D Level 1 Heading

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Appendix D

Computer Codes

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Computer codes are important to internal dosimetry because of the number and complexity of biokinetic models used for bioassay interpretation and dose assessment. The models have to factor in basic radiological decay parameters, intake parameters such as particle size and breathing rate, initial deposition within the body, subsequent distribution and translocation within body organs and tissues, excretion pathways, energy absorption in a target tissue from a radionuclide decay in a source tissue, and the various tissue weighting factors. An appropriate data-fitting routine is required for assessment of bioassay data and codes need various output routines to display data in useful formats such as reports and graphs. The Hanford Internal Dosimetry Program (HIDP) has several computer programs at its disposal to aid with internal dosimetry evaluations. These programs are listed below and discussed in the following sections:

- CINDY
- PUCALC
- AMERIN
- PU.EXE

The HIDP maintains historical archives of computer codes used. This appendix only addresses codes in current use. In addition to the currently used codes, the HIDP may have codes that are undergoing consideration or testing but are not used for formal Hanford applications. Also, common commercially available spreadsheet and database software are not described here.

D.1 CINDY

The Code for INternal DosimetrY (CINDY) is the principal computer code used by the HIDP for dosimetry. The code can do intake calculations based on curve-fitting of bioassay data; calculate committed (or any specified interval) organ, tissue, and effective dose equivalents; and make bioassay projections. The wide range of radionuclides encompassed by the code library includes all those

addressed by this manual. A two-part manual details the conceptual models used by the code (Strenge et al. 1992a) and provides a user's guide to loading and executing the code (Strenge et al. 1992b). The HIDP currently uses Version 1.4.

The code was developed at Pacific Northwest National Laboratory (PNNL) in the late 1980s and early 1990s under U.S. Department of Energy (DOE) funding specifically for implementing the dose provisions originally specified in DOE 5480.11 (1988). It is commercially available through Canberra Nuclear, Inc.[(a)] The code was originally designed for a DOS-based personal computer. The HIDP has also used the code on WINDOWS 3.1, WINDOWS 95, and WINDOWS 98 platforms. Difficulty was encountered when installing the code onto a WINDOWS 98 machine from the original disks. This was overcome by copying the files directly from a WINDOWS 95 machine. Initial attempts to install the code on a WINDOWS 2000 platform have been problematic.

D.1.1 Models Included in CINDY

CINDY incorporates the International Commission on Radiological Protection publication 30 (ICRP 1979) models for radionuclides, but permits modification of many parameters. Identification of some of the key adjustable parameters is discussed below.

The exposure scenario options permit inhalation, ingestion, and direct intake (which can be considered as either absorption through skin or wound injection). Inhalation and ingestion intakes use the ICRP 30 models. Inhalation permits use of class D, W, or Y, or any combination thereof, and allows for specification of particle size. Ingestion may be of soluble or insoluble forms (with user-variable f_1 factors). Direct intake allows uptake to blood from one or more independent compartments, each exhibiting a user-defined clearance half-time to blood. Exposures may be either acute (instantaneous) intakes or chronic (continuous over a user-specified interval).

The respiratory tract model permits adjustment of both the compartment fraction and clearance half-time for the individual compartments of the ICRP 30 model. Regional deposition fractions for the nasal-pharengeal, tracheobronchial, and pulmonary regions are set by the code based on the particle size specified.

The gastrointestinal (GI) tract model permits adjustment of the mean resident times (in hours) for the stomach, small intestine, upper large

(a) Canberra Nuclear, Inc., One State Street, Meriden, CT. 06450. Phone (203) 238-2351.

intestine, and lower large intestine. Absorption within the GI tract is established by setting the GI uptake (f_1) factor for individual radionuclide biokinetic models.

Systemic distribution, retention, and excretion models are provided based on chemical elements. Typically the parameters for distribution compartment fractions and clearance half-times are adjustable by the user. The default model used by CINDY for most elements is the ICRP 30 model, however element-specific models are also provided for iodine, alkaline earths, radium/radon, tritium, carbon, tellurium/iodine, and uranium. The GI uptake (f_1) factor is an element-specific variable. Detailed descriptions of the specific models are contained in Part 1 of the CINDY manual (Strenge et al. 1992a)

D.1.2 Bioassay Data Input

The excretion models used by CINDY are based on daily excretion rates. Because bioassay data are often provided using different formats, protocols for automatically manipulating data to give total daily bioassay values are incorporated into CINDY. The user must be aware of these protocols, otherwise biased conclusions can be reached by unanticipated, unrecognized, or unintended data adjustment. Table D.1 contains the CINDY bioassay data normalization protocols.

Table D.1. CINDY Normalization Protocols for Biosassay Data

Input Data	Sample Period	Sample Volume	Manipulation for Daily Result Used in Curve Fitting
Total activity units	Unknown (no input)	Unknown (no input)	Sample is assumed to be 1-day excretion. No data normalization.
Total activity units	Known (input)	Unknown (no input)	Sample is normalized to 24-hour period.
Total activity units	Unknown (no input)	Known (input)	Sample is normalized using reference daily volume.
Total activity units	Known (input)	Known (input)	Sample is normalized to 24-hour period. Volume ignored.
Concentration units	Unknown (no input)	Unknown (no input)	Concentration assumed for one day and daily result calculated based on reference daily volume.
Concentration units	Known (input)	Unknown (no input)	Daily result is calculated based on reference daily volume. Period ignored.
Concentration units	Unknown (no input)	Known (input)	Concentration assumed for one day and daily result calculated based on reference daily volume.
Concentration units	Known (input)	Known (input)	Concentration multiplied by volume and normalized by period to give daily result.

On the other hand, bioassay projection values, based on user-input intake values, are provided as instantaneous rates, so for the first few days after an intake, CINDY-generated excretion rates will not be exactly representative of total 24-hour excretion.

D.1.3 Intake Assessment Curve-Fitting Routines

Four methods for intake assessment by curve-fitting of bioassay data are included in CINDY. All are based on assumptions about the variance of the measurement value. Brief descriptions of the techniques are given below.

The unweighted least-squares (or uniform weighting) method assumes that weighting factors are constant and equal, implying that the variance is independent of the measurement magnitudes. This method is appropriate if all measured values are believed to have similar accuracy and are significantly above the detection limits of the measurement method.

The ratio of the means (or weighted least-squares) method assumes that data point weighting factors are inversely proportional to the expected value, implying that the variance is proportional to the magnitude of the expected value. This method avoids having the calculation dominated by a few large data points that may have poor precision.

The average of the slopes method assumes data point weighting factors are inversely proportional to the square of the expected value, implying that the variance is proportional to the square of the expected value. This method is appropriate when the variance is due primarily to biological factors rather than the detection precision of the measurement.

CINDY also has a user-defined weighting method in which the user supplies the estimate of variance for each measurement value. The weighting factors are calculated by CINDY as the inverse of the supplied variance.

D.1.4 Dose Calculation

CINDY calculates organ and tissue doses by determining the number of radionuclide transformations in a source organ or tissue over the time frame of interest (i.e., the time-integrated activity) and multiplying it by the specific effective energy (SEE) factor for the appropriate source-to-target combination contained in the code

library. The library SEE factors were obtained from the Oak Ridge National Laboratory (ORNL) modeling group that developed them for ICRP 30.

D.1.5 Acceptance Testing by the HIDP

Prior to its initial adoption in 1991 at Hanford, the CINDY Code underwent extensive testing and benchmarking by the HIDP. It was compared with the standard Hanford code then being used (GENMOD) and was found to be in reasonable agreement. The 1995 revision to CINDY (Version 1.4) also underwent HIDP testing prior to acceptance.

D.1.6 HIDP User Experience with CINDY

After 9 years of using CINDY, the HIDP has identified a number of caveats and recommendations for its use. Among them are the following:

- Don't mix intake units for different radionuclides in the same calculation. All units have to be the same.

- CINDY automatically uses three types of curve-fitting routines to determine intake from bioasaay data, and it allows for the user to insert a fourth method. Experience has not shown that any one method is always best. The user should carefully review the plot of the various fits to the actual data before choosing an intake value. An average intake value may be acceptable if none of the fits appear to be the best choice. The intake assessment mode data-plotting routine plots only those data used in a "connect-the-dots" straight-line approach. The bioassay projection mode shows the actual retention pattern, but does not show the bioassay data points themselves.

- Using the user-defined inverse variance method for curve-fitting can result in the greatest weight being given to data that show no detectable activity, even though bracketed by data showing detectable activity. Caution is needed no matter which curve-fitting scheme is used.

- The end time for a chronic intake cannot be given as 12/31/xxxx 24:00 or as 01/01/xxxx 00:00 (the exact end or start of a year). The end time must be offset by at least one minute if the end time is the actual end of the year. Otherwise, the year of the specified end time will not be reported in the calendar year results and a 2-year period will be used in its place.

- The maximum number of report times allowed for a calculation is 70 (69 for continuous intakes). More data may be inputted, but some must then be flagged to reduce the total number of data points used in any given calculation to 70.

- In the bioassay projection mode, including a report time of "0" can eliminate reporting of some organs that might be of interest (e.g., thyroid retention for iodines, bone surface for uranium, plutonium). If retention for a time immediately post intake is needed, 0.1 or 0.01 day can be used and will provide results for the full scope of organs and tissues included in the nuclide library.

- Bioassay projections for accumulated excretion values for early times post intake can be obtained by running the bioassay projection mode using increments of 0.1 day for the first few days of interest and summing the resulting instantaneous excretion rates over the period of interest.

- For tritium, the inhalation intake mode automatically factors in a skin absorption component equal to 50% of the inhalation. Thus, the total uptake from an inhalation is 1.5 times the inhalation intake.

- When two uranium isotopes are flagged as isotopes of concern, the intake assessment mode calculates the intake of the first correctly, but not the second. Run the uranium isotopes separately in the intake assessment mode.

- Ingrowth of ^{241}Am from ^{241}Pu is not accounted for in the intake assessment mode. Don't use long-term ^{241}Am in the lung to determine plutonium intakes if ^{241}Am ingrowth is a potential concern. Ingrowth is appropriately addressed in the bioassay projection mode.

- The error tolerance setting should be 1E-06 or 1E-07 when performing analyses using the Jones or Durbin excretion models. Instabilities can occur in the intake assessment or bioassay projection modes using the Jones or Durbin excretion models, usually at times following intake on the order of 1,000 to 10,000 days. The instabilities are easily observed in the display graphic results to screen mode. If instabilities are observed, rerun the case with a different error tolerance. Generally 1E-06 will provide acceptable results; be cautious of 1E-08.

D.2 PUCALC Family

PUCALC is a family of computer codes developed by the HIDP in the mid-1980s to simplify the process of determining the presystemic deposition of plutonium in an individual, based on urine data. The code uses the Jones excretion model to allow matching of observed excretion data to predicted excretion by varying the presystemic deposition magnitude and the its transfer rate into the systemic compartment. The PUCALC program creates a database of urine sample results. PCPLOT graphs the data points on the computer screen using a log-log scale, and upon input of values for presystemic deposition and transfer rate, overlays a curve on the screen. By iteration, the dosimetrist can quickly compare many different combinations and subjectively select a preferred fit. With the adoption of CINDY, the PUCALC family became seldom used, though it does include capability for addressing multiple intakes, which CINDY lacks. Much of the PUCALC family has been rendered obsolete by advances in personal computer (PC) technology and the code is seldom used now. No effort has been made to update the family to advanced microprocessors beyond the 486 and Pentium.

D.3 AMERIN

The AMERIN code is used for calculating the biological half-life and ingrowth for mixtures of ^{241}Am and ^{241}Pu. The code is executable on a PC from a WINDOWS 95 or 98 environment. It can calculate the biological clearance half-time from a single compartment using ^{241}Pu and ^{241}Am activities, or alternatively, calculate the activity of ^{241}Am at various times after intake when the biological half-time is given. The code was developed by the HIDP for use primarily with in vivo measurement data.

D.4 PU.EXE

PU.EXE is a plutonium utility developed at Hanford to calculate information about mixtures of plutonium isotopes. The HIDP uses it to show the isotopic composition of plutonium mixtures by weight, total mass, and total activity, and then age those mixtures and recompute the compositions. Heat generation rates, neutron production rates, and an inhalation dose factor are included in the utility but are not used by the HIDP. The utility was developed by Paul Rittman, based on his earlier work (Rittman 1984).

D.5 References

International Commission on Radiological Protection (ICRP). 1979. "Limits for intakes of radionuclides by workers." (ICRP publication 30, part 1.) *Annals of the ICRP*, 2:3-4, Pergamon Press, New York.

Strenge, D. L., R. A. Kennedy, M. J. Sula, and J. R. Johnson. 1992a. *Code for Internal Dosimetry (CINDY Version 1.2) Part 1: Conceptual Representation*. PNL-7493 Pt. 1, Rev. 1. Pacific Northwest Laboratory, Richland, Washington.

Strenge, D. L., R. A. Kennedy, M. J. Sula, and J. R. Johnson. 1992b. *Code for Internal Dosimetry (CINDY Version 1.2) Part 2: Users' Guide*. PNL-7493 Pt. 2, Rev. 1. Pacific Northwest Laboratory, Richland, Washington.

Rittmann, P. D. 1984. *Seven Health Physics Calculator Programs for the HP-41CV*. RHO-HS-ST-5P. Rockwell Hanford Operations, Richland, Washington.

U.S. Department of Energy (DOE). 1988. *Radiation Protection for Occupational Workers*. DOE 5480.11, Washington, D.C.