC_Lost*(*m*, *r*, −2000, &*ur1*, &*ut1*, &*uru*, &*utu*, &(*m.ur1_lost*), &(*m.ut1_lost*), &(*m.uru_lost*), &(*m.utu_lost*));
Get_Calc_State(&*old_mm*, &*old_rr*);
Set_Calc_State(*m*, *r*);
Calculate_Distance(M_R, M_T, &*distance*);
Set_Calc_State(*old_mm*, *old_rr*);
}
This code is used in section 41.

79. So, it turns out that the minimum measured M_R can be less than four percent for black glass! This is because the sphere efficiency is much worse for the glass than for the white standard.

⟨ Prototype for *Calculate_Minimum_MR* 79 ⟩ ≡
void *Calculate_Minimum_MR*(**struct measure_type** *m*, **struct invert_type** *r*, **double** ∗*mr*, **double** ∗*mt*)
This code is used in sections 42 and 80.

80. ⟨ Definition for *Calculate_Minimum_MR* 80 ⟩ ≡
⟨ Prototype for *Calculate_Minimum_MR* 79 ⟩
{
if (*r.default_b* ≡ UNINITIALIZED)
if (*r.slab.n_slab* > 1.0) *r.slab.b* = HUGE_VAL;
else *r.slab.b* = $1 \cdot 10^{-5}$;
else *r.slab.b* = *r.default_b*;
if (*r.default_a* ≡ UNINITIALIZED) *r.slab.a* = 0;
else *r.slab.a* = *r.default_a*;
if (*r.default_g* ≡ UNINITIALIZED) *r.slab.g* = 0.0;
else *r.slab.g* = *r.default_g*;
if (*r.search* ≡ FIND_G) *r.slab.a* = 0;
r.a = *r.slab.a*;
r.b = *r.slab.b*;
r.g = *r.slab.g*;
Calculate_MR_MT(*m*, *r*, 0, *mr*, *mt*);
∗*mt* = 0;
}
This code is used in section 41.

81. The minimum possible value of MR for a given MT will be when the albedo is zero and the maximum value will be when the albedo is one. In the first case there will be no light loss and in the second we will assume that any light loss is neglible (to maximize MR).

The second case is perhaps over-simplified. Obviously for a fixed thickness as the albedo increases, the reflectance will increase. So how does *U_Find_B*( ) work when the albedo is set to 1?

The problem is that to calculate these values one must know the optical thickness. Fortunately with the recent addition of constrained minimization, we can do exactly this.

The only thing that remains is to sort out the light lost effect.

⟨ Prototype for *MinMax_MR_MT* 81 ⟩ ≡

```
int MinMax_MR_MT(struct measure_type m, struct invert_type r)
```

This code is used in sections 42 and 82.

82. ⟨ Definition for *MinMax_MR_MT* 82 ⟩ ≡

```
⟨ Prototype for MinMax_MR_MT 81 ⟩
{
  double distance, measured_m_r, min_possible_m_r, max_possible_m_r, temp_m_t;
  if (m.m_r < 0) return IAD_MR_TOO_SMALL;
  if (m.m_r * m.rstd_r > 1) return IAD_MR_TOO_BIG;
  if (m.m_t < 0) return IAD_MT_TOO_SMALL;
  if (m.m_t ≡ 0) return IAD_NO_ERROR;
  measured_m_r = m.m_r;
  m.m_r = 0;
  r.search = FIND_B;
  r.default_a = 0;
  U_Find_B(m, &r);
  Calculate_Distance(&min_possible_m_r, &temp_m_t, &distance);
  if (measured_m_r < min_possible_m_r) return IAD_MR_TOO_SMALL;
  r.default_a = 1.0;
  U_Find_B(m, &r);
  Calculate_Distance(&max_possible_m_r, &temp_m_t, &distance);
  if (measured_m_r > max_possible_m_r) return IAD_MR_TOO_BIG;
  return IAD_NO_ERROR;
}
```

This code is used in section 41.

83. ⟨ Prototype for *Spheres_Inverse_RT2* 83 ⟩ ≡

```
void Spheres_Inverse_RT2(double *sample, double *illumination, double *sphere_r, double
    *sphere_t, double *analysis, double *measurement, double *a, double *b, double *g)
```

This code is used in sections 42, 43, and 84.

84. ⟨ Definition for *Spheres_Inverse_RT2* 84 ⟩ ≡

```
⟨ Prototype for Spheres_Inverse_RT2 83 ⟩
{
  struct measure_type m;
  struct invert_type r;
  long num_photons;
  double ur1, ut1, uru, utu;
  int i, mc_runs = 1;
  Initialize_Measure(&m);
  ⟨ handle2 sample 85 ⟩
  ⟨ handle2 illumination 86 ⟩
  ⟨ handle2 reflection sphere 87 ⟩
  ⟨ handle2 transmission sphere 88 ⟩
  ⟨ handle2 analysis 89 ⟩
  ⟨ handle2 measurement 90 ⟩
  Initialize_Result(m, &r);
  Inverse_RT(m, &r);
  for (i = 0; i < mc_runs; i++) {
    MC_Lost(m, r, num_photons, &ur1, &ut1, &uru, &utu, &m.ur1_lost, &m.ut1_lost, &m.uru_lost,
        &m.utu_lost);
    Inverse_RT(m, &r);
  }
  if (r.error ≡ IAD_NO_ERROR) {
    *a = r.a;
    *b = r.b;
    *g = r.g;
  }
}
```

This code is used in section 41.

85. Just move the values from the sample array into the right places

```
⟨ handle2 sample 85 ⟩ ≡
  m.slab_index = sample[0];
  m.slab_top_slide_index = sample[1];
  m.slab_bottom_slide_index = sample[2];
  m.slab_thickness = sample[3];
  m.slab_top_slide_thickness = sample[4];
  m.slab_bottom_slide_thickness = sample[5];
  m.slab_top_slide_thickness = 0;
  m.slab_bottom_slide_thickness = 0;
```

This code is used in section 84.

86. Just move the values from the illumination array into the right places. Need to spend time to figure out how to integrate items 2, 3, and 4

```
⟨ handle2 illumination 86 ⟩ ≡
  m.d_beam = illumination[0];      /* m.lambda = illumination[1]; */
    /* m.specular-reflection-excluded = illumination[2]; */      /* m.direct-transmission-excluded =
      illumination[3]; */      /* m.diffuse-illumination = illumination[4]; */
  m.num_spheres = illumination[5];
```

This code is used in section 84.

87.

⟨ handle2 reflection sphere 87 ⟩ ≡

```
{
  double d_sample_r, d_entrance_r, d_detector_r;
  m.d_sphere_r = sphere_r[0];
  d_sample_r = sphere_r[1];
  d_entrance_r = sphere_r[2];
  d_detector_r = sphere_r[3];
  m.rw_r = sphere_r[4];
  m.rd_r = sphere_r[5];
  m.as_r = (d_sample_r/m.d_sphere_r/2.0) * (d_sample_r/m.d_sphere_r/2.0);
  m.ae_r = (d_entrance_r/m.d_sphere_r/2.0) * (d_entrance_r/m.d_sphere_r/2.0);
  m.ad_r = (d_detector_r/m.d_sphere_r/2.0) * (d_detector_r/m.d_sphere_r/2.0);
  m.aw_r = 1.0 - m.as_r - m.ae_r - m.ad_r;
}
```

This code is used in section 84.

88.

⟨ handle2 transmission sphere 88 ⟩ ≡

```
{
  double d_sample_t, d_entrance_t, d_detector_t;
  m.d_sphere_t = sphere_t[0];
  d_sample_t = sphere_t[1];
  d_entrance_t = sphere_t[2];
  d_detector_t = sphere_t[3];
  m.rw_t = sphere_t[4];
  m.rd_t = sphere_t[5];
  m.as_t = (d_sample_t/m.d_sphere_t/2.0) * (d_sample_t/m.d_sphere_t/2.0);
  m.ae_t = (d_entrance_t/m.d_sphere_t/2.0) * (d_entrance_t/m.d_sphere_t/2.0);
  m.ad_t = (d_detector_t/m.d_sphere_t/2.0) * (d_detector_t/m.d_sphere_t/2.0);
  m.aw_t = 1.0 - m.as_t - m.ae_t - m.ad_t;
}
```

This code is used in section 84.

89.

⟨ handle2 analysis 89 ⟩ ≡

```
r.method.quad_pts = (int) analysis[0];
mc_runs = (int) analysis[1];
num_photons = (long) analysis[2];
```

This code is used in section 84.

90.

⟨ handle2 measurement 90 ⟩ ≡

```
m.rstd_r = measurement[0];
m.m_r = measurement[1];
m.m_t = measurement[2];
m.m_u = measurement[3];
m.num_measures = 3;
if (m.m_t ≡ 0) m.num_measures--;
if (m.m_u ≡ 0) m.num_measures--;
```

This code is used in section 84.

91. IAD Input Output.

The special define below is to get Visual C to suppress silly warnings.

⟨ iad_io.c 91 ⟩ ≡
```
#define _CRT_SECURE_NO_WARNINGS
#include <string.h>
#include <stdio.h>
#include <ctype.h>
#include <math.h>
#include "ad_globl.h"
#include "iad_type.h"
#include "iad_io.h"
#include "iad_pub.h"
#include "version.h"
```
⟨ Definition for *skip_white* 101 ⟩
⟨ Definition for *read_number* 103 ⟩
⟨ Definition for *check_magic* 105 ⟩
⟨ Definition for *Read_Header* 95 ⟩
⟨ Definition for *Write_Header* 107 ⟩
⟨ Definition for *Read_Data_Line* 99 ⟩

92. ⟨ iad_io.h 92 ⟩ ≡
⟨ Prototype for *Read_Header* 94 ⟩;
⟨ Prototype for *Write_Header* 106 ⟩;
⟨ Prototype for *Read_Data_Line* 98 ⟩;

93. Reading the file header.

94. ⟨ Prototype for *Read_Header* 94 ⟩ ≡

```
int Read_Header(FILE *fp, struct measure_type *m, int *params)
```

This code is used in sections 92 and 95.

95. Pretty straightforward stuff. The only thing that needs to be commented on is that only one slide thickness/index is specified in the file. This must be applied to both the top and bottom slides. Finally, to specify no slide, then either setting the slide index to 1.0 or the thickness to 0.0 should do the trick.

```
⟨ Definition for Read_Header 95 ⟩ ≡
  ⟨ Prototype for Read_Header 94 ⟩
  {
    double x;
    Initialize_Measure(m);
    if (check_magic(fp)) return 1;
    if (read_number(fp, &m→slab_index)) return 1;
    if (read_number(fp, &m→slab_top_slide_index)) return 1;
    if (read_number(fp, &m→slab_thickness)) return 1;
    if (read_number(fp, &m→slab_top_slide_thickness)) return 1;
    if (read_number(fp, &m→d_beam)) return 1;
    if (m→slab_top_slide_thickness ≡ 0.0) m→slab_top_slide_index = 1.0;
    if (m→slab_top_slide_index ≡ 1.0) m→slab_top_slide_thickness = 0.0;
    if (m→slab_top_slide_index ≡ 0.0) {
      m→slab_top_slide_thickness = 0.0;
      m→slab_top_slide_index = 1.0;
    }
    m→slab_bottom_slide_index = m→slab_top_slide_index;
    m→slab_bottom_slide_thickness = m→slab_top_slide_thickness;
    if (read_number(fp, &m→rstd_r)) return 1;
    if (read_number(fp, &x)) return 1;
    m→num_spheres = (int) x;
    m→method = SUBSTITUTION;
    ⟨ Read coefficients for reflection sphere 96 ⟩
    ⟨ Read coefficients for transmission sphere 97 ⟩
    if (read_number(fp, &x)) return 1;
    *params = (int) x;
    m→num_measures = (*params ≥ 3) ? 3 : *params;
    return 0;
  }
```

This code is used in section 91.

96. ⟨ Read coefficients for reflection sphere 96 ⟩ ≡

```
{
  double d_sample_r, d_empty_r, d_detector_r;
  if (read_number(fp, &m→d_sphere_r)) return 1;
  if (read_number(fp, &d_sample_r)) return 1;
  if (read_number(fp, &d_empty_r)) return 1;
  if (read_number(fp, &d_detector_r)) return 1;
  if (read_number(fp, &m→rw_r)) return 1;
  m→as_r = (d_sample_r/m→d_sphere_r/2.0) * (d_sample_r/m→d_sphere_r/2.0);
  m→ae_r = (d_empty_r/m→d_sphere_r/2.0) * (d_empty_r/m→d_sphere_r/2.0);
  m→ad_r = (d_detector_r/m→d_sphere_r/2.0) * (d_detector_r/m→d_sphere_r/2.0);
  m→aw_r = 1.0 - m→as_r - m→ae_r - m→ad_r;
}
```

This code is used in section 95.

97. ⟨ Read coefficients for transmission sphere 97 ⟩ ≡

```
{
  double d_sample_t, d_empty_t, d_detector_t;
  if (read_number(fp, &m→d_sphere_t)) return 1;
  if (read_number(fp, &d_sample_t)) return 1;
  if (read_number(fp, &d_empty_t)) return 1;
  if (read_number(fp, &d_detector_t)) return 1;
  if (read_number(fp, &m→rw_t)) return 1;
  m→as_t = (d_sample_t/m→d_sphere_t/2.0) * (d_sample_t/m→d_sphere_t/2.0);
  m→ae_t = (d_empty_t/m→d_sphere_t/2.0) * (d_empty_t/m→d_sphere_t/2.0);
  m→ad_t = (d_detector_t/m→d_sphere_t/2.0) * (d_detector_t/m→d_sphere_t/2.0);
  m→aw_t = 1.0 - m→as_t - m→ae_t - m→ad_t;
}
```

This code is used in section 95.

98. Reading just one line of a data file.

This reads a line of data based on the value of *params*.

If the first number is greater than one then it is assumed to be the wavelength and is ignored. test on the first value of the line.

A non-zero value is returned upon a failure.

⟨ Prototype for *Read_Data_Line* 98 ⟩ ≡

```
int Read_Data_Line(FILE *fp, struct measure_type *m, int params)
```

This code is used in sections 92 and 99.

99. ⟨ Definition for *Read_Data_Line* 99 ⟩ ≡

```
⟨ Prototype for Read_Data_Line 98 ⟩
{
  if (read_number(fp, &m→m_r)) return 1;
  if (m→m_r > 1) {
    m→lambda = m→m_r;
    if (read_number(fp, &m→m_r)) return 1;
  }
  if (params ≡ −1) {
    m→m_t = m→m_r;
    m→m_r = 0;
    return 0;
  }
  if (params ≡ 1) return 0;
  if (read_number(fp, &m→m_t)) return 1;
  if (params ≡ 2) return 0;
  if (read_number(fp, &m→m_u)) return 1;
  if (params ≡ 3) return 0;
  if (read_number(fp, &m→rw_r)) return 1;
  m→rw_t = m→rw_r;
  if (params ≡ 4) return 0;
  if (read_number(fp, &m→rw_t)) return 1;
  if (params ≡ 5) return 0;
  if (read_number(fp, &m→rstd_r)) return 1;
  if (params ≡ 6) return 0;
  if (read_number(fp, &m→rstd_t)) return 1;
  return 0;
}
```

This code is used in section 91.

100. Skip over white space and comments. It is assumed that # starts all comments and continues to the end of a line. This routine should work on files with nearly any line ending CR, LF, CRLF.

Failure is indicated by a non-zero return value.

⟨ Prototype for *skip_white* 100 ⟩ ≡

```
int skip_white(FILE *fp)
```

This code is used in section 101.

101. ⟨ Definition for *skip_white* 101 ⟩ ≡

```
⟨ Prototype for skip_white 100 ⟩
{
  int c = fgetc(fp);
  while (¬feof(fp)) {
    if (isspace(c)) c = fgetc(fp);
    else if (c ≡ '#') do c = fgetc(fp); while (¬feof(fp) ∧ c ≠ '\n' ∧ c ≠ '\r');
    else break;
  }
  if (feof(fp)) return 1;
  ungetc(c, fp);
  return 0;
}
```

This code is used in section 91.

102. Read a single number. Return 0 if there are no problems, otherwise return 1.

⟨ Prototype for *read_number* 102 ⟩ ≡

```
int read_number(FILE *fp, double *x)
```

This code is used in section 103.

103. ⟨ Definition for *read_number* 103 ⟩ ≡

```
⟨ Prototype for read_number 102 ⟩
{
  if (skip_white(fp)) return 1;
  if (fscanf(fp, "%lf", x)) return 0;
  else return 1;
}
```

This code is used in section 91.

104. Ensure that the data file is actually in the right form. Return 0 if the file has the right starting characters. Return 1 if on a failure.

⟨ Prototype for *check_magic* 104 ⟩ ≡

```
int check_magic(FILE *fp)
```

This code is used in section 105.

105. ⟨ Definition for *check_magic* 105 ⟩ ≡

```
⟨ Prototype for check_magic 104 ⟩
{
  char magic[] = "IAD1";
  int i, c;
  for (i = 0; i < 4; i++) {
    c = fgetc(fp);
    if (feof(fp) ∨ c ≠ magic[i]) {
      fprintf(stderr, "Sorry, but iad input files must begin with IAD1\n");
      fprintf(stderr, "␣␣␣␣␣␣␣␣as the first four characters of the file.\n");
      fprintf(stderr, "␣␣␣␣␣␣␣␣Perhaps you are using an old iad format?\n");
      return 1;
    }
  }
  return 0;
}
```

This code is used in section 91.

106. Formatting the header information.

⟨ Prototype for *Write_Header* 106 ⟩ ≡
void *Write_Header*(**struct measure_type** *m*, **struct invert_type** *r*, **int** *params*)

This code is used in sections 92 and 107.

107. ⟨ Definition for *Write_Header* 107 ⟩ ≡
⟨ Prototype for *Write_Header* 106 ⟩
{
⟨ Write slab info 108 ⟩
⟨ Write irradiation info 109 ⟩
⟨ Write general sphere info 110 ⟩
⟨ Write first sphere info 111 ⟩
⟨ Write second sphere info 112 ⟩
⟨ Write measure and inversion info 113 ⟩
}

This code is used in section 91.

108. ⟨ Write slab info 108 ⟩ ≡
double *xx*;
printf("# Inverse Adding-Doubling %s \n", *Version*);
printf("# \n");
printf("# Beam diameter = %7.1f mm\n", *m.d_beam*);
printf("# Sample thickness = %7.3f mm\n", *m.slab_thickness*);
printf("# Top slide thickness = %7.3f mm\n", *m.slab_top_slide_thickness*);
printf("# Bottom slide thickness = %7.3f mm\n", *m.slab_bottom_slide_thickness*);
printf("# Sample index of refraction = %7.4f\n", *m.slab_index*);
printf("# Top slide index of refraction = %7.4f\n", *m.slab_top_slide_index*);
printf("# Bottom slide index of refraction = %7.4f\n", *m.slab_bottom_slide_index*);

This code is used in section 107.

109. ⟨ Write irradiation info 109 ⟩ ≡
printf("# \n");

This code is used in section 107.

110. ⟨ Write general sphere info 110 ⟩ ≡
printf("# Percentage unscattered refl. in M_R = %7.1f %%\n", *m.fraction_of_rc_in_mr* ∗ 100);
printf("# Percentage unscattered trans. in M_T = %7.1f %%\n", *m.fraction_of_tc_in_mt* ∗ 100);
printf("# \n");

This code is used in section 107.

111. ⟨ Write first sphere info 111 ⟩ ≡

```
printf("#␣Reflection␣sphere");
if (m.baffle_r) printf("␣has␣a␣baffle␣between␣sample␣and␣detector␣");
else printf("␣has␣no␣baffle␣between␣sample␣and␣detector");
if (m.num_spheres > 0) printf("\n");
else printf("␣(all␣ignored␣since␣no␣spheres␣used)\n");
printf("#␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣sphere␣diameter␣=␣%7.1f␣mm\n", m.d_sphere_r);
printf("#␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣sample␣port␣diameter␣=␣%7.1f␣mm\n", 2 * m.d_sphere_r * sqrt(m.as_r));
printf("#␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣empty␣port␣diameter␣=␣%7.1f␣mm\n", 2 * m.d_sphere_r * sqrt(m.ae_r));
printf("#␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣detector␣port␣diameter␣=␣%7.1f␣mm\n", 2 * m.d_sphere_r * sqrt(m.ad_r));
printf("#␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣detector␣reflectance␣=␣%7.1f␣%%\n", m.rd_r * 100);
printf("#␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣wall␣reflectance␣=␣%7.1f␣%%\n", m.rw_r * 100);
printf("#␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣calibration␣standard␣=␣%7.1f␣%%\n", m.rstd_r * 100);
printf("#\n");
```

This code is used in section 107.

112. ⟨ Write second sphere info 112 ⟩ ≡

```
printf("#␣Transmission␣sphere");
if (m.baffle_t) printf("␣has␣a␣baffle␣between␣sample␣and␣detector␣");
else printf("␣has␣no␣baffle␣between␣sample␣and␣detector");
if (m.num_spheres > 0) printf("\n");
else printf("␣(all␣ignored␣since␣no␣spheres␣used)\n");
printf("#␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣sphere␣diameter␣=␣%7.1f␣mm\n", m.d_sphere_t);
printf("#␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣sample␣port␣diameter␣=␣%7.1f␣mm\n", 2 * m.d_sphere_r * sqrt(m.as_t));
printf("#␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣empty␣port␣diameter␣=␣%7.1f␣mm\n", 2 * m.d_sphere_r * sqrt(m.ae_t));
printf("#␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣detector␣port␣diameter␣=␣%7.1f␣mm\n", 2 * m.d_sphere_r * sqrt(m.ad_t));
printf("#␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣detector␣reflectance␣=␣%7.1f␣%%\n", m.rd_t * 100);
printf("#␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣wall␣reflectance␣=␣%7.1f␣%%", m.rw_t * 100);
if (m.ae_t ≡ 0) printf("␣(cal␣std␣since␣empty␣port␣is␣closed)");
printf("\n");
printf("#␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣calibration␣standard␣=␣%7.1f␣%%", m.rstd_t * 100);
if (m.ae_t ≡ 0) printf("␣(ignored)");
printf("\n");
```

This code is used in section 107.

113. ⟨ Write measure and inversion info 113 ⟩ ≡

```
printf("#\n");
switch (params) {
case −1: printf("# No M_R or M_T -- forward calculation.\n");
  break;
case 1: printf("# Just M_R was measured");
  break;
case 2: printf("# M_R and M_T were measured");
  break;
case 3: printf("# M_R, M_T, and M_U were measured");
  break;
case 4: printf("# M_R, M_T, M_U, and r_w were measured");
  break;
case 5: printf("# M_R, M_T, M_U, r_w, and t_w were measured");
  break;
case 6: printf("# M_R, M_T, M_U, r_w, t_w, and r_std were measured");
  break;
case 7: printf("# M_R, M_T, M_U, r_w, t_w, r_std and t_std were measured");
  break;
default: printf("# Something went wrong ... measures should be 1 to 5!\n");
  break;
}
if (1 ≤ params ∧ params ≤ 7) {
  if (m.flip_sample) printf(" (sample flipped) ");
  switch (m.method) {
  case UNKNOWN: printf(" using an unknown method.\n");
    break;
  case SUBSTITUTION: printf(" using the substitution (single-beam) method.\n");
    break;
  case COMPARISON: printf(" using the comparison (dual-beam) method.\n");
  }
}
switch (m.num_spheres) {
case 0: printf("# No sphere corrections were used");
  break;
case 1:
  if (m.method ≡ COMPARISON) printf("# No sphere corrections were needed");
  else printf("# Single sphere corrections were used");
  break;
case 2: printf("# Double sphere corrections were used");
  break;
}
printf(" and light was incident at %d degrees from the normal",
    (int)(acos(m.slab_cos_angle) ∗ 57.2958));
printf(".\n");
switch (r.search) {
case FIND_AB: printf("# The inverse routine varied the albedo and optical depth.\n");
  printf("# \n");
  xx = (r.default_g ≠ UNINITIALIZED) ? r.default_g : 0;
  printf("# Default single scattering anisotropy = %7.3f \n", xx);
  break;
case FIND_AG: printf("# The inverse routine varied the albedo and anisotropy.\n");
```

```
    printf("#␣\n");
    if (r.default_b ≠ UNINITIALIZED)
      printf("#␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣Default␣(mu_t*d)␣=␣%7.3g\n", r.default_b);
    else printf("#␣\n");
    break;
  case FIND_AUTO: printf("#␣The␣inverse␣routine␣adapted␣to␣the␣input␣data.\n");
    printf("#␣\n");
    printf("#␣\n");
    break;
  case FIND_A: printf("#␣The␣inverse␣routine␣varied␣only␣the␣albedo.\n");
    printf("#␣\n");
    xx = (r.default_g ≠ UNINITIALIZED) ? r.default_g : 0;
    printf("#␣Default␣single␣scattering␣anisotropy␣is␣%7.3f␣", xx);
    xx = (r.default_b ≠ UNINITIALIZED) ? r.default_b : HUGE_VAL;
    printf("␣and␣(mu_t*d)␣=␣%7.3g\n", xx);
    break;
  case FIND_B: printf("#␣The␣inverse␣routine␣varied␣only␣the␣optical␣depth.\n");
    printf("#␣\n");
    xx = (r.default_g ≠ UNINITIALIZED) ? r.default_g : 0;
    printf("#␣Default␣single␣scattering␣anisotropy␣is␣%7.3f␣", xx);
    if (r.default_a ≠ UNINITIALIZED) printf("and␣default␣albedo␣=␣%7.3g\n", r.default_a);
    else printf("\n");
    break;
  case FIND_Ba: printf("#␣The␣inverse␣routine␣varied␣only␣the␣absorption.\n");
    printf("#␣\n");
    xx = (r.default_bs ≠ UNINITIALIZED) ? r.default_bs : 0;
    printf("#␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣Default␣(mu_s*d)␣=␣%7.3g\n", xx);
    break;
  case FIND_Bs: printf("#␣The␣inverse␣routine␣varied␣only␣the␣scattering.\n");
    printf("#␣\n");
    xx = (r.default_ba ≠ UNINITIALIZED) ? r.default_ba : 0;
    printf("#␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣Default␣(mu_a*d)␣=␣%7.3g\n", xx);
    break;
  default: printf("#␣\n");
    printf("#␣\n");
    printf("#␣\n");
    break;
  }
  printf("#␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣AD␣quadrature␣points␣=␣%3d\n", r.method.quad_pts);
  printf("#␣␣␣␣␣␣␣␣␣␣␣␣␣␣AD␣tolerance␣for␣success␣=␣%9.5f\n", r.tolerance);
  printf("#␣␣␣␣␣␣␣MC␣tolerance␣for␣mu_a␣and␣mu_s'␣=␣%7.3f␣%%\n", r.MC_tolerance);
```

This code is used in section 107.

114. IAD Calculation.

```
⟨ iad_calc.c 114 ⟩ ≡
#include <math.h>
#include <string.h>
#include <stdio.h>
#include <stdlib.h>
#include "nr_util.h"
#include "nr_zbrent.h"
#include "ad_globl.h"
#include "ad_frsnl.h"
#include "ad_prime.h"
#include "iad_type.h"
#include "iad_util.h"
#include "iad_calc.h"
#define ABIT 1.0e-6
#define A_COLUMN 1
#define B_COLUMN 2
#define G_COLUMN 3
#define URU_COLUMN 4
#define UTU_COLUMN 5
#define UR1_COLUMN 6
#define UT1_COLUMN 7
#define REFLECTION_SPHERE 1
#define TRANSMISSION_SPHERE 0
#define GRID_SIZE 101
#define T_TRUST_FACTOR 1
#define MAX_ABS_G 0.999999
#define SWAP(a,b)
  {
    double swap = (a);
    (a) = (b);
    (b) = swap;
  }
  static int CALCULATING_GRID = 1;
  static struct measure_type MM;
  static struct invert_type RR;
  static struct measure_type MGRID;
  static struct invert_type RGRID;
  static double **The_Grid = Λ;
  static double GG_a;
  static double GG_b;
  static double GG_g;
  static double GG_bs;
  static double GG_ba;
  static boolean_type The_Grid_Initialized = FALSE;
  static boolean_type The_Grid_Search = -1;
  ⟨ Definition for Set_Calc_State 130 ⟩
  ⟨ Definition for Get_Calc_State 132 ⟩
  ⟨ Definition for Same_Calc_State 134 ⟩
  ⟨ Prototype for Fill_AB_Grid 152 ⟩;
  ⟨ Prototype for Fill_AG_Grid 156 ⟩;
```

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⟨ Definition for *Find_B_fn* 194 ⟩
⟨ Definition for *Find_G_fn* 196 ⟩
⟨ Definition for *Find_BG_fn* 198 ⟩
⟨ Definition for *Find_BaG_fn* 200 ⟩
⟨ Definition for *Find_BsG_fn* 202 ⟩
⟨ Definition for *maxloss* 204 ⟩
⟨ Definition for *Max_Light_Loss* 206 ⟩

115.

⟨ `iad_calc.h` 115 ⟩ ≡
⟨ Prototype for *Gain* 118 ⟩;
⟨ Prototype for *Gain_11* 120 ⟩;
⟨ Prototype for *Gain_22* 122 ⟩;
⟨ Prototype for *Two_Sphere_R* 124 ⟩;
⟨ Prototype for *Two_Sphere_T* 126 ⟩;
⟨ Prototype for *Set_Calc_State* 129 ⟩;
⟨ Prototype for *Get_Calc_State* 131 ⟩;
⟨ Prototype for *Same_Calc_State* 133 ⟩;
⟨ Prototype for *Valid_Grid* 139 ⟩;
⟨ Prototype for *Allocate_Grid* 135 ⟩;
⟨ Prototype for *Fill_Grid* 165 ⟩;
⟨ Prototype for *Near_Grid_Points* 147 ⟩;
⟨ Prototype for *Grid_ABG* 137 ⟩;
⟨ Prototype for *Find_AG_fn* 183 ⟩;
⟨ Prototype for *Find_AB_fn* 185 ⟩;
⟨ Prototype for *Find_Ba_fn* 187 ⟩;
⟨ Prototype for *Find_Bs_fn* 189 ⟩;
⟨ Prototype for *Find_A_fn* 191 ⟩;
⟨ Prototype for *Find_B_fn* 193 ⟩;
⟨ Prototype for *Find_G_fn* 195 ⟩;
⟨ Prototype for *Find_BG_fn* 197 ⟩;
⟨ Prototype for *Find_BsG_fn* 201 ⟩;
⟨ Prototype for *Find_BaG_fn* 199 ⟩;
⟨ Prototype for *Fill_BG_Grid* 159 ⟩;
⟨ Prototype for *Fill_BsG_Grid* 163 ⟩;
⟨ Prototype for *Fill_BaG_Grid* 161 ⟩;
⟨ Prototype for *Calculate_Distance_With_Corrections* 171 ⟩;
⟨ Prototype for *Calculate_Distance* 167 ⟩;
⟨ Prototype for *Calculate_Grid_Distance* 169 ⟩;
⟨ Prototype for *abg_distance* 145 ⟩;
⟨ Prototype for *maxloss* 203 ⟩;
⟨ Prototype for *Max_Light_Loss* 205 ⟩;

116. Initialization.

The functions in this file assume that the local variables `MM` and `RR` have been initialized appropriately. The variable `MM` contains all the information about how a particular experiment was done. The structure `RR` contains the data structure that is passed to the adding-doubling routines as well as the number of quadrature points.

117. Gain.

Assume that a sphere is illuminated with diffuse light having a power P. This light will undergo multiple reflections in the sphere walls that will increase the power falling on the detector.

The gain on the detector due to integrating sphere effects varies with the presence of a baffle between the sample and the detector. If a baffle is present then

$$G_{\text{no baffle}}(r_s) = \frac{1}{1 - a_w r_w - a_d r_d - a_s r_s}$$

or with a baffle as

$$G_{\text{baffle}}(r_s) = \frac{1}{1 - a_w r_w - r_w(1 - a_e)(a_d r_d + a_s r_s)}$$

For a black sphere the gain does not depend on the diffuse reflectivity of the sample and is unity. $G(r_s) = 1$, which is easily verified by setting $r_w = 0$.

118. ⟨ Prototype for *Gain* 118 ⟩ ≡

```
double Gain(int sphere, struct measure_type m, double URU)
```

This code is used in sections 115 and 119.

119. ⟨ Definition for *Gain* 119 ⟩ ≡

```
⟨ Prototype for Gain 118 ⟩
{
  double G, denom;
  if (sphere ≡ REFLECTION_SPHERE) {
    if (m.baffle_r) denom = 1.0 − m.rw_r ∗ (m.aw_r + (1 − m.ae_r) ∗ (m.ad_r ∗ m.rd_r + m.as_r ∗ URU));
    else denom = 1.0 − m.aw_r ∗ m.rw_r − m.ad_r ∗ m.rd_r − m.as_r ∗ URU;
  }
  else {
    if (m.baffle_t) denom = 1.0 − m.rw_t ∗ (m.aw_t + (1 − m.ae_t) ∗ (m.ad_t ∗ m.rd_t + m.as_t ∗ URU));
    else denom = 1.0 − m.aw_t ∗ m.rw_t − m.ad_t ∗ m.rd_t − m.as_t ∗ URU;
  }
  G = 1.0/denom;
  return G;
}
```

This code is used in section 114.

120. The gain for light on the detector in the first sphere for diffuse light starting in that same sphere is defined as

$$G_{1\to1}(r_s, t_s) \equiv \frac{P_{1\to1}(r_s, t_s)/A_d}{P/A}$$

then the full expression for the gain is

$$G_{1\to1}(r_s, t_s) = \frac{G(r_s)}{1 - a_s a'_s r_w r'_w (1 - a_e)(1 - a'_e) G(r_s) G'(r_s) t_s^2}$$

⟨ Prototype for *Gain_11* 120 ⟩ ≡

```
double Gain_11(struct measure_type m, double URU, double tdiffuse)
```

This code is used in sections 115 and 121.

121. ⟨ Definition for *Gain_11* 121 ⟩ ≡

```
⟨ Prototype for Gain_11 120 ⟩
{
  double G, GP, G11;
  G = Gain(REFLECTION_SPHERE, m, URU);
  GP = Gain(TRANSMISSION_SPHERE, m, URU);
  G11 = G/(1 − m.as_r ∗ m.as_t ∗ m.aw_r ∗ m.aw_t ∗ (1 − m.ae_r) ∗ (1 − m.ae_t) ∗ G ∗ GP ∗ tdiffuse ∗ tdiffuse);
  return G11;
}
```

This code is used in section 114.

122. Similarly, when the light starts in the second sphere, the gain for light on the detector in the second sphere $G_{2\to2}$ is found by switching all primed variables to unprimed. Thus $G_{2\to1}(r_s, t_s)$ is

$$G_{2\to2}(r_s, t_s) = \frac{G'(r_s)}{1 - a_s a'_s r_w r'_w (1 - a_e)(1 - a'_e) G(r_s) G'(r_s) t_s^2}$$

⟨ Prototype for *Gain_22* 122 ⟩ ≡

```
double Gain_22(struct measure_type m, double URU, double tdiffuse)
```

This code is used in sections 115 and 123.

123. ⟨ Definition for *Gain_22* 123 ⟩ ≡

```
⟨ Prototype for Gain_22 122 ⟩
{
  double G, GP, G22;
  G = Gain(REFLECTION_SPHERE, m, URU);
  GP = Gain(TRANSMISSION_SPHERE, m, URU);
  G22 = GP/(1 − m.as_r ∗ m.as_t ∗ m.aw_r ∗ m.aw_t ∗ (1 − m.ae_r) ∗ (1 − m.ae_t) ∗ G ∗ GP ∗ tdiffuse ∗ tdiffuse);
  return G22;
}
```

This code is used in section 114.

124. The reflected power for two spheres makes use of the formulas for *Gain_11* above.

The light on the detector in the reflection (first) sphere arises from three sources: the fraction of light directly reflected off the sphere wall $f r_w^2 (1 - a_e) P$, the fraction of light reflected by the sample $(1 - f) r_s^{\text{direct}} r_w^2 (1 - a_e) P$, and the light transmitted through the sample $(1 - f) t_s^{\text{direct}} r'_w (1 - a'_e) P$,

$$\begin{aligned} R(r_s^{\text{direct}}, r_s, t_s^{\text{direct}}, t_s) = {} & G_{1\to1}(r_s, t_s) \cdot a_d (1 - a_e) r_w^2 f P \\ & + G_{1\to1}(r_s, t_s) \cdot a_d (1 - a_e) r_w (1 - f) r_s^{\text{direct}} P \\ & + G_{2\to1}(r_s, t_s) \cdot a_d (1 - a'_e) r'_w (1 - f) t_s^{\text{direct}} P \end{aligned}$$

which simplifies slightly to

$$\begin{aligned} R(r_s^{\text{direct}}, r_s, t_s^{\text{direct}}, t_s) = {} & a_d (1 - a_e) r_w P \cdot G_{1\to1}(r_s, t_s) \\ & \times \left[(1 - f) r_s^{\text{direct}} + f r_w + (1 - f) a'_s (1 - a'_e) r'_w t_s^{\text{direct}} t_s G'(r_s) \right] \end{aligned}$$

⟨ Prototype for *Two_Sphere_R* 124 ⟩ ≡

```
double Two_Sphere_R(struct measure_type m, double UR1, double URU, double UT1, double UTU)
```

This code is used in sections 115 and 125.

125. ⟨ Definition for *Two_Sphere_R* 125 ⟩ ≡

```
⟨ Prototype for Two_Sphere_R 124 ⟩
{
  double x, GP;
  GP = Gain(TRANSMISSION_SPHERE, m, URU);
  x = m.ad_r * (1 - m.ae_r) * m.rw_r * Gain_11(m, URU, UTU);
  x *= (1 - m.f_r) * UR1 + m.rw_r * m.f_r + (1 - m.f_r) * m.as_t * (1 - m.ae_t) * m.rw_t * UT1 * UTU * GP;
  return x;
}
```

This code is used in section 114.

126. For the power on the detector in the transmission (second) sphere we have the same three sources. The only difference is that the subscripts on the gain terms now indicate that the light ends up in the second sphere

$$\begin{aligned} T(r_s^{\text{direct}}, r_s, t_s^{\text{direct}}, t_s) &= G_{1\to 2}(r_s, t_s) \cdot a'_d(1-a_e) r_w^2 f P \\ &\quad + G_{1\to 2}(r_s, t_s) \cdot a'_d(1-a_e) r_w (1-f) r_s^{\text{direct}} P \\ &\quad + G_{2\to 2}(r_s, t_s) \cdot a'_d(1-a'_e) r'_w (1-f) t_s^{\text{direct}} P \end{aligned}$$

or

$$\begin{aligned} T(r_s^{\text{direct}}, r_s, t_s^{\text{direct}}, t_s) &= a'_d(1-a'_e) r'_w P \cdot G_{2\to 2}(r_s, t_s) \\ &\quad \times \left[(1-f) t_s^{\text{direct}} + (1-a_e) r_w a_s t_s (f r_w + (1-f) r_s^{\text{direct}}) G(r_s) \right] \end{aligned}$$

⟨ Prototype for *Two_Sphere_T* 126 ⟩ ≡

```
double Two_Sphere_T(struct measure_type m, double UR1, double URU, double UT1, double UTU)
```

This code is used in sections 115 and 127.

127. ⟨ Definition for *Two_Sphere_T* 127 ⟩ ≡

```
⟨ Prototype for Two_Sphere_T 126 ⟩
{
  double x, G;
  G = Gain(REFLECTION_SPHERE, m, URU);
  x = m.ad_t * (1 - m.ae_t) * m.rw_t * Gain_22(m, URU, UTU);
  x *= (1 - m.f_r) * UT1 + (1 - m.ae_r) * m.rw_r * m.as_r * UTU * (m.f_r * m.rw_r + (1 - m.f_r) * UR1) * G;
  return x;
}
```

This code is used in section 114.

128. Grid Routines. There is a long story associated with these routines. I spent a lot of time trying to find an empirical function to allow a guess at a starting value for the inversion routine. Basically nothing worked very well. There were too many special cases and what not. So I decided to calculate a whole bunch of reflection and transmission values and keep their associated optical properties linked nearby.

I did the very simplest thing. I just allocate a matrix that is five columns wide. Then I fill every row with a calculated set of optical properties and observables. The distribution of values that I use could certainly use some work, but they currently work.

SO... how does this thing work anyway? There are two possible grids one for calculations requiring the program to find the albedo and the optical depth (a and b) and one to find the albedo and anisotropy (a and g). These grids must be allocated and initialized before use.

129. This is a pretty important routine that should have some explanation. The reason that it exists, is that we need some 'out-of-band' information during the minimization process. Since the light transport calculation depends on all sorts of stuff (e.g., the sphere parameters) and the minimization routines just vary one or two parameters this information needs to be put somewhere.

I chose the global variables `MM` and `RR` to save things in.

The bottom line is that you cannot do a light transport calculation without calling this routine first.

⟨ Prototype for *Set_Calc_State* 129 ⟩ ≡
```
void Set_Calc_State(struct measure_type m, struct invert_type r)
```
This code is used in sections 115 and 130.

130. ⟨ Definition for *Set_Calc_State* 130 ⟩ ≡
```
⟨ Prototype for Set_Calc_State 129 ⟩
{
  memcpy(&MM, &m, sizeof(struct measure_type));
  memcpy(&RR, &r, sizeof(struct invert_type));
  if (Debug(DEBUG_ITERATIONS) ∧ ¬CALCULATING_GRID) {
    fprintf(stderr, "MC␣Loss␣(UR1=%7.5f,␣UT1=%7.5f,␣", m.ur1_lost, m.ut1_lost);
    fprintf(stderr, "URU=%7.5f,␣UTU=%7.5f)\n", m.uru_lost, m.utu_lost);
  }
}
```
This code is used in section 114.

131. The inverse of the previous routine. Note that you must have space for the parameters m and r already allocated.

⟨ Prototype for *Get_Calc_State* 131 ⟩ ≡
```
void Get_Calc_State(struct measure_type *m, struct invert_type *r)
```
This code is used in sections 115 and 132.

132. ⟨ Definition for *Get_Calc_State* 132 ⟩ ≡
```
⟨ Prototype for Get_Calc_State 131 ⟩
{
  memcpy(m, &MM, sizeof(struct measure_type));
  memcpy(r, &RR, sizeof(struct invert_type));
}
```
This code is used in section 114.

133. The inverse of the previous routine. Note that you must have space for the parameters m and r already allocated.

```
⟨ Prototype for Same_Calc_State 133 ⟩ ≡
  boolean_type Same_Calc_State(struct measure_type m, struct invert_type r)
```

This code is used in sections 115 and 134.

134.
```
⟨ Definition for Same_Calc_State 134 ⟩ ≡
  ⟨ Prototype for Same_Calc_State 133 ⟩
  {
    if (The_Grid ≡ Λ) return FALSE;
    if (¬The_Grid_Initialized) return FALSE;
    if (r.search ≠ RR.search) return FALSE;
    if (r.method.quad_pts ≠ RR.method.quad_pts) return FALSE;
    if (r.slab.a ≠ RR.slab.a) return FALSE;
    if (r.slab.b ≠ RR.slab.b) return FALSE;
    if (r.slab.g ≠ RR.slab.g) return FALSE;
    if (r.slab.phase_function ≠ RR.slab.phase_function) return FALSE;
    if (r.slab.n_slab ≠ RR.slab.n_slab) return FALSE;
    if (r.slab.n_top_slide ≠ RR.slab.n_top_slide) return FALSE;
    if (r.slab.n_bottom_slide ≠ RR.slab.n_bottom_slide) return FALSE;
    if (r.slab.b_top_slide ≠ RR.slab.b_top_slide) return FALSE;
    if (r.slab.b_bottom_slide ≠ RR.slab.b_bottom_slide) return FALSE;
    if (r.slab.cos_angle ≠ RR.slab.cos_angle) return FALSE;
    if ((m.num_measures ≡ 3) ∧ (m.m_u ≠ MGRID.m_u)) return (FALSE);
    return TRUE;
  }
```

This code is used in section 114.

135.
```
⟨ Prototype for Allocate_Grid 135 ⟩ ≡
  void Allocate_Grid(search_type s)
```

This code is used in sections 115 and 136.

136.
```
⟨ Definition for Allocate_Grid 136 ⟩ ≡
  ⟨ Prototype for Allocate_Grid 135 ⟩
  {
    (void) s;
    The_Grid = dmatrix(0, GRID_SIZE * GRID_SIZE, 1, 7);
    if (The_Grid ≡ Λ) AD_error("unable␣to␣allocate␣the␣grid␣matrix");
    The_Grid_Initialized = FALSE;
  }
```

This code is used in section 114.

137. This routine will return the a, b, and g values for a particular row in the grid.

```
⟨ Prototype for Grid_ABG 137 ⟩ ≡
  void Grid_ABG(int i, int j, guess_type *guess)
```

This code is used in sections 115 and 138.

138. ⟨ Definition for *Grid_ABG* 138 ⟩ ≡

```
⟨ Prototype for Grid_ABG 137 ⟩
{
  if (0 ≤ i ∧ i < GRID_SIZE ∧ 0 ≤ j ∧ j < GRID_SIZE) {
    guess→a = The_Grid[GRID_SIZE * i + j][A_COLUMN];
    guess→b = The_Grid[GRID_SIZE * i + j][B_COLUMN];
    guess→g = The_Grid[GRID_SIZE * i + j][G_COLUMN];
    guess→distance = Calculate_Grid_Distance(i, j);
  }
  else {
    guess→a = 0.5;
    guess→b = 0.5;
    guess→g = 0.5;
    guess→distance = 999;
  }
}
```

This code is used in section 114.

139. This routine is used to figure out if the current grid is valid. This can fail for several reasons. First the grid may not have been allocated. Or it may not have been initialized. The boundary conditions may have changed. The number or values of the sphere parameters may have changed. It is tedious, but straightforward to check these cases out.

If this routine returns true, then it is a pretty good bet that the values in the current grid can be used to guess the next starting set of values.

```
⟨ Prototype for Valid_Grid 139 ⟩ ≡
  boolean_type Valid_Grid(struct measure_type m, search_type s)
```

This code is used in sections 115 and 140.

140. ⟨ Definition for *Valid_Grid* 140 ⟩ ≡

```
⟨ Prototype for Valid_Grid 139 ⟩
{
  ⟨ Tests for invalid grid 141 ⟩
  return (TRUE);
}
```

This code is used in section 114.

141. First check are to test if the grid has ever been filled

```
⟨ Tests for invalid grid 141 ⟩ ≡
  if (The_Grid ≡ Λ) {
    if (Debug(DEBUG_GRID)) fprintf(stderr, "GRID: Fill because NULL\n");
    return (FALSE);
  }
  if (¬The_Grid_Initialized) {
    if (Debug(DEBUG_GRID)) fprintf(stderr, "GRID: Fill because not initialized\n");
    return (FALSE);
  }
```

See also sections 142, 143, and 144.

This code is used in section 140.

142. If the type of search has changed then report the grid as invalid

```
⟨ Tests for invalid grid 141 ⟩ +≡
  if (The_Grid_Search ≠ s) {
    if (Debug(DEBUG_GRID)) fprintf(stderr, "GRID: Fill because search type changed\n");
    return (FALSE);
  }
```

143. Compare the $m.m\_u$ value only if there are three measurements

```
⟨ Tests for invalid grid 141 ⟩ +≡
  if ((m.num_measures ≡ 3) ∧ (m.m_u ≠ MGRID.m_u)) {
    if (Debug(DEBUG_GRID)) fprintf(stderr, "GRID: Fill because unscattered light changed\n");
    return (FALSE);
  }
```

144. Make sure that the boundary conditions have not changed.

```
⟨ Tests for invalid grid 141 ⟩ +≡
  if (m.slab_index ≠ MGRID.slab_index) {
    if (Debug(DEBUG_GRID))
      fprintf(stderr, "GRID: Fill because slab refractive index changed\n");
    return (FALSE);
  }
  if (m.slab_cos_angle ≠ MGRID.slab_cos_angle) {
    if (Debug(DEBUG_GRID)) fprintf(stderr, "GRID: Fill because light angle changed\n");
    return (FALSE);
  }
  if (m.slab_top_slide_index ≠ MGRID.slab_top_slide_index) {
    if (Debug(DEBUG_GRID)) fprintf(stderr, "GRID: Fill because top slide index changed\n");
    return (FALSE);
  }
  if (m.slab_bottom_slide_index ≠ MGRID.slab_bottom_slide_index) {
    if (Debug(DEBUG_GRID)) fprintf(stderr, "GRID: Fill because bottom slide index changed\n");
    return (FALSE);
  }
```

145. Routine to just figure out the distance to a particular a, b, g point

```
⟨ Prototype for abg_distance 145 ⟩ ≡
  void abg_distance(double a, double b, double g, guess_type *guess)
```

This code is used in sections 115 and 146.

146. ⟨ Definition for *abg_distance* 146 ⟩ ≡

```
⟨ Prototype for abg_distance 145 ⟩
{
  double m_r, m_t, distance;
  struct measure_type old_mm;
  struct invert_type old_rr;
  Get_Calc_State(&old_mm, &old_rr);
  RR.slab.a = a;
  RR.slab.b = b;
  RR.slab.g = g;
  Calculate_Distance(&m_r, &m_t, &distance);
  Set_Calc_State(old_mm, old_rr);
  guess→a = a;
  guess→b = b;
  guess→g = g;
  guess→distance = distance;
}
```

This code is used in section 114.

147. This just searches through the grid to find the minimum entry and returns the optical properties of that entry. The smallest, the next smallest, and the third smallest values are returned.

This has been rewritten to use *Calculate_Distance_With_Corrections* so that changes in sphere parameters won't necessitate recalculating the grid.

⟨ Prototype for *Near_Grid_Points* 147 ⟩ ≡

```
void Near_Grid_Points(double r, double t, search_type s, int *i_min, int *j_min)
```

This code is used in sections 115 and 148.

148. ⟨ Definition for *Near_Grid_Points* 148 ⟩ ≡

```
⟨ Prototype for Near_Grid_Points 147 ⟩
{
  int i, j;
  double fval;
  double smallest = 10.0;
  struct measure_type old_mm;
  struct invert_type old_rr;
  (void) r;
  (void) t;
  (void) s;
  Get_Calc_State(&old_mm, &old_rr);
  *i_min = 0;
  *j_min = 0;
  for (i = 0; i < GRID_SIZE; i++) {
    for (j = 0; j < GRID_SIZE; j++) {
      CALCULATING_GRID = 1;
      fval = Calculate_Grid_Distance(i, j);
      CALCULATING_GRID = 0;
      if (fval < smallest) {
        *i_min = i;
        *j_min = j;
        smallest = fval;
      }
    }
  }
  Set_Calc_State(old_mm, old_rr);
}
```

This code is used in section 114.

149. Routine to incorporate flipping of sample if needed. This is pretty simple. The assumption is that flipping is handled relative to the reflection side of the sphere. Thus even when flipping is needed, the usual call to `RT( )` will result in the correct values for the reflectances. The transmission values can then be calculated by swapping the top and bottom slides.

Technically, the value of slab should be **const** but it is not so that we don't pay a copying overhead whenever *flip* is false (the usual case).

⟨ Prototype for *RT_Flip* 149 ⟩ ≡

```
void RT_Flip(int flip, int n, struct AD_slab_type *slab, double *UR1, double *UT1, double
    *URU, double *UTU)
```

This code is used in section 150.

150. ⟨ Definition for *RT_Flip* 150 ⟩ ≡

```
⟨ Prototype for RT_Flip 149 ⟩
{
  double swap, correct_UR1, correct_URU;
  RT(n, slab, UR1, UT1, URU, UTU);
  if (flip) {
    correct_UR1 = *UR1;
    correct_URU = *URU;
    swap = slab→n_top_slide;
    slab→n_top_slide = slab→n_bottom_slide;
    slab→n_bottom_slide = swap;
    swap = slab→b_top_slide;
    slab→b_top_slide = slab→b_bottom_slide;
    slab→b_bottom_slide = swap;
    RT(n, slab, UR1, UT1, URU, UTU);
    swap = slab→n_top_slide;
    slab→n_top_slide = slab→n_bottom_slide;
    slab→n_bottom_slide = swap;
    swap = slab→b_top_slide;
    slab→b_top_slide = slab→b_bottom_slide;
    slab→b_bottom_slide = swap;
    *UR1 = correct_UR1;
    *URU = correct_URU;
  }
}
```

This code is used in section 114.

151. Simple routine to put values into the grid
Presumes that RR.*slab* is properly set up.

```
⟨ Definition for fill_grid_entry 151 ⟩ ≡
  static void fill_grid_entry(int i, int j)
  {
    double ur1, ut1, uru, utu;
    if (RR.slab.b ≤ 1 · 10^−6) RR.slab.b = 1 · 10^−6;
    if (Debug(DEBUG_EVERY_CALC)) {
      if (¬CALCULATING_GRID)
        fprintf(stderr, "a=%8.5f␣b=%10.5f␣g=%8.5f␣", RR.slab.a, RR.slab.b, RR.slab.g);
      else {
        if (j ≡ 0) fprintf(stderr, ".");
        if (i + 1 ≡ GRID_SIZE ∧ j ≡ 0) fprintf(stderr, "\n");
      }
    }
    RT_Flip(MM.flip_sample, RR.method.quad_pts, &RR.slab, &ur1, &ut1, &uru, &utu);
    if (Debug(DEBUG_EVERY_CALC) ∧ ¬CALCULATING_GRID)
      fprintf(stderr, "ur1=%8.5f␣ut1=%8.5f\n", ur1, ut1);
    The_Grid[GRID_SIZE * i + j][A_COLUMN] = RR.slab.a;
    The_Grid[GRID_SIZE * i + j][B_COLUMN] = RR.slab.b;
    The_Grid[GRID_SIZE * i + j][G_COLUMN] = RR.slab.g;
    The_Grid[GRID_SIZE * i + j][UR1_COLUMN] = ur1;
    The_Grid[GRID_SIZE * i + j][UT1_COLUMN] = ut1;
    The_Grid[GRID_SIZE * i + j][URU_COLUMN] = uru;
    The_Grid[GRID_SIZE * i + j][UTU_COLUMN] = utu;
    if (Debug(DEBUG_GRID_CALC)) {
      fprintf(stderr, "+␣%2d␣%2d␣", i, j);
      fprintf(stderr, "%10.5f␣%10.5f␣%10.5f␣|", RR.slab.a, RR.slab.b, RR.slab.g);
      fprintf(stderr, "%10.5f␣%10.5f␣|", MM.m_r, uru);
      fprintf(stderr, "%10.5f␣%10.5f␣\n", MM.m_t, utu);
    }
  }
```

This code is used in section 114.

152. This routine fills the grid with a proper set of values. With a little work, this routine could be made much faster by (1) only generating the phase function matrix once, (2) Making only one pass through the array for each albedo value, i.e., using the matrix left over from $b = 1$ to generate the solution for $b = 2$. Unfortunately this would require a complete revision of the *Calculate_Distance* routine. Fortunately, this routine should only need to be calculated once at the beginning of each run.

```
⟨ Prototype for Fill_AB_Grid 152 ⟩ ≡
  void Fill_AB_Grid(struct measure_type m, struct invert_type r)
```

This code is used in sections 114 and 153.

153. ⟨ Definition for *Fill_AB_Grid* 153 ⟩ ≡

```
⟨ Prototype for Fill_AB_Grid 152 ⟩
{
  int i, j;
  double a;
  double min_b = −8;      /* exp(-10) is smallest thickness */
  double max_b = +8;      /* exp(+8) is greatest thickness */
  if (Debug(DEBUG_GRID)) fprintf(stderr, "Filling␣AB␣grid\n");
  if (The_Grid ≡ Λ) Allocate_Grid(r.search);
  ⟨ Zero GG 158 ⟩
  Set_Calc_State(m, r);
  GG_g = RR.slab.g;
  for (i = 0; i < GRID_SIZE; i++) {
    double x = (double) i/(GRID_SIZE − 1.0);
    RR.slab.b = exp(min_b + (max_b − min_b) * x);
    for (j = 0; j < GRID_SIZE; j++) {
      ⟨ Generate next albedo using j 155 ⟩
      fill_grid_entry(i, j);
    }
  }
  The_Grid_Initialized = TRUE;
  The_Grid_Search = FIND_AB;
}
```

This code is used in section 114.

154. Now it seems that I must be a bit more subtle in choosing the range of albedos to use in the grid. Originally I just spaced them according to

$$a = 1 - \left[\frac{j-1}{n-1}\right]^3$$

where $1 \le j \le n$. Long ago it seems that I based things only on the square of the bracketed term, but I seem to remember that I was forced to change it from a square to a cube to get more global convergence.

So why am I rewriting this? Well, because it works very poorly for samples with small albedos. For example, when $n = 11$ then the values chosen for a are (1, .999, .992, .973, .936, .875, .784, .657, .488, .271, 0). Clearly very skewed towards high albedos.

I am considering a two part division. I'm not too sure how it should go. Let the first half be uniformly divided and the last half follow the cubic scheme given above. The list of values should then be (1, .996, .968, .892, 0.744, .5, .4, .3, .2, .1, 0).

Maybe it would be best if I just went back to a quadratic term. Who knows?

In the **if** statement below, note that it could read $j \ge k$ and still generate the same results.

⟨ Nonworking code 154 ⟩ ≡

```
k = floor((GRID_SIZE − 1)/2);
if (j > k) {
  a = 0.5 * (1 − (j − k − 1)/(GRID_SIZE − k − 1));
  RR.slab.a = a;
}
else {
  a = (j − 1.0)/(GRID_SIZE − k − 1);
  RR.slab.a = 1.0 − a * a * a/2;
}
```

155. Here is heuristic that seems to work well

```
⟨ Generate next albedo using j 155 ⟩ ≡
  a = (double) j/(GRID_SIZE − 1.0);
  RR.slab.a = (1.0 − a ∗ a) ∗ (1.0 − a) + (1.0 − a) ∗ (1.0 − a) ∗ a;
```

This code is used in sections 153 and 157.

156. This is quite similar to *Fill_AB_Grid*, with the exception of the little shuffle I do at the beginning to figure out the optical thickness to use. The problem is that the optical thickness may not be known. If it is known then the only way that we could have gotten here is if the user dictated `FIND_AG` and specified b and only provided two measurements. Otherwise, the user must have made three measurements and the optical depth can be figured out from $m.m\_u$.

This routine could also be improved by not recalculating the anisotropy matrix for every point. But this would only end up being a minor performance enhancement if it were fixed.

```
⟨ Prototype for Fill_AG_Grid 156 ⟩ ≡
  void Fill_AG_Grid(struct measure_type m, struct invert_type r)
```

This code is used in sections 114 and 157.

157.

```
⟨ Definition for Fill_AG_Grid 157 ⟩ ≡
  ⟨ Prototype for Fill_AG_Grid 156 ⟩
  {
    int i, j;
    double a;
    if (Debug(DEBUG_GRID)) fprintf(stderr, "Filling␣AG␣grid\n");
    if (The_Grid ≡ Λ) Allocate_Grid(r.search);
    ⟨ Zero GG 158 ⟩
    Set_Calc_State(m, r);
    GG_b = r.slab.b;
    for (i = 0; i < GRID_SIZE; i++) {
      RR.slab.g = MAX_ABS_G ∗ (2.0 ∗ i/(GRID_SIZE − 1.0) − 1.0);
      for (j = 0; j < GRID_SIZE; j++) {
        ⟨ Generate next albedo using j 155 ⟩
        fill_grid_entry(i, j);
      }
    }
    The_Grid_Initialized = TRUE;
    The_Grid_Search = FIND_AG;
  }
```

This code is used in section 114.

158.

```
⟨ Zero GG 158 ⟩ ≡
  GG_a = 0.0;
  GG_b = 0.0;
  GG_g = 0.0;
  GG_bs = 0.0;
  GG_ba = 0.0;
```

This code is used in sections 153, 157, 160, 162, and 164.

159. This is quite similar to *Fill_AB_Grid*, with the exception of the that the albedo is held fixed while b and g are varied.

This routine could also be improved by not recalculating the anisotropy matrix for every point. But this would only end up being a minor performance enhancement if it were fixed.

⟨ Prototype for *Fill_BG_Grid* 159 ⟩ ≡

```
void Fill_BG_Grid(struct measure_type m, struct invert_type r)
```

This code is used in sections 115 and 160.

160. ⟨ Definition for *Fill_BG_Grid* 160 ⟩ ≡

```
⟨ Prototype for Fill_BG_Grid 159 ⟩
{
  int i, j;
  if (The_Grid ≡ Λ) Allocate_Grid(r.search);
  ⟨ Zero GG 158 ⟩
  if (Debug(DEBUG_GRID)) fprintf(stderr, "Filling␣BG␣grid\n");
  Set_Calc_State(m, r);
  RR.slab.b = 1.0/32.0;
  RR.slab.a = RR.default_a;
  GG_a = RR.slab.a;
  for (i = 0; i < GRID_SIZE; i++) {
    RR.slab.b *= 2;
    for (j = 0; j < GRID_SIZE; j++) {
      RR.slab.g = MAX_ABS_G * (2.0 * j/(GRID_SIZE − 1.0) − 1.0);
      fill_grid_entry(i, j);
    }
  }
  The_Grid_Initialized = TRUE;
  The_Grid_Search = FIND_BG;
}
```

This code is used in section 114.

161. This is quite similar to *Fill_BG_Grid*, with the exception of the that the $b_s = \mu_s d$ is held fixed. Here b and g are varied on the usual grid, but the albedo is forced to take whatever value is needed to ensure that the scattering constant remains fixed.

⟨ Prototype for *Fill_BaG_Grid* 161 ⟩ ≡

```
void Fill_BaG_Grid(struct measure_type m, struct invert_type r)
```

This code is used in sections 115 and 162.

162. ⟨ Definition for *Fill_BaG_Grid* 162 ⟩ ≡

```
⟨ Prototype for Fill_BaG_Grid 161 ⟩
{
  int i, j;
  double bs, ba;
  if (The_Grid ≡ Λ) Allocate_Grid(r.search);
  ⟨ Zero GG 158 ⟩
  if (Debug(DEBUG_GRID)) fprintf(stderr, "Filling␣BaG␣grid\n");
  Set_Calc_State(m, r);
  ba = 1.0/32.0;
  bs = RR.default_bs;
  GG_bs = bs;
  for (i = 0; i < GRID_SIZE; i++) {
    ba *= 2;
    ba = exp((double) i/(GRID_SIZE − 1.0) ∗ log(1024.0))/16.0;
    RR.slab.b = ba + bs;
    if (RR.slab.b > 0) RR.slab.a = bs/RR.slab.b;
    else RR.slab.a = 0;
    for (j = 0; j < GRID_SIZE; j++) {
      RR.slab.g = MAX_ABS_G ∗ (2.0 ∗ j/(GRID_SIZE − 1.0) − 1.0);
      fill_grid_entry(i, j);
    }
  }
  The_Grid_Initialized = TRUE;
  The_Grid_Search = FIND_BaG;
}
```

This code is used in section 114.

163. Very similiar to the above routine. The value of $b_a = \mu_a d$ is held constant.

⟨ Prototype for *Fill_BsG_Grid* 163 ⟩ ≡

```
void Fill_BsG_Grid(struct measure_type m, struct invert_type r)
```

This code is used in sections 115 and 164.

164. ⟨ Definition for *Fill_BsG_Grid* 164 ⟩ ≡

```
⟨ Prototype for Fill_BsG_Grid 163 ⟩
{
  int i, j;
  double bs, ba;
  if (The_Grid ≡ Λ) Allocate_Grid(r.search);
  ⟨ Zero GG 158 ⟩
  Set_Calc_State(m, r);
  bs = 1.0/32.0;
  ba = RR.default_ba;
  GG_ba = ba;
  for (i = 0; i < GRID_SIZE; i++) {
    bs *= 2;
    RR.slab.b = ba + bs;
    if (RR.slab.b > 0) RR.slab.a = bs/RR.slab.b;
    else RR.slab.a = 0;
    for (j = 0; j < GRID_SIZE; j++) {
      RR.slab.g = MAX_ABS_G * (2.0 * j/(GRID_SIZE − 1.0) − 1.0);
      fill_grid_entry(i, j);
    }
  }
  The_Grid_Initialized = TRUE;
  The_Grid_Search = FIND_BsG;
}
```

This code is used in section 114.

165. ⟨ Prototype for *Fill_Grid* 165 ⟩ ≡

```
void Fill_Grid(struct measure_type m, struct invert_type r, int force_new)
```

This code is used in sections 115 and 166.

166. ⟨ Definition for *Fill_Grid* 166 ⟩ ≡

```
⟨ Prototype for Fill_Grid 165 ⟩
{
  if (force_new ∨ ¬Same_Calc_State(m, r)) {
    switch (r.search) {
    case FIND_AB:
      if (Debug(DEBUG_SEARCH)) fprintf(stderr, "filling␣AB␣Grid\n");
      Fill_AB_Grid(m, r);
      break;
    case FIND_AG:
      if (Debug(DEBUG_SEARCH)) fprintf(stderr, "filling␣AG␣Grid\n");
      Fill_AG_Grid(m, r);
      break;
    case FIND_BG:
      if (Debug(DEBUG_SEARCH)) fprintf(stderr, "filling␣BG␣Grid\n");
      Fill_BG_Grid(m, r);
      break;
    case FIND_BaG:
      if (Debug(DEBUG_SEARCH)) fprintf(stderr, "filling␣BaG␣Grid\n");
      Fill_BaG_Grid(m, r);
      break;
    case FIND_BsG:
      if (Debug(DEBUG_SEARCH)) fprintf(stderr, "filling␣BsG␣Grid\n");
      Fill_BsG_Grid(m, r);
      break;
    default: AD_error("Attempt␣to␣fill␣grid␣for␣unusual␣search␣case.");
    }
  }
  Get_Calc_State(&MGRID, &RGRID);
}
```

This code is used in section 114.

167. Calculating R and T.

Calculate_Distance returns the distance between the measured values in `MM` and the calculated values for the current guess at the optical properties. It assumes that the everything in the local variables `MM` and `RR` have been set appropriately.

⟨ Prototype for *Calculate_Distance* 167 ⟩ ≡

```
void Calculate_Distance(double *M_R, double *M_T, double *deviation)
```

This code is used in sections 115 and 168.

168. ⟨ Definition for *Calculate_Distance* 168 ⟩ ≡

```
⟨ Prototype for Calculate_Distance 167 ⟩
{
  double Rc, Tc, ur1, ut1, uru, utu;
  if (RR.slab.b ≤ 1 · 10^−6) RR.slab.b = 1 · 10^−6;
  if (0 ∧ Debug(DEBUG_EVERY_CALC))
    fprintf(stderr, "a=%8.5f␣b=%10.5f␣g=%8.5f␣", RR.slab.a, RR.slab.b, RR.slab.g);
  RT_Flip(MM.flip_sample, RR.method.quad_pts, &RR.slab, &ur1, &ut1, &uru, &utu);
  if (0 ∧ Debug(DEBUG_EVERY_CALC))
    fprintf(stderr, "ur1=%8.5f␣ut1=%8.5f␣(not␣M_R␣and␣M_T!)\n", ur1, ut1);
  Sp_mu_RT_Flip(MM.flip_sample, RR.slab.n_top_slide, RR.slab.n_slab, RR.slab.n_bottom_slide,
      RR.slab.b_top_slide, RR.slab.b, RR.slab.b_bottom_slide, RR.slab.cos_angle, &Rc, &Tc);
  if ((¬CALCULATING_GRID ∧ Debug(DEBUG_ITERATIONS)) ∨ (CALCULATING_GRID ∧
      Debug(DEBUG_GRID_CALC))) fprintf(stderr, "␣␣␣␣␣␣␣␣");
  Calculate_Distance_With_Corrections(ur1, ut1, Rc, Tc, uru, utu, M_R, M_T, deviation);
}
```

This code is used in section 114.

169. ⟨ Prototype for *Calculate_Grid_Distance* 169 ⟩ ≡

```
double Calculate_Grid_Distance(int i, int j)
```

This code is used in sections 115 and 170.

170. ⟨ Definition for *Calculate_Grid_Distance* 170 ⟩ ≡

```
⟨ Prototype for Calculate_Grid_Distance 169 ⟩
{
  double ur1, ut1, uru, utu, Rc, Tc, b, dev, LR, LT;
  if (Debug(DEBUG_GRID_CALC)) fprintf(stderr, "g␣%2d␣%2d␣", i, j);
  b = The_Grid[GRID_SIZE * i + j][B_COLUMN];
  ur1 = The_Grid[GRID_SIZE * i + j][UR1_COLUMN];
  ut1 = The_Grid[GRID_SIZE * i + j][UT1_COLUMN];
  uru = The_Grid[GRID_SIZE * i + j][URU_COLUMN];
  utu = The_Grid[GRID_SIZE * i + j][UTU_COLUMN];
  RR.slab.a = The_Grid[GRID_SIZE * i + j][A_COLUMN];
  RR.slab.b = The_Grid[GRID_SIZE * i + j][B_COLUMN];
  RR.slab.g = The_Grid[GRID_SIZE * i + j][G_COLUMN];
  Sp_mu_RT_Flip(MM.flip_sample, RR.slab.n_top_slide, RR.slab.n_slab, RR.slab.n_bottom_slide,
      RR.slab.b_top_slide, b, RR.slab.b_bottom_slide, RR.slab.cos_angle, &Rc, &Tc);
  CALCULATING_GRID = 1;
  Calculate_Distance_With_Corrections(ur1, ut1, Rc, Tc, uru, utu, &LR, &LT, &dev);
  CALCULATING_GRID = 0;
  return dev;
}
```

This code is used in section 114.

171. This is the routine that actually finds the distance. I have factored this part out so that it can be used in the *Near_Grid_Points* routine.

Rc and *Tc* refer to the unscattered (collimated) reflection and transmission.

The only tricky part is to remember that the we are trying to match the measured values. The measured values are affected by sphere parameters and light loss. Since the values `UR1` and `UT1` are for an infinite slab sample with no light loss, the light loss out the edges must be subtracted. It is these values that are used with the sphere formulas to convert the modified `UR1` and `UT1` to values for `*M_R` and `*M_T`.

```
⟨ Prototype for Calculate_Distance_With_Corrections 171 ⟩ ≡
  void Calculate_Distance_With_Corrections(double UR1, double UT1, double Rc, double Tc, double
      URU, double UTU, double *M_R, double *M_T, double *dev)
```

This code is used in sections 115 and 172.

172.

```
⟨ Definition for Calculate_Distance_With_Corrections 172 ⟩ ≡
  ⟨ Prototype for Calculate_Distance_With_Corrections 171 ⟩
  {
    double R_direct, T_direct, R_diffuse, T_diffuse;
    R_diffuse = URU - MM.uru_lost;
    if (R_diffuse < 0) R_diffuse = 0;
    T_diffuse = UTU - MM.utu_lost;
    if (T_diffuse < 0) T_diffuse = 0;
    R_direct = UR1 - MM.ur1_lost - (1.0 - MM.fraction_of_rc_in_mr) * Rc;
    T_direct = UT1 - MM.ut1_lost - (1.0 - MM.fraction_of_tc_in_mt) * Tc;
    switch (MM.num_spheres) {
    case 0: ⟨ Calc M_R and M_T for no spheres 173 ⟩
      break;
    case 1:
      if (MM.method ≡ COMPARISON) {
        ⟨ Calc M_R and M_T for dual beam sphere 177 ⟩
      }
      else {
        ⟨ Calc M_R and M_T for single beam sphere 174 ⟩
      }
      break;
    case 2: ⟨ Calc M_R and M_T for two spheres 178 ⟩
      break;
    default: fprintf(stderr, "Bad number of spheres = %d\n", MM.num_spheres);
    }
    ⟨ Calculate the deviation 179 ⟩
    ⟨ Print diagnostics 182 ⟩
  }
```

This code is used in section 114.

173. If no spheres were used in the measurement, then presumably the measured values are the reflection and transmission. Consequently, we just acertain what the irradiance was and whether the specular reflection ports were blocked and proceed accordingly. Note that blocking the ports does not have much meaning unless the light is collimated, and therefore the reflection and transmission is only modified for collimated irradiance.

⟨ Calc M_R and M_T for no spheres 173 ⟩ ≡
```
{
  *M_R = R_direct;
  *M_T = T_direct;
}
```
This code is used in section 172.

174. Define a bunch of temporary variable names

⟨ Calc M_R and M_T for single beam sphere 174 ⟩ ≡
```
double P_std, P, P_0, G, G_0, G_std;
int tmp;
```
See also sections 175 and 176.

This code is used in section 172.

175. In a reflection experiment, some fraction f of the incident light P_i might hit the wall first. Thus the incident power on the sample is $(1-f)P_i$ and the incident power on the sphere wall will be fP_i. The diffuse reflection entering the sphere depends on the presence of a baffle.

If a baffle is present then

$$P_d = [a_d(1-a_e)r_w P_i](r_s^{\text{direct}} * (1-f) + r_w f)G(r_s)$$

and when there is no baffle

$$P_d = [a_d P_i](r_s^{\text{direct}} * (1-f) + r_w f)G(r_s)$$

Since the quantities in square brackets are identical for $R(r_s^{\text{direct}}, r_s)$, $R(0,0)$, and $R(r_{\text{std}}, r_{\text{std}})$ and they all cancel out when calculating the normalized reflection measurement

$$M_R = r_{\text{std}} \cdot \frac{R(r_s^{\text{direct}}, r_s) - R(0,0)}{R(r_{\text{std}}, r_{\text{std}}) - R(0,0)}$$

This leads to the following code for M_R

⟨ Calc M_R and M_T for single beam sphere 174 ⟩ +≡
```
G_0 = Gain(REFLECTION_SPHERE, MM, 0.0);
G = Gain(REFLECTION_SPHERE, MM, R_diffuse);
G_std = Gain(REFLECTION_SPHERE, MM, MM.rstd_r);
P = G * (R_direct * (1 - MM.f_r) + MM.f_r * MM.rw_r);
P_std = G_std * (MM.rstd_r * (1 - MM.f_r) + MM.f_r * MM.rw_r);
P_0 = G_0 * (MM.f_r * MM.rw_r);
*M_R = MM.rstd_r * (P - P_0)/(P_std - P_0);
```

176. In a transmission experiment, the calculations are simpler and harder. First, the value of $T(0,0) = 0$ because computationally, there is no dark noise in the detector nor any possible light leakage from the outside into the sphere. This simplifies

$$M_T = r_0 \cdot \frac{T(t_s^{\text{direct}}, r_s) - T(0,0)}{T(t_{\text{std}}, r_{\text{std}}) - T(0,0)}$$

to

$$M_T = r_0 \cdot \frac{T(t_s^{\text{direct}}, r_s)}{T(t_{\text{std}}, r_{\text{std}})}$$

where r_0 might be r_{std} or r_w for the transmission sphere.

We do not need to worry about some fraction of the incident light P_i hitting the sphere wall before interacting with the sample.

Finally, if the transmission sphere has a baffle present for the sample measurement, then it is no longer in the right place and diffuse light entering the sphere is just $[a_d P_i] r_0$

When a baffle is present then the light falling on the detector in a transmission experiment is

$$P_d = T(t_s^{\text{direct}}, r_s) = [a_d P_i](1 - a_e) r_w t_s^{\text{direct}} G(r_s)$$

and with no baffle present

$$P_d = T(t_s^{\text{direct}}, r_s) = [a_d P_i] t_s^{\text{direct}} G(r_s)$$

The normalization $T(t_{\text{std}}, r_{\text{std}})$ can be measured in two ways.

When transmission measurements are made, typically the empty port (the one that let the light into the sphere for the reflection measurement) is filled with a white port cover whose reflectance matches the rest of the sphere. In this case, the natural way to make the standard transmission measurement is to shine the beam through the empty sample port onto the back side of the sphere. If the baffle was properly placed for the transmission experiment (between the sample port and the detector) then the calibration transmission measurement is now made in a sphere without a baffle. In addition, the beam is diffused only after bouncing off the sphere wall. Therefore the power falling on the detector is

$$P_{\text{std}} = T(1.0, r_w) = [a_d P_i] r_w G(0)$$

An alternate experiment is when there is an empty port in the sphere (perhaps to allow the unscattered light to leave). In any case, the calibration measurement is done by removing the sample and placing the calibration standare in what used to be the empty port. In this case, the roles of the sample and empty ports have switched. Consequently, the areas of the sample and empty ports must be swapped before the gain is calculated.

$$P_{\text{std}} = T(1.0, r_{\text{std}}) = [a_d P_i] r_{\text{std}} G(r_{\text{std}})$$

Note that r_w or r_{std} in P_{std} term cancel with r_0 when calculating M_T. Further, the quantities $a_d P_i$ also cancel.

```
⟨ Calc M_R and M_T for single beam sphere 174 ⟩ +≡
  P = T_direct * Gain(TRANSMISSION_SPHERE, MM, R_diffuse);
  if (MM.baffle_t) P *= (1 - MM.ae_t) * MM.rw_t;
  tmp = MM.baffle_t;
  MM.baffle_t = FALSE;
  if (MM.ae_t ≡ 0) {
    P_std = Gain(TRANSMISSION_SPHERE, MM, 0);
  }
  else {
    SWAP(MM.ae_t, MM.as_t);
    P_std = Gain(TRANSMISSION_SPHERE, MM, MM.rstd_t);
    SWAP(MM.ae_t, MM.as_t);
  }
  MM.baffle_t = tmp;
  *M_T = P/P_std;
```

177. The dual beam case is different because the sphere efficiency is equivalent for measurement of light hitting the sample first or hitting the reference standard first. The dual beam measurement should report the ratio of these two reflectance measurements, thereby eliminating the need to calculate the gain completely. The same holds when no sample is present.

The normalized reflectance measurement (the difference between dual beam measurement for a port with the sample and with nothing) is

$$M_R = r_{\rm std} \cdot \frac{(1-f)r_s^{\rm direct} + fr_w}{(1-f')r_{\rm std} - f'r_w} - r_{\rm std} \cdot \frac{(1-f)(0) + fr_w}{(1-f')r_{\rm std} - f'r_w}$$

or

$$M_R = \frac{(1-f)r_s^{\rm direct}}{(1-f') - f'r_w/r_{\rm std}}$$

When $f = f' = 1$, then $M_R = 1$ no matter what the reflectance is. (Leave it in this form to avoid division by zero when $f = 1$.)

The normalized transmittance is simply $t_s^{\rm direct}$.

When $f = 0$ then this result is essentially the same as the no spheres result (because no sphere corrections are needed). However if the number of spheres is zero, then no lost light calculations are made and therefore that is a potential error.

⟨ Calc `M_R` and `M_T` for dual beam sphere 177 ⟩ ≡

```
{
  *M_R = (1 - MM.f_r) * R_direct/((1 - MM.f_r) + MM.f_r * MM.rw_r/MM.rstd_r);
  *M_T = T_direct;
}
```

This code is used in section 172.

178. When two integrating spheres are present then the double integrating sphere formulas are slightly more complicated.

The normalized sphere measurements for two spheres are

$$M_R = \frac{R(r_s^{\rm direct}, r_s, t_s^{\rm direct}, t_s) - R(0,0,0,0)}{R(r_{\rm std}, r_{\rm std}, 0, 0) - R(0,0,0,0)}$$

and

$$M_T = \frac{T(r_s^{\rm direct}, r_s, t_s^{\rm direct}, t_s) - T(0,0,0,0)}{T(0,0,1,1) - T(0,0,0,0)}$$

Note that `R_0` and `T_0` will be zero unless one has explicitly set the fraction $m.f\_r$ or $m.f\_t$ to be non-zero.

⟨ Calc `M_R` and `M_T` for two spheres 178 ⟩ ≡

```
{
  double R_0, T_0;
  R_0 = Two_Sphere_R(MM, 0, 0, 0, 0);
  T_0 = Two_Sphere_T(MM, 0, 0, 0, 0);
  *M_R = MM.rstd_r * (Two_Sphere_R(MM, R_direct, R_diffuse, T_direct,
      T_diffuse) - R_0)/(Two_Sphere_R(MM, MM.rstd_r, MM.rstd_r, 0, 0) - R_0);
  *M_T = (Two_Sphere_T(MM, R_direct, R_diffuse, T_direct, T_diffuse) - T_0)/(Two_Sphere_T(MM, 0, 0, 1,
      1) - T_0);
}
```

This code is used in section 172.

179. There are at least three things that need to be considered here. First, the number of measurements. Second, is the metric is relative or absolute. And third, is the albedo fixed at zero which means that the transmission measurement should be used instead of the reflection measurement.

```
⟨ Calculate the deviation 179 ⟩ ≡
  if (RR.search ≡ FIND_A ∨ RR.search ≡ FIND_G ∨ RR.search ≡ FIND_B ∨ RR.search ≡ FIND_Bs ∨ RR.search ≡
        FIND_Ba) {
    ⟨ One parameter deviation 180 ⟩
  }
  else {
    ⟨ Two parameter deviation 181 ⟩
  }
```

This code is used in section 172.

180. This part was slightly tricky. The crux of the problem was to decide if the transmission or the reflection was trustworthy. After looking a bunches of measurements, I decided that the transmission measurement was almost always more reliable. So when there is just a single measurement known, then use the total transmission if it exists.

```
⟨ One parameter deviation 180 ⟩ ≡
  if (MM.m_t > 0) {
    if (RR.metric ≡ RELATIVE) *dev = fabs(MM.m_t − *M_T)/(MM.m_t + ABIT);
    else *dev = fabs(MM.m_t − *M_T);
  }
  else {
    if (RR.metric ≡ RELATIVE) *dev = fabs(MM.m_r − *M_R)/(MM.m_r + ABIT);
    else *dev = fabs(MM.m_r − *M_R);
  }
```

This code is used in section 179.

181. This stuff happens when we are doing two parameter searches. In these cases there should be information in both R and T. The distance should be calculated using the deviation from both. The albedo stuff might be able to be take out. We'll see.

```
⟨ Two parameter deviation 181 ⟩ ≡
  if (RR.metric ≡ RELATIVE) {
    double rc, tc;
    Absorbing_Glass_RT(1.0, MM.slab_top_slide_index, MM.slab_index, MM.slab_cos_angle, MM.slab_top_slide_b,
        &rc, &tc);
    rc *= MM.fraction_of_rc_in_mr;
    *dev = 0;
    if (MM.m_t > ABIT) *dev = T_TRUST_FACTOR * fabs(MM.m_t − *M_T)/(T_diffuse + ABIT);
    if (RR.default_a ≠ 0) {
      *dev += fabs(MM.m_r − *M_R)/(R_diffuse + ABIT);
    }
  }
  else {
    *dev = T_TRUST_FACTOR * fabs(MM.m_t − *M_T);
    if (RR.default_a ≠ 0) *dev += fabs(MM.m_r − *M_R);
  }
```

This code is used in section 179.

182. This is here so that I can figure out why the program is not converging. This is a little convoluted so that the global constants at the top of this file interact properly.

```
⟨ Print diagnostics 182 ⟩ ≡
  if ((Debug(DEBUG_ITERATIONS) ∧ ¬CALCULATING_GRID) ∨
        (Debug(DEBUG_GRID_CALC) ∧ CALCULATING_GRID)) {
    static int once;
    if (once ≠ MM.lambda) {
      fprintf(stderr, "%10s␣%10s␣%10s␣|␣%7s␣%7s␣|␣%7s␣%7s␣|%8s\n␣␣␣␣␣␣␣␣", "a", "b", "g", "m_r",
          "fit", "m_t", "fit", "delta");
      once = MM.lambda;
    }
    fprintf(stderr, "%10.5f␣%10.5f␣%10.5f␣|", RR.slab.a, RR.slab.b, RR.slab.g);
    fprintf(stderr, "␣%7.5f␣%7.5f␣|", MM.m_r, *M_R);
    fprintf(stderr, "␣%7.5f␣%7.5f␣|", MM.m_t, *M_T);
    fprintf(stderr, "%8.5f", *dev);
    if (RR.metric ≡ RELATIVE) fprintf(stderr, "␣(relative)\n");
    else fprintf(stderr, "␣(absolute)\n");
  }
```

This code is used in section 172.

183. ⟨ Prototype for *Find_AG_fn* 183 ⟩ ≡

```
double Find_AG_fn(double x[])
```

This code is used in sections 115 and 184.

184. ⟨ Definition for *Find_AG_fn* 184 ⟩ ≡

```
⟨ Prototype for Find_AG_fn 183 ⟩
{
  double m_r, m_t, deviation;
  RR.slab.a = acalc2a(x[1]);
  RR.slab.g = gcalc2g(x[2]);
  Calculate_Distance(&m_r, &m_t, &deviation);
  return deviation;
}
```

This code is used in section 114.

185. ⟨ Prototype for *Find_AB_fn* 185 ⟩ ≡

```
double Find_AB_fn(double x[])
```

This code is used in sections 115 and 186.

186. ⟨ Definition for *Find_AB_fn* 186 ⟩ ≡

```
⟨ Prototype for Find_AB_fn 185 ⟩
{
  double m_r, m_t, deviation;
  RR.slab.a = acalc2a(x[1]);
  RR.slab.b = bcalc2b(x[2]);
  Calculate_Distance(&m_r, &m_t, &deviation);
  return deviation;
}
```

This code is used in section 114.

187. ⟨ Prototype for *Find_Ba_fn* 187 ⟩ ≡

```
double Find_Ba_fn(double x)
```

This code is used in sections 115 and 188.

188. This is tricky only because the value in RR.*slab*.*b* is used to hold the value of *bs* or $d \cdot \mu_s$. It must be switched to the correct value for the optical thickness and then switched back at the end of the routine.

⟨ Definition for *Find_Ba_fn* 188 ⟩ ≡

```
⟨ Prototype for Find_Ba_fn 187 ⟩
{
  double m_r, m_t, deviation, ba, bs;
  bs = RR.slab.b;
  ba = bcalc2b(x);
  RR.slab.b = ba + bs;      /* unswindle */
  RR.slab.a = bs/(ba + bs);
  Calculate_Distance(&m_r, &m_t, &deviation);
  RR.slab.b = bs;      /* swindle */
  return deviation;
}
```

This code is used in section 114.

189. See the comments for the *Find_Ba_fn* routine above. Play the same trick but use *ba*.

⟨ Prototype for *Find_Bs_fn* 189 ⟩ ≡

```
double Find_Bs_fn(double x)
```

This code is used in sections 115 and 190.

190. ⟨ Definition for *Find_Bs_fn* 190 ⟩ ≡

```
⟨ Prototype for Find_Bs_fn 189 ⟩
{
  double m_r, m_t, deviation, ba, bs;
  ba = RR.slab.b;      /* unswindle */
  bs = bcalc2b(x);
  RR.slab.b = ba + bs;
  RR.slab.a = bs/(ba + bs);
  Calculate_Distance(&m_r, &m_t, &deviation);
  RR.slab.b = ba;      /* swindle */
  return deviation;
}
```

This code is used in section 114.

191. ⟨ Prototype for *Find_A_fn* 191 ⟩ ≡

```
double Find_A_fn(double x)
```

This code is used in sections 115 and 192.

192. ⟨ Definition for *Find_A_fn* 192 ⟩ ≡
```
⟨ Prototype for Find_A_fn 191 ⟩
{
  double m_r, m_t, deviation;
  RR.slab.a = acalc2a(x);
  Calculate_Distance(&m_r, &m_t, &deviation);
  return deviation;
}
```
This code is used in section 114.

193. ⟨ Prototype for *Find_B_fn* 193 ⟩ ≡
```
double Find_B_fn(double x)
```
This code is used in sections 115 and 194.

194. ⟨ Definition for *Find_B_fn* 194 ⟩ ≡
```
⟨ Prototype for Find_B_fn 193 ⟩
{
  double m_r, m_t, deviation;
  RR.slab.b = bcalc2b(x);
  Calculate_Distance(&m_r, &m_t, &deviation);
  return deviation;
}
```
This code is used in section 114.

195. ⟨ Prototype for *Find_G_fn* 195 ⟩ ≡
```
double Find_G_fn(double x)
```
This code is used in sections 115 and 196.

196. ⟨ Definition for *Find_G_fn* 196 ⟩ ≡
```
⟨ Prototype for Find_G_fn 195 ⟩
{
  double m_r, m_t, deviation;
  RR.slab.g = gcalc2g(x);
  Calculate_Distance(&m_r, &m_t, &deviation);
  return deviation;
}
```
This code is used in section 114.

197. ⟨ Prototype for *Find_BG_fn* 197 ⟩ ≡
```
double Find_BG_fn(double x[])
```
This code is used in sections 115 and 198.

198. ⟨ Definition for *Find_BG_fn* 198 ⟩ ≡
```
⟨ Prototype for Find_BG_fn 197 ⟩
{
  double m_r, m_t, deviation;
  RR.slab.b = bcalc2b(x[1]);
  RR.slab.g = gcalc2g(x[2]);
  RR.slab.a = RR.default_a;
  Calculate_Distance(&m_r, &m_t, &deviation);
  return deviation;
}
```
This code is used in section 114.

199. For this function the first term $x[1]$ will contain the value of $\mu_s d$, the second term will contain the anisotropy. Of course the first term is in the bizarre calculation space and needs to be translated back into normal terms before use. We just at the scattering back on and voilá we have a useable value for the optical depth.

⟨ Prototype for *Find_BaG_fn* 199 ⟩ ≡
```
double Find_BaG_fn(double x[])
```
This code is used in sections 115 and 200.

200. ⟨ Definition for *Find_BaG_fn* 200 ⟩ ≡
```
⟨ Prototype for Find_BaG_fn 199 ⟩
{
  double m_r, m_t, deviation;
  RR.slab.b = bcalc2b(x[1]) + RR.default_bs;
  if (RR.slab.b ≤ 0) RR.slab.a = 0;
  else RR.slab.a = RR.default_bs/RR.slab.b;
  RR.slab.g = gcalc2g(x[2]);
  Calculate_Distance(&m_r, &m_t, &deviation);
  return deviation;
}
```
This code is used in section 114.

201. ⟨ Prototype for *Find_BsG_fn* 201 ⟩ ≡
```
double Find_BsG_fn(double x[])
```
This code is used in sections 115 and 202.

202. ⟨ Definition for *Find_BsG_fn* 202 ⟩ ≡
```
⟨ Prototype for Find_BsG_fn 201 ⟩
{
  double m_r, m_t, deviation;
  RR.slab.b = bcalc2b(x[1]) + RR.default_ba;
  if (RR.slab.b ≤ 0) RR.slab.a = 0;
  else RR.slab.a = 1.0 − RR.default_ba/RR.slab.b;
  RR.slab.g = gcalc2g(x[2]);
  Calculate_Distance(&m_r, &m_t, &deviation);
  return deviation;
}
```
This code is used in section 114.

203. Routine to figure out if the light loss exceeds what is physically possible. Returns the descrepancy betweent the current values and the maximum possible values for the the measurements *m_r* and *m_t*.

⟨ Prototype for *maxloss* 203 ⟩ ≡
double *maxloss*(**double** *f*)
This code is used in sections 115 and 204.

204. ⟨ Definition for *maxloss* 204 ⟩ ≡
⟨ Prototype for *maxloss* 203 ⟩
{
struct measure_type *m_old*;
struct invert_type *r_old*;
double *m_r*, *m_t*, *deviation*;
Get_Calc_State(&*m_old*, &*r_old*);
RR.*slab*.*a* = 1.0;
MM.*ur1_lost* *= *f*;
MM.*ut1_lost* *= *f*;
Calculate_Distance(&*m_r*, &*m_t*, &*deviation*);
Set_Calc_State(*m_old*, *r_old*);
deviation = ((MM.*m_r* + MM.*m_t*) − (*m_r* + *m_t*));
return *deviation*;
}
This code is used in section 114.

205. This checks the two light loss values *ur1_loss* and *ut1_loss* to see if they exceed what is physically possible. If they do, then these values are replaced by a couple that are the maximum possible for the current values in *m* and *r*.

⟨ Prototype for *Max_Light_Loss* 205 ⟩ ≡
void *Max_Light_Loss*(**struct measure_type** *m*, **struct invert_type** *r*, **double** **ur1_loss*, **double** **ut1_loss*)
This code is used in sections 115 and 206.

206. ⟨ Definition for *Max_Light_Loss* 206 ⟩ ≡

```
⟨ Prototype for Max_Light_Loss 205 ⟩
{
  struct measure_type m_old;
  struct invert_type r_old;
  *ur1_loss = m.ur1_lost;
  *ut1_loss = m.ut1_lost;
  if (Debug(DEBUG_LOST_LIGHT))
    fprintf(stderr, "\nlost␣before␣ur1=%7.5f,␣ut1=%7.5f\n", *ur1_loss, *ut1_loss);
  Get_Calc_State(&m_old, &r_old);
  Set_Calc_State(m, r);
  if (maxloss(1.0) * maxloss(0.0) < 0) {
    double frac;
    frac = zbrent(maxloss, 0.00, 1.0, 0.001);
    *ur1_loss = m.ur1_lost * frac;
    *ut1_loss = m.ut1_lost * frac;
  }
  Set_Calc_State(m_old, r_old);
  if (Debug(DEBUG_LOST_LIGHT))
    fprintf(stderr, "lost␣after␣␣ur1=%7.5f,␣ut1=%7.5f\n", *ur1_loss, *ut1_loss);
}
```

This code is used in section 114.

207. this is currently unused

```
⟨ Unused diffusion fragment 207 ⟩ ≡
  typedef struct {
    double f;
    double aprime;
    double bprime;
    double gprime;
    double boundary_method;
    double n_top;
    double n_bottom;
    double slide_top;
    double slide_bottom;
    double F0;
    double depth;
    double Exact_coll_flag;
  } slabtype;
  static void DE_RT(int nfluxes, AD_slab_type slab, double *UR1, double *UT1, double *URU, double
          *UTU)
  {
    slabtype s;
    double rp, tp, rs, ts;
    s.f = slab.g * slab.g;
    s.gprime = slab.g/(1 + slab.g);
    s.aprime = (1 - s.f) * slab.a/(1 - slab.a * s.f);
    s.bprime = (1 - slab.a * s.f) * slab.b;
    s.boundary_method = Egan;
    s.n_top = slab.n_slab;
    s.n_bottom = slab.n_slab;
    s.slide_top = slab.n_top_slide;
    s.slide_bottom = slab.n_bottom_slide;
    s.F0 = 1/M_PI;
    s.depth = 0.0;
    s.Exact_coll_flag = FALSE;
    if (MM.illumination ≡ collimated) {
      compute_R_and_T(&s, 1.0, &rp, &rs, &tp, &ts);
      *UR1 = rp + rs;
      *UT1 = tp + ts;
      *URU = 0.0;
      *UTU = 0.0;
      return;
    }
    quad_Dif_Calc_R_and_T(&s, &rp, &rs, &tp, &ts);
    *URU = rp + rs;
    *UTU = tp + ts;
    *UR1 = 0.0;
    *UT1 = 0.0;
  }
```

208. IAD Find. March 1995. Incorporated the *quick_guess* algorithm for low albedos.

```
⟨ iad_find.c 208 ⟩ ≡
#include <math.h>
#include <stdio.h>
#include <stdlib.h>
#include "ad_globl.h"
#include "nr_util.h"
#include "nr_mnbrk.h"
#include "nr_brent.h"
#include "nr_amoeb.h"
#include "iad_type.h"
#include "iad_util.h"
#include "iad_calc.h"
#include "iad_find.h"
#define NUMBER_OF_GUESSES 10
  guess_type guess[NUMBER_OF_GUESSES];
  int compare_guesses(const void *p1, const void *p2)
  {
    guess_type *g1 = (guess_type *) p1;
    guess_type *g2 = (guess_type *) p2;
    if (g1→distance < g2→distance) return -1;
    else if (g1→distance ≡ g2→distance) return 0;
    else return 1;
  }
  ⟨ Definition for U_Find_Ba 222 ⟩
  ⟨ Definition for U_Find_Bs 220 ⟩
  ⟨ Definition for U_Find_A 224 ⟩
  ⟨ Definition for U_Find_B 228 ⟩
  ⟨ Definition for U_Find_G 226 ⟩
  ⟨ Definition for U_Find_AG 231 ⟩
  ⟨ Definition for U_Find_AB 211 ⟩
  ⟨ Definition for U_Find_BG 236 ⟩
  ⟨ Definition for U_Find_BaG 242 ⟩
  ⟨ Definition for U_Find_BsG 247 ⟩
```

209. All the information that needs to be written to the header file `iad_find.h`. This eliminates the need to maintain a set of header files as well.

```
⟨ iad_find.h 209 ⟩ ≡
  ⟨ Prototype for U_Find_Ba 221 ⟩;
  ⟨ Prototype for U_Find_Bs 219 ⟩;
  ⟨ Prototype for U_Find_A 223 ⟩;
  ⟨ Prototype for U_Find_B 227 ⟩;
  ⟨ Prototype for U_Find_G 225 ⟩;
  ⟨ Prototype for U_Find_AG 230 ⟩;
  ⟨ Prototype for U_Find_AB 210 ⟩;
  ⟨ Prototype for U_Find_BG 235 ⟩;
  ⟨ Prototype for U_Find_BaG 241 ⟩;
  ⟨ Prototype for U_Find_BsG 246 ⟩;
```

210. Fixed Anisotropy.
This is the most common case.

```
⟨ Prototype for U_Find_AB 210 ⟩ ≡
  void U_Find_AB(struct measure_type m, struct invert_type *r)
```

This code is used in sections 209 and 211.

211. ⟨ Definition for *U_Find_AB* 211 ⟩ ≡

```
⟨ Prototype for U_Find_AB 210 ⟩
{
  ⟨ Allocate local simplex variables 212 ⟩
  if (Debug(DEBUG_SEARCH)) {
    fprintf(stderr, "In␣U_Find_AB");
    fprintf(stderr, "␣(mu=%6.4f)", r→slab.cos_angle);
    if (r→default_g ≠ UNINITIALIZED) fprintf(stderr, "␣␣default_g␣=␣%8.5f", r→default_g);
    fprintf(stderr, "\n");
  }
  r→slab.g = (r→default_g ≡ UNINITIALIZED) ? 0 : r→default_g;
  Set_Calc_State(m, *r);
  ⟨ Get the initial a, b, and g 213 ⟩
  ⟨ Initialize the nodes of the a and b simplex 214 ⟩
  ⟨ Evaluate the a and b simplex at the nodes 215 ⟩
  amoeba(p, y, 2, r→tolerance, Find_AB_fn, &r→iterations);
  ⟨ Choose the best node of the a and b simplex 216 ⟩
  ⟨ Free simplex data structures 218 ⟩
  ⟨ Put final values in result 217 ⟩
}
```

This code is used in section 208.

212. To use the simplex algorithm, we need to vectors and a matrix.

```
⟨ Allocate local simplex variables 212 ⟩ ≡
  int i, i_best, j_best;
  double *x, *y, **p;
  x = dvector(1, 2);
  y = dvector(1, 3);
  p = dmatrix(1, 3, 1, 2);
```

This code is used in sections 211, 231, 236, 242, and 247.

213. Just get the optimal optical properties to start the search process.

I had to add the line that tests to make sure the albedo is greater than 0.2 because the grid just does not work so well in this case. The problem is that for low albedos there is really very little information about the anisotropy available. This change was also made in the analagous code for a and b.

```
⟨ Get the initial a, b, and g 213 ⟩ ≡
  {     /* double a3,b3,g3; */
    size_t count = NUMBER_OF_GUESSES;     /* distance to last result */
    abg_distance(r→slab.a, r→slab.b, r→slab.g, &(guess[0]));
    if (¬Valid_Grid(m, r→search)) Fill_Grid(m, *r, 1);     /* distance to nearest grid point */
    Near_Grid_Points(m.m_r, m.m_t, r→search, &i_best, &j_best);
    Grid_ABG(i_best, j_best, &(guess[1]));
    Grid_ABG(i_best + 1, j_best, &(guess[2]));
    Grid_ABG(i_best − 1, j_best, &(guess[3]));
    Grid_ABG(i_best, j_best + 1, &(guess[4]));
    Grid_ABG(i_best, j_best − 1, &(guess[5]));
    Grid_ABG(i_best + 1, j_best + 1, &(guess[6]));
    Grid_ABG(i_best − 1, j_best − 1, &(guess[7]));
    Grid_ABG(i_best + 1, j_best − 1, &(guess[8]));
    Grid_ABG(i_best − 1, j_best + 1, &(guess[9]));
    qsort((void *) guess, count, sizeof(guess_type), compare_guesses);
    if (Debug(DEBUG_BEST_GUESS)) {
      int k;
      fprintf(stderr, "Best␣Grid␣Guesses\n");
      fprintf(stderr, "␣␣k␣␣␣␣␣␣albedo␣␣␣␣␣␣␣␣␣␣␣b␣␣␣␣␣␣␣␣␣␣␣g␣␣␣␣␣distance\n");
      for (k = 0; k ≤ 6; k++) {
        fprintf(stderr, "%3d␣␣␣", k);
        fprintf(stderr, "%10.5f␣␣", guess[k].a);
        fprintf(stderr, "%10.5f␣␣", guess[k].b);
        fprintf(stderr, "%10.5f␣␣", guess[k].g);
        fprintf(stderr, "%10.5f\n", guess[k].distance);
      }
    }
  }
```

This code is used in sections 211, 231, 236, 242, and 247.

214. ⟨ Initialize the nodes of the a and b simplex 214 ⟩ ≡

```
{
  int k, kk;
  p[1][1] = a2acalc(guess[0].a);
  p[1][2] = b2bcalc(guess[0].b);
  for (k = 1; k < 7; k++) {
    if (guess[0].a ≠ guess[k].a) break;
  }
  p[2][1] = a2acalc(guess[k].a);
  p[2][2] = b2bcalc(guess[k].b);
  for (kk = 1; kk < 7; kk++) {
    if (k ≡ kk) continue;
    if (guess[0].b ≠ guess[kk].b ∨ guess[k].b ≠ guess[kk].b) break;
  }
  p[3][1] = a2acalc(guess[kk].a);
  p[3][2] = b2bcalc(guess[kk].b);
  if (Debug(DEBUG_BEST_GUESS)) {
    fprintf(stderr, "------------------------------------------------\n");
    fprintf(stderr, "␣<1>␣");
    fprintf(stderr, "%10.5f␣", guess[0].a);
    fprintf(stderr, "%10.5f␣", guess[0].b);
    fprintf(stderr, "%10.5f␣", guess[0].g);
    fprintf(stderr, "%10.5f\n", guess[0].distance);
    fprintf(stderr, "␣<2>␣");
    fprintf(stderr, "%10.5f␣", guess[k].a);
    fprintf(stderr, "%10.5f␣", guess[k].b);
    fprintf(stderr, "%10.5f␣", guess[k].g);
    fprintf(stderr, "%10.5f\n", guess[k].distance);
    fprintf(stderr, "␣<3>␣");
    fprintf(stderr, "%10.5f␣", guess[kk].a);
    fprintf(stderr, "%10.5f␣", guess[kk].b);
    fprintf(stderr, "%10.5f␣", guess[kk].g);
    fprintf(stderr, "%10.5f\n\n", guess[kk].distance);
  }
}
```

This code is used in section 211.

215. ⟨ Evaluate the a and b simplex at the nodes 215 ⟩ ≡

```
for (i = 1; i ≤ 3; i++) {
  x[1] = p[i][1];
  x[2] = p[i][2];
  y[i] = Find_AB_fn(x);
}
```

This code is used in section 211.

216. ⟨ Choose the best node of the a and b simplex 216 ⟩ ≡

```
r→final_distance = 10;
for (i = 1; i ≤ 3; i++) {
  if (y[i] < r→final_distance) {
    r→slab.a = acalc2a(p[i][1]);
    r→slab.b = bcalc2b(p[i][2]);
    r→final_distance = y[i];
  }
}
```

This code is used in section 211.

217. ⟨ Put final values in result 217 ⟩ ≡

```
if (Debug(DEBUG_ITERATIONS)) fprintf(stderr, "amoeba␣iterations␣=␣%d\n", r→iterations);
r→a = r→slab.a;
r→b = r→slab.b;
r→g = r→slab.g;
r→found = (r→tolerance ≤ r→final_distance);
Set_Calc_State(m, *r);
```

This code is used in sections 211, 220, 222, 224, 226, 228, 231, 236, 242, and 247.

218. Since we allocated these puppies, we got to get rid of them.

⟨ Free simplex data structures 218 ⟩ ≡

```
free_dvector(x, 1, 2);
free_dvector(y, 1, 3);
free_dmatrix(p, 1, 3, 1, 2);
```

This code is used in sections 211, 231, 236, 242, and 247.

219. Fixed Absorption and Anisotropy. Typically, this routine is called when the absorption coefficient is known, the anisotropy is known, and the physical thickness of the sample is known. This routine calculates the varies the scattering coefficient until the measurements are matched.

This was written for Ted Moffitt to analyze some intralipid data. We wanted to know what the scattering coefficient of the Intralipid was and made total transmission measurements through a sample with a fixed physical thickness. We did not make reflection measurements because the light source diverged too much, and we could not make reflection measurements easily.

In retrospect, we could have made URU measurements by illuminating the wall of the integrating sphere. However, these diffuse type of measurements are very difficult to make accurately.

This is tricky only because the value in *slab.b* is used to hold the value of *ba* or $d \cdot \mu_a$ when the *Find_Bs_fn* is used.

⟨ Prototype for *U_Find_Bs* 219 ⟩ ≡

```
void U_Find_Bs(struct measure_type m, struct invert_type *r)
```

This code is used in sections 209 and 220.

220. ⟨ Definition for *U_Find_Bs* 220 ⟩ ≡

```
⟨ Prototype for U_Find_Bs 219 ⟩
{
  double ax, bx, cx, fa, fb, fc, bs;
  if (Debug(DEBUG_SEARCH)) {
    fprintf(stderr, "In␣U_Find_Bs");
    fprintf(stderr, "␣(mu=%6.4f)", r→slab.cos_angle);
    if (r→default_ba ≠ UNINITIALIZED) fprintf(stderr, "␣␣default_ba␣=␣%8.5f", r→default_ba);
    if (r→default_g ≠ UNINITIALIZED) fprintf(stderr, "␣␣default_g␣=␣%8.5f", r→default_g);
    fprintf(stderr, "\n");
  }
  if (m.m_t ≡ 0) {
    r→slab.b = HUGE_VAL;
    U_Find_A(m, r);
    return;
  }
  r→slab.a = 0;
  r→slab.g = (r→default_g ≡ UNINITIALIZED) ? 0 : r→default_g;
  r→slab.b = (r→default_ba ≡ UNINITIALIZED) ? HUGE_VAL : r→default_ba;
  Set_Calc_State(m, *r);      /* store ba in RR.slab.b */
  ax = b2bcalc(0.1);      /* first try for bs */
  bx = b2bcalc(1.0);
  mnbrak(&ax, &bx, &cx, &fa, &fb, &fc, Find_Bs_fn);
  r→final_distance = brent(ax, bx, cx, Find_Bs_fn, r→tolerance, &bs);      /* recover true values */
  r→slab.a = bcalc2b(bs)/(bcalc2b(bs) + r→slab.b);
  r→slab.b = bcalc2b(bs) + r→slab.b;
  ⟨ Put final values in result 217 ⟩
}
```

This code is used in section 208.

221. Fixed Absorption and Scattering. Typically, this routine is called when the scattering coefficient is known, the anisotropy is known, and the physical thickness of the sample is known. This routine calculates the varies the absorption coefficient until the measurements are matched.

This is tricky only because the value in *slab.b* is used to hold the value of *bs* or $d \cdot \mu_s$ when the *Find_Ba_fn* is used.

```
⟨ Prototype for U_Find_Ba 221 ⟩ ≡
  void U_Find_Ba(struct measure_type m, struct invert_type *r)
```

This code is used in sections 209 and 222.

222.

```
⟨ Definition for U_Find_Ba 222 ⟩ ≡
  ⟨ Prototype for U_Find_Ba 221 ⟩
  {
    double ax, bx, cx, fa, fb, fc, ba;
    if (Debug(DEBUG_SEARCH)) {
      fprintf(stderr, "In U_Find_Bs");
      fprintf(stderr, " (mu=%6.4f)", r->slab.cos_angle);
      if (r->default_bs ≠ UNINITIALIZED) fprintf(stderr, "  default_bs = %8.5f", r->default_bs);
      if (r->default_g ≠ UNINITIALIZED) fprintf(stderr, "  default_g = %8.5f", r->default_g);
      fprintf(stderr, "\n");
    }
    r->slab.a = 0;
    r->slab.g = (r->default_g ≡ UNINITIALIZED) ? 0 : r->default_g;
    r->slab.b = (r->default_bs ≡ UNINITIALIZED) ? HUGE_VAL : r->default_bs;
    if (m.m_t ≡ 0) {
      r->slab.b = HUGE_VAL;
      U_Find_A(m, r);
      return;
    }
    Set_Calc_State(m, *r);      /* store bs in RR.slab.b */
    ax = b2bcalc(0.1);      /* first try for ba */
    bx = b2bcalc(1.0);
    mnbrak(&ax, &bx, &cx, &fa, &fb, &fc, Find_Ba_fn);
    r->final_distance = brent(ax, bx, cx, Find_Ba_fn, r->tolerance, &ba);      /* recover true values */
    r->slab.a = (r->slab.b)/(bcalc2b(ba) + r->slab.b);
    r->slab.b = bcalc2b(ba) + r->slab.b;      /* actual value of b */
    ⟨ Put final values in result 217 ⟩
  }
```

This code is used in section 208.

223. Fixed Optical Depth and Anisotropy. Typically, this routine is called when the optical thickness is assumed infinite. However, it may also be called when the optical thickness is assumed to be fixed at a particular value. Typically the only reasonable situation for this to occur is when the diffuse transmission is non-zero but the collimated transmission is zero. If this is the case then there is no information in the collimated transmission measurement and there is no sense even using it because the slab is not infinitely thick.

```
⟨ Prototype for U_Find_A 223 ⟩ ≡
  void U_Find_A(struct measure_type m, struct invert_type *r)
```

This code is used in sections 209 and 224.

224.

```
⟨ Definition for U_Find_A 224 ⟩ ≡
  ⟨ Prototype for U_Find_A 223 ⟩
  {
    double Rt, Tt, Rd, Rc, Td, Tc;
    if (Debug(DEBUG_SEARCH)) {
      fprintf(stderr, "In U_Find_A");
      fprintf(stderr, " (mu=%6.4f)", r->slab.cos_angle);
      if (r->default_b ≠ UNINITIALIZED) fprintf(stderr, "  default_b = %8.5f", r->default_b);
      if (r->default_g ≠ UNINITIALIZED) fprintf(stderr, "  default_g = %8.5f", r->default_g);
      fprintf(stderr, "\n");
    }
    Estimate_RT(m, *r, &Rt, &Tt, &Rd, &Rc, &Td, &Tc);
    r->slab.g = (r->default_g ≡ UNINITIALIZED) ? 0 : r->default_g;
    r->slab.b = (r->default_b ≡ UNINITIALIZED) ? HUGE_VAL : r->default_b;
    r->slab.a = 0.0;
    r->final_distance = 0.0;
    Set_Calc_State(m, *r);
    if (Rt > 0.99999) {
      r->final_distance = Find_A_fn(a2acalc(1.0));
      r->slab.a = 1.0;
    }
    else {
      double x, ax, bx, cx, fa, fb, fc;
      ax = a2acalc(0.3);
      bx = a2acalc(0.5);
      mnbrak(&ax, &bx, &cx, &fa, &fb, &fc, Find_A_fn);
      r->final_distance = brent(ax, bx, cx, Find_A_fn, r->tolerance, &x);
      r->slab.a = acalc2a(x);
    }
    ⟨ Put final values in result 217 ⟩
  }
```

This code is used in section 208.

225. Fixed Optical Depth and Albedo.

```
⟨ Prototype for U_Find_G 225 ⟩ ≡
  void U_Find_G(struct measure_type m, struct invert_type *r)
```

This code is used in sections 209 and 226.

226. ⟨ Definition for *U_Find_G* 226 ⟩ ≡

```
⟨ Prototype for U_Find_G 225 ⟩
{
  double Rt, Tt, Rd, Rc, Td, Tc;
  if (Debug(DEBUG_SEARCH)) {
    fprintf(stderr, "In U_Find_G");
    fprintf(stderr, " (mu=%6.4f)", r->slab.cos_angle);
    if (r->default_a ≠ UNINITIALIZED) fprintf(stderr, "  default_a = %8.5f", r->default_a);
    if (r->default_b ≠ UNINITIALIZED) fprintf(stderr, "  default_b = %8.5f", r->default_b);
    fprintf(stderr, "\n");
  }
  Estimate_RT(m, *r, &Rt, &Tt, &Rd, &Rc, &Td, &Tc);
  r->slab.a = (r->default_a ≡ UNINITIALIZED) ? 0.5 : r->default_a;
  r->slab.b = (r->default_b ≡ UNINITIALIZED) ? HUGE_VAL : r->default_b;
  r->slab.g = 0.0;
  r->final_distance = 0.0;
  Set_Calc_State(m, *r);
  if (Rd > 0.0) {
    double x, ax, bx, cx, fa, fb, fc;
    ax = g2gcalc(-0.99);
    bx = g2gcalc(0.99);
    mnbrak(&ax, &bx, &cx, &fa, &fb, &fc, Find_G_fn);
    r->final_distance = brent(ax, bx, cx, Find_G_fn, r->tolerance, &x);
    r->slab.g = gcalc2g(x);
    Set_Calc_State(m, *r);
  }
  ⟨ Put final values in result 217 ⟩
}
```

This code is used in section 208.

227. Fixed Anisotropy and Albedo. This routine can be called in three different situations: (1) the albedo is zero, (2) the albedo is one, or (3) the albedo is fixed at a default value. I calculate the individual reflections and transmissions to establish which of these cases we happen to have.

```
⟨ Prototype for U_Find_B 227 ⟩ ≡
  void U_Find_B(struct measure_type m, struct invert_type *r)
```

This code is used in sections 209 and 228.

228.

```
⟨ Definition for U_Find_B 228 ⟩ ≡
  ⟨ Prototype for U_Find_B 227 ⟩
  {
    double Rt, Tt, Rd, Rc, Td, Tc;
    if (Debug(DEBUG_SEARCH)) {
      fprintf(stderr, "In␣U_Find_B");
      fprintf(stderr, "␣(mu=%6.4f)", r→slab.cos_angle);
      if (r→default_a ≠ UNINITIALIZED) fprintf(stderr, "␣␣default_a␣=␣%8.5f", r→default_a);
      if (r→default_g ≠ UNINITIALIZED) fprintf(stderr, "␣␣default_g␣=␣%8.5f", r→default_g);
      fprintf(stderr, "\n");
    }
    Estimate_RT(m, *r, &Rt, &Tt, &Rd, &Rc, &Td, &Tc);
    r→slab.g = (r→default_g ≡ UNINITIALIZED) ? 0 : r→default_g;
    r→slab.a = (r→default_a ≡ UNINITIALIZED) ? 0 : r→default_a;
    r→slab.b = 0.5;
    r→final_distance = 0.0;
    Set_Calc_State(m, *r);
    ⟨ Iteratively solve for b 229 ⟩
    ⟨ Put final values in result 217 ⟩
    if (Debug(DEBUG_SEARCH)) {
      fprintf(stderr, "In␣U_Find_B␣final␣(a,b,g)␣=␣");
      fprintf(stderr, "(%8.5f,%8.5f,%8.5f)\n", r→a, r→b, r→g);
    }
  }
```

This code is used in section 208.

229. This could be improved tremendously. I just don't want to mess with it at the moment.

```
⟨ Iteratively solve for b 229 ⟩ ≡
  {
    double x, ax, bx, cx, fa, fb, fc;
    ax = b2bcalc(0.1);
    bx = b2bcalc(10);
    mnbrak(&ax, &bx, &cx, &fa, &fb, &fc, Find_B_fn);
    r→final_distance = brent(ax, bx, cx, Find_B_fn, r→tolerance, &x);
    r→slab.b = bcalc2b(x);
    Set_Calc_State(m, *r);
  }
```

This code is used in section 228.

230. Fixed Optical Depth.

We can get here a couple of different ways.

First there can be three real measurements, i.e., t_c is not zero, in this case we want to fix b based on the t_c measurement.

Second, we can get here if a default value for b has been set.

Otherwise, we really should not be here. Just set $b = 1$ and calculate away.

```
⟨ Prototype for U_Find_AG 230 ⟩ ≡
  void U_Find_AG(struct measure_type m, struct invert_type *r)
```

This code is used in sections 209 and 231.

231.

```
⟨ Definition for U_Find_AG 231 ⟩ ≡
  ⟨ Prototype for U_Find_AG 230 ⟩
  {
    ⟨ Allocate local simplex variables 212 ⟩
    if (Debug(DEBUG_SEARCH)) {
      fprintf(stderr, "In␣U_Find_AG");
      fprintf(stderr, "␣(mu=%6.4f)", r→slab.cos_angle);
      if (r→default_b ≠ UNINITIALIZED) fprintf(stderr, "␣␣default_b␣=␣%8.5f", r→default_b);
      fprintf(stderr, "\n");
    }
    if (m.num_measures ≡ 3) r→slab.b = What_Is_B(r→slab, m.m_u);
    else if (r→default_b ≡ UNINITIALIZED) r→slab.b = 1;
    else r→slab.b = r→default_b;
    Set_Calc_State(m, *r);
    ⟨ Get the initial a, b, and g 213 ⟩
    ⟨ Initialize the nodes of the a and g simplex 232 ⟩
    ⟨ Evaluate the a and g simplex at the nodes 233 ⟩
    amoeba(p, y, 2, r→tolerance, Find_AG_fn, &r→iterations);
    ⟨ Choose the best node of the a and g simplex 234 ⟩
    ⟨ Free simplex data structures 218 ⟩
    ⟨ Put final values in result 217 ⟩
  }
```

This code is used in section 208.

232. ⟨ Initialize the nodes of the a and g simplex 232 ⟩ ≡

```
{
  int k, kk;
  p[1][1] = a2acalc(guess[0].a);
  p[1][2] = g2gcalc(guess[0].g);
  for (k = 1; k < 7; k++) {
    if (guess[0].a ≠ guess[k].a) break;
  }
  p[2][1] = a2acalc(guess[k].a);
  p[2][2] = g2gcalc(guess[k].g);
  for (kk = 1; kk < 7; kk++) {
    if (kk ≡ k) continue;
    if (guess[0].g ≠ guess[kk].g ∨ guess[k].g ≠ guess[kk].g) break;
  }
  p[3][1] = a2acalc(guess[kk].a);
  p[3][2] = g2gcalc(guess[kk].g);
  if (Debug(DEBUG_BEST_GUESS)) {
    fprintf(stderr, "guess␣1");
    fprintf(stderr, "%10.5f␣", guess[0].a);
    fprintf(stderr, "%10.5f␣", guess[0].b);
    fprintf(stderr, "%10.5f␣", guess[0].g);
    fprintf(stderr, "%10.5f\n", guess[0].distance);
    fprintf(stderr, "guess␣2");
    fprintf(stderr, "%10.5f␣", guess[k].a);
    fprintf(stderr, "%10.5f␣", guess[k].b);
    fprintf(stderr, "%10.5f␣", guess[k].g);
    fprintf(stderr, "%10.5f\n", guess[k].distance);
    fprintf(stderr, "guess␣3");
    fprintf(stderr, "%10.5f␣", guess[kk].a);
    fprintf(stderr, "%10.5f␣", guess[kk].b);
    fprintf(stderr, "%10.5f␣", guess[kk].g);
    fprintf(stderr, "%10.5f\n", guess[kk].distance);
  }
}
```

This code is used in section 231.

233. ⟨ Evaluate the a and g simplex at the nodes 233 ⟩ ≡

```
for (i = 1; i ≤ 3; i++) {
  x[1] = p[i][1];
  x[2] = p[i][2];
  y[i] = Find_AG_fn(x);
}
```

This code is used in section 231.

234. Here we find the node of the simplex that gave the best result and save that one. At the same time we save the whole simplex for later use if needed.

```
⟨ Choose the best node of the a and g simplex 234 ⟩ ≡
  r→final_distance = 10;
  for (i = 1; i ≤ 3; i++) {
    if (y[i] < r→final_distance) {
      r→slab.a = acalc2a(p[i][1]);
      r→slab.g = gcalc2g(p[i][2]);
      r→final_distance = y[i];
    }
  }
```

This code is used in section 231.

235. Fixed Albedo. Here the optical depth and the anisotropy are varied (for a fixed albedo).

```
⟨ Prototype for U_Find_BG 235 ⟩ ≡
  void U_Find_BG(struct measure_type m, struct invert_type *r)
```

This code is used in sections 209 and 236.

236.

```
⟨ Definition for U_Find_BG 236 ⟩ ≡
  ⟨ Prototype for U_Find_BG 235 ⟩
  {
    ⟨ Allocate local simplex variables 212 ⟩
    if (Debug(DEBUG_SEARCH)) {
      fprintf(stderr, "In␣U_Find_BG");
      fprintf(stderr, "␣(mu=%6.4f)", r→slab.cos_angle);
      if (r→default_a ≠ UNINITIALIZED) fprintf(stderr, "␣␣default_a␣=␣%8.5f", r→default_a);
      fprintf(stderr, "\n");
    }
    r→slab.a = (r→default_a ≡ UNINITIALIZED) ? 0 : r→default_a;
    Set_Calc_State(m, *r);
    ⟨ Get the initial a, b, and g 213 ⟩
    ⟨ Initialize the nodes of the b and g simplex 238 ⟩
    ⟨ Evaluate the bg simplex at the nodes 239 ⟩
    amoeba(p, y, 2, r→tolerance, Find_BG_fn, &r→iterations);
    ⟨ Choose the best node of the b and g simplex 240 ⟩
    ⟨ Free simplex data structures 218 ⟩
    ⟨ Put final values in result 217 ⟩
  }
```

This code is used in section 208.

237. A very simple start for variation of b and g. This should work fine for the cases in which the absorption or scattering are fixed.

238. ⟨ Initialize the nodes of the b and g simplex 238 ⟩ ≡

```
{
  int k, kk;
  p[1][1] = b2bcalc(guess[0].b);
  p[1][2] = g2gcalc(guess[0].g);
  for (k = 1; k < 7; k++) {
    if (guess[0].b ≠ guess[k].b) break;
  }
  p[2][1] = b2bcalc(guess[k].b);
  p[2][2] = g2gcalc(guess[k].g);
  for (kk = 1; kk < 7; kk++) {
    if (kk ≡ k) continue;
    if (guess[0].g ≠ guess[kk].g ∨ guess[k].g ≠ guess[kk].g) break;
  }
  p[3][1] = b2bcalc(guess[kk].b);
  p[3][2] = g2gcalc(guess[kk].g);
  if (Debug(DEBUG_BEST_GUESS)) {
    fprintf(stderr, "guess␣1");
    fprintf(stderr, "%10.5f␣", guess[0].a);
    fprintf(stderr, "%10.5f␣", guess[0].b);
    fprintf(stderr, "%10.5f␣", guess[0].g);
    fprintf(stderr, "%10.5f\n", guess[0].distance);
    fprintf(stderr, "guess␣2");
    fprintf(stderr, "%10.5f␣", guess[k].a);
    fprintf(stderr, "%10.5f␣", guess[k].b);
    fprintf(stderr, "%10.5f␣", guess[k].g);
    fprintf(stderr, "%10.5f\n", guess[k].distance);
    fprintf(stderr, "guess␣3");
    fprintf(stderr, "%10.5f␣", guess[kk].a);
    fprintf(stderr, "%10.5f␣", guess[kk].b);
    fprintf(stderr, "%10.5f␣", guess[kk].g);
    fprintf(stderr, "%10.5f\n", guess[kk].distance);
  }
}
```

This code is used in section 236.

239. ⟨ Evaluate the bg simplex at the nodes 239 ⟩ ≡

```
for (i = 1; i ≤ 3; i++) {
  x[1] = p[i][1];
  x[2] = p[i][2];
  y[i] = Find_BG_fn(x);
}
```

This code is used in section 236.

240. Here we find the node of the simplex that gave the best result and save that one. At the same time we save the whole simplex for later use if needed.

```
⟨ Choose the best node of the b and g simplex 240 ⟩ ≡
  r→final_distance = 10;
  for (i = 1; i ≤ 3; i++) {
    if (y[i] < r→final_distance) {
      r→slab.b = bcalc2b(p[i][1]);
      r→slab.g = gcalc2g(p[i][2]);
      r→final_distance = y[i];
    }
  }
```

This code is used in section 236.

241. Fixed Scattering. Here I assume that a constant b_s,

$$b_s = \mu_s d$$

where d is the physical thickness of the sample and μ_s is of course the absorption coefficient. This is just like *U_Find_BG* except that $b_a = \mu_a d$ is varied instead of b.

```
⟨ Prototype for U_Find_BaG 241 ⟩ ≡
  void U_Find_BaG(struct measure_type m, struct invert_type *r)
```

This code is used in sections 209 and 242.

242.

```
⟨ Definition for U_Find_BaG 242 ⟩ ≡
  ⟨ Prototype for U_Find_BaG 241 ⟩
  {
    ⟨ Allocate local simplex variables 212 ⟩
    Set_Calc_State(m, *r);
    ⟨ Get the initial a, b, and g 213 ⟩
    ⟨ Initialize the nodes of the ba and g simplex 243 ⟩
    ⟨ Evaluate the BaG simplex at the nodes 244 ⟩
    amoeba(p, y, 2, r→tolerance, Find_BaG_fn, &r→iterations);
    ⟨ Choose the best node of the ba and g simplex 245 ⟩
    ⟨ Free simplex data structures 218 ⟩
    ⟨ Put final values in result 217 ⟩
  }
```

This code is used in section 208.

243.

```
⟨ Initialize the nodes of the ba and g simplex 243 ⟩ ≡
  if (guess[0].b > r→default_bs) {
    p[1][1] = b2bcalc(guess[0].b − r→default_bs);
    p[2][1] = b2bcalc(2 * (guess[0].b − r→default_bs));
    p[3][1] = p[1][1];
  }
  else {
    p[1][1] = b2bcalc(0.0001);
    p[2][1] = b2bcalc(0.001);
    p[3][1] = p[1][1];
  }
  p[1][2] = g2gcalc(guess[0].g);
  p[2][2] = p[1][2];
  p[3][2] = g2gcalc(0.9 * guess[0].g + 0.05);
```

This code is used in section 242.

244.

```
⟨ Evaluate the BaG simplex at the nodes 244 ⟩ ≡
  for (i = 1; i ≤ 3; i++) {
    x[1] = p[i][1];
    x[2] = p[i][2];
    y[i] = Find_BaG_fn(x);
  }
```

This code is used in section 242.

245. Here we find the node of the simplex that gave the best result and save that one. At the same time we save the whole simplex for later use if needed.

```
⟨ Choose the best node of the ba and g simplex 245 ⟩ ≡
  r→final_distance = 10;
  for (i = 1; i ≤ 3; i++) {
    if (y[i] < r→final_distance) {
      r→slab.b = bcalc2b(p[i][1]) + r→default_bs;
      r→slab.a = r→default_bs/r→slab.b;
      r→slab.g = gcalc2g(p[i][2]);
      r→final_distance = y[i];
    }
  }
```

This code is used in section 242.

246. Fixed Absorption. Here I assume that a constant b_a,

$$b_a = \mu_a d$$

where d is the physical thickness of the sample and μ_a is of course the absorption coefficient. This is just like *U_Find_BG* except that $b_s = \mu_s d$ is varied instead of b.

```
⟨ Prototype for U_Find_BsG 246 ⟩ ≡
  void U_Find_BsG(struct measure_type m, struct invert_type *r)
```

This code is used in sections 209 and 247.

247.

```
⟨ Definition for U_Find_BsG 247 ⟩ ≡
  ⟨ Prototype for U_Find_BsG 246 ⟩
  {
    ⟨ Allocate local simplex variables 212 ⟩
    if (Debug(DEBUG_SEARCH)) {
      fprintf(stderr, "In␣U_Find_BsG");
      fprintf(stderr, "␣(mu=%6.4f)", r→slab.cos_angle);
      if (r→default_ba ≠ UNINITIALIZED) fprintf(stderr, "␣␣default_ba␣=␣%8.5f", r→default_ba);
      fprintf(stderr, "\n");
    }
    Set_Calc_State(m, *r);
    ⟨ Get the initial a, b, and g 213 ⟩
    ⟨ Initialize the nodes of the bs and g simplex 248 ⟩
    ⟨ Evaluate the BsG simplex at the nodes 249 ⟩
    amoeba(p, y, 2, r→tolerance, Find_BsG_fn, &r→iterations);
    ⟨ Choose the best node of the bs and g simplex 250 ⟩
    ⟨ Free simplex data structures 218 ⟩
    ⟨ Put final values in result 217 ⟩
  }
```

This code is used in section 208.

248.

```
⟨ Initialize the nodes of the bs and g simplex 248 ⟩ ≡
  p[1][1] = b2bcalc(guess[0].b − r→default_ba);
  p[1][2] = g2gcalc(guess[0].g);
  p[2][1] = b2bcalc(2 * guess[0].b − 2 * r→default_ba);
  p[2][2] = p[1][2];
  p[3][1] = p[1][1];
  p[3][2] = g2gcalc(0.9 * guess[0].g + 0.05);
```

This code is used in section 247.

249.

```
⟨ Evaluate the BsG simplex at the nodes 249 ⟩ ≡
  for (i = 1; i ≤ 3; i++) {
    x[1] = p[i][1];
    x[2] = p[i][2];
    y[i] = Find_BsG_fn(x);
  }
```

This code is used in section 247.

250. ⟨ Choose the best node of the *bs* and *g* simplex 250 ⟩ ≡

```
r→final_distance = 10;
for (i = 1; i ≤ 3; i++) {
  if (y[i] < r→final_distance) {
    r→slab.b = bcalc2b(p[i][1]) + r→default_ba;
    r→slab.a = 1 − r→default_ba/r→slab.b;
    r→slab.g = gcalc2g(p[i][2]);
    r→final_distance = y[i];
  }
}
```

This code is used in section 247.

251. IAD Utilities.
March 1995. Reincluded *quick_guess* code.

⟨ iad_util.c 251 ⟩ ≡
```
#include <math.h>
#include <float.h>
#include <stdio.h>
#include "nr_util.h"
#include "ad_globl.h"
#include "ad_frsnl.h"
#include "ad_bound.h"
#include "iad_type.h"
#include "iad_calc.h"
#include "iad_pub.h"
#include "iad_util.h"
  unsigned long g_util_debugging = 0;
  ⟨ Preprocessor definitions ⟩
  ⟨ Definition for What_Is_B 254 ⟩
  ⟨ Definition for Estimate_RT 260 ⟩
  ⟨ Definition for a2acalc 266 ⟩
  ⟨ Definition for acalc2a 268 ⟩
  ⟨ Definition for g2gcalc 270 ⟩
  ⟨ Definition for gcalc2g 272 ⟩
  ⟨ Definition for b2bcalc 274 ⟩
  ⟨ Definition for bcalc2b 276 ⟩
  ⟨ Definition for twoprime 278 ⟩
  ⟨ Definition for twounprime 280 ⟩
  ⟨ Definition for abgg2ab 282 ⟩
  ⟨ Definition for abgb2ag 284 ⟩
  ⟨ Definition for quick_guess 291 ⟩
  ⟨ Definition for Set_Debugging 304 ⟩
  ⟨ Definition for Debug 306 ⟩
  ⟨ Definition for Print_Invert_Type 308 ⟩
  ⟨ Definition for Print_Measure_Type 310 ⟩
```

252. ⟨ iad_util.h 252 ⟩ ≡
```
  ⟨ Prototype for What_Is_B 253 ⟩;
  ⟨ Prototype for Estimate_RT 259 ⟩;
  ⟨ Prototype for a2acalc 265 ⟩;
  ⟨ Prototype for acalc2a 267 ⟩;
  ⟨ Prototype for g2gcalc 269 ⟩;
  ⟨ Prototype for gcalc2g 271 ⟩;
  ⟨ Prototype for b2bcalc 273 ⟩;
  ⟨ Prototype for bcalc2b 275 ⟩;
  ⟨ Prototype for twoprime 277 ⟩;
  ⟨ Prototype for twounprime 279 ⟩;
  ⟨ Prototype for abgg2ab 281 ⟩;
  ⟨ Prototype for abgb2ag 283 ⟩;
  ⟨ Prototype for quick_guess 290 ⟩;
  ⟨ Prototype for Set_Debugging 303 ⟩;
  ⟨ Prototype for Debug 305 ⟩;
  ⟨ Prototype for Print_Invert_Type 307 ⟩;
  ⟨ Prototype for Print_Measure_Type 309 ⟩;
```

253. Finding optical thickness.

This routine figures out what the optical thickness of a slab based on the index of refraction of the slab and the amount of collimated light that gets through it.

It should be pointed out right here in the front that this routine does not work for diffuse irradiance, but then the whole concept of estimating the optical depth for diffuse irradiance is bogus anyway.

In version 1.3 changed all error output to *stderr*. Version 1.4 included cases involving absorption in the boundaries.

```
#define BIG_A_VALUE 999999.0
#define SMALL_A_VALUE 0.000001
```

⟨ Prototype for *What_Is_B* 253 ⟩ ≡

```
double What_Is_B(struct AD_slab_type slab, double Tc)
```

This code is used in sections 252 and 254.

254. ⟨ Definition for *What_Is_B* 254 ⟩ ≡

```
⟨ Prototype for What_Is_B 253 ⟩
{
  double r1, r2, t1, t2, mu_in_slab;
  ⟨ Calculate specular reflection and transmission 255 ⟩
  ⟨ Check for bad values of Tc 256 ⟩
  ⟨ Solve if multiple internal reflections are not present 257 ⟩
  ⟨ Find thickness when multiple internal reflections are present 258 ⟩
}
```

This code is used in section 251.

255. The first thing to do is to find the specular reflection for light interacting with the top and bottom air-glass-sample interfaces. I make a simple check to ensure that the the indices are different before calculating the bottom reflection. Most of the time the $r1 \equiv r2$, but there are always those annoying special cases.

⟨ Calculate specular reflection and transmission 255 ⟩ ≡

```
Absorbing_Glass_RT(1.0, slab.n_top_slide, slab.n_slab, slab.cos_angle, slab.b_top_slide, &r1, &t1);
mu_in_slab = Cos_Snell(1.0, slab.cos_angle, slab.n_slab);
Absorbing_Glass_RT(slab.n_slab, slab.n_bottom_slide, 1.0, mu_in_slab, slab.b_bottom_slide, &r2, &t2);
```

This code is used in section 254.

256. Bad values for the unscattered transmission are those that are non-positive, those greater than one, and those greater than are possible in a non-absorbing medium, i.e.,

$$T_c > \frac{t_1 t_2}{1 - r_1 r_2}$$

Since this routine has no way to report errors, I just set the optical thickness to the natural values in these cases.

⟨ Check for bad values of *Tc* 256 ⟩ ≡

```
if (Tc ≤ 0) return (HUGE_VAL);
if (Tc ≥ t1 * t2/(1 − r1 * r2)) return (0.001);
```

This code is used in section 254.

257. If either *r1* or *r2* $\equiv 0$ then things are very simple because the sample does not sustain multiple internal reflections and the unscattered transmission is

$$T_c = t_1 t_2 \exp(-b/\nu)$$

where b is the optical thickness and ν is *slab.cos_angle*. Clearly,

$$b = -\nu \ln\left(\frac{T_c}{t_1 t_2}\right)$$

⟨ Solve if multiple internal reflections are not present 257 ⟩ ≡
if (*r1* $\equiv 0 \vee$ *r2* $\equiv 0$) **return** (−*slab.cos_angle* ∗ *log*(*Tc*/*t1*/*t2*));
This code is used in section 254.

258. Well I kept putting it off, but now comes the time to solve the following equation for b

$$T_c = \frac{t_1 t_2 \exp(-b)}{1 - r_1 r_2 \exp(-2b)}$$

We note immediately that this is a quadratic equation in $x = \exp(-b)$.

$$r_1 r_2 T_c x^2 + t_1 t_2 x - T_c = 0$$

Sufficient tests have been made above to ensure that none of the coefficients are exactly zero. However, it is clear that the leading quadratic term has a much smaller coefficient than the other two. Since r_1 and r_2 are typically about four percent the product is roughly 10^{-3}. The collimated transmission can be very small and this makes things even worse. A further complication is that we need to choose the only positive root.

Now the roots of $ax^2 + bx + c = 0$ can be found using the standard quadratic formula,

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

This is very bad for small values of a. Instead I use

$$q = -\frac{1}{2}\left[b + \mathrm{sgn}(b)\sqrt{b^2 - 4ac}\right]$$

with the two roots

$$x = \frac{q}{a} \qquad \text{and} \qquad x = \frac{c}{q}$$

Substituting our coefficients

$$q = -\frac{1}{2}\left[t_1 t_2 + \sqrt{t_1^2 t_2^2 + 4 r_1 r_2 T_c^2}\right]$$

With some algebra, this can be shown to be

$$q = -t_1 t_2 \left[1 + \frac{r_1 r_2 T_c^2}{t_1^2 t_2^2} + \cdots\right]$$

The only positive root is $x = -T_c/q$. Therefore

$$x = \frac{2T_c}{t_1 t_2 + \sqrt{t_1^2 t_2^2 + 4 r_1 r_2 T_c^2}}$$

(Not very pretty, but straightforward enough.)

⟨ Find thickness when multiple internal reflections are present 258 ⟩ ≡

```
{
  double B;
  B = t1 * t2;
  return (-slab.cos_angle * log(2 * Tc/(B + sqrt(B * B + 4 * Tc * Tc * r1 * r2))));
}
```

This code is used in section 254.

259. Estimating R and T.

In several places, it is useful to know an *estimate* for the values of the reflection and transmission of the sample based on the measurements. This routine provides such an estimate, but it currently ignores anything corrections that might be made for the integrating spheres.

Good values are only really obtainable when $num\_measures \equiv 3$, otherwise we need to make pretty strong assumptions about the reflection and transmission values. If $num\_measures < 3$, then we will assume that no collimated light makes it all the way through the sample. The specular reflection is then just that for a semi-infinite sample and $Tc = 0$. If $num\_measures \equiv 1$, then Td is also set to zero.

rt	total reflection
rc	primary or specular reflection
rd	diffuse or scattered reflection
tt	total transmission
tp	primary or unscattered transmission
td	diffuse or scattered transmission

⟨ Prototype for *Estimate_RT* 259 ⟩ ≡

void *Estimate_RT*(**struct measure_type** *m*, **struct invert_type** *r*, **double** ∗*rt*, **double** ∗*tt*, **double** ∗*rd*, **double** ∗*rc*, **double** ∗*td*, **double** ∗*tc*)

This code is used in sections 252 and 260.

260. ⟨ Definition for *Estimate_RT* 260 ⟩ ≡

```
⟨ Prototype for Estimate_RT 259 ⟩
{
  ⟨ Calculate the unscattered transmission and reflection 261 ⟩
  ⟨ Estimate the backscattered reflection 262 ⟩
  ⟨ Estimate the scattered transmission 263 ⟩
}
```

This code is used in section 251.

261. If there are three measurements then the specular reflection can be calculated pretty well. If there are fewer then the unscattered transmission is assumed to be zero. This is not necessarily the case, but after all, this routine only makes estimates of the various reflection and transmission quantities.

If there are three measurements, the optical thickness of the sample is required. Of course if there are three measurements then the illumination must be collimated and we can call *What_Is_B* to find out the optical thickness. We pass this value to a routine in the `fresnel.h` unit and sit back and wait.

All the above is true if sphere corrections are not needed. Now, we just fob this off on another function.

⟨ Calculate the unscattered transmission and reflection 261 ⟩ ≡

```
Calculate_Minimum_MR(m, r, rc, tc);
```

This code is used in section 260.

262. Finding the diffuse reflection is now just a matter of checking whether V1% contains the specular reflection from the sample or not and then just adding or subtracting the specular reflection as appropriate.

```
⟨ Estimate the backscattered reflection 262 ⟩ ≡
  if (m.fraction_of_rc_in_mr) {
    *rt = m.m_r;
    *rd = *rt − m.fraction_of_rc_in_mr * (*rc);
    if (*rd < 0) {
      *rd = 0;
      *rc = *rt;
    }
  }
  else {
    *rd = m.m_r;
    *rt = *rd + *rc;
  }
  if (Debug(DEBUG_SEARCH)) {
    fprintf(stderr, "␣␣␣␣␣␣␣␣rt␣=␣%.5f\n", *rt);
    fprintf(stderr, "␣␣␣␣est␣rd␣=␣%.5f\n", *rd);
  }
```

This code is used in section 260.

263. The transmission values follow in much the same way as the diffuse reflection values — just subtract the specular transmission from the total transmission.

```
⟨ Estimate the scattered transmission 263 ⟩ ≡
  if (m.num_measures ≡ 1) {
    *tt = 0.0;
    *td = 0.0;
  }
  else if (m.fraction_of_tc_in_mt) {
    *tt = m.m_t;
    *td = *tt − *tc;
    if (*td < 0) {
      *tc = *tt;
      *td = 0;
    }
  }
  else {
    *td = m.m_t;
    *tt = *td + *tc;
  }
  if (Debug(DEBUG_SEARCH)) {
    fprintf(stderr, "␣␣␣␣␣␣␣␣tt␣=␣%.5f\n", *tt);
    fprintf(stderr, "␣␣␣␣est␣td␣=␣%.5f\n", *td);
  }
```

This code is used in section 260.

264. Transforming properties. Routines to convert optical properties to calculation space and back.

265. *a2acalc* is used for the albedo transformations according to

$$a_{calc} = \frac{2a - 1}{a(1 - a)}$$

Care is taken to avoid division by zero. Why was this function chosen? Well mostly because it maps the region between $[0, 1] \to (-\infty, +\infty)$.

⟨ Prototype for *a2acalc* 265 ⟩ ≡
```
double a2acalc(double a)
```
This code is used in sections 252 and 266.

266. ⟨ Definition for *a2acalc* 266 ⟩ ≡
```
⟨ Prototype for a2acalc 265 ⟩
{
  if (a ≤ 0) return -BIG_A_VALUE;
  if (a ≥ 1) return BIG_A_VALUE;
  return ((2 * a - 1)/a/(1 - a));
}
```
This code is used in section 251.

267. *acalc2a* is used for the albedo transformations Now when we solve

$$a_calc = \frac{2a - 1}{a(1 - a)}$$

we obtain the quadratic equation

$$a_{calc}a^2 + (2 - a_{calc})a - 1 = 0$$

The only root of this equation between zero and one is

$$a = \frac{-2 + a_{calc} + \sqrt{a_{calc}^2 + 4}}{2a_{calc}}$$

I suppose that I should spend the time to recast this using the more appropriate numerical solutions of the quadratic equation, but this worked and I will leave it as it is for now.

⟨ Prototype for *acalc2a* 267 ⟩ ≡
```
double acalc2a(double acalc)
```
This code is used in sections 252 and 268.

268. ⟨ Definition for *acalc2a* 268 ⟩ ≡
```
⟨ Prototype for acalc2a 267 ⟩
{
  if (acalc ≡ BIG_A_VALUE) return 1.0;
  else if (acalc ≡ -BIG_A_VALUE) return 0.0;
  else if (fabs(acalc) < SMALL_A_VALUE) return 0.5;
  else return ((-2 + acalc + sqrt(acalc * acalc + 4))/(2 * acalc));
}
```
This code is used in section 251.

269. *g2gcalc* is used for the anisotropy transformations according to

$$g_{calc} = \frac{g}{1 + |g|}$$

which maps $(-1, 1) \to (-\infty, +\infty)$.

⟨ Prototype for *g2gcalc* 269 ⟩ ≡
```
double g2gcalc(double g)
```
This code is used in sections 252 and 270.

270. ⟨ Definition for *g2gcalc* 270 ⟩ ≡
```
⟨ Prototype for g2gcalc 269 ⟩
{
  if (g ≤ −0.99999) return (−HUGE_VAL);
  if (g ≥ 0.99999) return (HUGE_VAL);
  return (g/(1 − fabs(g)));
}
```
This code is used in section 251.

271. *gcalc2g* is used for the anisotropy transformations it is the inverse of *g2gcalc*. The relation is

$$g = \frac{g_{calc}}{1 + |g_{calc}|}$$

⟨ Prototype for *gcalc2g* 271 ⟩ ≡
```
double gcalc2g(double gcalc)
```
This code is used in sections 252 and 272.

272. ⟨ Definition for *gcalc2g* 272 ⟩ ≡
```
⟨ Prototype for gcalc2g 271 ⟩
{
  if (gcalc ≡ −HUGE_VAL) return −0.99999;
  if (gcalc ≡ HUGE_VAL) return 0.99999;
  return (gcalc/(1 + fabs(gcalc)));
}
```
This code is used in section 251.

273. *b2bcalc* is used for the optical depth transformations it is the inverse of *bcalc2b*. The relation is

$$b_{calc} = \ln(b)$$

The only caveats are to ensure that I don't take the logarithm of something big or non-positive.

⟨ Prototype for *b2bcalc* 273 ⟩ ≡
```
double b2bcalc(double b)
```
This code is used in sections 252 and 274.

274. ⟨ Definition for *b2bcalc* 274 ⟩ ≡

```
⟨ Prototype for b2bcalc 273 ⟩
{
  if (b ≡ HUGE_VAL) return HUGE_VAL;
  if (b ≤ 0) return 0.0;
  return (log(b));
}
```

This code is used in section 251.

275. *bcalc2b* is used for the anisotropy transformations it is the inverse of *b2bcalc*. The relation is

$$b = \exp(b_{calc})$$

The only tricky part is to ensure that I don't exponentiate something big and get an overflow error. In ANSI C the maximum value for x such that 10^x is in the range of representable finite floating point numbers (for doubles) is given by `DBL_MAX_10_EXP`. Thus if we want to know if

$$e^{b_{calc}} > 10^x$$

or

$$b_{calc} > x \ln(10) \approx 2.3x$$

and this is the criterion that I use.

⟨ Prototype for *bcalc2b* 275 ⟩ ≡

```
double bcalc2b(double bcalc)
```

This code is used in sections 252 and 276.

276. ⟨ Definition for *bcalc2b* 276 ⟩ ≡

```
⟨ Prototype for bcalc2b 275 ⟩
{
  if (bcalc ≡ HUGE_VAL) return HUGE_VAL;
  if (bcalc > 2.3 * DBL_MAX_10_EXP) return HUGE_VAL;
  return (exp(bcalc));
}
```

This code is used in section 251.

277. *twoprime* converts the true albedo a, optical depth b to the reduced albedo ap and reduced optical depth bp that correspond to $g = 0$.

⟨ Prototype for *twoprime* 277 ⟩ ≡

```
void twoprime(double a, double b, double g, double *ap, double *bp)
```

This code is used in sections 252 and 278.

278. ⟨ Definition for *twoprime* 278 ⟩ ≡

```
⟨ Prototype for twoprime 277 ⟩
{
  if (a ≡ 1 ∧ g ≡ 1) *ap = 0.0;
  else *ap = (1 − g) * a/(1 − a * g);
  if (b ≡ HUGE_VAL) *bp = HUGE_VAL;
  else *bp = (1 − a * g) * b;
}
```

This code is used in section 251.

279. *twounprime* converts the reduced albedo ap and reduced optical depth bp (for $g = 0$) to the true albedo a and optical depth b for an anisotropy g.

⟨ Prototype for *twounprime* 279 ⟩ ≡
```
void twounprime(double ap, double bp, double g, double *a, double *b)
```
This code is used in sections 252 and 280.

280. ⟨ Definition for *twounprime* 280 ⟩ ≡
```
⟨ Prototype for twounprime 279 ⟩
{
  *a = ap/(1 - g + ap * g);
  if (bp ≡ HUGE_VAL) *b = HUGE_VAL;
  else *b = (1 + ap * g/(1 - g)) * bp;
}
```
This code is used in section 251.

281. *abgg2ab* assume a, b, g, and *g1* are given this does the similarity translation that you would expect it should by converting it to the reduced optical properties and then transforming back using the new value of g

⟨ Prototype for *abgg2ab* 281 ⟩ ≡
```
void abgg2ab(double a1, double b1, double g1, double g2, double *a2, double *b2)
```
This code is used in sections 252 and 282.

282. ⟨ Definition for *abgg2ab* 282 ⟩ ≡
```
⟨ Prototype for abgg2ab 281 ⟩
{
  double a, b;
  twoprime(a1, b1, g1, &a, &b);
  twounprime(a, b, g2, a2, b2);
}
```
This code is used in section 251.

283. *abgb2ag* translates reduced optical properties to unreduced values assuming that the new optical thickness is given i.e., *a1* and *b1* are a' and b' for $g = 0$. This routine then finds the appropriate anisotropy and albedo which correspond to an optical thickness *b2*.

If both *b1* and *b2* are zero then just assume $g = 0$ for the unreduced values.

⟨ Prototype for *abgb2ag* 283 ⟩ ≡
```
void abgb2ag(double a1, double b1, double b2, double *a2, double *g2)
```
This code is used in sections 252 and 284.

284. ⟨ Definition for *abgb2ag* 284 ⟩ ≡

```
⟨ Prototype for abgb2ag 283 ⟩
{
  if (b1 ≡ 0 ∨ b2 ≡ 0) {
    *a2 = a1;
    *g2 = 0;
  }
  if (b2 < b1) b2 = b1;
  if (a1 ≡ 0) *a2 = 0.0;
  else {
    if (a1 ≡ 1) *a2 = 1.0;
    else {
      if (b1 ≡ 0 ∨ b2 ≡ HUGE_VAL) *a2 = a1;
      else *a2 = 1 + b1/b2 * (a1 − 1);
    }
  }
  if (*a2 ≡ 0 ∨ b2 ≡ 0 ∨ b2 ≡ HUGE_VAL) *g2 = 0.5;
  else *g2 = (1 − b1/b2)/(*a2);
}
```

This code is used in section 251.

285. Guessing an inverse.
This routine is not used anymore.

```
⟨ Prototype for slow_guess 285 ⟩ ≡
  void slow_guess(struct measure_type m, struct invert_type *r, double *a, double *b, double *g)
```

This code is used in section 286.

286.
```
⟨ Definition for slow_guess 286 ⟩ ≡
  ⟨ Prototype for slow_guess 285 ⟩
  {
    double fmin = 10.0;
    double fval;
    double *x;
    x = dvector(1, 2);
    switch (r→search) {
    case FIND_A: ⟨ Slow guess for a alone 287 ⟩
      break;
    case FIND_B: ⟨ Slow guess for b alone 288 ⟩
      break;
    case FIND_AB: case FIND_AG: ⟨ Slow guess for a and b or a and g 289 ⟩
      break;
    }
    *a = r→slab.a;
    *b = r→slab.b;
    *g = r→slab.g;
    free_dvector(x, 1, 2);
  }
```

287.
```
⟨ Slow guess for a alone 287 ⟩ ≡
  r→slab.b = HUGE_VAL;
  r→slab.g = r→default_g;
  Set_Calc_State(m, *r);
  for (r→slab.a = 0.0; r→slab.a ≤ 1.0; r→slab.a += 0.1) {
    fval = Find_A_fn(a2acalc(r→slab.a));
    if (fval < fmin) {
      r→a = r→slab.a;
      fmin = fval;
    }
  }
  r→slab.a = r→a;
```

This code is used in section 286.

288. Presumably the only time that this will need to be called is when the albedo is fixed or is one. For now, I'll just assume that it is one.

```
⟨ Slow guess for b alone 288 ⟩ ≡
  r→slab.a = 1;
  r→slab.g = r→default_g;
  Set_Calc_State(m, *r);
  for (r→slab.b = 1/32.0; r→slab.b ≤ 32; r→slab.b *= 2) {
    fval = Find_B_fn(b2bcalc(r→slab.b));
    if (fval < fmin) {
      r→b = r→slab.b;
      fmin = fval;
    }
  }
  r→slab.b = r→b;
```

This code is used in section 286.

289.

```
⟨ Slow guess for a and b or a and g 289 ⟩ ≡
  {
    double min_a, min_b, min_g;
    if (¬Valid_Grid(m, r→search)) Fill_Grid(m, *r);
    Near_Grid_Points(m.m_r, m.m_t, r→search, &min_a, &min_b, &min_g);
    r→slab.a = min_a;
    r→slab.b = min_b;
    r→slab.g = min_g;
  }
```

This code is used in section 286.

290.

```
⟨ Prototype for quick_guess 290 ⟩ ≡
  void quick_guess(struct measure_type m, struct invert_type r, double *a, double *b, double *g)
```

This code is used in sections 252 and 291.

291.

```
⟨ Definition for quick_guess 291 ⟩ ≡
  ⟨ Prototype for quick_guess 290 ⟩
  {
    double UR1, UT1, rd, td, tc, rc, bprime, aprime, alpha, beta, logr;
    Estimate_RT(m, r, &UR1, &UT1, &rd, &rc, &td, &tc);
    ⟨ Estimate aprime 292 ⟩
    switch (m.num_measures) {
    case 1: ⟨ Guess when only reflection is known 294 ⟩
      break;
    case 2: ⟨ Guess when reflection and transmission are known 295 ⟩
      break;
    case 3: ⟨ Guess when all three measurements are known 296 ⟩
      break;
    }
    ⟨ Clean up guesses 301 ⟩
  }
```

This code is used in section 251.

292. ⟨ Estimate *aprime* 292 ⟩ ≡

```
if (UT1 ≡ 1) aprime = 1.0;
else if (rd/(1 − UT1) ≥ 0.1) {
  double tmp = (1 − rd − UT1)/(1 − UT1);
  aprime = 1 − 4.0/9.0 ∗ tmp ∗ tmp;
}
else if (rd < 0.05 ∧ UT1 < 0.4) aprime = 1 − (1 − 10 ∗ rd) ∗ (1 − 10 ∗ rd);
else if (rd < 0.1 ∧ UT1 < 0.4) aprime = 0.5 + (rd − 0.05) ∗ 4;
else {
  double tmp = (1 − 4 ∗ rd − UT1)/(1 − UT1);
  aprime = 1 − tmp ∗ tmp;
}
```

This code is used in section 291.

293. ⟨ Estimate *bprime* 293 ⟩ ≡

```
if (rd < 0.01) {
  bprime = What_Is_B(r.slab, UT1);
  fprintf(stderr, "low rd<0.01! ut1=%f aprime=%f bprime=%f\n", UT1, aprime, bprime);
}
else if (UT1 ≤ 0) bprime = HUGE_VAL;
else if (UT1 > 0.1) bprime = 2 ∗ exp(5 ∗ (rd − UT1) ∗ log(2.0));
else {
  alpha = 1/log(0.05/1.0);
  beta = log(1.0)/log(0.05/1.0);
  logr = log(UR1);
  bprime = log(UT1) − beta ∗ log(0.05) + beta ∗ logr;
  bprime /= alpha ∗ log(0.05) − alpha ∗ logr − 1;
}
```

This code is used in sections 295, 299, and 300.

294.

⟨ Guess when only reflection is known 294 ⟩ ≡

```
∗g = r.default_g;
∗a = aprime/(1 − ∗g + aprime ∗ (∗g));
∗b = HUGE_VAL;
```

This code is used in section 291.

295. ⟨ Guess when reflection and transmission are known 295 ⟩ ≡

```
⟨ Estimate bprime 293 ⟩
∗g = r.default_g;
∗a = aprime/(1 − ∗g + aprime ∗ ∗g);
∗b = bprime/(1 − ∗a ∗ ∗g);
```

This code is used in section 291.

296. ⟨ Guess when all three measurements are known 296 ⟩ ≡
```
switch (r.search) {
case FIND_A: ⟨ Guess when finding albedo 297 ⟩
  break;
case FIND_B: ⟨ Guess when finding optical depth 298 ⟩
  break;
case FIND_AB: ⟨ Guess when finding the albedo and optical depth 299 ⟩
  break;
case FIND_AG: ⟨ Guess when finding anisotropy and albedo 300 ⟩
  break;
}
```
This code is used in section 291.

297.
⟨ Guess when finding albedo 297 ⟩ ≡
```
*g = r.default_g;
*a = aprime/(1 - *g + aprime * *g);
*b = What_Is_B(r.slab, m.m_u);
```
This code is used in section 296.

298.
⟨ Guess when finding optical depth 298 ⟩ ≡
```
*g = r.default_g;
*a = 0.0;
*b = What_Is_B(r.slab, m.m_u);
```
This code is used in section 296.

299.
⟨ Guess when finding the albedo and optical depth 299 ⟩ ≡
```
*g = r.default_g;
if (*g ≡ 1) *a = 0.0;
else *a = aprime/(1 - *g + aprime * *g);
⟨ Estimate bprime 293 ⟩
if (bprime ≡ HUGE_VAL ∨ *a * *g ≡ 1) *b = HUGE_VAL;
else *b = bprime/(1 - *a * *g);
```
This code is used in section 296.

300.
⟨ Guess when finding anisotropy and albedo 300 ⟩ ≡
```
*b = What_Is_B(r.slab, m.m_u);
if (*b ≡ HUGE_VAL ∨ *b ≡ 0) {
  *a = aprime;
  *g = r.default_g;
}
else {
  ⟨ Estimate bprime 293 ⟩
  *a = 1 + bprime * (aprime - 1)/(*b);
  if (*a < 0.1) *g = 0.0;
  else *g = (1 - bprime/(*b))/(*a);
}
```
This code is used in section 296.

301.

⟨ Clean up guesses 301 ⟩ ≡

```
if (*a < 0) *a = 0.0;
if (*g < 0) *g = 0.0;
else if (*g ≥ 1) *g = 0.5;
```

This code is used in section 291.

302. Some debugging stuff.

303. ⟨ Prototype for *Set_Debugging* 303 ⟩ ≡
```
void Set_Debugging(unsigned long debug_level)
```
This code is used in sections 252 and 304.

304.
⟨ Definition for *Set_Debugging* 304 ⟩ ≡
```
⟨ Prototype for Set_Debugging 303 ⟩
{
  g_util_debugging = debug_level;
}
```
This code is used in section 251.

305.
⟨ Prototype for *Debug* 305 ⟩ ≡
```
int Debug(unsigned long mask)
```
This code is used in sections 252 and 306.

306.
⟨ Definition for *Debug* 306 ⟩ ≡
```
⟨ Prototype for Debug 305 ⟩
{
  if (g_util_debugging & mask) return 1;
  else return 0;
}
```
This code is used in section 251.

307.
⟨ Prototype for *Print_Invert_Type* 307 ⟩ ≡
```
void Print_Invert_Type(struct invert_type r)
```
This code is used in sections 252 and 308.

308.
⟨ Definition for *Print_Invert_Type* 308 ⟩ ≡
```
⟨ Prototype for Print_Invert_Type 307 ⟩
{
  fprintf(stderr, "\n");
  fprintf(stderr, "default␣␣a=%10.5f␣␣␣b=%10.5f␣␣␣␣g=%10.5f\n", r.default_a, r.default_b, r.default_g);
  fprintf(stderr, "slab␣␣␣␣␣a=%10.5f␣␣␣b=%10.5f␣␣␣␣g=%10.5f\n", r.slab.a, r.slab.b, r.slab.g);
  fprintf(stderr, "n␣␣␣␣␣␣␣top=%10.5f␣mid=%10.5f␣␣bot=%10.5f\n", r.slab.n_top_slide, r.slab.n_slab,
      r.slab.n_bottom_slide);
  fprintf(stderr, "thick␣␣top=%10.5f␣cos=%10.5f␣␣bot=%10.5f\n", r.slab.b_top_slide, r.slab.cos_angle,
      r.slab.b_bottom_slide);
  fprintf(stderr, "search␣=␣%d␣quadrature␣points␣=␣%d\n", r.search, r.method.quad_pts);
}
```
This code is used in section 251.

309.

⟨ Prototype for *Print_Measure_Type* 309 ⟩ ≡
void *Print_Measure_Type*(**struct measure_type** *m*)

This code is used in sections 252 and 310.

310.

```
⟨ Definition for Print_Measure_Type 310 ⟩ ≡
  ⟨ Prototype for Print_Measure_Type 309 ⟩
  {
    fprintf(stderr, "\n");
    fprintf(stderr, "#                        Beam diameter = %7.1f mm\n", m.d_beam);
    fprintf(stderr, "#                      Sample thickness = %7.1f mm\n", m.slab_thickness);
    fprintf(stderr, "#                  Top slide thickness = %7.1f mm\n",
        m.slab_top_slide_thickness);
    fprintf(stderr, "#               Bottom slide thickness = %7.1f mm\n",
        m.slab_bottom_slide_thickness);
    fprintf(stderr, "#           Sample index of refraction = %7.3f\n", m.slab_index);
    fprintf(stderr, "#        Top slide index of refraction = %7.3f\n", m.slab_top_slide_index);
    fprintf(stderr, "#     Bottom slide index of refraction = %7.3f\n", m.slab_bottom_slide_index);
    fprintf(stderr, "#     Fraction unscattered light in M_R = %7.1f %%\n",
        m.fraction_of_rc_in_mr * 100);
    fprintf(stderr, "#     Fraction unscattered light in M_T = %7.1f %%\n",
        m.fraction_of_tc_in_mt * 100);
    fprintf(stderr, "# \n");
    fprintf(stderr, "# Reflection sphere\n");
    fprintf(stderr, "#                    sphere diameter = %7.1f mm\n", m.d_sphere_r);
    fprintf(stderr, "#                sample port diameter = %7.1f mm\n",
        2 * m.d_sphere_r * sqrt(m.as_r));
    fprintf(stderr, "#              entrance port diameter = %7.1f mm\n",
        2 * m.d_sphere_r * sqrt(m.ae_r));
    fprintf(stderr, "#              detector port diameter = %7.1f mm\n",
        2 * m.d_sphere_r * sqrt(m.ad_r));
    fprintf(stderr, "#                    wall reflectance = %7.1f %%\n", m.rw_r * 100);
    fprintf(stderr, "#                standard reflectance = %7.1f %%\n", m.rstd_r * 100);
    fprintf(stderr, "#                detector reflectance = %7.1f %%\n", m.rd_r * 100);
    fprintf(stderr, "#                             spheres = %7d\n", m.num_spheres);
    fprintf(stderr, "#                            measures = %7d\n", m.num_measures);
    fprintf(stderr, "#                              method = %7d\n", m.method);
    fprintf(stderr, "area_r as=%10.5f  ad=%10.5f    ae=%10.5f  aw=%10.5f\n", m.as_r, m.ad_r,
        m.ae_r, m.aw_r);
    fprintf(stderr, "refls  rd=%10.5f  rw=%10.5f  rstd=%10.5f    f=%10.5f\n", m.rd_r, m.rw_r,
        m.rstd_r, m.f_r);
    fprintf(stderr, "area_t as=%10.5f  ad=%10.5f    ae=%10.5f  aw=%10.5f\n", m.as_t, m.ad_t,
        m.ae_t, m.aw_t);
    fprintf(stderr, "refls  rd=%10.5f  rw=%10.5f  rstd=%10.5f    f=%10.5f\n", m.rd_t, m.rw_t,
        m.rstd_t, m.f_t);
    fprintf(stderr, "lost  ur1=%10.5f ut1=%10.5f   uru=%10.5f  utu=%10.5f\n", m.ur1_lost,
        m.ut1_lost, m.utu_lost, m.utu_lost);
  }
```

This code is used in section 251.

311. Index. Here is a cross-reference table for the inverse adding-doubling program. All sections in which an identifier is used are listed with that identifier, except that reserved words are indexed only when they appear in format definitions, and the appearances of identifiers in section names are not indexed. Underlined entries correspond to where the identifier was declared. Error messages and a few other things like "ASCII code dependencies" are indexed here too.

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