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Simulation-Based Computation of Dose to Humans in Radiological Environments

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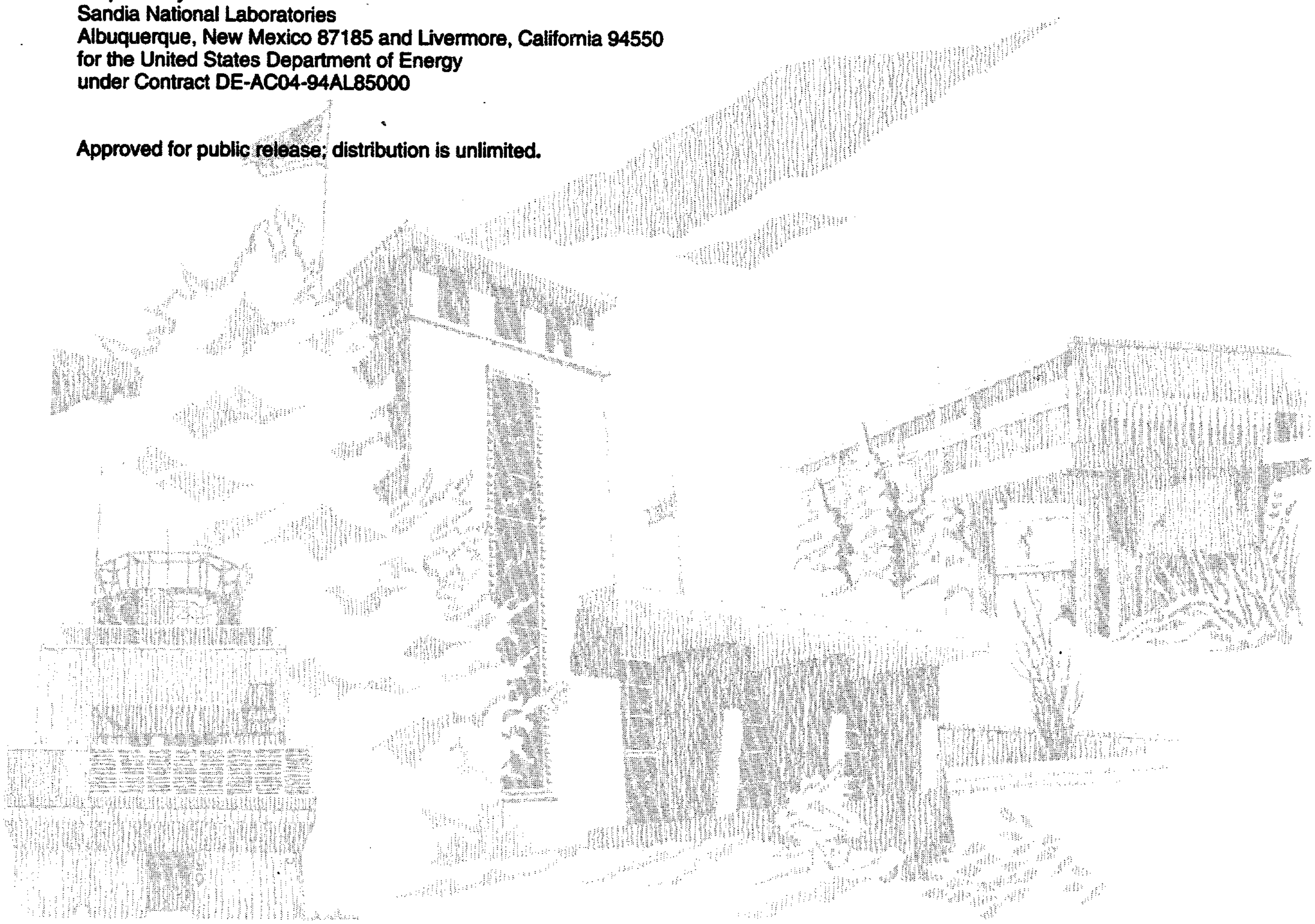

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Simulation-Based Computation of Dose to Humans in Radiological Environments

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ABSTRACT

The Radiological Environment Modeling System (REMS) quantifies dose to humans working in radiological environments using the IGRIP (Interactive Graphical Robot Instruction Program) and Deneb/ERGO simulation software. These commercially available products are augmented with custom C code to provide radiation exposure information to, and collect radiation dose information from, workcell simulations.

Through the use of any radiation transport code or measured data, a radiation exposure input database may be formulated. User-specified IGRIP simulations utilize these databases to compute and accumulate dose to programmable human models operating around radiation sources. Timing, distances, shielding, and human activity may be modeled accurately in the simulations. The accumulated dose is recorded in output files, and the user is able to process and view this output. The entire REMS capability can be operated from a single graphical user interface.

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1.0 INTRODUCTION

Historically, the process of estimating radiation doses[1] to workers has been performed through the combined use of equipment and facility mock-ups, data on existing radiation fields, time-motion studies, and radiation transport calculations of static worker-source geometries. This method is both time and labor intensive. Also, due to the uncertainties of merging information from various origins, the accuracy of the resulting dose estimates can be poor.

The effectiveness of this method is reduced further when a facility or process is only in the design stages and there is no existing radiological environment in which dose rate measurements can be taken. This is mainly due to a lack of accurate data on worker/environment interactions, which is particularly important when operating in the highly non-uniform radiation fields near concentrated sources. Under these conditions, conservative assumptions must be employed in the dose estimates to compensate for the large uncertainties.

The reduction in the annual radiation dose limits for the U.S. Department of Energy (DOE) Nuclear Weapons Complex essentially amplifies the effect these dose inaccuracies have on follow-on cost estimates. This results in a much greater likelihood of creating unreasonable biases in subsequent cost-benefit determinations. Therefore, a capability that computes high-confidence dose predictions is needed in order to estimate crew sizes and/or rotation costs accurately.

The Radiological Environment Modeling System is a CAD-based workcell simulation capability. It was designed to provide the radiological engineer with rapid, high-confidence dose estimates for evaluating both existing operations and operating options in design-stage facilities and processes. Using REMS, existing and proposed operations and worker interactions within these operations can be simulated realistically in terms of dimensions, process times, worker actions, and the proximity of numerous sensor locations on the simulated human to radiation

[1] The term "radiation dose" is generically defined as the amount of energy per unit mass deposited in a volume of tissue; the units are rad (radiation absorbed dose). The rad unit does not take into account the differences in "quality" among the dosimetric entities (e.g., X and gamma rays, and alpha, beta, and neutron particles). "Dose equivalent" accounts for the differences in quality factors and is expressed in units of rem (roentgen equivalent man or radiation equivalent in man). Therefore, while the absorbed dose for equal amounts of gamma ray and alpha particle energy might be 1 rad each, the gamma ray dose equivalent would be 1 rem, whereas the alpha particle dose equivalent would be 20 rem. Finally, "effective dose equivalent," often referred to as whole body dose, is defined as the summation of the products of the dose equivalent received by specified tissues of the body and the appropriate weighting factors [1,2]. REMS is capable of providing gamma-ray and neutron-particle dose equivalents at numerous tissue and organ locations within the body in addition to effective dose equivalents.

sources in various configurations. In general terms, the simulated worker dose is generated by compiling sensor-source distances at one-second intervals and multiplying these distances by the dose rates generated using a one-dimensional radiation transport code. The transport code can model the source in both unshielded and shielded configurations. The present version of REMS uses a particular transport code to generate the radiation exposure input database for the simulations, but it allows input of data from other origins and can be modified to operate with other transport codes.

To date, the primary application of the REMS capability has been the modeling of weapon dismantlement activities at Pantex. The types of weapons being dismantled and the activities at Pantex are described in [3]. The core of a nuclear weapon, termed the pit, emits ionizing radiation and needs to be handled safely. After the weapons are dismantled, pits undergo certain operations such as weighing, leak-checking, radiographing, and packaging into containers.

Currently, pit operations are being performed manually, but the reduction in the DOE dose limits will preclude or require changes in many of these manual operations. Robotic systems are being designed at Sandia National Laboratories' Intelligent Systems and Robotics Center to replace manual operations in hazardous radiological environments. Actually, REMS was developed originally to allow the potential dose benefits of automation to be quantified and understood. The benefits of these robotic systems are not limited to dose reduction, however, but may include increased process speed, reduced costs, enhanced safety, and improved quality as well.

Although REMS was developed for the specific purpose of evaluating nuclear weapon activities, it is not limited to these types of operations. REMS could also be used to evaluate nuclear power and nuclear medicine environments or any other radiological environment involving humans and radiation sources for which dose rate data exists or can be calculated.

The primary focus of this report is on the extensions to existing capabilities developed by the authors. A graphical user interface (GUI) has been created to help users run REMS; this GUI and an overview of the entire modeling system are presented in Chapter 2. Chapter 3 contains information about the structure of the radiation exposure input database files. A description of the human model, including the placement of sensors used for dose computations, is presented in Chapter 4. Chapter 5 contains information on how the IGRIP simulation package was adapted to be able to perform the dose computations. Chapter 6 discusses the contents and format of the output files from each workcell simulation. A sample problem is presented in Chapter 7, and the report concludes with a summary in Chapter 8.

2.0 REMS OVERVIEW AND GRAPHICAL USER INTERFACE

REMS is designed to be used by IGRIP users capable of modeling human activity in a workcell. The programming interface of the Deneb/ERGO human simplifies the modeling effort by defining the posture for the entire body (approximately 50 joints) with simple commands like “Walk from here to there” and “Teach Arm: Reach for Surface”. A motion sequence consists of an ordered collection of postures. The time to move between postures is set by the user.

The IGRIP workcell simulations use the input radiation data in a distance versus dose rate form. Although REMS was configured for a particular transport code, this type of data can be supplied by any transport code calculations or measured data that the user may possess.

The dose computations and output reporting for the simulations in REMS are performed by custom C language routines. Because these are written in C, much of the infrastructure was in place prior to integrating IGRIP and the Deneb/ERGO products into REMS. Using Deneb’s shared library, it was possible to access these external, user-written C routines within IGRIP.

Use of REMS has been simplified through the development of a top-level graphical user interface. This GUI allows the user to select any of the functions found in the system from a single interface screen. A copy of this screen is shown in Figure 2.1. The modules in REMS, activated by buttons on the user interface, can be interchanged with other products. Examples might be a different editor or a

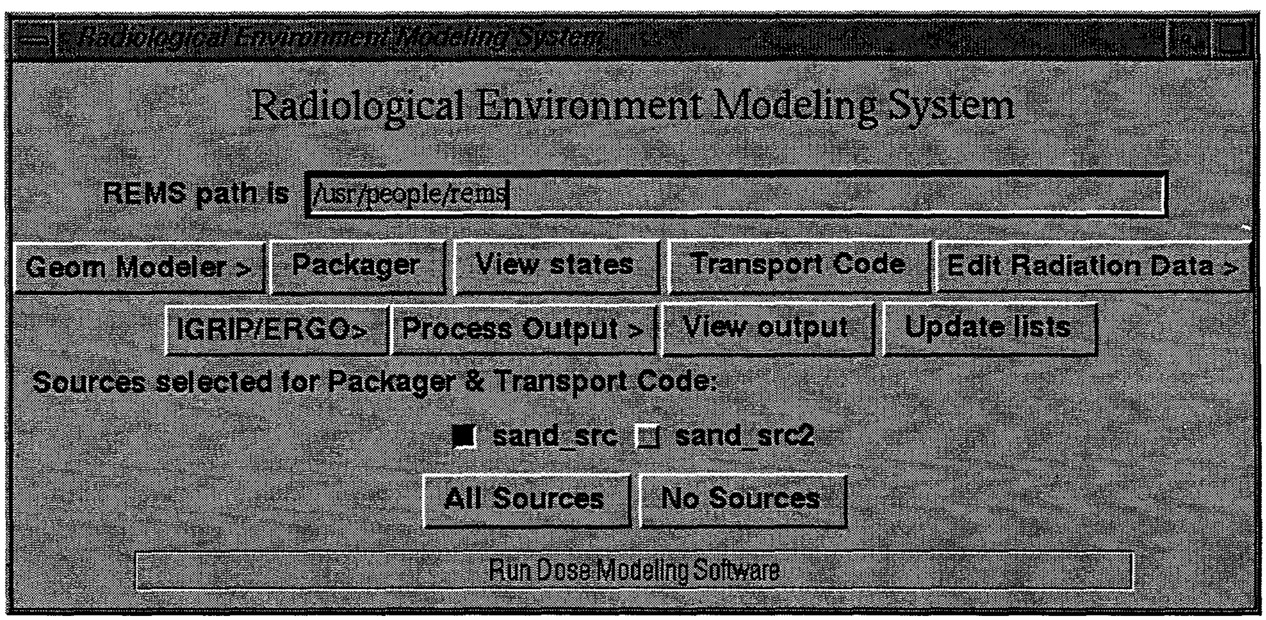

Figure 2.1: REMS Top-Level Graphical User Interface

different device simulator than IGRIP. The current collection of capabilities in REMS is appropriate for the weapon activities it was developed to assess.

The buttons on the GUI are laid out in the order that a simulation session would use them. The suboptions to the IGRIP/ERGO button form a pull-down menu of the different radiation exposure database files available for use as input to the simulations. The chosen database file is used by the IGRIP simulation to compute the dose to the workers in the simulation. Chapter 5 discusses the use of IGRIP, including the external C programs for dose computations, the GSL (Graphic Simulation Language) naming conventions, and the state changes to account for different packaging of the sources during the simulations.

The user is given a great deal of flexibility in how the output can be processed. The suboptions to the Process Output button include Sum Tables, Multiply by Stockpile, and Edit Stockpile Data. These allow the user to sum doses from a number of different simulated operations or to multiply them by the number of sources to be processed. Any of the files created in the processing of the output can be viewed through the View Output button on the GUI.

3.0 SOURCE INPUT DATABASE STRUCTURE

The radiation exposure input databases used by REMS contain data for each source and for the different configurations of each source. Examples of these configurations, also referred to as states, include a bare source, a source in a container, a source in a bell jar being leak-checked, or a source behind some type of shielding. Any of these states can be utilized in the IGRIP simulations through the GSL programs described in Chapter 5. Each input database file must contain distance versus dose rate data for each combination of source and state, and it must follow a prescribed format. The dose rate values in these database files must have the quality factors and any appropriate multiplying factors incorporated.

An example of an input database file is provided in Table 3.1, which will be used in the sample problem described in Chapter 7. The file contains data for two different sources whose names are "sand_src" and "sand_src2". The "sand_src" source is 3 years old, as indicated by the "-3" extension. Similarly, "sand_src2" is 7 years old. The term "radius 5" indicates that the outer spherical radius of both sources is five centimeters.

Each source possesses three states: state 0, the bare source; state 1, the source in a lead container; and state 2, the source in a steel container. Both containers are 2 cm thick, with inner and outer radii of 20 cm and 22 cm, respectively.

Table 3.1: Sample Radiation Exposure Input Database

```
sand_src-3 state 0 radius 5 [bare]
    0.000      0.000      5.000    400.000    100.000
    0.000      0.000     25.000     16.000      4.000
    0.000      0.000     40.000      6.250      1.563
    0.000      0.000     70.000      2.000      0.500
    0.000      0.000    100.000      1.000      0.250
    0.000      0.000    110.000      0.800      0.200
    0.000      0.000    210.000      0.250      0.063
    0.000      0.000    310.000      0.100      0.025
    0.000      0.000    410.000      0.060      0.015
sand_src-3 state 1 radius 5 [lead]
    0.000      0.000      5.000    400.800    100.200
    0.000      0.000     19.990     33.000      8.250
    0.000      0.000     22.000      1.200      4.800
    0.000      0.000     25.000      0.900      3.600
    0.000      0.000     40.000      0.350      1.400
    0.000      0.000     70.000      0.110      0.440
    0.000      0.000    100.000      0.055      0.220
    0.000      0.000    110.000      0.045      0.180
    0.000      0.000    210.000      0.013      0.050
    0.000      0.000    310.000      0.006      0.022
    0.000      0.000    410.000      0.003      0.012
```

Table 3.1 Sample Radiation Exposure Input Database (continued)

sand_src-3 state 2 radius 5 [steel]				
0.000	0.000	5.000	400.400	100.100
0.000	0.000	19.990	30.000	7.500
0.000	0.000	22.000	4.000	6.000
0.000	0.000	25.000	3.000	4.500
0.000	0.000	40.000	1.000	1.500
0.000	0.000	70.000	0.350	0.525
0.000	0.000	100.000	0.175	0.263
0.000	0.000	110.000	0.150	0.225
0.000	0.000	210.000	0.040	0.060
0.000	0.000	310.000	0.020	0.030
0.000	0.000	410.000	0.010	0.015
sand_src2-7 state 0 radius 5 [bare]				
0.000	0.000	5.000	180.000	20.000
0.000	0.000	25.000	7.200	0.800
0.000	0.000	40.000	2.813	0.313
0.000	0.000	70.000	0.900	0.100
0.000	0.000	100.000	0.450	0.050
0.000	0.000	110.000	0.360	0.040
0.000	0.000	210.000	0.113	0.013
0.000	0.000	310.000	0.045	0.005
0.000	0.000	410.000	0.027	0.003
sand_src2-7 state 1 radius 5 [lead]				
0.000	0.000	5.000	180.360	20.040
0.000	0.000	19.990	14.850	1.650
0.000	0.000	22.000	0.540	0.960
0.000	0.000	25.000	0.405	0.720
0.000	0.000	40.000	0.158	0.280
0.000	0.000	70.000	0.050	0.088
0.000	0.000	100.000	0.025	0.044
0.000	0.000	110.000	0.020	0.036
0.000	0.000	210.000	0.006	0.010
0.000	0.000	310.000	0.002	0.004
0.000	0.000	410.000	0.001	0.002
sand_src2-7 state 2 radius 5 [steel]				
0.000	0.000	5.000	180.180	20.020
0.000	0.000	19.990	13.500	1.500
0.000	0.000	22.000	1.800	1.200
0.000	0.000	25.000	1.350	0.900
0.000	0.000	40.000	0.450	0.300
0.000	0.000	70.000	0.158	0.105
0.000	0.000	100.000	0.079	0.053
0.000	0.000	110.000	0.068	0.045
0.000	0.000	210.000	0.018	0.012
0.000	0.000	310.000	0.009	0.006
0.000	0.000	410.000	0.005	0.003

The file is made up of six sections corresponding to the combinations of two sources and three states. Each section begins with a line of data containing the source name-age, state number, outer radius in centimeters, and state name. Following this section header is the distance versus dose rate information for the source/state combination. The five columns of information represent: PHI, angular measure in degrees; THETA, angular measure in degrees; RHO, radius in centimeters; gamma dose rate, mrem/hr; and neutron dose rate, mrem/hr. The PHI and THETA columns are placeholders so that 2-D and/or 3-D data can be used in the future. REMS presently uses only one-dimensional information, so PHI and THETA are zero for all RHOs. With all PHIs and THETAs being zero, the database files will be sorted by RHO.

On the top-level GUI screen, the user is able to edit a database file and save it under a new name. With this capability, REMS isn't limited to using transport code data as input; it allows a user with measured data to use it in an IGRIP simulation. Once the user has saved the new file with a new name and invoked the "Update lists" button, this new input database file name will become an option to the "Edit Radiation Data" and "IGRIP/ERGO" pull-down menus on the REMS main GUI. Alternative data may be input at any values of RHO and do not have to be sorted by ascending values of RHO. A sorting operation is performed prior to this data being used in the IGRIP/ERGO simulation.

It is important to note that REMS allows for multiple sources to be present in a workcell simulation. However, the nuclear interactions between the multiple sources, and the potential for criticality, are not addressed in the current version of REMS. Also, it is understood that the accuracy of the simulation results is predicated on accurate source input data to the simulation. Any shielding provided by objects in the workcell is not taken into account automatically by REMS; the user must explicitly handle these situations by providing the input data and specifying this state of the source during the simulation.

4.0 SIMULATED HUMAN MODEL

In the capability described in this paper, numerous sensors have been placed on the simulated human so that radiation dose readings can be made at locations inside and outside the body. These readings may be used to report doses at individual sensor locations or may be combined with weighting factors to produce an effective dose equivalent. The REMS capability assumes zero tissue attenuation when computing dose to internal organs and bones.

4.1 Description of the Simulated Human

The Deneb/ERGO product includes 5, 50, and 95th percentile male and female human models. In REMS, the 50th percentile male has been outfitted with sensors as described below. The size of this male model is approximately 71 inches (180 centimeters) tall, and all other dimensions can be found in [4]. The human model has 50 movable joints; this does not include finger joints, which could be used if desired.

Each sensor is a 1 centimeter cube. In order for the sensor to move with the correct part of the body, it must be attached to that body part. Examples might be the wrist dosimeter attached to the forearm or the right eye sensor attached to the simulated worker's head.

4.2 Description of the Sensor Locations

Sensors have been attached to the human model to satisfy three primary objectives. The DOE presently maintains annual limits on dose to radiological workers for the whole body, lens of the eye, extremities, and any organ or tissue and skin [2]. Therefore, it is desired to produce sensor dose readings at locations that facilitate comparisons with these limits. Additionally, humans working in radiological environments are outfitted with dosimeters situated at specific locations on the body. Examples of these locations include wrists, fingers (in the form of rings), neck, and chest or navel. Thus, sensors are also attached to the human model at locations that allow comparisons with actual dosimeter readings. Additional sensors are present to allow the computation of an effective dose equivalent.

In total, 43 sensors have been attached to the human model in REMS [5]. The first four of these listed in Table 4.1 are in locations of dosimeters worn by radiological workers. The next six represent extremity locations. Next, thirteen organ and tissue locations are listed, followed by two eye locations. The list concludes with eighteen bone marrow and bone surface locations. The sensor-laden ERGO-Man is illustrated in Figure 4.1.

Table 4.1: Sensor Descriptions and Locations

Sensor Name	Sensor Description/Location
DOSIMETERS:	
rwd*	right wrist dosimeter
lwd*	left wrist dosimeter
neck_dosimeter	neck dosimeter (front part of neck)
WBD*	whole body (navel) dosimeter
EXTREMITIES:	
lhandd*	left hand (palm) detector
rhandd*	right hand (palm) detector
llad*	lower left arm detector
lrad*	lower right arm detector
llld*	lower left leg detector
lrld*	lower right leg detector
ORGANS/TISSUES:	
gonads*	one sensor in crotch
breast_left*	left breast
breast_right*	right breast
intestine	intestine
kidney_l	left kidney
kidney_r	right kidney
liver	liver
lung_l	left lung
lung_r	right lung
stomach	stomach
thyroid	thyroid
pancreas	pancreas
head*	front of face

Table 4.1: Description of Sensors (continued)

Sensor Name	Sensor Description/Location
EYES:	
eye_r*	right eye
eye_l*	left eye
BONES/BONE MARROW:	
ulad*	upper left arm detector
urad*	upper right arm detector
ulld*	upper left leg detector
urld*	upper right leg detector
skull_r	right side of skull at temple
skull_l	left side of skull at temple
pelvis_l	left pelvis behind hip
pelvis_r	right pelvis behind hip
spine_u	upper spine
spine_m	mid spine
spine_l	lower spine (small of back)
sternum	center of sternum
rib_lb	rib left back
rib_rm	rib right front
rib_rb	rib right back
rib_lm	rib left front
scapulae_r	right scapulae
scapulae_l	left scapulae

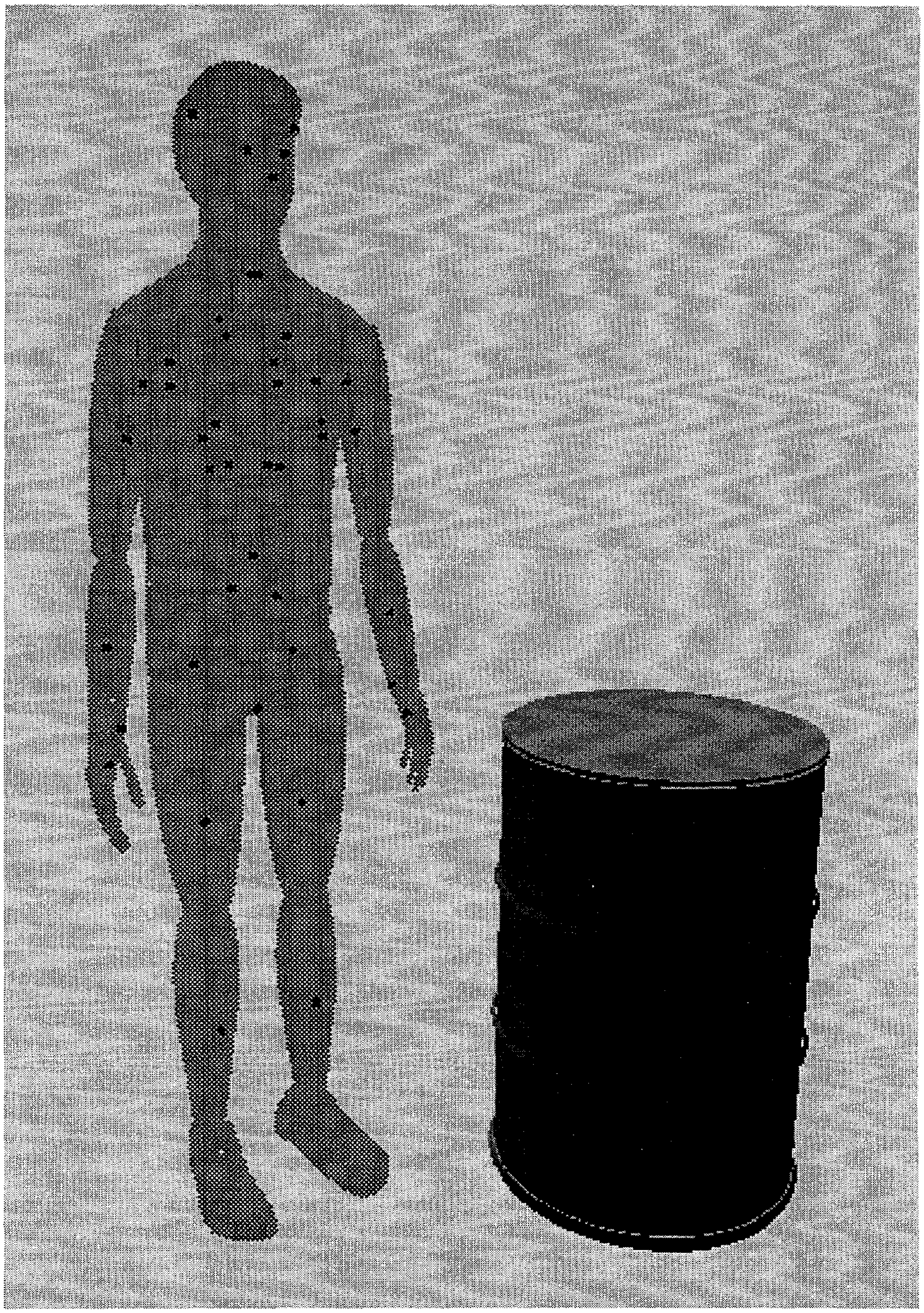

Figure 4.1: ERGO-Man with Attached Sensors

4.3 Dose Computations and Reporting Using the Sensor Locations

REMS provides the flexibility to sum doses for any collection of the 43 sensor locations in Table 4.1 to meet the specific needs of the user. REMS also allows the user to perform ancillary computations and define the structure, content, and format of the output files.

The subset of sensors used in the "Pantex format" of the output files are designated by asterisks in the table. For the Pantex application, the whole body dosimeter sensor was placed at the navel. Also, both left and right wrist dosimeters/sensors were included in the Pantex subset and output report. Pantex radiological workers are outfitted with dosimeters at these locations, so the simulations provide information that is readily comparable with actual readings. The Pantex format of the output files is described in Chapter 6. Samples of these output files can be found in Tables 7.2 and 7.3, which are for the sample problem described in Chapter 7.

Though not part of the Pantex output format, REMS is also capable of computing an effective dose equivalent by summing doses at certain sensor locations and applying appropriate weighting factors. The methodology for this type of computation is detailed below.

From ICRP 26 [6], the following weighting factors are used to compute an effective dose equivalent:

Table 4.2: Effective Dose Equivalent Weighting Factors

Organ or Tissue	Weighting Factor
Gonads	0.25
Breasts	0.15
Red Bone Marrow	0.12
Lungs	0.12
Thyroid	0.03
Bone Surfaces	0.03
Remainder (5 organs)	0.30

The gonads and thyroid dose values are merely the accumulated doses at their respective sensor locations. There are left and right sensors in REMS for the breasts and lungs, so their dose values are taken as the average of the accumulated doses at their respective left and right sensor locations. For the five remainder organs in Table 4.2, REMS currently uses the following locations: liver, kidney, pancreas, stomach and intestine. Each of these carries a weight of 0.06, with the kidney dose value being taken as the average of the accumulated doses at the left and right kidneys.[2]

Additional weighting factors are needed to compute the red bone marrow and bone surfaces portion of this effective dose equivalent equation. For red bone marrow, the following relative weighting factors are used [8]:

Table 4.3: Red Bone Marrow Weighting Factors

Region	Weighting Factor (Total Active Marrow Fraction)
Pelvis	0.362
Vertebrae (spine)	0.284
Skull	0.131
Ribs and sternum	0.102
Scapulae	0.048
Legs	0.038
Arms	0.019
Clavicles	0.016

[2] ICRP 26 [6] defines the remainder organs as the liver, kidney, spleen, thymus, adrenal, pancreas, stomach, small intestine, upper large intestine, and lower large intestine. A weighting factor of 0.06 is assigned to the five organs from the above group with the highest doses. Sensors could be added to REMS to accommodate this methodology. For further discussion of the remainder tissue computations, see [7].

Weighting factors for the bone surface calculations are based on estimates from information in [8] and summarized in the following table:

Table 4.4: Bone Surface Weighting Factors

Region	Weighting Factor
Head	0.15
Lower arms	0.15
Upper arms	0.15
Lower legs	0.18
Upper legs	0.18
Bones in chest	0.19

Therefore, using Tables 4.3 and 4.4, values for bone marrow and bone surface doses can be generated. These values are used in the weighted summation outlined in Table 4.2 to compute an effective dose equivalent, which can then be compared to simulated and actual readings from the whole body dosimeter.

5.0 IMPLEMENTATION USING IGRIP

REMS uses the IGRIP commercial simulation software package with the additional Ergonomics option to do the realistic modeling of workers and sources in workcells. IGRIP, a product of Deneb Robotics, Inc., has a 3-D CAD package and kinematic device modeling, collision detection, and workcell generation capabilities. The REMS user must be familiar with these aspects of IGRIP. The user develops a simulation of a manual operation using IGRIP and Deneb/ERGO, and then uses REMS to compute and accumulate dose to the workers in the simulation.

This chapter describes the steps for setting up a workcell in IGRIP to use the capabilities in REMS. Starting with an established IGRIP workcell, the user introduces humans and radiation sources and assigns programs to the humans. Next, a generic meterbox is brought in and assigned a program to call the external C routines that perform the dose computations and accumulate the dose to the workers in the simulation. Descriptions of the external C routines, and the IGRIP shared library that is used to call them, are given in this chapter.

5.1 Workstation Requirements

REMS is configured to operate on a Silicon Graphics (SGI) workstation. The minimum recommended computer configuration consists of an Indigo2 Extreme workstation, IRIX 5.2 operating system, 64 megabytes of RAM, a 1 gigabyte hard drive, and a DAT tape drive to facilitate file transfers. In addition to the workstation, a Version 2.4 IGRIP software license with the LLTI (Low-Level Telerobotics Interface) and ERGO (Ergonomics) options is required. Also, please see the shared library section below for requirements about building the shared library that is used during the IGRIP session.

5.2 Workcell Definition

5.2.1 Introduction of Human and Radiation Source Devices

The 50th percentile male Deneb/ERGO human model with sensors, as described in Chapter 4, must be used in REMS. This is because the dose calculation routines use the names of the sensors to do the distance measuring from the sources in the workcell. The male model with sensors has been saved with the name "P50_sensors".

Upon the first retrieval of this device by the user, IGRIP will name it "P50_sensors". Subsequent retrievals will be named "P50_sensors#2", "P50_sensors#3", etc. in order to allow multiple copies of the same human device in the workcell for which doses will be summed. For radiation sources, a sphere of the user's desired size is needed. Again, a similar naming scheme is employed, where the base name is "ball". The names of all sources in the workcell might be named "ball", "ball#2", "ball#3", etc. The coorsys (coordinate system) of all sources must be at the center of the source since the IGRIP distpos (straight-line distance) function measures from coorsys to coorsys between parts.

5.2.2 Programming of Human Devices

Once employees and sources have been brought into a workcell, the user is required to program the employees as in a normal IGRIP simulation. Each object that moves in the workcell needs a GSL program associated with it. The exception to this is the meterbox, which doesn't move but requires the meterbox.gsl program described in Section 5.2.3. GSL programs associated with employees need to be edited so that the employees will move along user-defined sequences of postures and change the states of sources when they are packed/unpacked or moved to certain locations. Also, each employee's program must set a variable, named "done", in the global array to one when its GSL program is finished. The meterbox program will continue to run until all employees have set their values in the global done array to one.

Most of the editing needed in the employees' GSL programs has been automated. When a user selects Ergo → Analyze → Playback, IGRIP can create a GSL program that includes sequences of postures for that worker. This newly created GSL program will only have statements like "MOVE ALONG seq". In the editing session of the GSL program, a macro is used to insert additional REMS interface code, including setting the done[n] variable. Additionally, the initial states and changes of states for the sources in the workcell must be added to the GSL program through editing.

5.2.3 The Meterbox Program

In REMS, many value-added extensions to IGRIP have been made. The meterbox.gsl program contains a majority of these generic features. This program should not need to be edited because it contains only generic features independent of the workcell being simulated. A separate meterbox.gsl program should be created for each IGRIP workcell being simulated in REMS. This is true of the worker GSL programs as well; no GSL program should be used by more than one device.

The meterbox.gsl program is associated with an invisible meterbox cube that needs to be included in every workcell being simulated with REMS. The first feature found in this program is the ability to count the number of employees and sources in the workcell as long as the PERSON_NAME and SOURCE_NAME constants are set properly in the meterbox.gsl program. For the simulated employees, the user is required to use the device file "P50_sensors". "P50_sensors" is both the base name for all employees collecting dose and the definition of the PERSON_NAME constant in meterbox.gsl. There is nothing special about the source devices; the user can use any type of device, but they must all be named with the same base name as defined by the SOURCE_NAME constant.

In addition to the simulation summing dose for the correct number of employees from the correct number of sources in the workcell, the numbers of employees and sources are used later in the output reporting. The user is prompted for the base name of all output files by the meterbox.gsl program. Six different output files are created, as described in Chapter 6.

5.3 External C Files and Routines

After counting the numbers of employees and sources in the workcell and setting up the output arrays, the meterbox.gsl program calls the accumulate_dose routine every second to sum the dose to all employees' sensors. The IGRIP LLTI option is needed to make these external C function calls. The measurements from the distpos function are passed to the accumulate_dose routine, where a lookup is made into the chosen distance versus dose rate database file. Interpolations are made when distances lie between data points in the database file, and extrapolations are made when distances lie beyond the last data point.

Accumulate_dose is one of the C routines visible from GSL through the c_exec function. This routine takes six arguments: the employee ID number, the source ID number, the weapon system number, the state of the source, an array of distances between the source and each sensor, and the number of seconds the exposure lasted. In the Pantex format, the "weapon systems" are the different sources in the radiation exposure input database. Also, in the current version of REMS, meterbox.gsl calls accumulate_dose once every second for every possible employee/source/weapon system combination.

Write_results, another C routine visible from GSL, creates the six output files associated with the simulation. For input, it needs the base name for the output files. The meterbox.gsl program calls write_results after a simulation has finished. Similarly, the meterbox program calls routines to allocate and free memory for the arrays of output data. Since meterbox counts the numbers of employees and sources, it knows how much memory to allocate.

5.4 IGRIP Shared Library

The shared library has been built and included with REMS. Before a user can call external, user-written C routines with the IGRIP GSL c_exec function, the C routines must be compiled into the shared library. The shared library is called "libdnbusr.so" and is located in a specified directory. There are three sub-directories of this directory: Make, User, and cust. The Make sub-directory contains a makefile and configuration files provided by Deneb. The User directory contains default library routines used by IGRIP. The cust directory contains the REMS C code. If one of the C files is modified, the shared library must be rebuilt. To do this, one would change to the Make directory and type "make". This, in turn, would re-create the libdnbusr.so file.

Shared libraries are a UNIX System V facility to provide libraries of code to applications at run-time rather than at link-time. When IGRIP is started, this library of code is run as part of the IGRIP session. IGRIP looks for the shared library in the directory contained in the environment variable LD_LIBRARY_PATH. Users must make sure that this environment variable is set properly before using custom C code as is found in REMS. The current version of IGRIP (Version 2.411) was built using IRIX 5.2 for SGI platforms. Users must build their shared libraries using nothing newer than IRIX 5.2 to assure compatibility.

6.0 OUTPUT VIEWING AND PROCESSING

Each REMS simulation produces two types of Pantex format output files: detailed IGRIP dose output (`.igout`) files and more compact table (`.tbl`) files. For each workcell simulation, REMS produces six total output files: gamma-only detailed and compact files, neutron-only detailed and compact files, and total (gamma plus neutron) detailed and compact files. Examples of `.tbl` and `.igout` output files for the sample problem can be found in Tables 7.2 and 7.3, respectively.

The Pantex format of the `.igout` files are a collection of sets of dose data, with each set of dose data having the following information and format:

Table 6.1: Pantex Dose Data Set Format

```
Whole Body:
  Head                 :     a.aaa mrem
  Right Chest          :     b.bbb mrem
  Left  Chest          :     c.ccc mrem
  Upper Arm, Right     :     d.ddd mrem *
  Upper Arm, Left      :     e.eee mrem *
  Gonad                :     f.fff mrem
  Upper Leg, Right     :     g.ggg mrem
  Upper Leg, Left      :     h.hhh mrem

Extremities:
  Lower Arm, Right     :     i.iii mrem
  Lower Arm, Left      :     j.jjj mrem
  Right Hand           :     k.kkk mrem *
  Left  Hand           :     l.lll mrem *
  Lower Leg, Right     :     m.mmm mrem
  Lower Leg, Left      :     n.nnn mrem

Eyes:
  Right Eye:           :     o.ooo mrem
  Left Eye:            :     p.ppp mrem

Dosimeters:
  Whole Body:          :     q.qqq mrem
  Right Wrist:         :     r.rrr mrem
  Left Wrist:          :     s.sss mrem
```

Individual dose values are accumulated for each of the sensor locations listed above. If the dose reading at an individual whole body sensor exceeds the dose reading at the whole body dosimeter by over fifty percent, then that sensor's dose reading is flagged with an asterisk. In the above example format, the dose readings at the upper right and left arm sensors (`d.ddd` and `e.eee`) are flagged, so they are at least 1.5 times the whole body dosimeter reading (`q.qqq`). Similarly, if the dose reading at an individual extremity sensor exceeds the minimum dose reading at the extremity dosimeters by over fifty percent, then that sensor's dose reading is flagged with an asterisk. In the above example format, the dose readings at the right and left hand sensors (k.kkk and l.lll) are flagged, so they are at least 1.5 times the lesser of the two wrist dosimeter readings (r.rrr or s.sss).

For a simulation problem with "i+1" employees and "j+1" sources in the workcell and "k+1" weapon systems in the radiation exposure input database, the .igout file will have (i+1 × j+1 × k+1) sets of dose data organized in the following manner:

Table 6.2: Organization of Pantex Detailed Output File

```
Employee 0
  Source 0
    Weapon system 0 ["WS_0_name"]
      (Dose data(0,0,0))
              :
    Weapon system k ["WS_k_name"]
      (Dose data(0,0,k))
              :
  Source j
    Weapon system 0 ["WS_0_name"]
      (Dose data(0,j,0))
              :
    Weapon system k ["WS_k_name"]
      (Dose data(0,j,k))
              :
              :
Employee i
  Source 0
    Weapon system 0 ["WS_0_name"]
      (Dose data(i,0,0))
              :
    Weapon system k ["WS_k_name"]
      (Dose data(i,0,k))
              :
  Source j
    Weapon system 0 ["WS_0_name"]
      (Dose data(i,j,0))
              :
    Weapon system k ["WS_k_name"]
      (Dose data(i,j,k))
```

where:

"WS_k_name" is the name of the k'th weapon system, and

(Dose data(i,j,k)) is the set of dose data for the i'th employee from the j'th source in the workcell, with that source being from the k'th weapon system.

The .tbl files only provide the dosimeter millirem dose readings in the following format, for the same conditions outlined for the .igout file format:

Table 6.3: Organization of Pantex Compact Output File

System	Whole Body		Right Wrist	Left Wrist
Employee 0				
Source 0				
0 "WS_0_name"	q.qqq		r.rrr	s.sss
		⋮		
k "WS_k_name"	q.qqq		r.rrr	s.sss
		⋮		
Source j				
0 "WS_0_name"	q.qqq		r.rrr	s.sss
		⋮		
k "WS_k_name"	q.qqq		r.rrr	s.sss
Totals:				
0 "WS_0_name"	q.qqq		r.rrr	s.sss
		⋮		
k "WS_k_name"	q.qqq		r.rrr	s.sss
		⋮		
		⋮		
Employee i				
Source 0				
0 "WS_0_name"	q.qqq		r.rrr	s.sss
		⋮		
k "WS_k_name"	q.qqq		r.rrr	s.sss
		⋮		
Source j				
0 "WS_0_name"	q.qqq		r.rrr	s.sss
		⋮		
k "WS_k_name"	q.qqq		r.rrr	s.sss
Totals:				
0 "WS_0_name"	q.qqq		r.rrr	s.sss
		⋮		
k "WS_k_name"	q.qqq		r.rrr	s.sss

Note that the dose from all sources in the workcell are summed to provide a total dose for each employee/weapon system combination in the .tbl file.

Under the REMS Process Output pull-down menu, there are three options: Sum Tables, Multiply by Stockpile, and Edit Stockpile Data. These options only work on the compact output files:

(1) The Sum Tables function allows users to sum doses from several compact output files to get a total dose for a process that has been modeled in multiple REMS simulations. Long processes may be broken up in order to help identify those operations that are dose-intensive to the workers. When the Sum Tables option is selected, it opens a pop-up window listing all the compact files in the output directory. The user merely defines the file name

for the summed data, highlights the desired files to be summed, and clicks on the sum button.

(2) The Multiply by Stockpile option is used to multiply dose values by the total number of pits for each weapon system in the stockpile. To do this, the user selects Multiply by Stockpile from the Process Output pull-down menu. A pop-up window will appear as described above.

(3) Prior to multiplying by stockpile, the user may wish to use the Edit Stockpile Data option to verify that the correct weapon systems and numbers of pits are used in the multiplication operation.

The Multiply by Stockpile and Edit Stockpile Data options access a file that holds the number of pits for each weapon system.

7.0 SAMPLE PROBLEM

This chapter describes a sample problem used to illustrate the basic principles of the simulation capability.

7.1 Definition of Problem

The sample problem involves two technicians and two sources in a workcell. Additionally, there are two different weapon systems defined in the radiation exposure input database. Therefore, there will be eight sets of data in each of the two output files, one for each technician/source/weapon system combination.

The radiation exposure input database for this sample problem was provided in Table 3.1 and described in Chapter 3. The "sand_src" source provides the greater dose of the two sources and a higher proportion of neutron dose. The gamma and neutron dose rates for the bare sources are assumed to be proportional to the inverse of the squared radius from the center of the source. Recall that each source possesses three states: the bare source, state 0; the source in a lead container, state 1; and the source in a steel container, state 2.

At the start of the simulation, both technicians are about to enter the work area, as shown in Figure 7.1. One of the technicians is the "worker," while the other technician serves as an "observer." Initially, the two sources are in the two steel drums on the right side of the work area. A timetable of the simulated operations is provided in Table 7.1.

Table 7.1: Timetable of Operations for the Sample Problem

Time (sec)	Operation
0	The worker (Employee 0) approaches container nearest table. Simultaneously, the observer (Employee 1) moves into observation position in work area. The observer's "done" variable is changed to 1 after he reaches the observation position. Both sources are initially in state 2 (steel container).
13	The worker removes the container lid and places it on the table.
30	The worker removes the source (Source 0) from the container, as shown in Figure 7.2, and places it on the table. The state of Source 0 is changed to 0 (bare) in the GSL program of the worker. The state of the source in the container farthest from the table (Source 1) remains unchanged throughout the simulation.
40	The worker begins cleaning the source, as shown in Figure 7.3. Note that he is holding the pit with his right hand and cleaning with his left.
56	The worker finishes cleaning the source and begins to exit the work area.
78	The worker's simulated movements are complete; his "done" variable is changed to 1, and the simulation is terminated with the final positions shown in Figure 7.4.

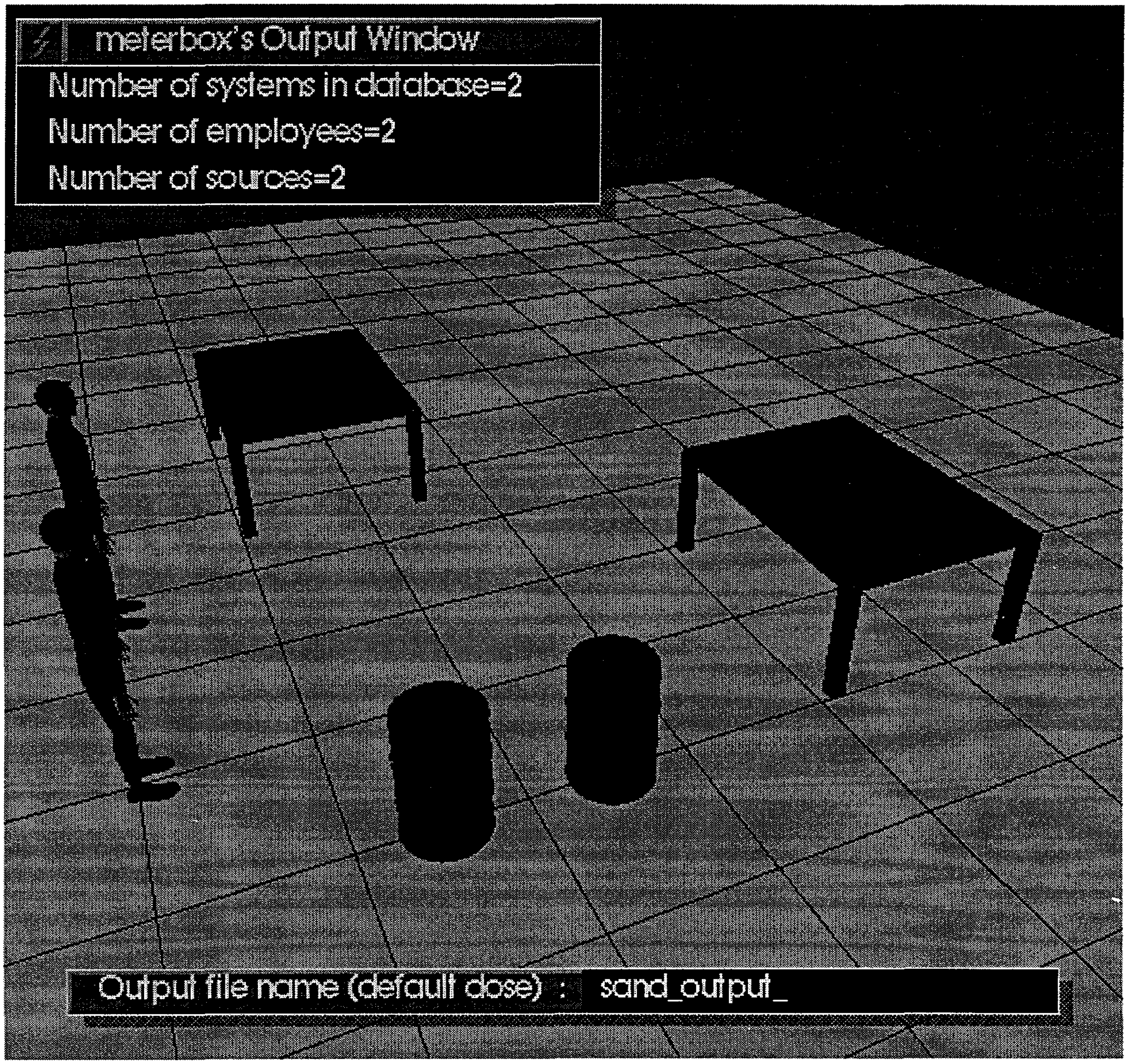

Figure 7.1: Start of Sample Problem Simulation

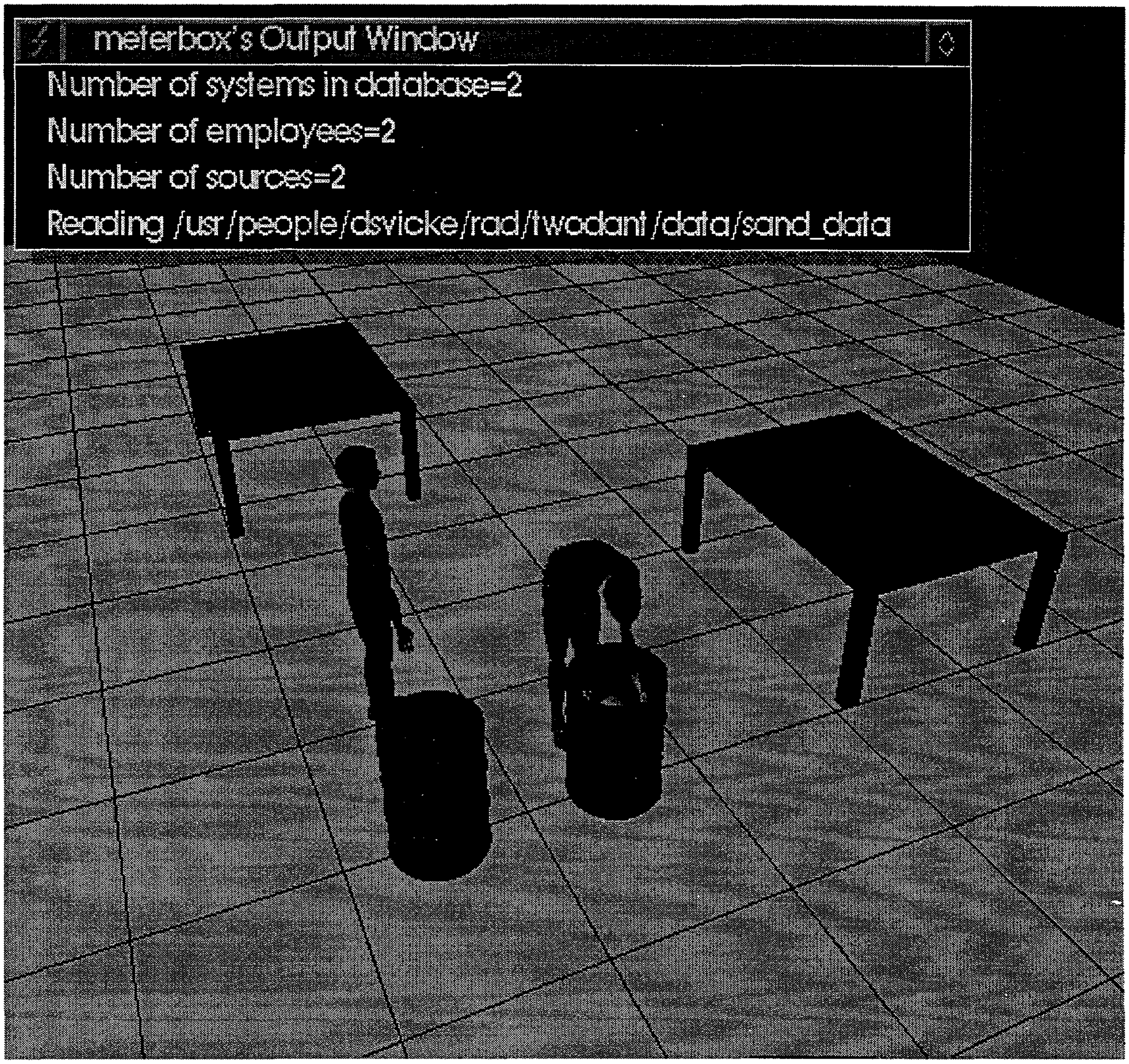

Figure 7.2: Worker Removing Source from Container

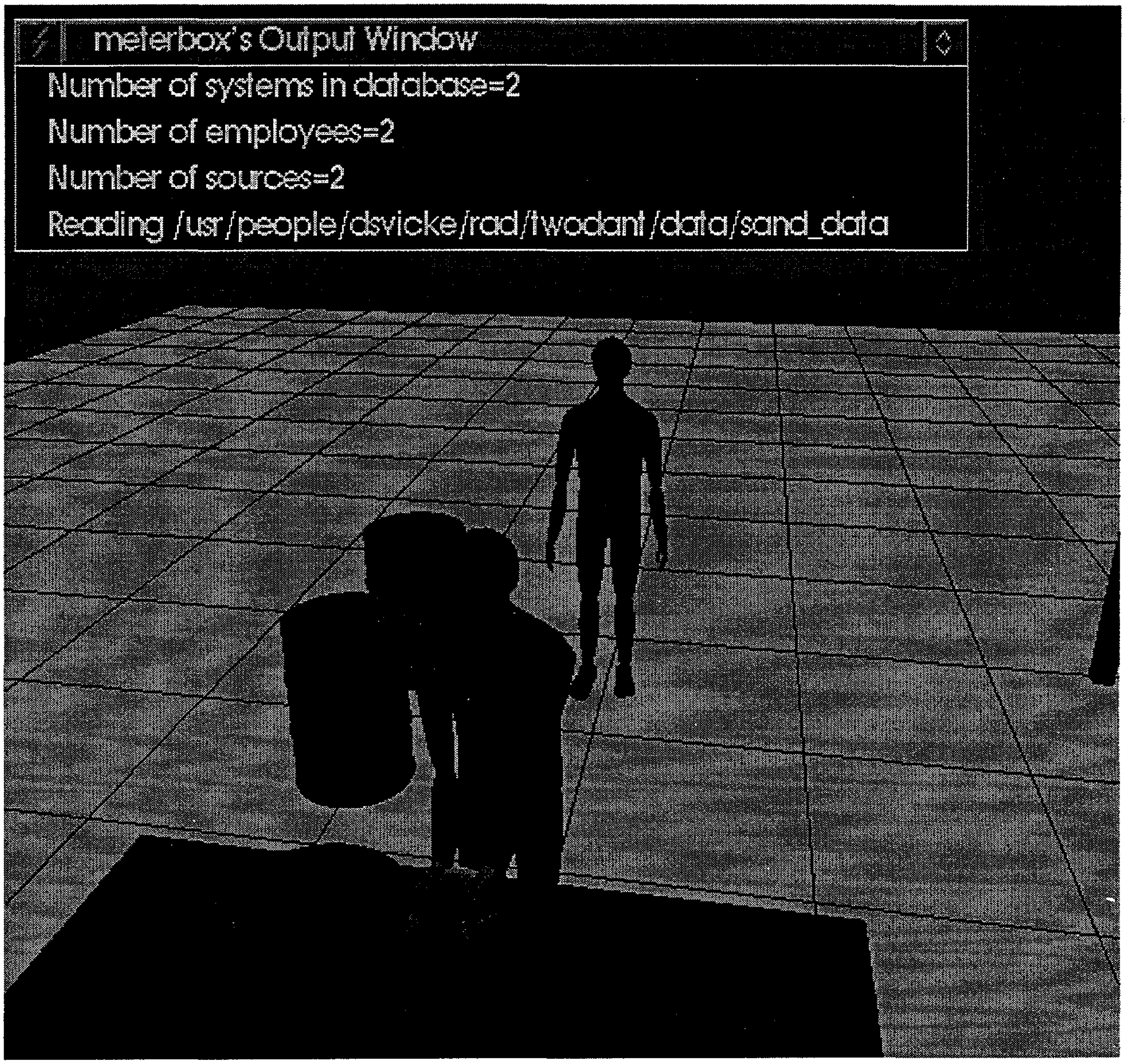

Figure 7.3: Worker Cleaning Pit at Table

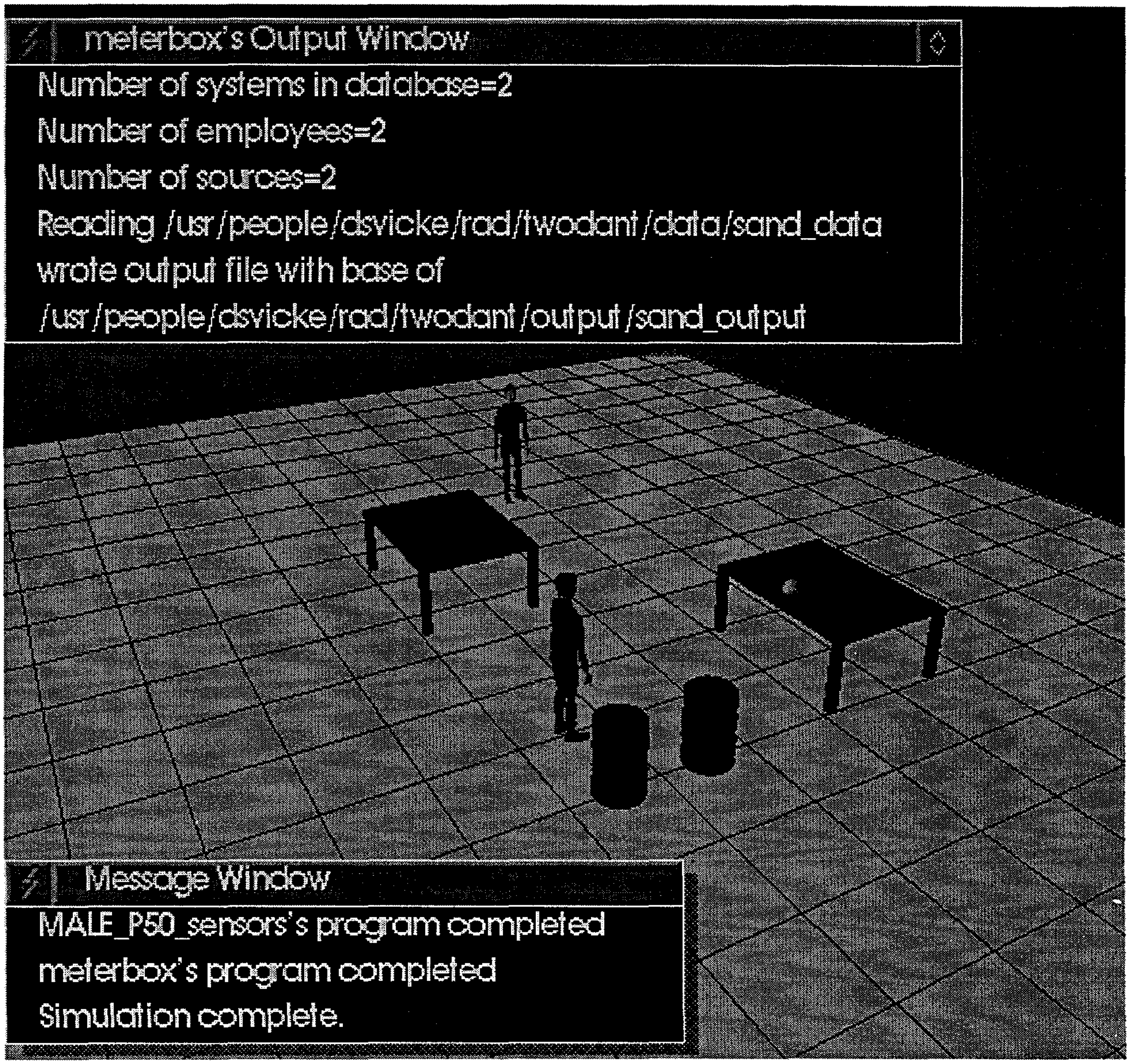

Figure 7.4: Final Positions at End of Sample Problem Simulation

7.2 Results/Observations

Representative dose results from this simulation are provided in Tables 7.2 and 7.3. These two tables are the compact and detailed Pantex-format output files for the total (gamma plus neutron) dose summations, respectively.

The compact table shows dosimeter readings for the worker (Employee 0) are over an order of magnitude greater than those of the observer (Employee 1). Dose from "sand_src" is greater than that from "sand_src2", and dose from the source that was cleaned is greater for the worker, but less for the observer, than the dose from the source that remained in the drum. There are significant differences between the right and left wrist dosimeter readings consistent with the asymmetric positioning of the sources relative to the technicians. The right wrist dosimeter for the worker registers doses an order of magnitude greater than his whole body dosimeter; extremity dose for the worker would be even more dominant if normal types of whole body shielding were included.

Table 7.2: Compact Total-Dose Output File for Sample Problem

System	Whole Body	Right Wrist	Left Wrist
Employee 0			
Source 0			
0 sand_src-3	0.074	0.754	0.554
1 sand_src2-7	0.030	0.301	0.221
Source 1			
0 sand_src-3	0.006	0.007	0.006
1 sand_src2-7	0.003	0.003	0.002
Totals:			
0 sand_src-3	0.080671	0.760972	0.559024
1 sand_src2-7	0.032168	0.304227	0.223483
Employee 1			
Source 0			
0 sand_src-3	0.007	0.008	0.006
1 sand_src2-7	0.003	0.003	0.002
Source 1			
0 sand_src-3	0.020	0.037	0.016
1 sand_src2-7	0.008	0.015	0.006
Totals:			
0 sand_src-3	0.026759	0.045118	0.021692
1 sand_src2-7	0.010641	0.017961	0.008633

Table 7.3: Detailed Total-Dose Output File for Sample Problem

```
Employee 0
  Source 0
    Weapon system 0 [sand_src-3]
      Whole Body:
        Head                 :     0.022 mrem
        Right Chest          :     0.052 mrem
        Left  Chest          :     0.051 mrem
        Upper Arm, Right     :     0.046 mrem
        Upper Arm, Left      :     0.043 mrem
        Gonad                :     0.048 mrem
        Upper Leg, Right     :     0.039 mrem
        Upper Leg, Left      :     0.038 mrem

      Extremities:
        Lower Arm, Right     :     0.176 mrem
        Lower Arm, Left      :     0.152 mrem
        Right Hand           :     1.241 mrem *
        Left  Hand           :     0.808 mrem
        Lower Leg, Right     :     0.026 mrem
        Lower Leg, Left      :     0.026 mrem

      Eyes:
        Right Eye:           :     0.023 mrem
        Left Eye:            :     0.023 mrem

      Dosimeters:
        Whole Body:          :     0.074 mrem
        Right Wrist:         :     0.754 mrem
        Left Wrist:          :     0.554 mrem
    Weapon system 1 [sand_src2-7]
      Whole Body:
        Head                 :     0.009 mrem
        Right Chest          :     0.021 mrem
        Left  Chest          :     0.020 mrem
        Upper Arm, Right     :     0.018 mrem
        Upper Arm, Left      :     0.017 mrem
        Gonad                :     0.019 mrem
        Upper Leg, Right     :     0.015 mrem
        Upper Leg, Left      :     0.015 mrem

      Extremities:
        Lower Arm, Right     :     0.070 mrem
        Lower Arm, Left      :     0.061 mrem
        Right Hand           :     0.496 mrem *
        Left  Hand           :     0.323 mrem
        Lower Leg, Right     :     0.010 mrem
        Lower Leg, Left      :     0.010 mrem

      Eyes:
        Right Eye:           :     0.009 mrem
        Left Eye:            :     0.009 mrem

      Dosimeters:
        Whole Body:          :     0.030 mrem
        Right Wrist:         :     0.301 mrem
        Left Wrist:          :     0.221 mrem
```

Table 7.3: Detailed Total-Dose Output File for Sample Problem (continued)

```
Source 1
  Weapon system 0 [sand_src-3]
    Whole Body:
      Head                 :     0.005 mrem
      Right Chest          :     0.006 mrem
      Left  Chest          :     0.006 mrem
      Upper Arm, Right     :     0.006 mrem
      Upper Arm, Left      :     0.005 mrem
      Gonad                :     0.007 mrem
      Upper Leg, Right     :     0.008 mrem
      Upper Leg, Left      :     0.007 mrem

    Extremities:
      Lower Arm, Right     :     0.007 mrem
      Lower Arm, Left      :     0.005 mrem
      Right Hand           :     0.007 mrem
      Left  Hand           :     0.005 mrem
      Lower Leg, Right     :     0.008 mrem
      Lower Leg, Left      :     0.007 mrem

    Eyes:
      Right Eye:           :     0.005 mrem
      Left Eye:            :     0.005 mrem

    Dosimeters:
      Whole Body:          :     0.006 mrem
      Right Wrist:         :     0.007 mrem
      Left Wrist:          :     0.006 mrem
  Weapon system 1 [sand_src2-7]
    Whole Body:
      Head                 :     0.002 mrem
      Right Chest          :     0.002 mrem
      Left  Chest          :     0.002 mrem
      Upper Arm, Right     :     0.003 mrem
      Upper Arm, Left      :     0.002 mrem
      Gonad                :     0.003 mrem
      Upper Leg, Right     :     0.003 mrem
      Upper Leg, Left      :     0.003 mrem

    Extremities:
      Lower Arm, Right     :     0.003 mrem
      Lower Arm, Left      :     0.002 mrem
      Right Hand           :     0.003 mrem
      Left  Hand           :     0.002 mrem
      Lower Leg, Right     :     0.003 mrem
      Lower Leg, Left      :     0.003 mrem

    Eyes:
      Right Eye:           :     0.002 mrem
      Left Eye:            :     0.002 mrem

    Dosimeters:
      Whole Body:          :     0.003 mrem
      Right Wrist:         :     0.003 mrem
      Left Wrist:          :     0.002 mrem
```

Table 7.3: Detailed Total-Dose Output File for Sample Problem (continued)

```
Employee 1
  Source 0
    Weapon system 0 [sand_src-3]
      Whole Body:
        Head                  :     0.005 mrem
        Right Chest           :     0.006 mrem
        Left  Chest           :     0.006 mrem
        Upper Arm, Right      :     0.006 mrem
        Upper Arm, Left       :     0.005 mrem
        Gonad                 :     0.006 mrem
        Upper Leg, Right      :     0.007 mrem
        Upper Leg, Left       :     0.006 mrem

      Extremities:
        Lower Arm, Right      :     0.007 mrem
        Lower Arm, Left       :     0.005 mrem
        Right Hand            :     0.008 mrem
        Left  Hand            :     0.006 mrem
        Lower Leg, Right      :     0.007 mrem
        Lower Leg, Left       :     0.006 mrem

      Eyes:
        Right Eye:            :     0.005 mrem
        Left Eye:             :     0.005 mrem

      Dosimeters:
        Whole Body:           :     0.007 mrem
        Right Wrist:          :     0.008 mrem
        Left Wrist:           :     0.006 mrem
    Weapon system 1 [sand_src2-7]
      Whole Body:
        Head                  :     0.002 mrem
        Right Chest           :     0.002 mrem
        Left  Chest           :     0.002 mrem
        Upper Arm, Right      :     0.002 mrem
        Upper Arm, Left       :     0.002 mrem
        Gonad                 :     0.003 mrem
        Upper Leg, Right      :     0.003 mrem
        Upper Leg, Left       :     0.002 mrem

      Extremities:
        Lower Arm, Right      :     0.003 mrem
        Lower Arm, Left       :     0.002 mrem
        Right Hand            :     0.003 mrem
        Left  Hand            :     0.002 mrem
        Lower Leg, Right      :     0.003 mrem
        Lower Leg, Left       :     0.002 mrem

      Eyes:
        Right Eye:            :     0.002 mrem
        Left Eye:             :     0.002 mrem

      Dosimeters:
        Whole Body:           :     0.003 mrem
        Right Wrist:          :     0.003 mrem
        Left Wrist:           :     0.002 mrem
```

Table 7.3: Detailed Total-Dose Output File for Sample Problem (continued)

```
Source 1
  Weapon system 0 [sand_src-3]
    Whole Body:
      Head                    :      0.012 mrem
      Right Chest             :      0.018 mrem
      Left  Chest             :      0.015 mrem
      Upper Arm, Right        :      0.021 mrem
      Upper Arm, Left         :      0.014 mrem
      Gonad                   :      0.023 mrem
      Upper Leg, Right        :      0.031 mrem *
      Upper Leg, Left         :      0.021 mrem

    Extremities:
      Lower Arm, Right        :      0.034 mrem *
      Lower Arm, Left         :      0.015 mrem
      Right Hand              :      0.041 mrem *
      Left  Hand              :      0.016 mrem
      Lower Leg, Right        :      0.030 mrem *
      Lower Leg, Left         :      0.021 mrem

    Eyes:
      Right Eye:              :      0.012 mrem
      Left Eye:               :      0.012 mrem

    Dosimeters:
      Whole Body:             :      0.020 mrem
      Right Wrist:            :      0.037 mrem
      Left Wrist:             :      0.016 mrem
  Weapon system 1 [sand_src2-7]
    Whole Body:
      Head                    :      0.005 mrem
      Right Chest             :      0.007 mrem
      Left  Chest             :      0.006 mrem
      Upper Arm, Right        :      0.008 mrem
      Upper Arm, Left         :      0.005 mrem
      Gonad                   :      0.009 mrem
      Upper Leg, Right        :      0.012 mrem *
      Upper Leg, Left         :      0.008 mrem

    Extremities:
      Lower Arm, Right        :      0.013 mrem *
      Lower Arm, Left         :      0.006 mrem
      Right Hand              :      0.016 mrem *
      Left  Hand              :      0.006 mrem
      Lower Leg, Right        :      0.012 mrem *
      Lower Leg, Left         :      0.008 mrem

    Eyes:
      Right Eye:              :      0.005 mrem
      Left Eye:               :      0.005 mrem

    Dosimeters:
      Whole Body:             :      0.008 mrem
      Right Wrist:            :      0.015 mrem
      Left Wrist:             :      0.006 mrem
```

The detailed table shows even more interesting results. The hand doses for the worker are nearly double those at the wrist dosimeters, illustrating the steep gradient of the dose-versus-distance data. The right hand dose of the worker is over 1.5 times that of the left hand dose; even small perturbations in positional symmetry can lead to major asymmetries in dose. Numerous sensor readings are flagged with asterisks, signifying that they exceed the relative dosimeter reading by over fifty percent as described in Chapter 6.

None of these observations is unexpected. The point here is to illustrate that the simulation capability allows the dose and resulting comparisons to be quantified. By modeling mitigation strategies, the benefits in dose reduction could be expressed in explicit terms.

8.0 SUMMARY

The goal of this development effort was to be able to simulate human operations in radiological environments so that dose could be quantified. Other inherent requirements existed, such as ease of use and accuracy of human activity modeling. The collection of capabilities in the Radiological Environment Modeling System satisfies these goals. REMS can be used to quantify the benefits of optimization methods, including process automation.

The REMS capability may be enhanced with some possible future additions. These include sensing shielding in the workcell automatically using IGRIP/LLTI functions, automating state changes of the sources, and being able to model 2-D and 3-D sources such as line sources and spills.

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1	1006	L. Meirans, 9671
1	1006	C.L. Montoya, 9671
1	1006	L. P. Ray, 9671
1	1006	J.P. Rebeil, 9671
1	1006	W.P. Wapman, 9671
1	1006	R.O. Woods, 9671
10	1007	K.R. Davis, 9672
1	1007	J.C. Fahrenholtz, 9672
1	1007	R.D. Foral, 9672
1	1007	J.F. Jones, 9672
1	1007	H.R. Kimberly, 9672
1	1007	M.A. Kincy, 9672
1	1007	D.M. Kozlowski, 9672
1	1007	J.L. Kuhlmann, 9672
1	1007	R.C. Lennox, 9672
1	1007	G.R. McKee, 9672
1	1007	A.K. Morimoto, 9672
1	1007	L.R. Shipers, 9672
3	1007	R.A. Watson, 9672

1	0453	D.L. McCoy, 2100
1	0427	P.A. Longmire, 2106
1	0656	D.L. Mangan, 5314
1	0761	F.L. Luetters, 5822
1	0718	E.A. Kjeldgaard, 6641
1	1095	J.A. Campisi, 7001
1	1144	J.S. Philbin, 9365
1	0571	R.L. Ewing, 5914
1	0571	T.W. Laub, 5914
1	0571	K.W. Marlow, 5914
1	0571	D.J. Mitchell, 5914
1	0571	H.C. Shefelbine, 5914

SNL/CA	Mailstops	Names, Orgs
1	9001	T.O. Hunter, 8000
1	9004	M.E. John, 8100
1	9003	D.L. Crawford, 8900
1	9201	L.D. Brandt, 8112
1	9201	M.F. Hawley, 8112
5	9201	D.S. Vickers, 8112
1	9201	M. Abrams, 8114
1	9201	W.A. Swansiger, 8114
3	9011	N.L. Breazeal, 8920
1	9011	J.E. Costa, 8920
1	9405	D.L. Lindner, 1809
1	9006	D.J. Bohrer, 2203
1	9005	W.G. Wilson, 2204
1	9015	C.A. Pura, 2221
1	9014	B.M. Mickelsen, 2271

OTHER SNL	Mailstops	Names, Orgs
1	9018	Central Technical Files, 8523-2
5	0899	Technical Library, 4414
1	0619	Print Media, 12615
2	0100	Document Processing, 7613-2 For DOE/OSTI

PANTEX	Mailstops	Names
5	12-122	Michael S. Ford
1	16-12	Matthew Brown
1	12-122	Larry Auman
1	12-122	Roby Enge
1	12-122	Linda Farrell
1	11-2	Ken Franklin
1	12-69	Don Hugus
1	12-122	Michael Knight
1	12-122	Michael McAdams
1	12-107	Vic McLauren
1	12-102	Dave Morris
1	12-102	Scott Olds
1	12-122	Chris Passmore
1	12-42D	Timothy Pederson
1	12-7	Steve Peterschmidt
1	12-42D	Penny Shamblin
1	12-107	Jon Spanos
1	12-42D	Linda Vickers
1	12-42D	Ron Wilcox
1	12-132	Richard Watkins

DOE	Mailstops	Names
1	MD-3	Howard Canter
1	MD-3	Lisa Chan
1	MD-3	Andre I. Cygleman
1	MD-3	Damian Peko
1	MD-3	Patrick Rhoads

YMSCO/DOE	Mailstops	Names
1		Diane Harrison

LANL	Mailstops	Names
1	E501	James Balkey
1	K551	John Buksa
1	E500	Dana Christensen
1	E513	Teresa Cremers
1	E506	David Horrell

1	E505	Carl W. Hoth
1	E510	Timothy O. Nelson
1	E510	Vicente Sandoval
1	F628	James W. Toevs
1	E530	Warren T. Wood
LLNL	Mailstops	Names
1	L592	Leonard W. Gray
1	L369	Bill Halsey
1	L592	Tehmau Kan
1	L166	Jeffrey Kass
ORNL	Mailstops	Names
1	8057	Sherrell R. Greene
1	8038	Gordon E. Michaels
WSRC	Mailstops	Names
1	704-F	Paul Maddux
Y-12/LMES	Mailstops	Names
1	8207	Gordon W. Cagle
1	8207	James D. Stout
1	8207	C. Ken Williams
YMSCO/TRW	Mailstops	Names
1		S.S. Sareen
FDI	Mailstops	Names
1	512M	Chuck Guenther
ANRCP	University	Names
1	TTU	Alan A. Barhorst
1	UT	Dale Klein
1	TTU	Jose A. Macedo
1	TAMU	Jeff Trinkle
1	TAMU	Richard A. Volz